# Fossil Fuels in Transition:

## Committing to the phase-down of all fossil fuels

November 2023

Energy
Transitions
Commission

# Fossil Fuels in Transition:

## Committing to the phase-down of all fossil fuels

**The Energy Transitions Commission (ETC) is a global coalition of leaders from across the energy landscape committed to achieving net-zero emissions by mid-century, in line with the Paris climate objective of limiting global warming to well below 2°C and ideally to 1.5°C.**

Our Commissioners come from a range of organisations – energy producers, energy-intensive industries, technology providers, finance players and environmental NGOs – which operate across developed and developing countries and play different roles in the energy transition. This diversity of viewpoints informs our work: our analyses are developed with a systems perspective through extensive exchanges with experts and practitioners. The ETC is chaired by Lord Adair Turner who works with the ETC team, led by Faustine Delasalle (Vice-Chair), Ita Kettleborough (Director), and Mike Hemsley (Deputy Director).

The ETC's *Fossil Fuels in Transition* was developed by the Commissioners with the support of the ETC Secretariat, provided by Systemiq. This report constitutes a collective view of the Energy Transitions Commission. Members of the ETC endorse the general thrust of the arguments made in this publication but should not be taken as agreeing with every finding or recommendation. The institutions with which the Commissioners are affiliated have not been asked to formally endorse this briefing paper.

In addition to this report and accompanying executive summary, we will also be publishing Infographics, setting out the reduction in fossil fuel demand achievable in our scenarios and the implications for supply, as well as outlining the limited but vital need for carbon capture utilisation and storage (CCUS) and the significant scale up of carbon dioxide removals (CDR) to reach net-zero by mid-century. Additionally, an accompanying technical Annex covers in further detail the methodology and sources for the revised ETC scenarios.

The ETC team would like to thank the ETC members, member experts and the ETC's broader network of external experts for their active participation in the development of this report.

The ETC Commissioners not only agree on the importance of reaching net-zero carbon emissions from the energy and industrial systems by mid-century but also share a broad vision of how the transition can be achieved. The fact that this agreement is possible between leaders from companies and organisations with different perspectives on and interests in the energy system should give decision-makers across the world confidence that it is possible simultaneously to grow the global economy and to limit global warming to well below 2°C. Many of the key actions to achieve these goals are clear and can be pursued without delay.

This report should be cited as: ETC (2023), *Fossil Fuels in Transition*.

Learn more at:

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# Major ETC reports and working papers

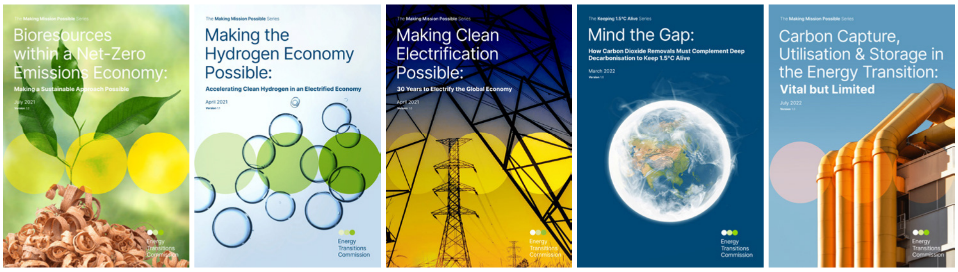
To download all ETC reports, papers, explainers and factsheets visit www.energy-transitions.org

Global Reports

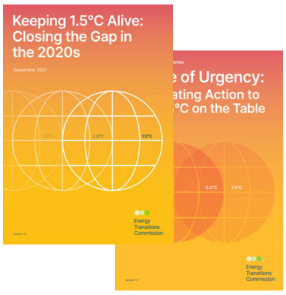

**Better Energy, Greater Prosperity** (2017) outlined four complementary decarbonisation strategies, positioning power decarbonisation and clean electrification as major progress levers.


**Mission Possible** (2018) outlines pathways to reach net-zero emissions from the harder-to-abate sectors in heavy industry (cement, steel, plastics) and heavy-duty transport (trucking, shipping, aviation).

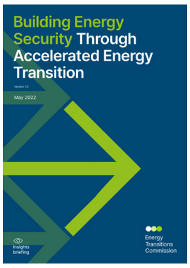

**Making Mission Possible** (2020) shows that a net-zero global economy is technically and economically possible by mid-century and will require a profound transformation of the global energy system.




**Making Mission Possible Series** (2021–2022) outlines how to scale up clean energy provision to achieve a net-zero emissions economy by mid-century.



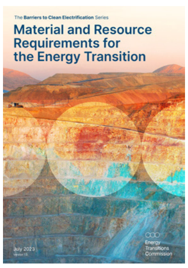

**Keeping 1.5°C Alive Series** (2021–2022) COP special reports outlining actions and agreements required in the 2020s to keep 1.5°C within reach.




**Building Energy Security** (2022) explores how Europe, and other regions, can build energy security while also accelerating the required energy transition.


**Financing the Transition** (2023) quantifies the finance needed to achieve a net-zero global economy and identifies policies needed to unleash investment on the scale required.


**Barriers to Clean Electrification Series** (2022–2024) recommends actions to overcome key obstacles to clean electrification scale-up, including planning and permitting, supply chains and power grids.

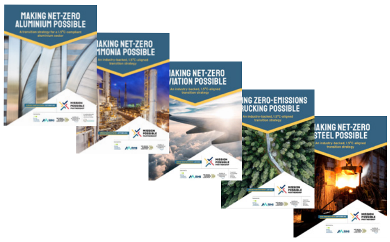



**Material and Resource Requirements for the Energy Transition** (2023) dives into the natural resources and materials required to meet the needs of the transition.by mid-century, and recommends actions to expand supply rapidly and sustainably.

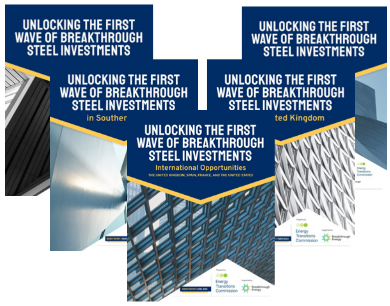
## Sectoral and cross-sectoral focuses


Sectoral focuses provided detailed decarbonisation analyses on six of the harder-to-abate sectors after the publication of the **Mission Possible** report (2019).

As a core partner of the MPP, the ETC also completes analysis to support a range of sectorial decarbonisation initiatives:




**MPP Sector Transition Strategies** (2022–2023) a series of reports that guide the decarbonisation of seven of the hardest-to-abate sectors. Of these, four are from the materials industries: aluminium, chemicals, concrete, and steel, and three are from the mobility and transport sectors – aviation, shipping, and trucking.




**Unlocking the First Wave of Breakthrough Steel Investments** (2023) This ETC series of reports looks at how to scale up near-zero emissions primary (ore-based) steelmaking this decade within specific regional contexts: the UK, Southern Europe, France and USA.

## Geographical focuses


**China 2050: A Fully Developed Rich Zero-carbon Economy** (2019) Analyses China's energy sources, technologies and policy interventions required to reach net-zero carbon emissions by 2050.


**A series of reports on the Indian power system,** outlining decarbonisation roadmaps for India's electricity supply and heavy industry.


**Canada's Electrification Advantage in the Race to Net-Zero** (2022) identifies 5 catalysts that can serve as a starting point for a national electrification strategy led by Canada's premieres at the province level.


**Setting up industrial regions for net zero** (2021–2022) explore the state of play in Australia, and identifies opportunities for transitioning to net-zero emissions in five hard-to-abate supply chains.


**Pathways to Net-Zero for the US Energy Transition** (2022–2023) examines the trendlines, challenges, and opportunities for meeting the US net-zero objective.


**A Path Across the Rift** (2023) reviews an analysis of African energy transitions and pinpoints critical questions we need to answer to foster science-based policymaking to enable decisions informed by clear and objective country-specific analysis.

# Glossary

**AFOLU sectors:** Agriculture, forestry and other land use sectors.

**Ambitious but Clearly Feasible (ACF) scenario:** This scenario is clearly technically and economically feasible, but in some sectors will require more forceful policy support than currently in place. If combined with significant carbon removals, this scenario would be broadly compatible with limiting global warming below 2°C, but would not deliver a 1.5°C limit.

**Ammonia ($NH_3$):** Is a compound of nitrogen and hydrogen. It can be used directly as a fuel in direct combustion process, and in fuel cells or as a hydrogen carrier. To be a low-carbon fuel, ammonia must be produced from low-carbon hydrogen and electricity needs are met by low-carbon electricity.

**Anthropogenic emissions:** Emissions of greenhouse gases (GHGs), precursors of GHGs and aerosols caused by human activities.[1]

**Bioenergy with Carbon Capture and Storage (BECCS):** A technology that combines bioenergy with carbon capture and storage to produce energy and net negative greenhouse gas emissions, i.e., removal of carbon dioxide from the atmosphere.

**BEV:** Battery-electric vehicle.

**Blue Hydrogen:** $H_2$ produced from splitting natural gas (or methane ($CH_4$)) into $H_2$ and $CO_2$ and capturing the $CO_2$.

**Carbon budgets:** The maximum amount of cumulative net global anthropogenic $CO_2$ emissions that would result in limiting global warming to a given level with a given probability, taking into account the effect of other greenhouse gas reductions. The remaining carbon budget indicates how much $CO_2$ could still be emitted while keeping warming below a specific temperature level. Carbon Budgets provide directional insight only and remain highly uncertain. They relate only to anthropogenic emissions or emissions from natural sources arising because of human activity (e.g., land use change), and already allow for the significant carbon sequestration which naturally occurs in forests and oceans.

**Carbon capture and use or storage (CCUS):** We use the term "carbon capture" to refer to the process of capturing $CO_2$ on the back of energy and industrial processes. Unless specified otherwise, we do not include direct air capture (DAC) when using this term. The term "carbon capture and storage" refers to the combination of carbon capture with underground carbon storage; while "carbon capture and use" refers to the use of carbon in carbon-based products in which $CO_2$ is sequestered over the long term (e.g., in concrete, aggregates, carbon fibre). Carbon-based products that only delay emissions in the short term (e.g., synfuels) are excluded when using this terminology.

**Carbon credits:** Reductions in emissions of carbon dioxide ($CO_2$) or greenhouse gases made by a company, sector or economy to compensate for emissions made elsewhere in the economy. These can be purchased via voluntary or compliance carbon markets.

**Carbon dioxide removals (CDR):** sometimes shortened to "carbon removals" refers to actions such as NCS or DACCS that can result in a net removal of $CO_2$ from the atmosphere.

**Carbon emissions/$CO_2$ emissions:** We use these terms interchangeably to describe anthropogenic emissions of carbon dioxide in the atmosphere.

**Carbon offsets:** Reductions in emissions of carbon dioxide ($CO_2$) or greenhouse gases made by a company, sector or economy to compensate or neutralise emissions made elsewhere in the economy.

**Carbon price:** A government-imposed pricing mechanism, the two main types being either a tax on products and services based on their carbon intensity, or a quota system setting a cap on permissible emissions in the country or region and allowing companies to trade the right to emit carbon (i.e. as allowances). This should be distinguished from some companies' use of what are sometimes called "internal" or "shadow" carbon prices, which are not prices or levies, but individual project screening values.

**Cost of capital:** a measure of the risk associated with investments; it expresses the expected financial return, or the minimum required rate, for investing in a company or a project.

**Decarbonisation solutions:** We use the term "decarbonisation solutions" to describe technologies or business models that reduce anthropogenic carbon emissions by unit of product or service delivered though energy productivity improvement, fuel/feedstock switch, process change or carbon capture. This does not necessarily entail a complete elimination of $CO_2$ use, since (i) fossil fuels might still be used combined with CCUS, (ii) the use of biomass or synthetic fuels can result in the release of $CO_2$, which would have been previously sequestered from the atmosphere though biomass growth or direct air capture, and (iii) $CO_2$ might still be embedded in the materials (e.g., in plastics).

**Direct air carbon capture (DACC):** the collective term for various technologies which use chemical processes to separate carbon dioxide from the atmosphere. This term does not carry any implications regarding the subsequent treatment of the $CO_2$ – it may be utilised or stored.

**Direct air carbon capture and storage (DACCS):** specifically refers to post-capture subsurface sequestration as the explicit end of life destination. Direct Air Carbon Capture & Utilisation (DACCU) refers to utilisation of captured $CO_2$ after capture.

**EBIT sectors:** energy, building, industry and transport sectors.

**Electrolysis:** A technique that uses electric current to drive an otherwise non-spontaneous chemical reaction. One form of electrolysis is the process that decomposes water into hydrogen and oxygen, taking place in an electrolyser and producing "green hydrogen". It can be zero-carbon if the electricity used is zero-carbon.

**Embedded carbon emissions:** Lifecycle carbon emissions from a product, including carbon emissions from the materials input production and manufacturing process.

**Emissions from the energy and industrial system:** All emissions arising either from the use of energy or from chemical reactions in industrial processes across the energy, industry, transport and buildings sectors. It excludes emissions from the agriculture sector and from land use changes.

**Enhanced oil recovery (EOR):** Captured $CO_2$ is used to increase output of oil and gas from existing wells.

**Final Investment Decision (FID):** The last stage in determining whether investment in an infrastructure project will go ahead or not.

**Fossil fuel reserves:** the subset of resources that have been proven to be both technically and economically recoverable from reservoirs.

**Fossil fuel resources:** the total estimated quantities of underground resources based on geological assessment of potential reservoirs.

**Fuel cell electric vehicle (FCEV):** Electric vehicle using a fuel cell generating electricity to power the motor, generally using oxygen from the air and compressed hydrogen.

1 IPCC (2018), *An IPCC Special Report on the impacts of global warming of 1.5°C, Glossary.*

**Fugitive emissions:** Any unintended release of gas or vapour from anthropogenic activities such as the processing or transportation of gas or petroleum.

**Global Warming Potential (GWP):** Global warming potential is a measure of the contribution to warming from one ton of a gas, relative to the warming induced by one ton of carbon dioxide.

**"Green" hydrogen, ammonia:** refers to fuels produced using electricity from low-carbon sources (i.e., variable renewables such as wind and solar).

**Green premium:** the additional cost of a clean technology over a high-carbon alternative.

**Greenhouse gases (GHGs):** Gases that trap heat in the atmosphere. Global GHG emission contributions by gas – $CO_2$ (76%), methane (16%), nitrous oxide (6%) and fluorinated gases (2%).

**Internal combustion engine (ICE):** A traditional engine, powered by gasoline, diesel, biofuels or natural gas. It is also possible to burn ammonia or hydrogen in an ICE.

**IOC:** International Oil Company.

**Just Energy Transition Partnership (JETP):** a financial cooperation mechanism, established at COP26, to support coal-dependent emerging economies achieve a just energy transition.

**Levelised cost of electricity (LCOE):** A measure of the average net present cost of electricity generation for a generating plant over its lifetime. The LCOE is calculated as the ratio between all the discounted costs over the lifetime of an electricity-generating plant divided by a discounted sum of the actual energy amounts delivered.

**Lifecycle emissions:** Emissions from the energy, material, and waste flows of a product and their impact on the environment.[2] Life cycle assessments (LCAs) should take into account the greenhouse gas impacts across land use change (if applicable), growth, harvesting, transportation, conversion, and use of bioresources.

**Liquified Natural Gas (LNG):** LNG is the clear and non-toxic liquid state of natural gas at temperatures below -162°C. It enables the transport and storage of natural gas without pressurisation, especially over longer distances via ships.

**Liquified Petroleum Gas (LPG):** is a hydrocarbon gas that exists in a liquefied form supplied in two main forms, propane ($C_3H_8$) and butane ($C_4H_{10}$). LPG has a low boiling temperature and is typically stored in pressurised steel vessels.[3]

**Multilateral development banks (MDBs):** an international financial institution chartered by two or more countries for the purpose of encouraging economic development. They can include Global, Regional or Sub-Regional Banks (e.g. World Bank, EIB).

**Nature-based solutions (NBS):** Actions to protect, sustainably manage and restore natural or modified ecosystems which constitute natural carbon sinks, while simultaneously providing human, societal and biodiversity benefits.

**Negative emissions (or "net negative" emissions):** is used for the case where the combination of all sector $CO_2$ emissions plus carbon removals results in an absolute negative (and thus a reduction in the stock of atmospheric $CO_2$).

**Net-zero-carbon-emissions / Net-zero-carbon / Net-zero:** We use these terms interchangeably to describe the situation in which the energy and industrial system as a whole or a specific economic sector releases no $CO_2$ emissions – either because it doesn't produce any or because it captures the $CO_2$ it produces to use or store. In this situation, the use of offsets from other sectors ("real net-zero") should be extremely limited and used only to compensate for residual emissions from imperfect levels of carbon capture, unavoidable end-of-life emissions, or remaining emissions from the agriculture sector.

**NOC:** A national oil company (NOC) is an oil and gas company fully or in the majority-owned by a national government. According to the World Bank, NOCs accounted for 75% global oil production and controlled 90% of proven oil reserves in 201.

**Non-Operated Joint Ventures (NOJV):** joint ventures that are independently managed and operated which have their own governance frameworks as defined in each joint venture agreement.[4]

**Point source carbon capture:** CCUS attached to a single, identifiable entity from which $CO_2$ originates. This is in contrast to of Direct Air Capture which isolates $CO_2$ from the atmosphere.

**Possible but Stretching (PBS) scenario:** This scenario is technically and economically feasible, but would require very significant strengthening of current commitments and policies. Combined with significant carbon removals, this scenario would come close to delivering a 50% chance of limiting global warming to 1.5°C in 2100.

**Process emissions:** $CO_2$ and other greenhouse gases emissions generated as consequence of a chemical reaction other than combustion occurring during an industrial process.

**Sanctioned developments:** How much supply might result from new developments of proven reserves which have already received final investment decision.

**Scope 1 emissions:** emissions from sources that an organisation owns or controls directly – for example from burning fuel in its own fleet of vehicles.[5]

**Scope 2 emissions:** emissions that a company causes indirectly and come from where the energy it purchases and uses is produced. For example, emissions caused when generating the electricity to power the equipment required to extract fossil fuels.

**Scope 3 emissions:** emissions that are not produced by the company itself and are not the result of activities from assets owned or controlled by them, but by those that it's indirectly responsible for up and down its value chain. An example of this is buying, using and disposing of products from suppliers; for fossil fuel companies, scope 3 emissions are those emissions that result from the combustion of the energy products they sell. Scope 3 emissions include all sources not within the scope 1 and 2 boundaries.

**Sequestration:** Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide.

**Synfuels (or syngases):** Hydrocarbon liquid fuels produced from hydrogen, carbon dioxide and electricity. They can be zero-carbon if the electricity input is zero-carbon and the $CO_2$ is from direct air capture. Also known as "synthetic fuels", "power-to-fuels" or "electro-fuels".

**Technology Readiness Level (TRL):** Describes the level of matureness a certain technology has reached from initial idea to large-scale, stable commercial operation. The IEA reference scale is used.

**Traditional Use of Biomass (TUOB):** the combustion of biomass in such forms as wood, animal waste and traditional charcoal.[6]

2 BP (2014), *Biomass in the Energy Industry – an introduction.*
3 Calor (2023), *Liquefied Petroleum Gas (LPG).*
4 BHP (2023), *Non-operated joint ventures.*
5 National Grid (2023), *What are scope 1, 2 and 3 carbon emissions?*
6 IRENA (2023), *Bioenergy & biofuels.*

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**Note on supplementary material to the report**

This report is accompanied by a technical annex which provides further details on our revised scenarios, and in particular:

- Key sources, methodology and assumptions for estimating future fossil fuel demand by sector.
- Detailed modelling outputs.
- Key uncertainties and sensitivities

This main report published in November 2023 will be followed by a **supplementary discussion paper** published in 2024. The list of topics is laid out in the introduction.

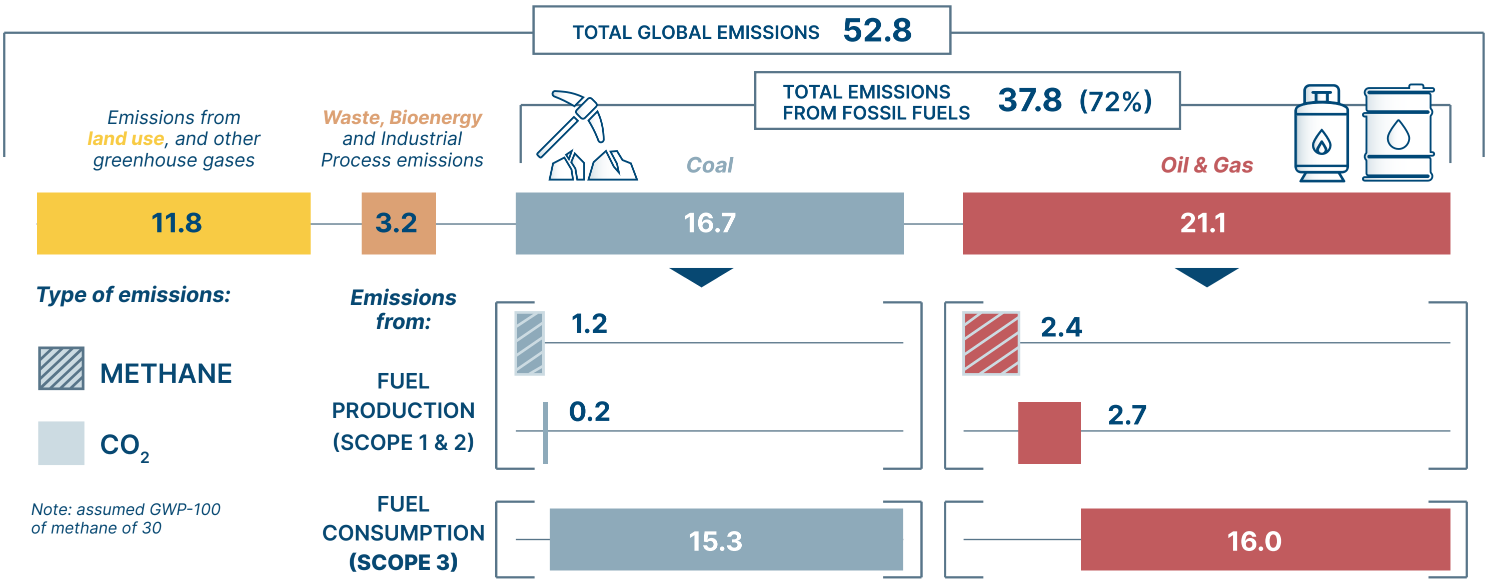
Energy Transitions Commission

# FOSSIL FUELS IN TRANSITION

## Any credible plans to achieve 1.5°C or well below 2°C will require a significant reduction in fossil fuel demand

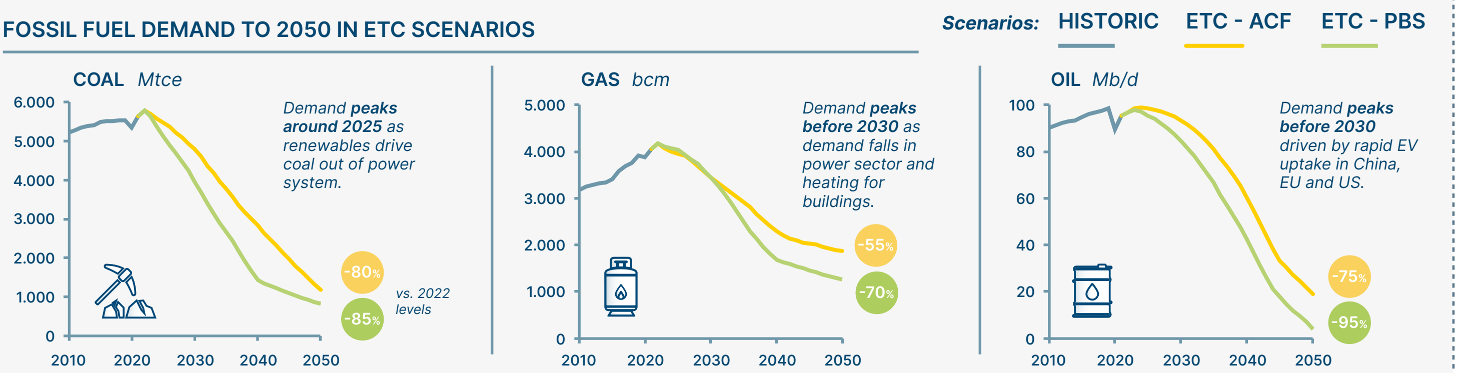
### FOSSIL FUELS ARE RESPONSIBLE FOR THE MAJORITY OF GLOBAL EMISSIONS

$GtCO_2eq$

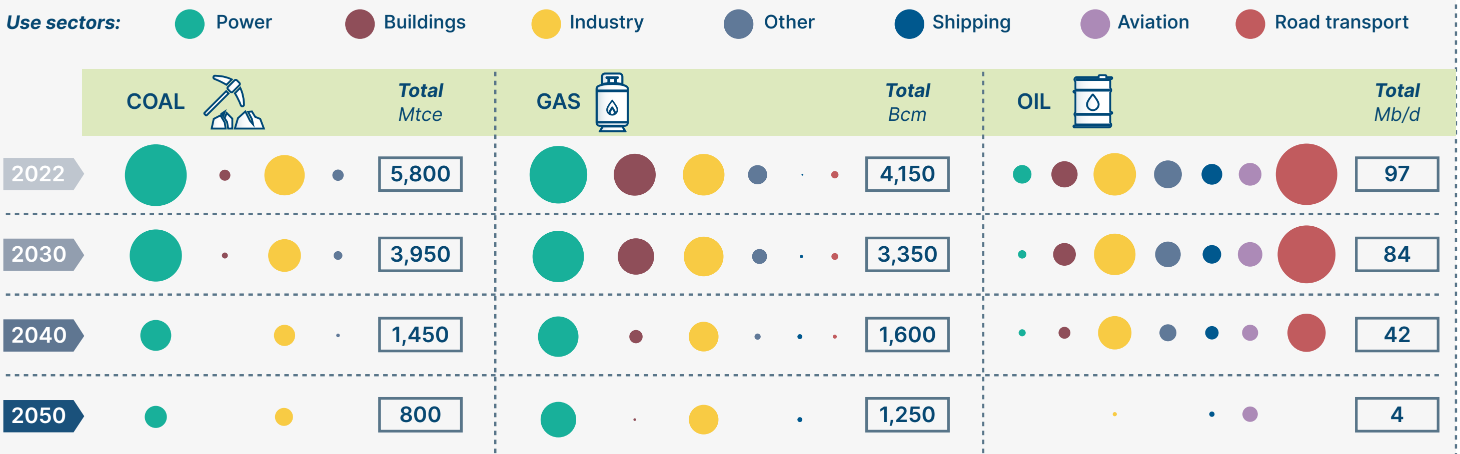



### Reducing emissions from fossil production is important, but reducing fossil fuel demand is crucial

#### FOSSIL FUEL DEMAND TO 2050 IN ETC SCENARIOS




#### ANNUAL FOSSIL FUEL DEMAND BY SECTOR IN PBS SCENARIO




| KEY ACTIONS: | COAL | GAS | OIL |
|---|---|---|---|
| | **3x** total renewables capacity can displace 1,000 Mtce of coal in power by 2030 | **3x** renewables and **3x** installed heat pumps in buildings can displace around 600 Bcm of gas by 2030 | Growing passenger EV fleet to over 300m helps displace **5 Mb/d** of oil by 2030 |

# Introduction

At COP21 in Paris, and again at COP26 in Glasgow, the **vast majority of the world's nations agreed that it is essential to limit global warming to well below 2°C, and ideally to 1.5°C**, with limited overshoot. Since then, 99 countries have committed to such targets, with another 60 countries currently in talks to make these commitments.[1] Recent extreme weather events across the world have illustrated the vital importance of meeting those objectives.[2]

But we are **running out of time** to achieve such targets. The IPCC concluded in 2020 that to have a 50% chance of limiting global warming to 1.5°C, the world would need to cut $CO_2$ emissions to net-zero by around mid-century, and limit cumulative emissions between 2020 and 2050 to 500 $GtCO_2$.[3] Three years on, $CO_2$ emissions have continued at over 40 $GtCO_2$ per annum,[4] reducing the 1.5°C-compatible budget to around 380 $GtCO_2$.[5] Latest scientific analysis suggests it may be smaller still, and potentially as low as 250 $GtCO_2$.[6]

Best estimates from the International Energy Agency (IEA) suggest that if all government pledges to reduce emissions, whether included in Nationally Determined Contributions (NDCs), mid-century targets or other commitments, were turned into specific policies, global warming might be limited to 1.7°C. However, based on policies already enacted, we are on a path to global warming of 2.4–2.7°C by 2100.[7]

Fossil fuel production, processing and combustion in end-uses is responsible for 90% of global anthropogenic $CO_2$ and 35% of methane emissions.[8,9] Limiting global warming to well below 2°C will be impossible unless these emissions are reduced to net-zero by around mid-century. That implies a combination of:

- Reductions in fossil fuel production and use.
- Abatement of residual fossil fuel use in mid-century by carbon capture, utilisation and storage (CCUS).
- Scaling up carbon removals (CDR) in order to reach net-zero greenhouse gas emissions and neutralise any temperature overshoot beyond 1.5°C.

This is equivalent to **all fossil fuel-producing companies reaching net-zero scope 1, 2 and 3 emissions by mid-century.**

The crucial question is **how net-zero emissions are achieved**, and in particular, the **balance between reductions in fossil fuel use, CCUS and removals in reaching net-zero.** The many possible answers to this question, together with varying degrees of commitment to meeting climate objectives, result in a large array of scenarios for future fossil fuel use [Exhibit 0.1]. This range is currently too large to be useful to policy and corporate decision-makers. For example [Exhibit 0.2]:

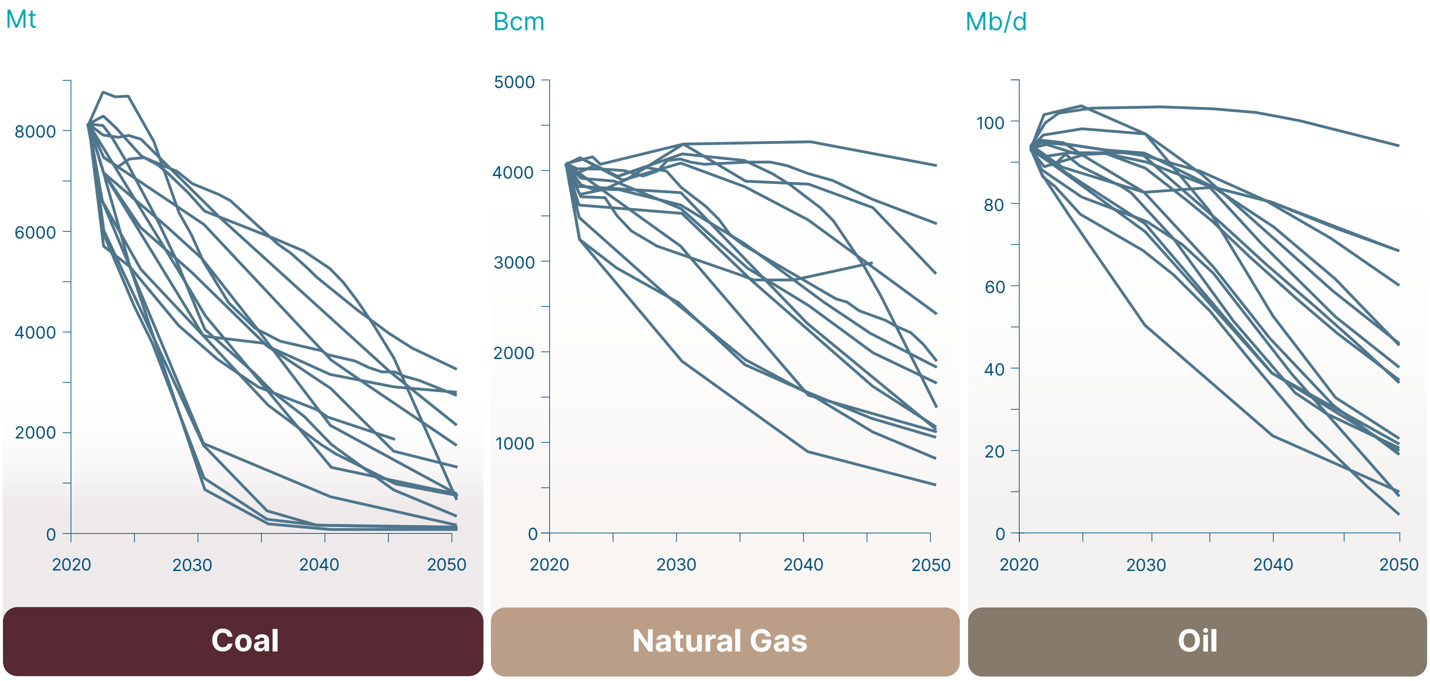
- At the upper end of the spectrum for fossil fuel demand, OPEC has published its *Advanced Technology Scenario*, which they describe as aligned with the long-term goals of the Paris Agreement, and which assumes that oil demand will stay broadly constant between 94–104 million barrels per day (Mb/d) up to 2045. This scenario can only be compatible with limiting global warming to well below 2°C because it assumes that all emissions from oil use in industrial sectors, especially in chemicals (17 Mb/d today), are captured and stored via CCUS, and that all oil use in transport (60 Mb/d today) is neutralised by carbon removals.[10] As we describe in Chapter 3, we do not believe that these assumptions are credible.
- The IEA's 2023 *Net-Zero Scenario* illustrates that a reduction in oil demand from 97 Mb/d today[11] to 77 Mb/d by 2030, and 22 Mb/d by 2050, is technically feasible and would be essential if we are to limit global warming to 1.5°C without the use of nature-based removals.[12] However, achieving these significant reductions by 2030 is only possible through significant progress in energy efficiency improvements, combined with major changes in behaviour for energy consumers with, for instance, adjustments to heating and cooling temperatures in homes, 100 km/h speed limits on major roads, and reduced demand for air business travel, as detailed in Box D.[13]

1 Energy & Climate (2023), *Net-Zero Scorecard*.
2 Summer 2023 was the hottest on record from Copernicus Climate Change Service (2023); Libya experienced the most devastating floods in the country's history in September, 2023 wildfires in Greece are confirmed to be Europe's largest single fire in history from Earth.org (2023), *Another Year For the Record Books: A Recap of the Main Extreme Weather Events in Summer 2023*.
3 IPCC (2021), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the 6th Assessment Report of the Intergovernmental Panel on Climate Change*.
4 Including emissions from fossil fuels combustion, industrial processes and land use change.
5 Our World in Data (2023), *$CO_2$ and Greenhouse Gas Emissions database*.
6 Forster et al. (2023), *Indicators of global climate change 2022: annual update of large-scale indicators of the state the climate system and human influence*.
7 The IEA's Stated Policies scenario (STEPS) reflects current enforced policies, while the Announced Pledges scenario (APS) illustrated what would occur under government and company pledges. According to Climate Action Tracker (CAT) Thermometer (2023), current policy will lead to a warming of 2.7°C in 2100, but will also continue to rise after that date.
8 $CO_2$ emissions from fossil fuels were 34.2 $GtCO_2$ in 2022, out of a total of 37.9 $GtCO_2$ from UNEP (2022), *Emissions Gap Report 2022*. Note: UNEP values are for 2021; excludes $CO_2$ emissions from LULUCF. Systemiq analysis for the ETC; IEA (2023), *Scope 1 & 2 GHG emissions from oil and gas operations in the Net-Zero Scenario*; IEA (2023), *$CO_2$ emissions in 2022, US Congressional Research Service (2015)*.
9 Fossil fuel-related methane emissions were 124.1 Mt in 2022, out of a total of ~350 $MtCH_4$ of anthropogenic methane emissions. Source: IEA (2023), *Global Methane Tracker 2023*.
10 OPEC (2022), *World Oil Outlook 2022*.
11 Crude oil demand only, excluding biofuels and processing gains.
12 IEA (2023), *Net-Zero Roadmap: A global pathway to keep the 1.5°C goal in reach*.
13 Ibid.

EXHIBIT 0.1

## Range of decline in fossil fuel demand in decarbonisation scenarios to 2050

Fossil fuel demand
Specific units




**NOTE:** 2021 values for all scenarios are fixed using the IEA's 2021 data, Shell scenarios are linearly interpolated between 2019-2025 due to data availability. Figures reflect primary fossil fuel supply and not final demand. Decarbonisation scenarios are non-business-as-usual energy system projections that imply some degree of decarbonisation, not all decarbonisation reach net-zero by 2050 or at later dates, and reflect a range of temperature assessments and emissions overshoot.
Mt = million tonnes of coal, bcm = billion cubic meters, mb/d = million barrels per day.

**SOURCE:** Systemiq analysis for the ETC; IEA (2022), *Global Energy and Climate Model*; BNEF (2022), *New Energy Outlook*; Equinor (2023), *Energy Perspectives*; BP (2023), *Energy Outlook*; Shell (2023), *The Energy Security Scenarios*; IPCC (2023), *Sixth Assessment Report*; TotalEnergies (2022), *Energy Outlook*; NGFS (2022), *Climate Scenarios Database*; DNV (2022), *Energy Transition Outlook*; OPEC (2020), *World Oil Outlook 2045*.

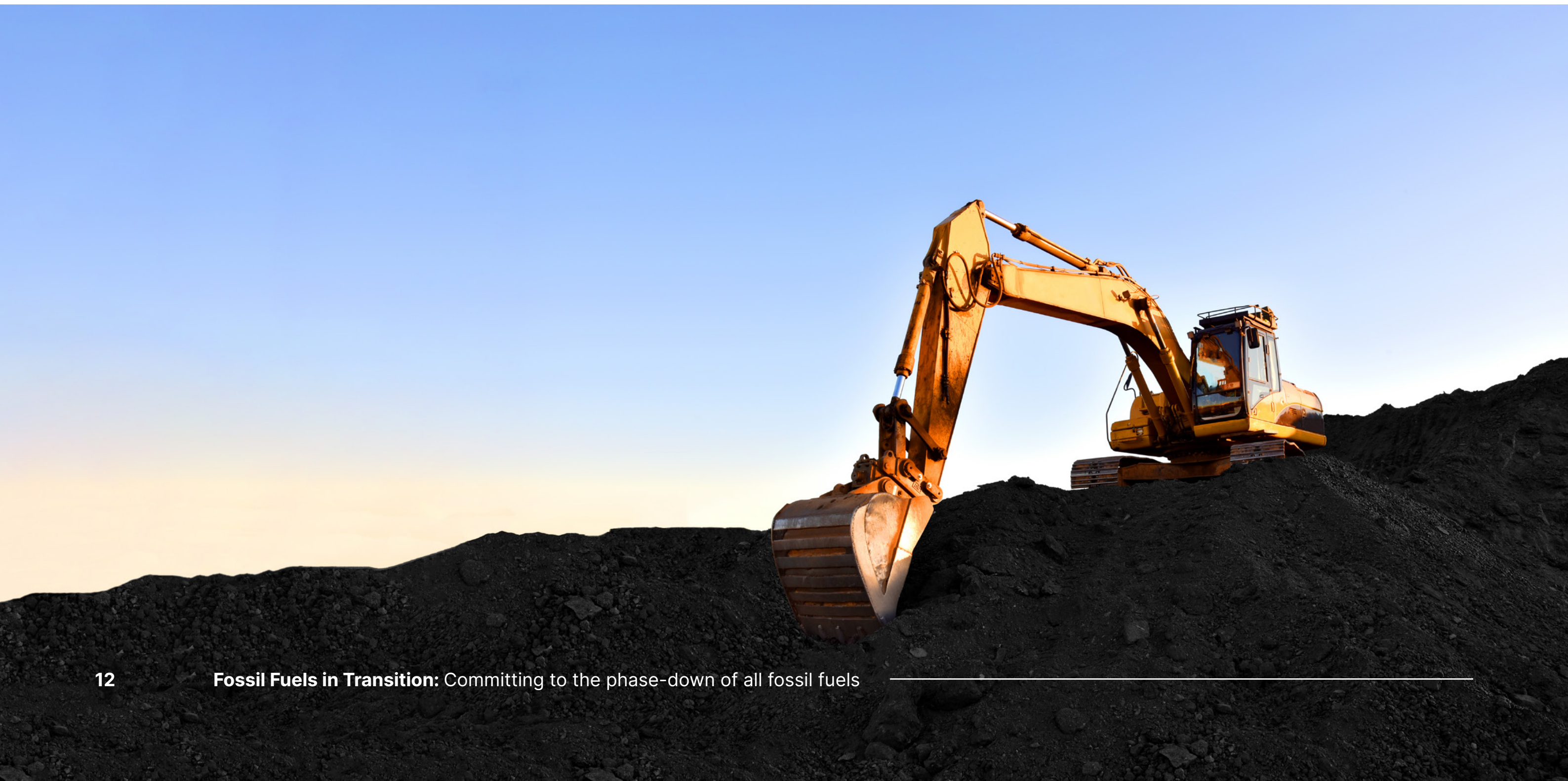
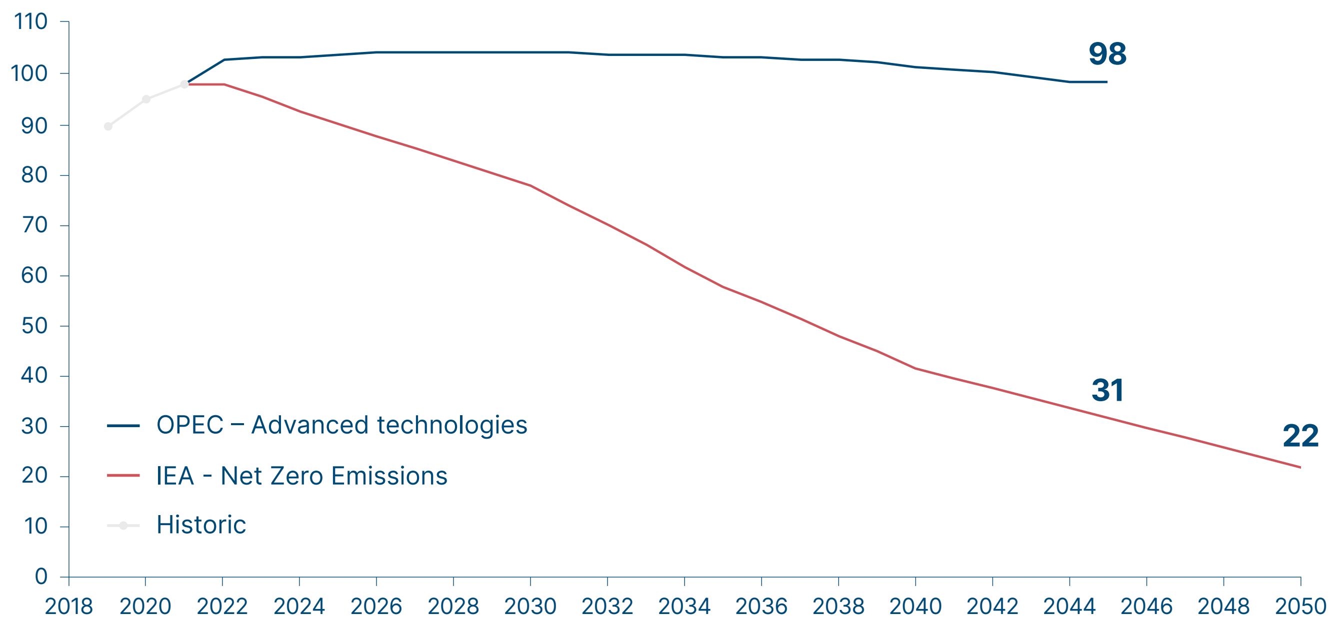


EXHIBIT 0.2

## Oil demand in net-zero outlooks from IEA and OPEC

Oil demand in IEA *Net-Zero Emissions* and OPEC *Advanced Technologies* scenario
Mb/d




**NOTE:** OPEC scenarios are only modelled up to 2045.

**SOURCE:** Systemiq analysis for the ETC; IEA (2023), *World Energy Outlook 2023*; OPEC (2023), *World Oil Outlook 2023*.

The ETC published initial projections of potential future coal, oil and gas demand in our *Making Mission Possible* report of 2020. Since then, several clean technologies have continued to achieve rapid progress, and the ETC has conducted more detailed analysis of the feasible and optimal pathways to decarbonisation, including in particular:

- Analysis of the relative role which could be played by clean electrification, hydrogen, and carbon capture, utilisation, and storage.[14]
- The role which removals, whether nature-based (e.g., reforestation), engineered (e.g., direct air carbon capture and storage (DACCS)) or hybrid (e.g., bioenergy and carbon capture and storage (BECCS)) might play in neutralising remaining fossil fuel use both prior to and after 2050, and the risks entailed in placing too much reliance on removals to achieve climate goals.[15]

In addition, the Mission Possible Partnership (MPP) has set out detailed pathways for the decarbonisation of the long-distance transportation (aviation, shipping and trucking) and heavy industry sectors (aluminium, steel, ammonia and cement).[16] Each of these pathways is based on detailed modelling of the technological possibilities and cost involved in reaching net-zero emissions by mid-century. For most sectors, two scenarios are set out, reflecting more cautious or optimistic assumptions about technological progress and costs.

In the present report, we synthesise the **implications of these pathways for future demand for coal, oil and gas, and complement these with analysis for specific sectors not previously covered** in detail. These include passenger road transport, building heating and cooking, and light industry. This results in two preliminary scenarios for the technically and

14 ETC (2020), *Making Mission Possible*; ETC(2021), *Making Clean Electrification Possible*; ETC (2021), *Making the Hydrogen Economy Possible*; ETC (2021), *Bioresources within a Net-Zero Emissions Economy*; ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited.*

15 ETC (2022), *Mind the Gap.*

16 MPP (2023), *Making net-zero aviation possible*; MPP (2022), *Making net-zero trucking possible*; MPP (2021), *A Strategy for the Transition to Zero-Emission Shipping*; MPP (2022), *Making net-zero steel possible*; MPP (2022), *Making net-zero ammonia possible*; MPP (2023), *Making net-zero aluminium possible*; MPP (forthcoming – 2023), *Making net-zero concrete and cement possible.*

economically feasible global level of future fossil fuel demand. Chapter 1 describes the two scenarios we have developed, and how the nature of these scenarios compares with those produced by the IEA.

Having developed the two scenarios for demand, we then:

- Assess the implications of the combination of future fossil fuel demand and the level of CCUS and carbon removals for future global temperatures.
- Assess how future demand for fossil fuels compares with the supply available from existing coal mines and oil and gas fields, given different levels of investments.
- Identify both, (i) the policies required to ensure that fossil fuel demand falls at a pace which is both feasible and compatible with climate goals, and (ii) the commitments which countries, fossil fuel companies and financial institutions should make to align future supply with declining demand.

This report is being published in the run-up to COP28, and is designed to contribute to the crucial debate which should be launched at that conference: **how fast can and should global fossil fuel use decline, and with what implications for the balance between demand and prospective supply?**

Precise answers to that question can be debated, and will continue to evolve in the light of technological progress and climate science. The scenarios presented in this report should therefore be considered as a preliminary ETC contribution, which we will revise during 2024 in the light of comments and further analysis, including in particular a focus on key uncertainties which are described in Chapter 3.1. While the details are uncertain, we believe the analysis conducted so far supports the broad conclusions set out in Box A. Specifically, it is not prudent nor credible to assume significantly higher CCUS and removals than we outline, and therefore not possible to meet climate objectives while declining fossil fuel use more slowly than in our scenarios.

Our **supplementary report in 2024** will also address several issues which are not covered in this report. These include:

- The implications of global supply requirements for regional supply, given issues relating to energy security and climate justice, which could argue for a different allocation of supply than would result from global cost minimisation.
- The role which fossil fuel companies, in particular oil and gas companies, could and should play in the energy transition, and how this might differ between national and international oil companies (NOCs and IOCs).
- The growing liability to decommission upstream fossil fuel infrastructure, and the potential to repurpose these assets and infrastructure to meet the needs of a zero-carbon energy system.
- The impact of declining fossil fuel revenues on specific countries, and the potential and opportunity to phase out fossil fuel subsidies.
- Uncertainties related to the decarbonisation of the petrochemicals sector and implications for continued fossil fuel demand.

These – and in particular the first – are important and potentially contentious issues. But they can only be addressed effectively within the context of broad consensus on the rate of global fossil fuel use decline which is both feasible and required to achieve climate objectives. This report aims to contribute to achieving that consensus.

We describe our scenarios, analysis and their implications in 9 chapters:

1. The challenge and the purpose of the ETC scenarios.
2. Feasible reductions in fossil fuel demand by sector and the role of different technologies.
3. Aggregate demand, uncertainties, and comparison with other scenarios.
4. The role of carbon capture, utilisation and storage, and carbon removals in getting to net-zero: vital but limited.
5. Temperature increase and policies required to reduce demand.
6. The mid-century destination: committing to net-zero scope 1, 2 and 3 emissions.
7. The pathway to 2050: aligning supply with falling demand.
8. Drastic reductions in scope 1 and 2 emissions: a vital short-term priority.
9. Recommendations for governments, fossil fuel-producing companies and financial institutions.

**BOX A: KEY CONCLUSIONS**

**Feasible and required reductions in fossil fuel use** [Exhibit 1.3]:

- By 2050, it is technically and economically feasible to reduce demand of coal by 80–85% from 2022 levels, oil by 77–95%, and gas by 55–70%. Reductions of this scale are essential to limit global warming to well below 2°C, and ideally to 1.5°C.
- By 2030, demand must be on a strong downward path, but with limits to feasible reductions by that date. Demand of coal could fall by around 15–30% from 2022 levels, oil by 5–15% and gas by around 15%.
- By 2040 however, very significant reductions are possible: coal demand down by 50–75% from 2022 levels, oil by 35–55% and gas by 40–60%. Public policy and business strategies must focus on ensuring these reductions are achieved.
- These reductions can and must be balanced by the dramatic expansion of new clean energy sources, with electricity use growing around two times in high-income economies, four to five times in middle- and lower middle-income countries, and by far more in low-income countries. Provided these new clean energy sources grow as fast as required and implied in our projections, significant reductions in fossil fuels use are compatible with rapid economic growth and rising living standards in lower-income countries.

**The role of carbon capture and removals:**

- To limit global warming to well below 2°C, and ideally 1.5°C, these fossil fuel demand reductions must be combined with point source CCUS, rising to 4.0–4.8 Gt per annum by 2050, BECCS and DACCS reaching 3.7 Gt per annum by 2050, and cumulative removals of around 150 $GtCO_2$ between now and 2050.
- Current progress towards these CCUS and carbon removal levels is, however, too slow, and the required levels will not be achieved without stronger policy support for CCUS, and the mobilisation of large scale finance for removals.
- It is neither prudent nor credible to assume significantly higher CCUS and removals, and therefore not possible to meet climate objectives while using significantly more fossil fuels than our scenarios assume.

**Policies to reduce demand for fossil fuels:**

- Demand side policies must play the primary role in achieving these feasible and necessary reductions in fossil fuel use. And if significantly strengthened demand side policies are not introduced, constraints on fossil fuel supply will be ineffective, and/or could produce significant adverse effects.
- Demand side policies must combine regulations, financial support for new technology deployment and carbon pricing.
- Large scale mobilisation of finance is also required to support rapid development of new clean energy sources in lower-income economies.

- Matching reductions in fossil fuel demand with reductions in supply is essential to manage the transition to net-zero emissions by mid-century. Policies that ensure that supply develops in line with the reductions in demand that result from strong demand side policies, if introduced gradually, are effective tools to limit emissions lock-in and/or stranded assets.

**Reducing scope 1 and 2 emissions:**

- Of the 37.8 $GtCO_2e$ of emissions from fossil fuels, 6.5 $GtCO_2e$ are scope 1 and 2 emissions resulting from the production, processing and transport of fuels, rather than end use. These can and should be reduced by 55% by 2030, with methane emissions in particular reduced by 75% by that date for oil and gas, and 30% for coal, and reaching near-zero by 2050 at the latest.
- But no serious response to climate change can focus solely on scope 1 and 2 emissions. To limit global warming to 1.5°C, aggregate scope 1, 2 and 3 emissions from all fossil fuel companies must reach net-zero by mid-century.

**Policies to limit excess supply:**

- Proven fossil fuel reserves, and even more so, estimated resources, massively exceed the amount that can be safely used while staying within agreed climate objectives. Limiting global warming to acceptable levels requires that around 60% of all proven oil and gas reserves and 90% of coal reserves must be left in the ground.
- Further investment will be needed to maintain existing oil and gas production, and for some development of short lead time and payback projects. But there is no need for any new coal development, for exploration to discover new oil and gas basins/fields, or for the development of new conventional oil and gas fields capable of producing over the long-term.
- The stated strategies of oil and gas producing countries and companies imply significantly more aggregate oil supply than required in our scenarios.
- Total investment in fossil fuels must therefore now be on a strong downward path, falling by around 30–35% by 2030 and 45–65% by 2040.

Government policies, and company and financial institution strategies and commitments should be aligned with the required reduction in fossil fuel demand and supply.

COP28 should provide the framework for detailed policy and strategy design by committing to the phase-down of all fossil fuels.

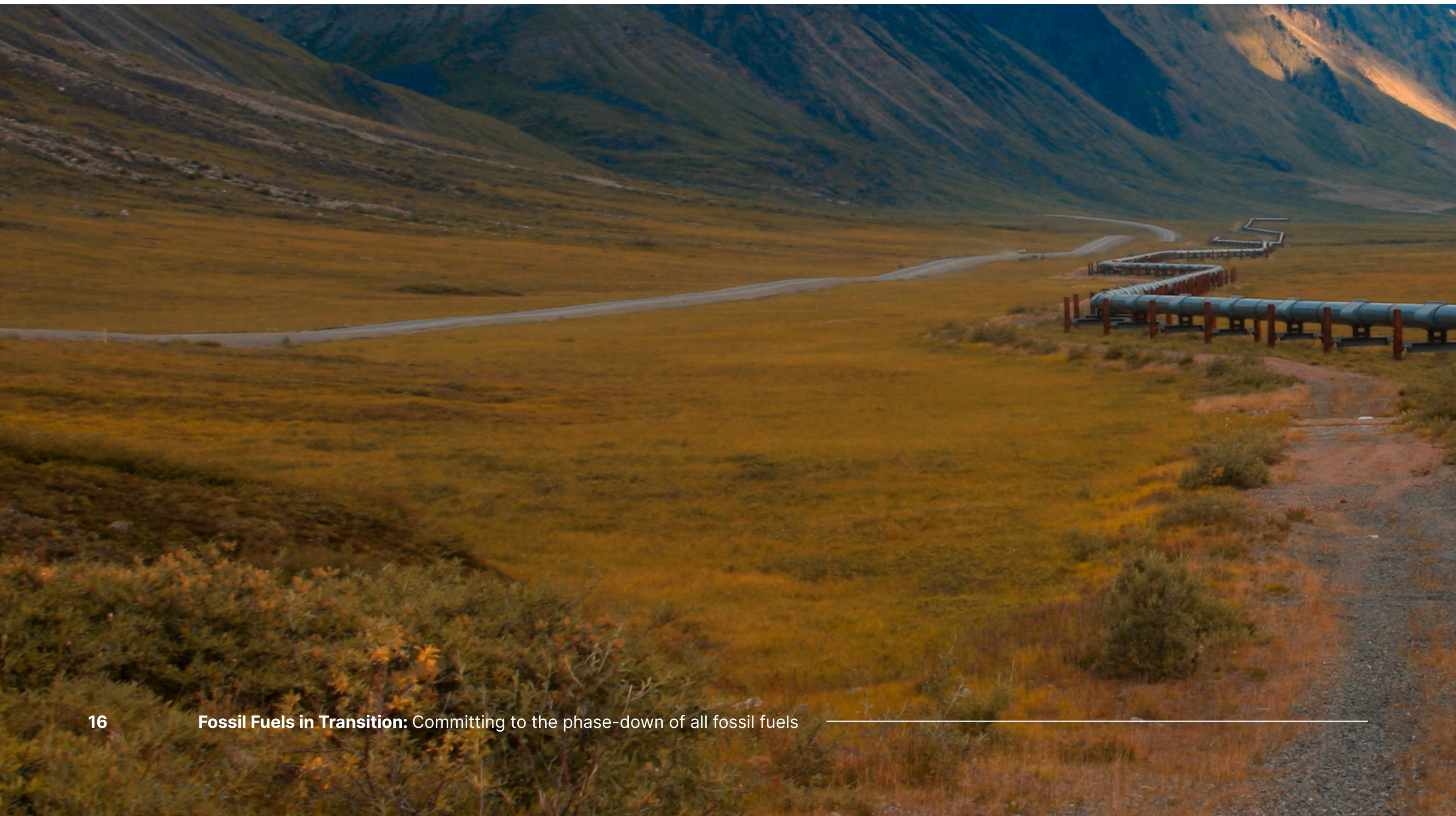
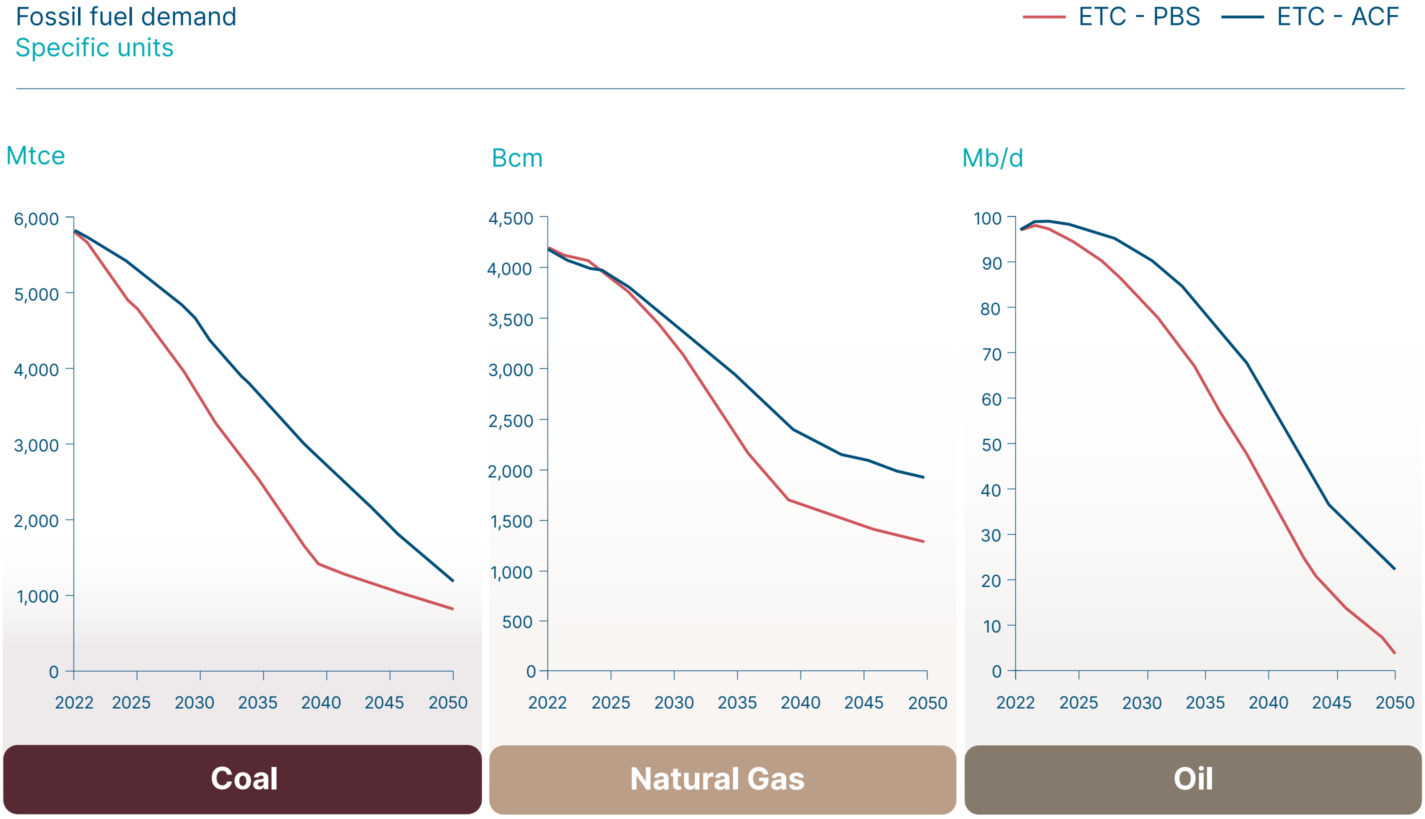


EXHIBIT 0.3

## Fossil fuel demand in ACF and PBS to 2050

Fossil fuel demand
Specific units




**NOTE:** PBS: Possible But Stretching, ACF: Accelerated but Clearly Feasible, Mtce = million tonnes of coal equivalent, bcm = billion cubic meters, mb/d = million barrels per day.

**SOURCE:** Systemiq analysis for the ETC.

# Chapter 1

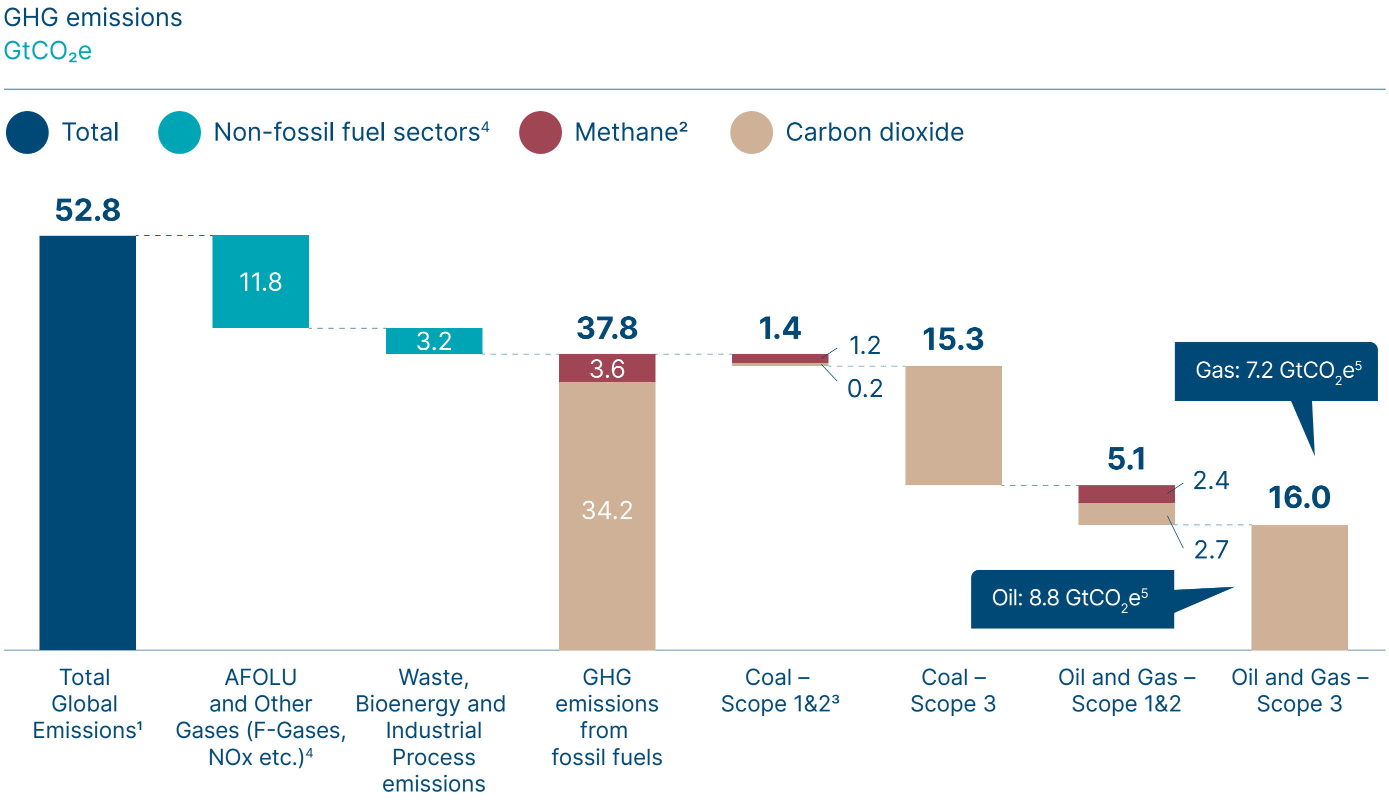
# The challenge and the purpose of the ETC scenarios

In 2022, fossil fuel production, transport and use resulted in 34.2 Gt of $CO_2$ emissions and 124 Mt of methane ($CH_4$) emissions.[17] The $CO_2$ equivalent effect of methane depends on the time period considered, with a multiplier of 30 applicable over a 100-year period, but 82.5 times over a 20-year period.[18] Using the former approach, the 124 Mt of $CH_4$ emissions are equivalent to ~3.6 $GtCO_2e$, and total emissions from fossil fuels amount to 37.8 $GtCO_2e$. This is about 70% of all greenhouse gases contributing to global warming.[19] Within this total, about 16.7 $GtCO_2e$ arises from the production and use of coal, and 21.1 $GtCO_2e$ from oil and natural gas, as illustrated in Exhibit 1.1.[20,21] Exhibit 1.2 shows the figures on a $CO_2$ equivalent basis using the alternative 20-year approach.

Out of the 37.8 $GtCO_2e$ in total, about 17%, or 6.5 $GtCO_2e$, are scope 1 or 2 emissions which arise during the production, refining and transport of fossil fuels. These emissions could be mitigated by improving operational efficiency and deploying proven technologies and processes,[22] even if fossil fuels continue to be used in end-use applications. Given that it will inevitably take time to reduce fossil fuel use, it is critical that these scope 1 and 2 emissions are reduced as rapidly as possible.[23] Chapter 8 focuses on how these emissions can be abated, appropriate reduction targets, and policies to achieve them.

**EXHIBIT 1.1**

## Breakdown of global greenhouse gas emissions ($GWP_{100}$) by source for 2022




**NOTE:** ¹ Total global GHG emissions are from 2021; UNEP data; ² using a methane $GWP_{100}$ = 30; ³ Coal production and transport emissions are estimated as ~1.4% of life-cycle emissions, based on US Congressional Research Service (2015); ⁴ Of which 0.3 $GtCO_2e$ of NOx are fossil fuels emissions, using $GWP_{100}$ = 273; ⁵ Taking average emissions intensity from oil and gas combustion from OCI+ database, 45/55 split between gas/oil.

**SOURCE:** Systemiq analysis for the ETC; IEA (2023), *Scope 1 and 2 GHG emission from oil and gas operations in the Net Zero Scenario*; IEA (2023), *Global Methane Tracker*; IEA (2023), *$CO_2$ Emissions in 2022*; UNEP (2022), *Emissions gap report 2022*; US Congressional Research Service (2015).

17 Systemiq analysis for the ETC; IEA (2023), *Scope 1 and 2 GHG emission from oil and gas operations in the Net-Zero Scenario*; IEA (2023), *Global Methane Tracker*; IEA (2023), *$CO_2$ Emissions in 2022*; UNEP (2022), *Emissions gap report 2022*; US Congressional Research Service (2015). Note that specific estimates of methane emissions are subject to significant uncertainty.

18 The exact 20-year $CO_2$ equivalence multiplier for methane is 29.8, but is rounded to 30 throughout the report. IPCC (2021), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*.

19 Assuming a value for the global warming potential (GWP) over 100 years of 30. Global warming potential is a measure of the contribution to warming from one ton of a gas, relative to the warming induced by one ton of carbon dioxide. The impact of different gases on global greenhouse gas emissions is discussed further in ETC (2021), *Keeping 1.5°C Alive*; ETC (2022), *Mind the Gap*.

20 Systemiq analysis for the ETC, IEA (2023), *Scope 1 and 2 GHG emission from oil and gas operations in the Net-Zero Scenario*; IEA (2023), *Global Methane Tracker*; IEA (2023), *$CO_2$ Emissions in 2022*; UNEP (2022), *Emissions gap report 2022*; US Congressional Research Service (2015).

21 Assuming a $GWP_{100}$ of 30 for methane emissions; scope 1 & 2 emissions for oil and gas are hard to distinguish given their co-production; total scope 1 & 2 emissions for oil and gas are 5.1 $GtCO_2e$, of which 2.4 $GtCO_2e$ from methane. Emissions for oil and gas combustion are calculated as 7.2 $GtCO_2e$ and 8.8 $GtCO_2e$ for gas and oil respectively. Systemiq analysis of OCI (2023), *Oil and gas emissions database*.

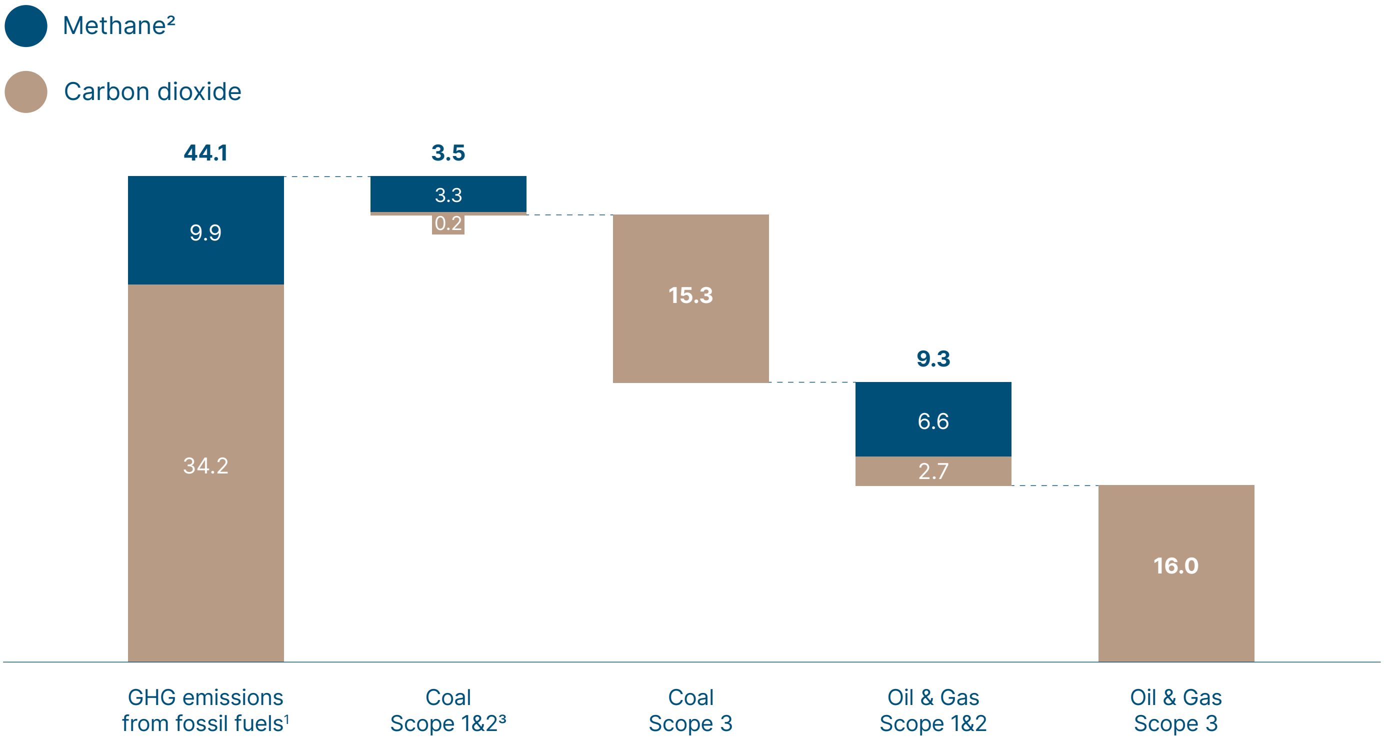
22 Including clean electrification of operations, carbon capture on gas processing and refining operations, and use of green hydrogen in refineries. See Chapter 6.

23 "Scope 1" indicates direct greenhouse gas (GHG) emissions that are from sources owned or controlled by the reporting entity. "Scope 2" indicates indirect GHG emissions associated with the production of electricity, heat, or steam purchased by the reporting entity. "Scope 3" indicates all other indirect emissions, i.e. emissions associated with the extraction and production of purchased materials, fuels, and services, including transport in vehicles not owned or controlled by the reporting entity, outsourced activities, waste disposal, etc. WBCSD and WRI (2004), *A Corporate Accounting and Reporting Standard*.

EXHIBIT 1.2

## Breakdown of global greenhouse gas emissions from fossil fuels ($GWP_{20}$)

Global GHG emissions by source for 2022
$GtCO_2e$




**NOTE:** ¹ Total global GHG emissions are from 2021; UNEP data; ² using a methane $GWP_{20}$ = 82.5; ³ Coal production and transport emissions are estimated as ~1.4% of life-cycle emissions, based on US Congressional Research Service (2015).

**SOURCE:** Systemiq analysis for the ETC; IEA (2023), *Scope 1 and 2 GHG emission from oil and gas operations in the Net Zero Scenario*; IEA (2023), *Global Methane Tracker*; IEA (2023), *$CO_2$ Emissions in 2022*; US Congressional Research Service (2015).

But over 80% of total emissions from fossil fuels, or 31 $GtCO_2e$, are scope 3 emissions which result from the combustion of fossil fuels, and which will only fall if either:

- The quantity of fossil fuels produced and used declines, or
- The $CO_2$ emissions generated during the combustion of fossil fuels are captured and stored ("point-source CCUS").[24]

In addition, it might be possible to offset the emissions produced by remaining fossil fuel use through carbon removals, whether "nature-based" (e.g., reforestation), "engineered" (e.g., DACCS), or hybrid (e.g., BECCS). Chapter 4 considers what role point-source CCUS or removals can and should feasibly play in reaching net-zero emissions by mid-century. Chapter 2 and 3 focus on how fast the use of fossil fuels could and should decline.

Published scenarios for future fossil fuel use vary widely, as Box B illustrates. This reflects different assumptions about technological progress and relative costs, but also different objectives, with some scenarios describing what the authors believe **will** occur, while others describe what **must** occur if the world is to achieve specific temperature limits. Thus, for instance, the IEA publishes three scenarios, two of which (the STEPS and APS scenarios) describe what it believes would occur if existing policy commitments or pledges were achieved,[25] but one which (their net-zero scenario (NZE)) is a normative scenario which sets out what **must** occur if the world is to limit global warming to 1.5°C.[26]

24 Some applications of carbon capture and use (CCU) can also meet such criteria. ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited.*

25 STEPS = Stated Policies Scenario. APS = Announced Pledges Scenario. Neither scenario is designed to achieve a particular outcome in terms of emissions or temperatures. See Box B for a full description.

26 NZE = Net-Zero Emissions by 2050 Scenario, which is a normative scenario designed to achieve net-zero $CO_2$ emissions by 2050, consistent with a 50% chance of limiting the global temperature rise to 1.5°C. See Box B for a full description.

In this report, we present **two ETC scenarios for future fossil fuel demand**, and describe the key policies required to achieve those pathways:

- The **Accelerated but Clearly Feasible** scenario **(ACF):** This scenario is clearly technically and economically feasible, but in some sectors will require more forceful policy support than currently in place.[27] If combined with significant carbon removals, this scenario would be compatible with limiting global warming below 2°C (specifically to 1.7°C), but would not deliver a 1.5°C limit.

- The **Possible But Stretching** scenario **(PBS):** This is also technically and economically feasible, but would require significant strengthening of current commitments and policies. Combined with significant carbon removals, this scenario would come close to delivering a 50% chance of limiting global warming to 1.5°C in 2050, and a level below 1.5°C in 2100 if removals could continue in the second half of the century.

These two scenarios in part reflect previous sectoral analysis conducted by the ETC and MPP. Most of the MPP reports for instance, present a more aggressive and less aggressive path of sectoral emissions reduction, and we reflect these two variants in our sectoral inputs to the ACF and PBS. In modelling the non-MPP sectors (passenger road transport, light industry, building heating, and power sectors), we also define two scenarios which reflect different assumptions about both technological progress and the forcefulness with which policy drives progress.

But it is important to note that, unlike the IEA scenarios, neither our ACF nor PBS scenario is entirely descriptive or entirely normative:

- Both are **partly normative** since we seek to define pathways which, if combined with credible removal assumptions, would result in meeting climate objectives – in the case of the ACF, limiting warming to 1.7°C, and in the case of PBS to close to 1.5°C. And several of the sectoral analyses which input to the aggregate scenarios also impose a normative constraint: in each of the MPP sectoral pathways, the more rapid reduction scenario was designed to stay within a sector-specific carbon budget compatible with 1.5°C.

- But both scenarios are **constrained by a judgement** about what reductions can credibly be achieved over the short-term (i.e. before 2030) given current trends and policy settings, and the difficulty of radically changing these in a short period of time.

We believe that such **"long-term normative but short-term constrained"** scenarios can make a useful contribution to debates about the actions which governments, companies and financial institutions should now take. Chapter 3.2 discusses how our scenarios, developed on this basis, differ from the IEA's, and the implications for appropriate action which follow.

Our scenarios are also designed to be **compatible** with a world in which economic growth enables rising **prosperity in developing and emerging economies.** Since our scenarios build on bottom-up sectoral analyses, and from country-specific studies of power system decarbonisation, they are not based on an explicit forecast of global GDP, nor its regional breakdown. But each of the scenarios reflects rapid growth in energy services demanded across the world, and in particular in emerging and developing economies. Thus, for instance:

- The number of passenger vehicles on the road, whether cars or two- and three-wheelers, is projected to grow from 2,500 million today to 3,800 million by 2050.

- The traditional use of biomass (TUOB) in cooking is entirely eliminated by 2050, and replaced by universal access to modern bioenergy or electricity.

- Electricity consumption in both our scenarios increases 4–5 times in just 27 years in lower middle-income countries such as India, and far faster in low-income regions such as Sub-Saharan Africa.

- And consistent with the principle of common but differentiated responsibilities enshrined in the Paris Agreement, in all sectors we describe pathways in which rich developed economies decarbonise at a faster pace than emerging and developing countries. Thus in our power model, the US and the EU reach near-zero carbon electricity systems by 2035, while many emerging economies only achieve this objective by 2050.

We will set out the implications for energy service use per capita in more detail in our 2024 supplementary report, and explore the implications for assumed global GDP growth. That report will also set out updated estimates of the total cost of the energy transition.

In our 2020 report *Making Mission Possible*, we estimated that the total cost of achieving a fully decarbonised global economy around mid-century would lie between 0.2 to 0.5% of global GDP in that year, with the biggest cost increases deriving from shipping, aviation, cement, and building heating. That estimate reflected analysis of how large the "green

27 Technically feasible implies that demand reductions can be delivered by technologies that are already known and being deployed, even if only on a small scale today. Economically feasible implies that demand reductions can be delivered with limited impacts on prices and thus living standards (relative to business-as-usual) and thus politically feasible.

cost premium" might be in different sectors of the economy in 2050, and necessarily therefore reflected judgments about future technological and cost trends.

Since 2020, each of the MPP sectoral pathway reports has included updated estimates of the green cost premium which are broadly consistent with those we assumed in our 2021 report, and have confirmed that while these premia can be significant at the level of the business product (e.g., a ton of cement, or shipping freight rates), their impact on consumer prices will in most cases be very small. Meanwhile, technological progress has continued at least as fast (and in some sectors faster) than we assumed in 2021.

We therefore believe it unlikely that an updated cost analysis will suggest aggregate costs significantly above those we estimated in 2021. In addition, we note that the IEA, in its latest *Net-Zero Roadmap* report, estimates that the net effect of achieving its net-zero scenario (which is very slightly more ambitious than our PBS) would by 2050 result in total energy investment plus fuel spending being lower as a percentage of GDP than today.[28]

Even if the aggregate total costs of moving to a net-zero economy are small, or even negative at times, there could be significant distributional effects on different categories of consumers or countries, and achieving a net-zero economy will require higher global energy sector investment during the transition. Our 2024 supplementary report will therefore update our analysis of these distributional effects and required investment levels.

Annex A provides more detail on our methodology for developing the scenarios, and the sources on which we have drawn.

28 IEA (2023), *Net-Zero Roadmap*.

**BOX B: DRIVERS OF DIVERGENT SCENARIOS FOR FUTURE FOSSIL FUEL USE**

Different organisations have produced a wide range of forecasts for future fossil fuel use. This wide range reflects **four key factors:**

- Whether the scenario describes what the organisation believes **will/might occur** ("descriptive scenarios") or what **must** occur ("normative scenarios") to limit global warming to a defined temperature increase.
- For normative scenarios, the specific temperature objective - e.g., "well below 2°C" or 1.5°C, which defines the overall carbon emissions budget available.
- Assumptions relating to technological progress and future relative costs, and thus to the economically feasible pace of fossil fuel use reduction.
- Assumptions on the technically feasible and economically optimal role of CCS and carbon removals.

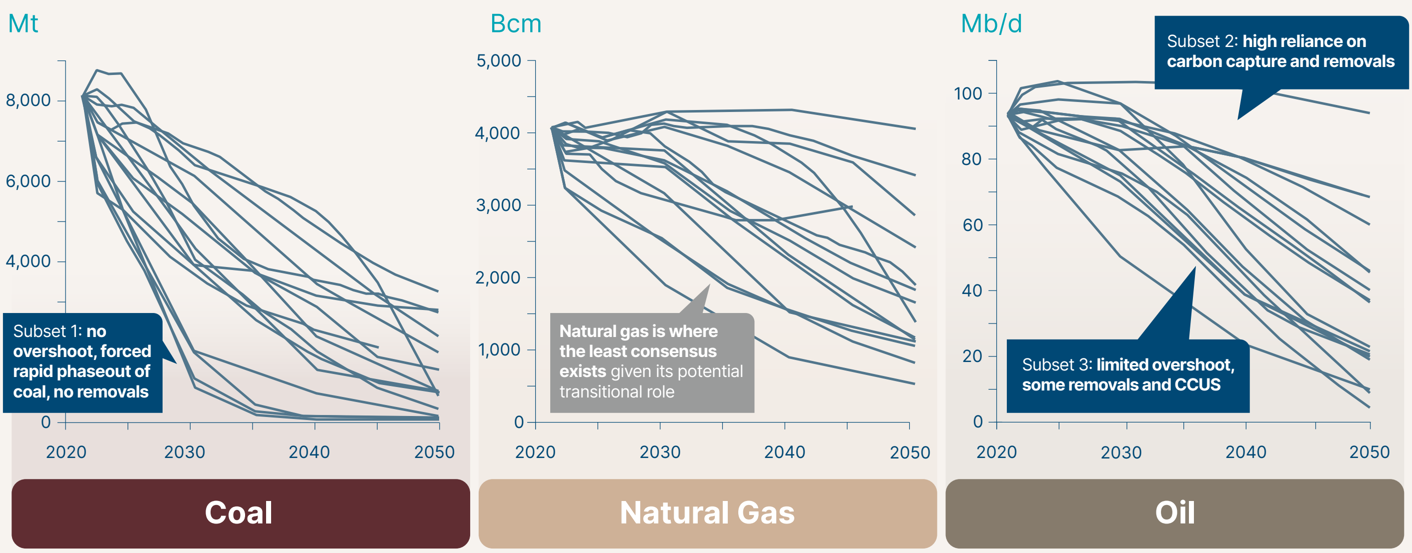
These factors produce a wide range of scenarios which can be grouped into **three categories** [Exhibit 1.3]:

- Scenarios with **no or limited overshoot of the carbon budget**, leading to a rapid reduction in fossil fuels.
- Scenarios with **high continued fossil use** going into the second half of the century, which must rely on high levels of carbon capture and removals if they are to be compatible with climate objectives.
- Scenarios with a more **balanced mix** of the two assumptions above.

**EXHIBIT 1.3**

# Subsets of energy decarbonisation scenarios

Fossil fuels demand in decarbonisation outlooks scenarios
Specific units




**NOTE:** 2021 values for all scenarios are fixed using the IEA's 2021 data, Shell scenarios are linearly interpolated between 2019–2025 due to data availability. Figures reflect primary fossil fuel supply and not final demand. Decarbonisation scenarios are non-business-as-usual energy system projections that imply some degree of decarbonisation, not all decarbonisation reach net-zero by 2050 or at later dates, and reflect a range of temperature assessments and emissions overshoot.

**SOURCE:** Systemiq analysis for the ETC; IEA (2022), *Global Energy and Climate Model*; BNEF (2022), *New Energy Outlook*; Equinor (2023), *Energy Perspectives*; BP (2023), *Energy Outlook*; Shell (2023), *The Energy Security Scenarios*; IPCC (2023), *Sixth Assessment Report*; TotalEnergies (2022), *Energy Outlook*; NGFS (2022), *Climate Scenarios Database*; DNV (2022), *Energy Transition Outlook*; OPEC (2022), *World Oil Outlook*.

Within this wide range, it is useful to focus in particular on the three scenarios produced by the IEA, given its authoritative reputation figure in energy forecasts. These are all designed to be technically and economically feasible, but with different objectives:[29]

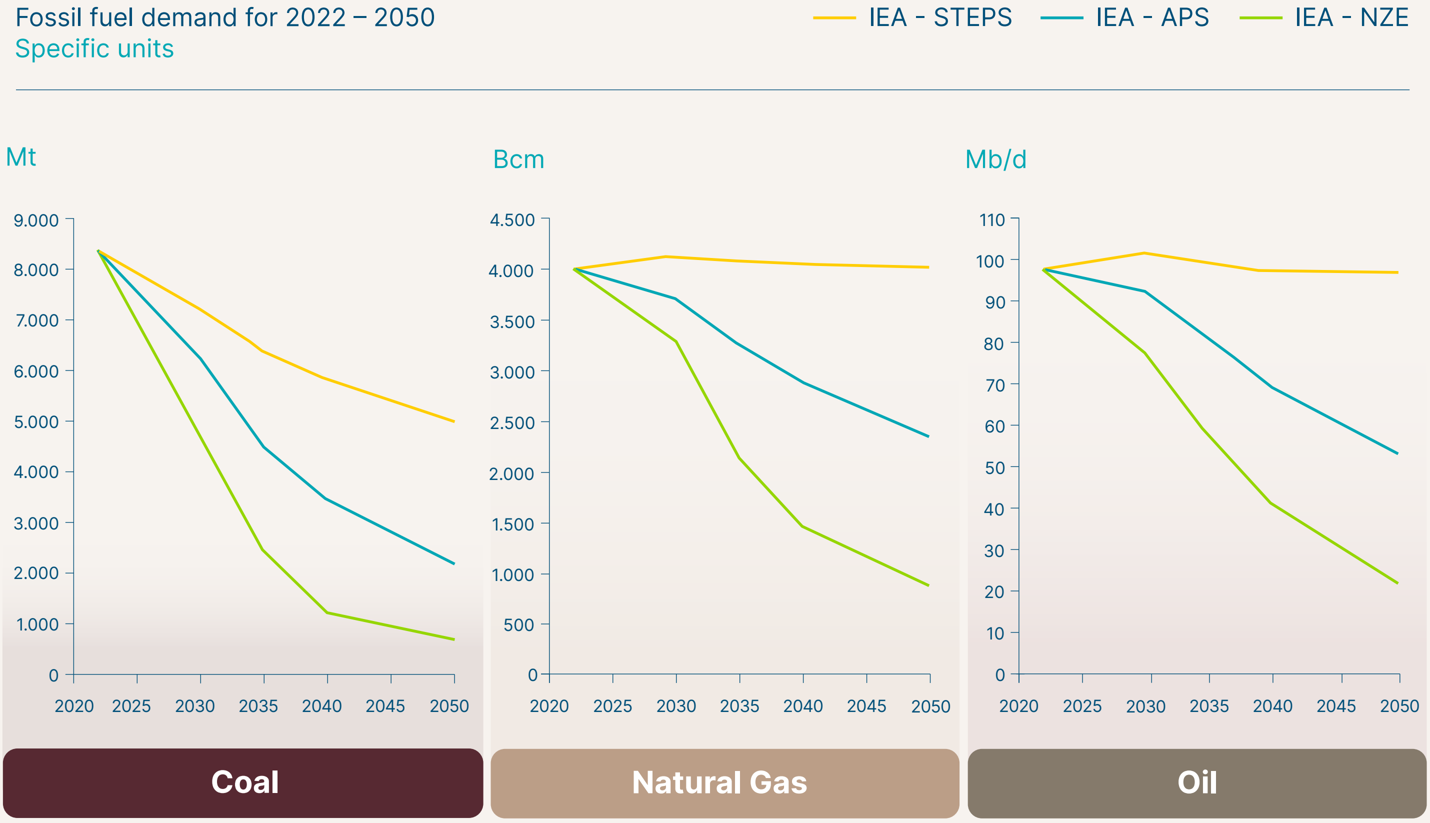
- The *Stated Policies Scenario* (STEPS): This scenario describes how fossil fuel use might evolve, given the specific policies already in place and assuming no additional strengthening of policy. Although not designed to achieve a specific emissions or temperature target, the IEA estimates that this would give a median expected global warming of 2.3°C, with a more than 10% chance of exceeding 3.5°C in 2100.[30]
- The *Announced Pledges Scenario* (APS): This scenario projects how fossil fuel use and emissions would fall if governments met the emission reduction pledges they have made, even if those pledges are not yet matched by specific policies. Although not designed to achieve a specific emissions or temperature target, the IEA estimates this scenario would deliver a median expected global warming of 1.7°C.[31]
- The *Net-Zero Emissions scenario* (NZE): This is a normative scenario which describes what the world must do to reach net-zero $CO_2$ emissions by 2050 and have a 50% chance of limiting global warming to 1.5°C by 2100,[32] without relying on offsets or removals from outside the energy sector.[33] This scenario is defined to be clearly technically feasible, but would require a significant strengthening of government pledges and policies and some significant changes in consumer behaviour.

Given these different objectives, the three IEA scenarios imply very different paths for fossil fuel use decline, as shown in Exhibit 1.4.

EXHIBIT 1.4

## Fossil fuel demand in IEA scenarios for 2022–2050

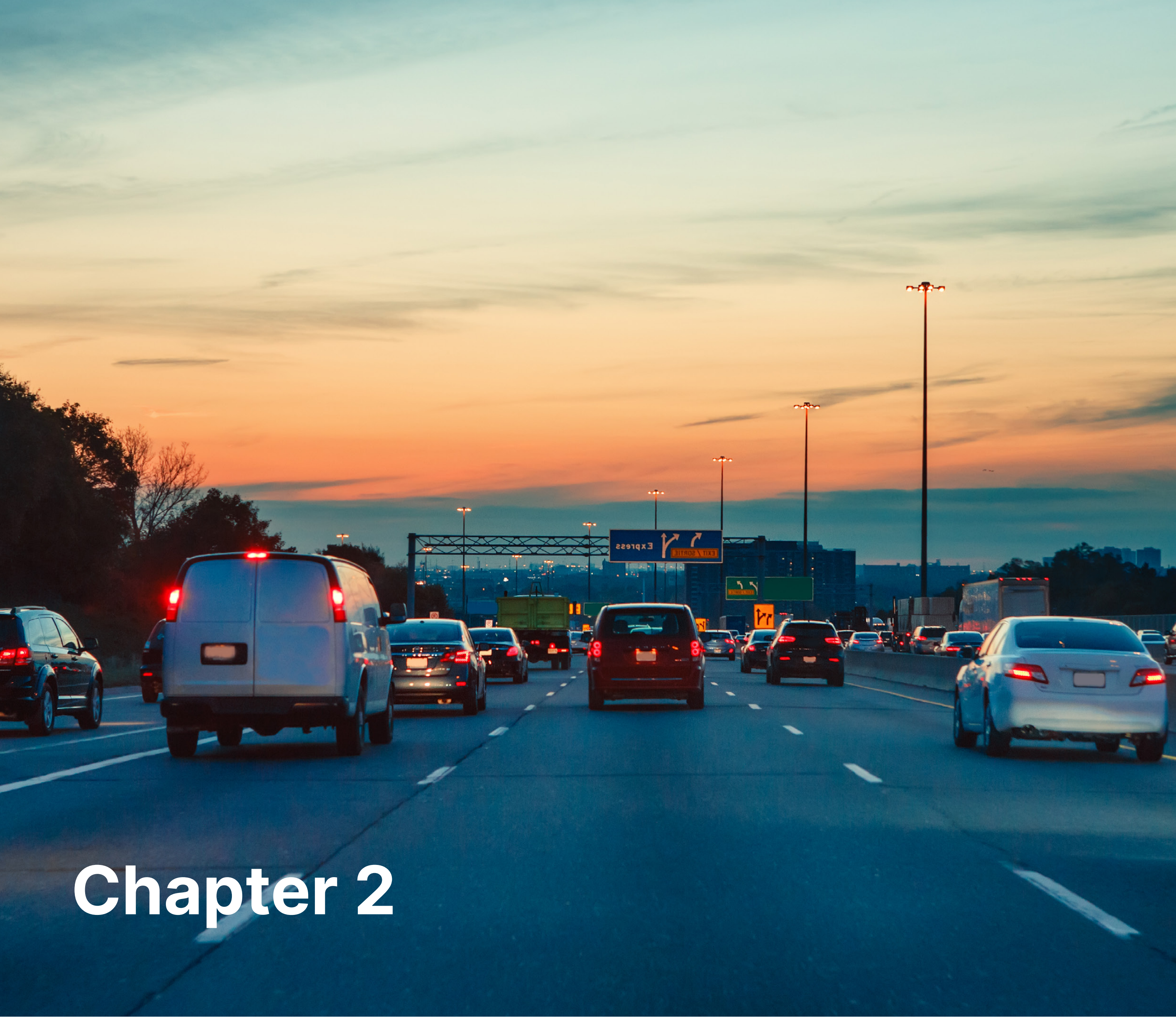
Fossil fuel demand for 2022 – 2050
Specific units




**NOTE:** STEPS = Stated Policies Scenario, APS = Announced Pledges Scenario, NZE = Net Zero Emissions. STEPS, APS and NZE values are taken for the 2023 updated IEA NZE roadmap. Values are fixed to the IEA NZE 2023 starting point. Values shown here are primary energy demand.

**SOURCE:** Systemiq analysis for the ETC; IEA (2023), *World energy outlook 2023*; IEA (2023), *Net zero roadmap: A global pathway to keep the 1.5°C goal in reach.*

29 IEA (2022), *Global energy and climate model.*
30 IEA (2022), *World Energy Outlook 2022.*
31 IEA (2022), *Global energy and climate model.*
32 Ibid.
33 IEA (2022), *Net-zero by 2050, A roadmap for the global energy sector.*



# Chapter 2

# Feasible reductions in fossil fuel demand by sector and role of different technologies

In the sections below we set out:

- The starting point for fossil fuel use by sector today.
- Projected fossil fuel use by sector of the economy to 2050.
- The pathway for the decarbonisation of the power system and implications for coal and gas demand.
- Cross-cutting technologies – CCUS, hydrogen and bioenergy.
- The role of energy efficiency improvements.

## 2.1 The starting point – fossil fuel use by sector today

In 2022, the global economy used around 8.4 billion tonnes of coal,[34] 4,200 Bcm of gas and 96.7 Mb/d of oil.[35] In energy equivalent terms, this amounted to 82% of total primary energy demand from 169 EJ of coal, 150 EJ of gas, and 194 EJ of oil, the combustion of which resulted in 15.3, 7.2 and 8.8 Gt of $CO_2$ emissions respectively [Exhibit 1.1].

The sectoral mix of end-use of the three fuels is shown in Exhibits 2.1 to 2.3. For each of the three fuels, some fuel is used during the production, processing, and refining of the fuel before end use, especially for oil refining and natural gas processing. Some of these processes are tied to specific end uses, but most are relevant to all end uses and will therefore decline as those uses decline. In Exhibits 2.1 to 2.3, we therefore identify the "energy sector own use" element explicitly on the left-hand side, but allocate this across end-use categories on the right.

The sectoral mix of end-uses differs significantly between the three fossil fuels and as a result, so does the technical feasibility of applying carbon capture:

- **Coal** use is concentrated in power and steel production, with use in the cement industry also significant [Exhibit 2.1]. In each of these sectors, it is technically feasible to apply carbon capture, but in the power and steel sectors in particular, alternative technologies may allow lower cost decarbonisation.[36]
- **Gas** is predominantly used across the power, industry, and buildings sectors [Exhibit 2.2]. Within industry, gas serves both as an energy source and feedstock for the production of chemicals. It is also widely used in various industrial sectors as a source of heat for a wide variety of processes.[37] In buildings, it plays a pivotal role in supplying space and water heating in many countries. Point source CCS is technically feasible in the power sector and certain industrial applications but is unfeasible for most building applications due to their decentralised nature. As with coal, alternative decarbonisation technologies will often be more cost-effective, even in many cases where carbon capture is technically viable.
- **Oil** use is predominantly found in transport, which accounts for 56 Mb/d out of the total 96.7 Mb/d, or 60 Mb/d if we include transport's share of oil used in refining [Exhibit 2.3]. Point-source CCUS is very unlikely to be technically and economically feasible in these sectors,[38,39] implying that decarbonisation will almost always require reduced oil use. The other major use is in the chemicals sector, accounting for 17 Mb/d, where oil serves as both an energy source and feedstock. In some cases, carbon capture is technically feasible in this sector. Additionally, around 20 Mb/d is used in a wide variety of applications across power generation, other industries, and the buildings sector. Oil is also used to produce various non-energy products, such as bitumen or adhesives.[40]

34 Types of coal differ widely in energy density (or calorific value) and a standardised measure of "million tonnes of coal equivalent" (Mtce) is therefore often used to compare coal consumption by sector on an energy equivalent basis. Using this approach, the 8.4 billion tonnes of physical coal consumed is 5.8 billion tonnes of coal equivalent. In most of our analysis below, we use the coal-equivalent measure, but occasionally use the physical measure for comparison with other published scenarios.

35 IEA (2023), *World Energy Outlook 2023.*

36 ETC analysis shows that wind and solar can make up 75–90% of the majority of global power systems without increasing overall system costs. Some flexible generation (such as fossil fuel power with CCS, or hydrogen power plants) is likely to be required within the remaining 10–25%, alongside nuclear power, hydropower, other renewables and other flexibility options such as battery storage, interconnection and demand-side response. ETC (2021), *Making clean electrification possible.*

37 Systemiq analysis for the ETC; IEA (2023), *Energy balance dataset.*

38 With the exception of shipping and aviation, where captured $CO_2$ can be used as a feedstock, together with low-carbon hydrogen, for transportation fuels. Chapter 4 of this report and ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited.*

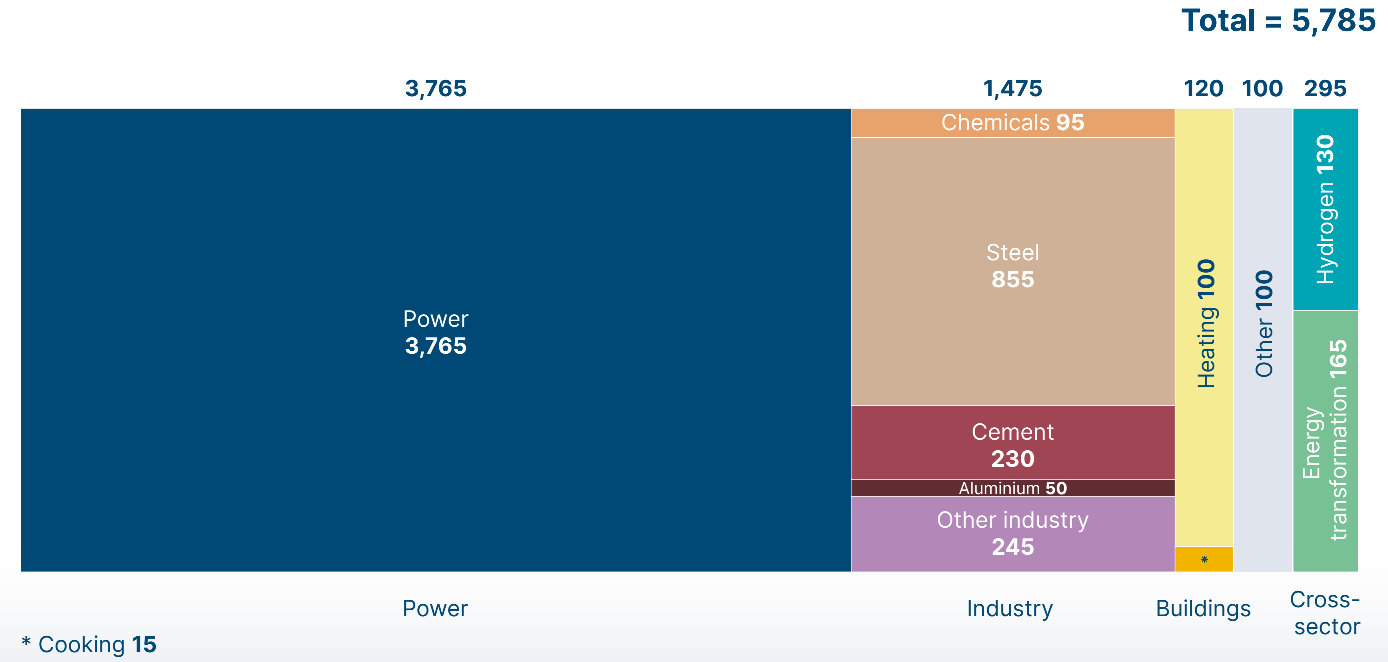
39 Note that the shipping industry is exploring the potential role of onboard carbon capture. Maersk Mc-Kinney Moller Center for Zero Carbon Shipping (2022), *The role of onboard carbon capture in maritime decarbonisation.*

40 RystadEnergy (2022), *Oil market transition report.*

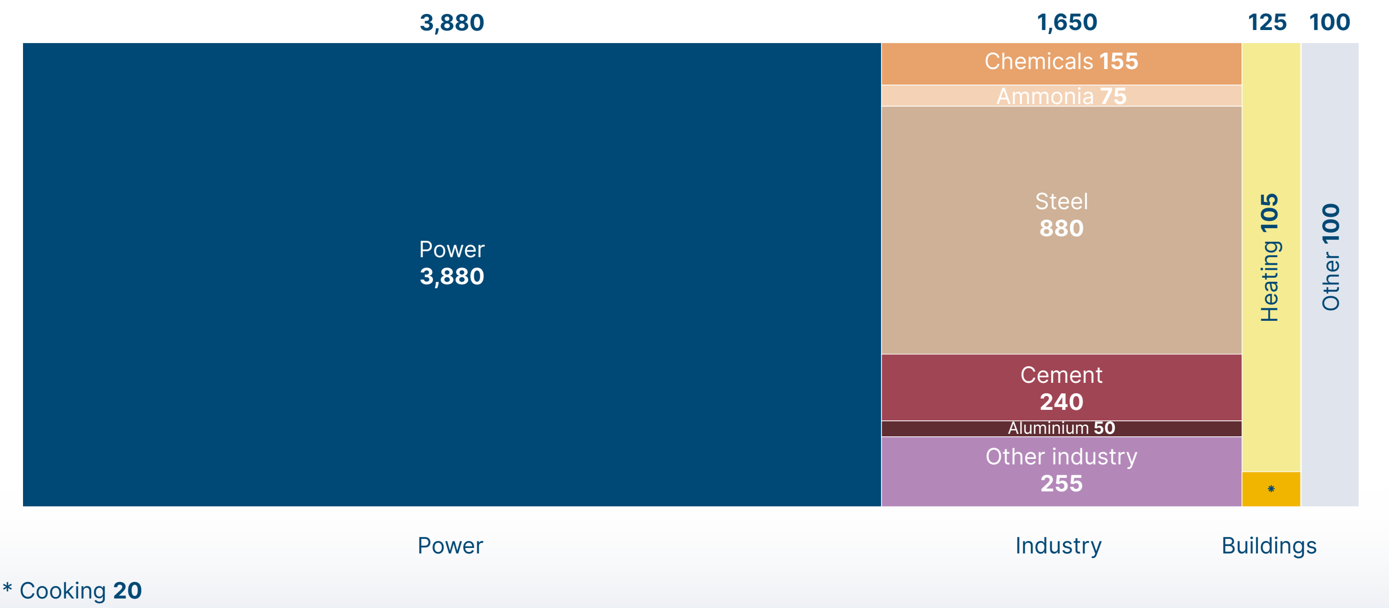
EXHIBIT 2.1

# Coal demand by end use

Sectoral breakdown of coal consumption for 2022
Mtce




Not allocating energy transformation and hydrogen




Allocating energy transformation and hydrogen to final energy end-uses

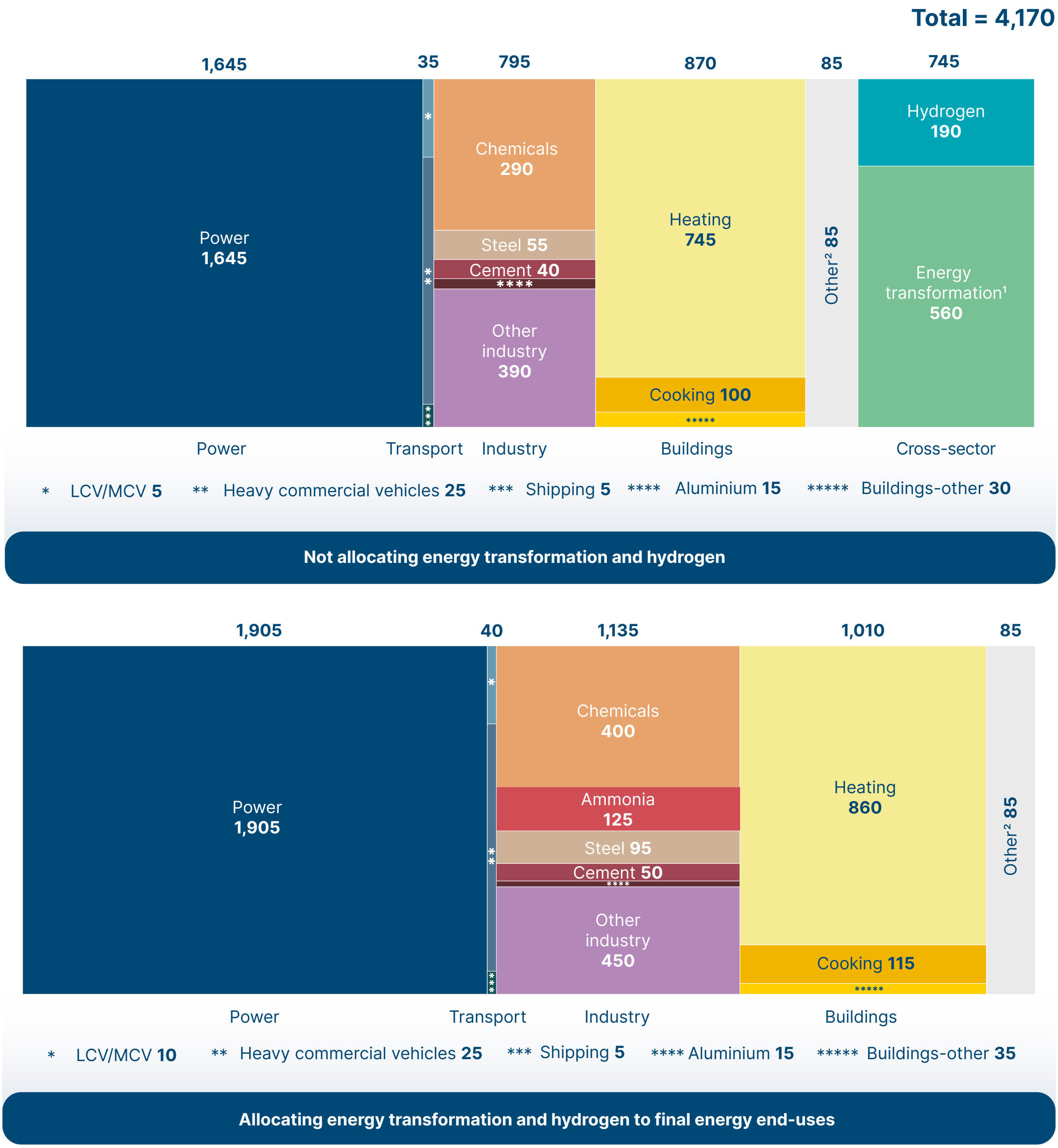
**NOTE:** All numbers are rounded. Final Energy Demand showed, units for coal consumption are shown in million tons of coal equivalent, with 1 EJ = 34.12 Mtce, and is a unit of energy that accounts for the various coal grades used in end-use applications. Another frequently used unit is the volumetric million tons of coal, with 1 EJ = 49.1 Mt, which results in ~8,400 Mt of coal being used today.

**SOURCE:** Systemiq analysis for the ETC; BNEF (2023), *New Energy Outlook 2022*; IEA (2022), *World Energy Outlook 2022*.

EXHIBIT 2.2

# Natural gas demand by end use

Sectoral breakdown of gas consumption for 2022
Bcm



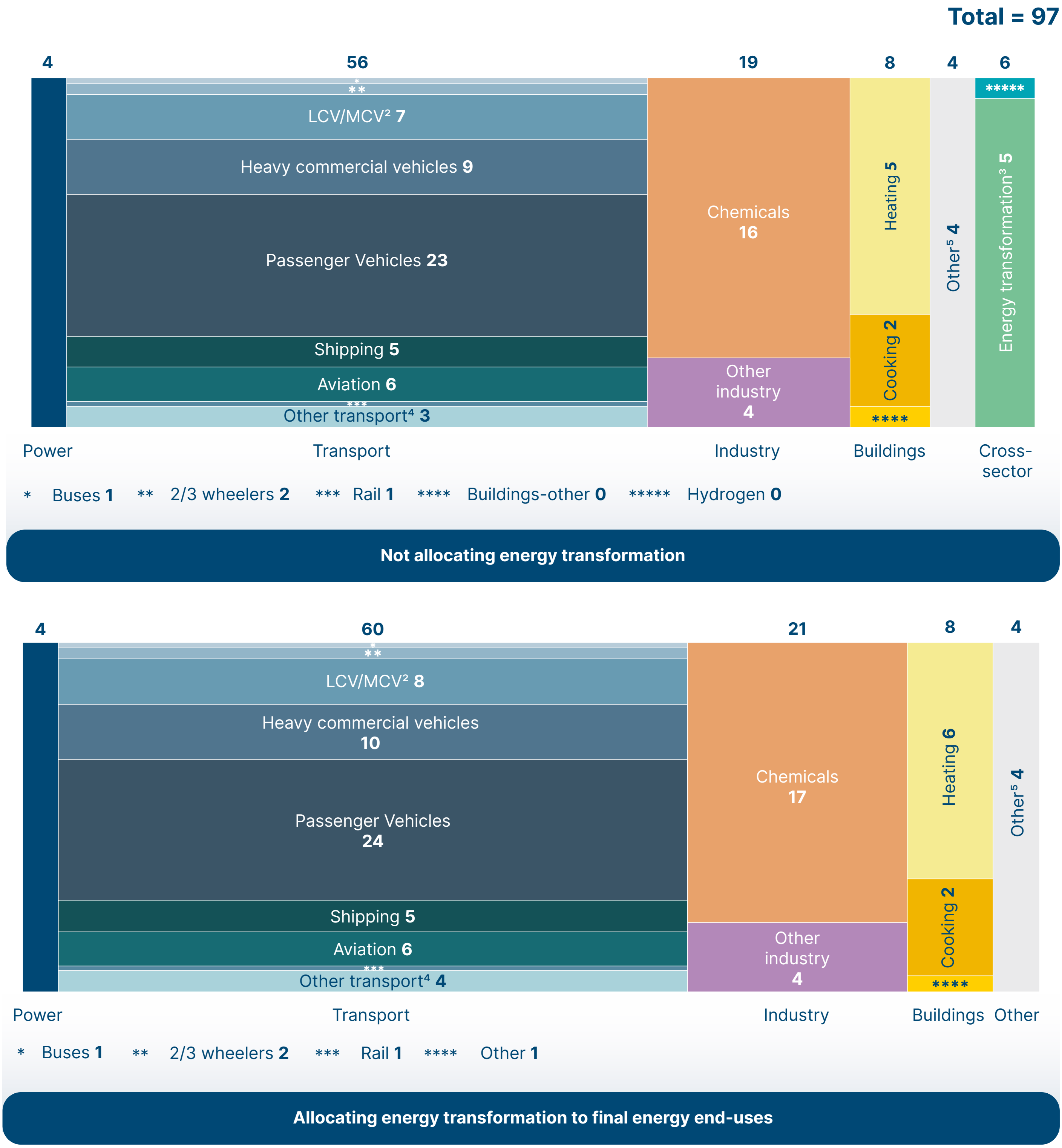

**NOTE:** All numbers are rounded. Final Energy Demand showed, all non-energy use assumed to be petrochemical feedstock (as per BNEF definition), "Energy Industry" considered as being all refining (as per BNEF definition); almost all natural gas use in road transportation is for heavy road transport. ¹ refining; ² incl. Non energy uses.

**SOURCE:** Systemiq analysis for the ETC; BNEF (2023), *New Energy Outlook 2022*; IEA, *World Energy Outlook 2022*.

EXHIBIT 2.3

# Oil demand by end use

Sectoral breakdown of oil[1] consumption for 2022
Mb/d




**NOTE:** All numbers are rounded. [1] Represents total liquids demand, including biofuels and processing gains from refineries; [2] Light and Medium Commercial Vehicles. [3] refining; [4] incl. Agriculture, mining etc; [5] incl. Non energy uses; assumed 90%/10% split for oil use in feedstock and energy for the petrochemicals sector, difference from bottom-up aggregation with reported total demand with IEA (2.8%) is equally allocated across sectors.

**SOURCE:** Systemiq analysis for the ETC; RystadEnergy (2022), *Oil Market Transition Report 2022*; IEA (2023), *World Energy Outlook 2023*; IEA (2023), *Oil Market Report*; IEA (2019), *The Future of Petrochemicals*.

## 2.2 Fossil fuel demand in energy-using sectors

In a series of past reports, the ETC has described feasible pathways to decarbonise the energy, building, industry, and transport sectors of the economy.[41] By far, the most important driver of decarbonisation is widespread electrification, combined with the decarbonisation of power production. However, hydrogen, bioenergy, continued fossil fuel use, and CCS will also play important roles in decarbonising the energy system.

In the sub-sections below, we first consider the optimal mix of these technologies and the feasible pace of their deployment in the transport, industry, and building sectors, and the resulting implications for declining fossil fuel use. This decline is offset by rising demand for either electricity, bioenergy, or hydrogen. We then assess the optimal and feasible pathway for power sector decarbonisation, the role of CCUS and the balance between green hydrogen production (using zero-carbon electricity) and blue hydrogen production (using methane with CCS). Annex A presents our assumptions and findings in more detail.

### 2.2.1 Transport

The use of oil in transport is likely to fall dramatically (e.g., more than 90%) by 2050. However, there are limits to the pace at which the existing stock of assets (e.g., cars, trucks, planes, ships) can be turned over and new technologies can be deployed. These limits restrict the feasible reduction to 13% by 2030 even in our PBS scenario. Progress towards decarbonisation should be fastest in road transport, but by 2050, it is also possible for aviation and shipping to achieve net-zero emissions with only minimal use of offsets.

#### Road transport

Almost half of all oil today is consumed in road transport (i.e. 43 Mb/d), the majority of which (around 24 Mb/d) is consumed in passenger cars.[42]

Prospects for road transport electrification have developed faster than anticipated [Exhibit 2.4]. Globally, 14% of passenger vehicles sold in 2022 were all-electric vehicles – 10 times more than just five years ago.[43] Passenger EV sales are likely to reach approximately 15 million (20% of the global market) in 2023, and approach 40% of total passenger vehicle sales in China.[44]

Advances in battery technology are driving rapid improvements in range and charging speed, and an increasing number of countries and companies are committed to phasing out sales of new ICE cars beyond specific dates.[45] ICE passenger car sales (with only small exceptions) will cease in 2025 in Norway and 2035 in the UK and the whole of the EU.[46] Jaguar is committed to 100% electric sales by 2025, Stellantis by 2029, Volvo by 2030, Mitsubishi by 2035,[47] and Land Rover by 2036 [Exhibit 2.5].[48] BYD has only produced EVs since March 2022.[49]

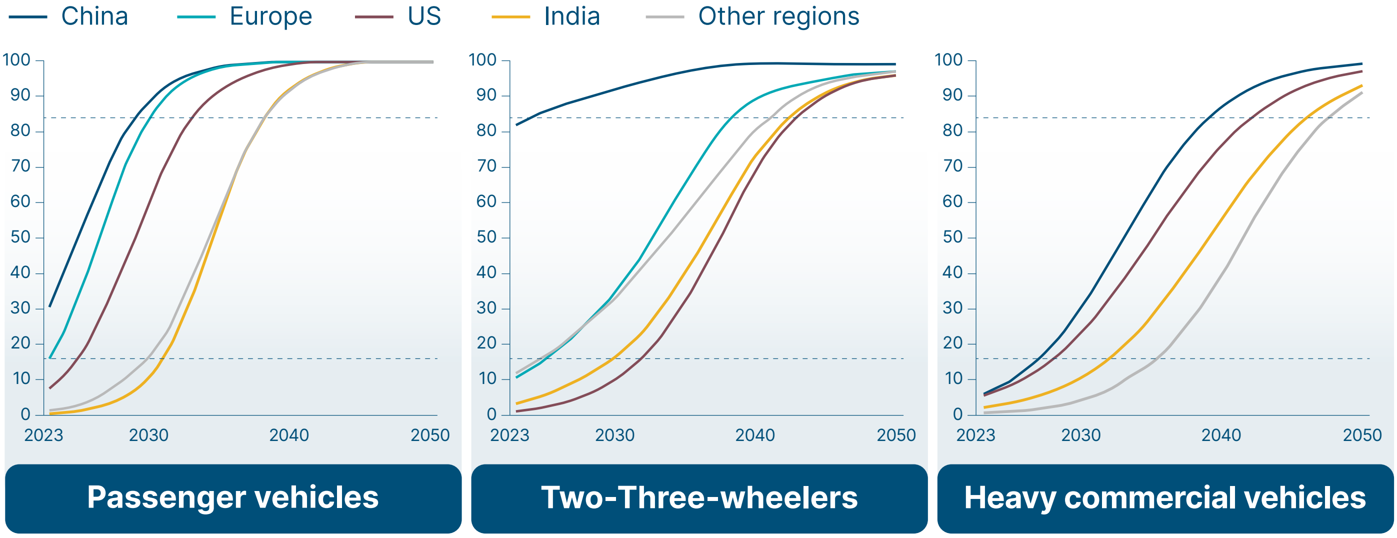
Prospects for the electrification of heavy-duty trucks, including pure battery electric models rather than fuel cell electric, have also progressed faster than previously anticipated.

41 ETC (2020), *Making Mission Possible*; ETC (2021), *Making Clean Electrification Possible*; ETC (2021), *Making the Hydrogen Economy Possible*; ETC (2021), *Bioresources within a Net-Zero Emissions Economy*; ETC (2022), *Carbon Capture, Utilisation & Storage in the Energy Transition: Vital but limited;* ETC (2022), *Mind the Gap*.
42 RystadEnergy (2022), *Oil market transition report*.
43 BNEF (2023), *Long-term electric vehicle outlook*.
44 Ibid.
45 IEA (2023), *Global EV outlook 2023*.
46 European Union (2023), *'Fit for 55': Council adopts regulation on $CO_2$ emissions for new cars and vans.*
47 Mitsubishi (2023), *FY2023–2025 Mid-Term Business Plan*.
48 Jaguar (2021), *Public announcement*.
49 BYD (2022), *Public announcement*.

## EXHIBIT 2.4

# Share of electric vehicles as a function of total vehicle sales in the ACF scenario

Electric vehicle sales over time
% of total vehicle sales

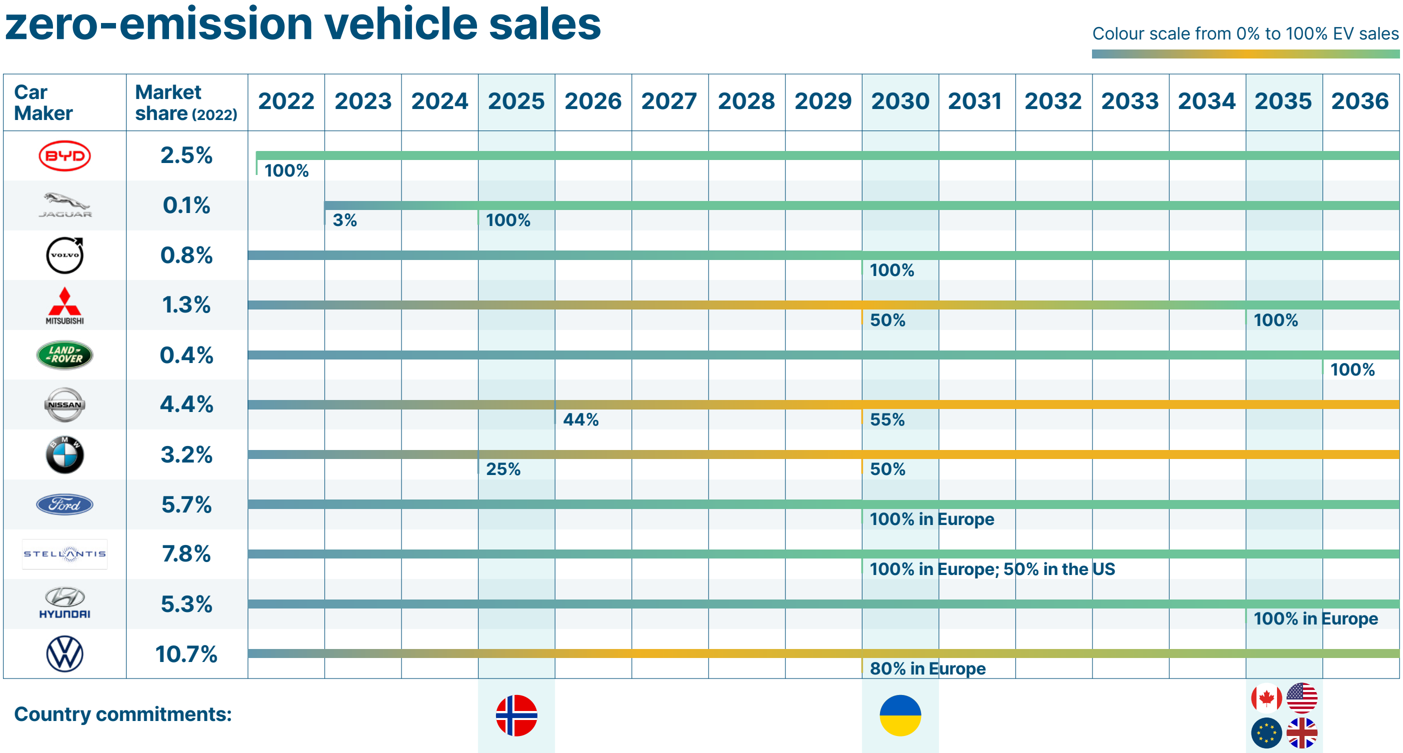



**NOTE:** Electric vehicles include both battery electric and fuel-cell vehicles for heavy commercial vehicles. S-curve methodology is based on Rogers' innovation diffusion theory (1962). Dotted lines represent the maximum growth and inflection points, respectively equivalent to 16 and 84% of sales. These points are defined as points on the curve in which the concavity changes. Growth and inflection points are calculated based on BNEF (2023), *Electric Vehicle Outlook*. Europe and the US exhibit similar s-curve patterns in heavy commercial vehicles, with the US slope obscuring that of Europe.

**SOURCE:** Systemiq analysis for the ETC; BNEF (2023), *Electric Vehicle Outlook*; MPP (2022), *Making Zero-Emissions Trucking Possible.*

## EXHIBIT 2.5

# Passenger vehicle company commitments and targets for zero-emission vehicle sales




**NOTE:** Company = Original Equipment Manufacturer. Blue shaded areas correspond to 100% zero-emission vehicle sales targets from countries/regions. Yellow lines indicate a >50% share of zero-emission vehicle sales, 100% sales are indicated in green. Market shares are calculated for 2022. Table updated as of October 2023.

**SOURCE:** Systemiq analysis for the ETC; IEA (2023), *Global EV Outlook 2023*; BNEF (2023), *Electric Vehicle Outlook*; 2022 annual reports from selected car manufacturers.

Given these developments, we expect that by sometime around mid-century, ICE vehicles will be almost entirely eliminated from the global fleet and replaced primarily by electric vehicles, with a possible role for hydrogen fuel cell electric vehicles in the heavy-duty sector.[50] The precise composition of the passenger vehicle fleet in 2050, and the trajectory from today, will depend on the proportion of new vehicle sales that are electric in each year, the rate at which existing ICE vehicles are retired from the global fleet, and the size of that fleet which in turn could be influenced by the growth of car-sharing models and robotaxis, which could make it possible to meet demand for transport with fewer vehicles on the road.

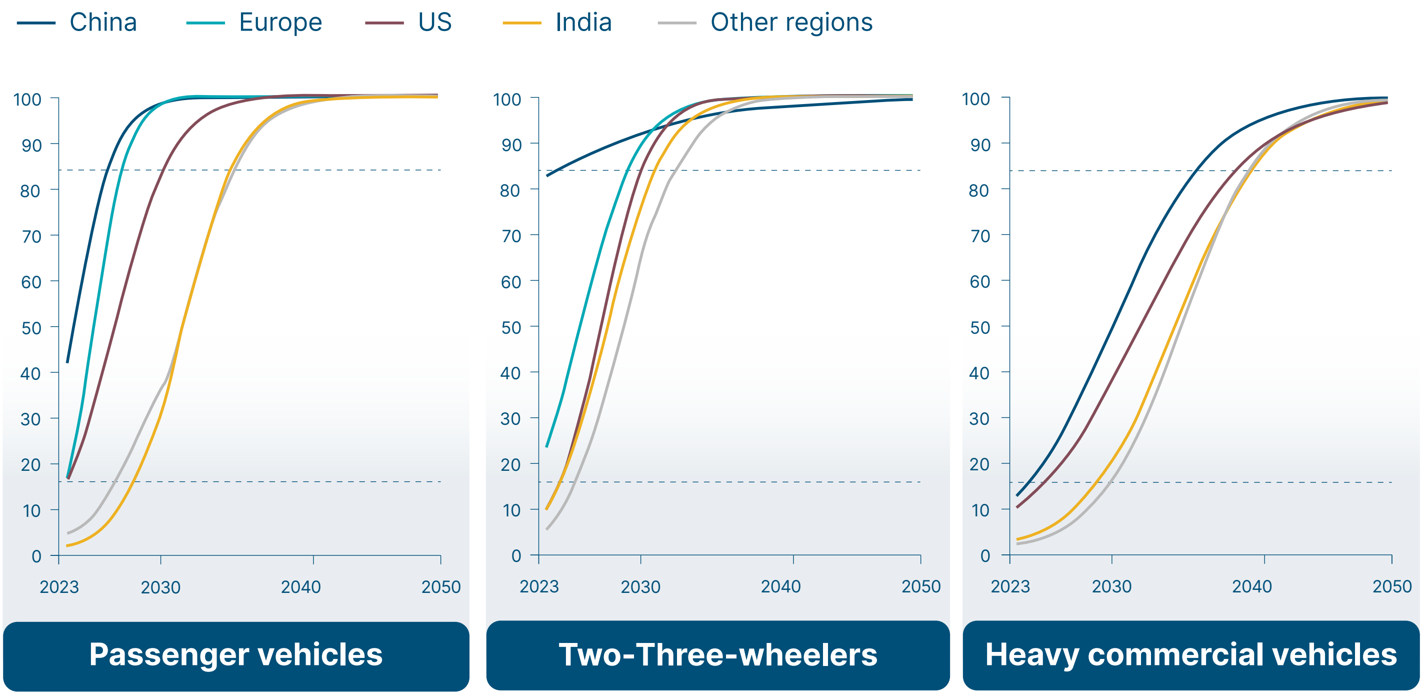
The sales assumptions in our PBS scenario are set out in Exhibit 2.6:[51]

- For passenger cars and light-duty commercial vehicles, EV sales could exceed 90% in several major markets, including China, as early as 2030; some lower-income countries may experience this transition at considerably later dates.
- Two- or three-wheeler markets could experience an even more dramatic shift to EVs.
- Electric shares in heavy-duty commercial vehicles will grow more slowly but could reach around 75% in several major markets by 2035 in our PBS scenario.

EXHIBIT 2.6

## Share of electric vehicles as a function of total vehicle sales in the PBS scenario

Electric vehicle sales over time
% of total vehicle sales




**NOTE:** Electric vehicles include both battery electric and fuel-cell vehicles. S-curve methodology based on Rogers' innovation diffusion theory (1962). Dotted lines represent the maximum growth and inflection points, respectively equivalent to 16 and 84% of sales. These points are defined as points on the curve in which the concavity changes. Growth and inflection point are calculated based on BNEF 2023 Electric Vehicle Outlook. Europe and the US exhibit similar s-curve patterns in heavy commercial vehicles, with the US slope obscuring that of Europe.

**SOURCE:** Systemiq analysis for the ETC; BNEF (2023), *Electric Vehicle Outlook*, MPP (2022), *Making Zero-Emissions Trucking Possible.*

50 There may also be a role for hydrogen-based combustion engines in the trucking sector depending on geographical specificities and availability of low-carbon hydrogen supply and refuelling infrastructure readiness. This includes oil demand in "Other transportation" in our analysis, such as heavy vehicle uses in logging, farming and mining.

51 See Annex A for sales assumptions in the ACF.

The uptake of battery electric vehicles will only be possible if charging networks grow at an adequate pace, which will require significant investment in grid infrastructure. For passenger EVs, we believe this infrastructure challenge will be overcome, with charging patterns favouring slow charging overnight in areas with existing grid availability.

But for trucks, overcoming this barrier will require overt policies to develop and reinforce grid infrastructure, in particular regional, middle voltage distribution grids (10 –130 kV). These will need to support, at each major truck recharging location, both large numbers of slow chargers (80 kW) for overnight charging and more limited numbers of fast chargers (350–700 kW) for intraday charging.[52] Without clear strategies to develop this infrastructure, the penetration of EV trucks could grow more slowly than our scenarios assume.

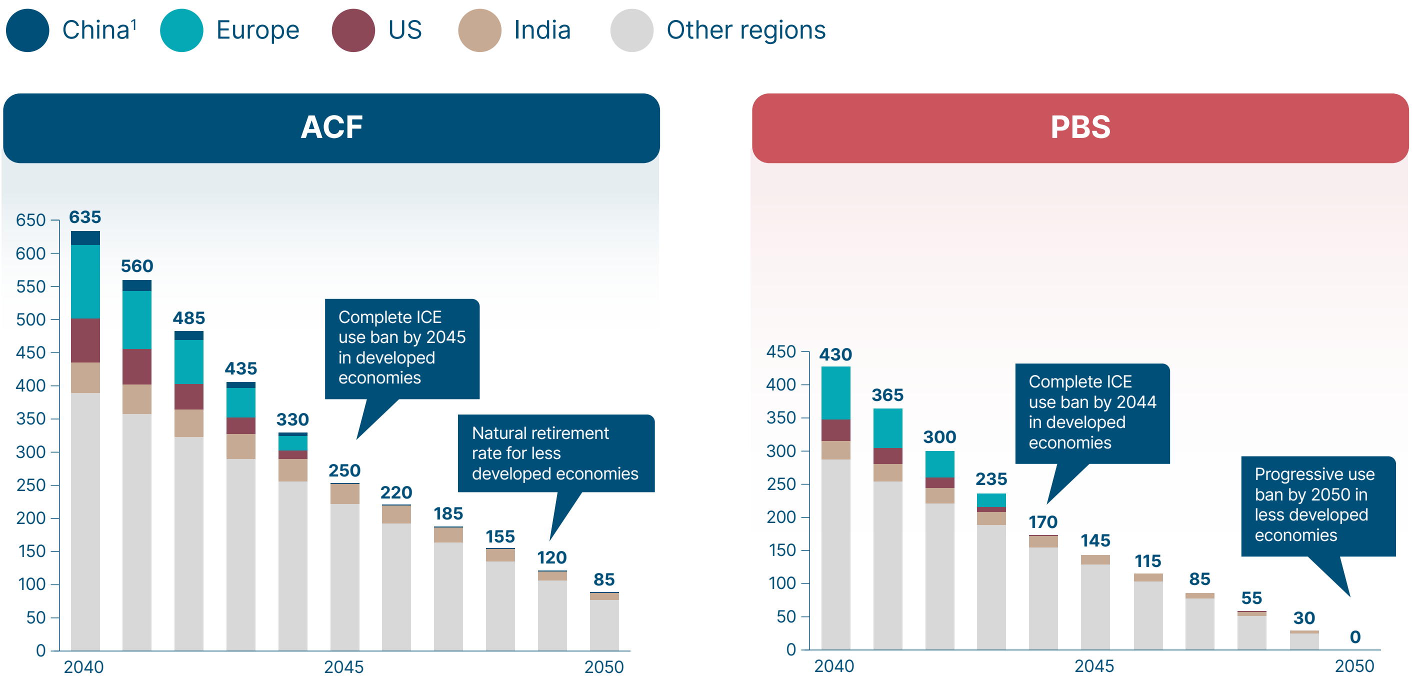
The pace at which existing ICE vehicles are retired from operation will vary significantly by country, and could be notably low in some low-income countries where vehicle fleets often include a significant share of second-hand vehicles imported from developed economies.[53] However, retirement rates could also be influenced by public policies, such as restrictions on the use of ICE vehicles in major cities, or financial incentives like subsidies for scrappage.[54]

In both the ACF and PBS scenarios, we assume a normal average vehicle lifespan in line with the historical average of about 15 years for passenger vehicles.[55] In the PBS scenario, we assume that public policies could accelerate the early retirement of ICE vehicles in the 2040s [Exhibit 2.7].

**EXHIBIT 2.7**

## Evolution of the passenger ICE fleet by region in ACF and PBS

Passenger ICE fleet size by region
Million vehicles (2040–2050)




**NOTE:** All numbers are rounded. The natural retirement of a passenger vehicle occurs 15 years after its sale. Forceful use bans are implemented to accelerate the retirement of remaining ICE vehicles by 2050. [1] China doesn't appear in the PBS fleet bar chart because all ICE cars have already been naturally replaced by EVs.

**SOURCE:** Systemiq analysis for the ETC; BNEF (2023), *Electric Vehicle Outlook*.

52 Volvo (2023), *Internal research on grid capacity bottlenecks*.
53 IEA (2023), *Global EV outlook 2023*.
54 For example, India introduced a Vehicle Scrappage Policy in 2022 requiring passenger vehicles more than 20 years old, and commercial vehicles more than 15 years old, to pass emissions tests to keep their registration, and France provides payments for scrappage of old vehicles. IEA (2023), *Policies database – transport*.
55 Systemiq analysis for the ETC.

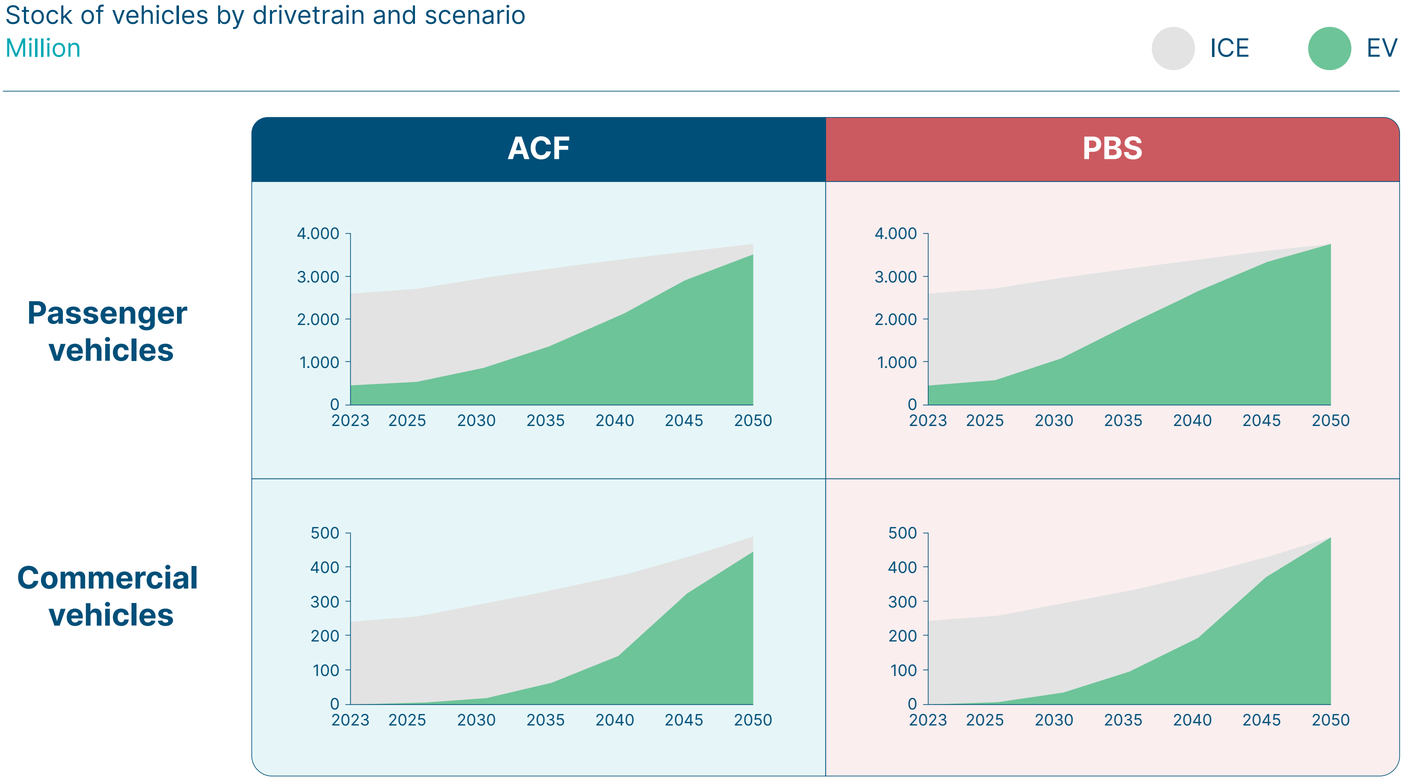
The combination of our assumptions regarding sales and retirement rates leads to the distribution of EV and ICE vehicles on the road as depicted in Exhibit 2.8:

- In each scenario, the share of non-ICE vehicles (whether electric or fuel-cell vehicles) approaches 100% by 2050. And while slower progress is possible (in particular in the heavy trucks segment), there is a high degree of certainty that this close-to-zero ICE end point will be reached at some time around mid-century.
- But even in our PBS scenario, over 75% of passenger cars on the road in 2030 will be ICE, and approximately 90% for heavy trucks, limiting the fall in oil demand possible by that date.

**EXHIBIT 2.8**

## Breakdown of vehicle fleet by powertrain and vehicle type in ACF and PBS

Stock of vehicles by drivetrain and scenario
Million




**NOTE:** Passenger vehicles include buses, passenger cars and two-three-wheelers. Commercial vehicles include light, medium and heavy commercial vehicles.

**SOURCE:** Systemiq analysis for the ETC; BNEF (2023), *Electric Vehicle Outlook*; MPP (2022), *Making Zero-Emissions Trucking Possible*.

With a large ICE fleet still operating for many years, oil demand will be influenced not only by the speed of electrification, but also by the average fuel efficiency of the remaining ICE fleet. Technical progress has enabled the continued improvement in fuel efficiency for a given category of automobile, but the recent rise in the average weight of vehicles, driven by Sports Utility Vehicle (SUV) sales, has counteracted this progress.[56] Robust policies would be required to negate this trend and attain achievable efficiency enhancements. In the PBS scenario, we assume that such policies could be put into action, while the ACF scenario adopts a more pessimistic projection for the evolution of ICE fuel efficiency, as explained in Box C.

56 IEA (2021), *Global SUV sales set another record in 2021, setting back efforts to reduce emissions.*

**BOX C: FUEL ECONOMY OF THE INTERNAL COMBUSTION ENGINE FLEET**

Despite continuous advancements in fuel efficiency due to technical innovations, progress in fuel economy has stalled in recent years. This can be primarily attributed to the trend of vehicles becoming increasingly larger and more powerful. Between 2010 and 2019, the average sales-weighted new light-duty vehicle saw a 6.2% increase in weight, a 20% boost in power, and a 7% expansion in its footprint.[57] In that period, increasing vehicle size and power have negated up to 40% of the potential fuel consumption improvements that could have otherwise been achieved.

Going forward, technical fuel efficiency improvements may slow down as a car OEMs increasingly focus R&D efforts and spending on alternative powertrains rather than internal combustion engines. But further improvements are still possible, unless offset by further increases in average vehicle size and weight.

In our PBS scenario, we assume that the average fuel efficiency of the global ICE fleet improves by 1.6% p.a., in line with continued historic improvements. This will require the imposition of fuel economy standards specifically focused on ICE vehicles, and could also be supported by increased taxation of larger vehicles, and incentives to accelerate the retirement of less fuel-efficient ICEs.

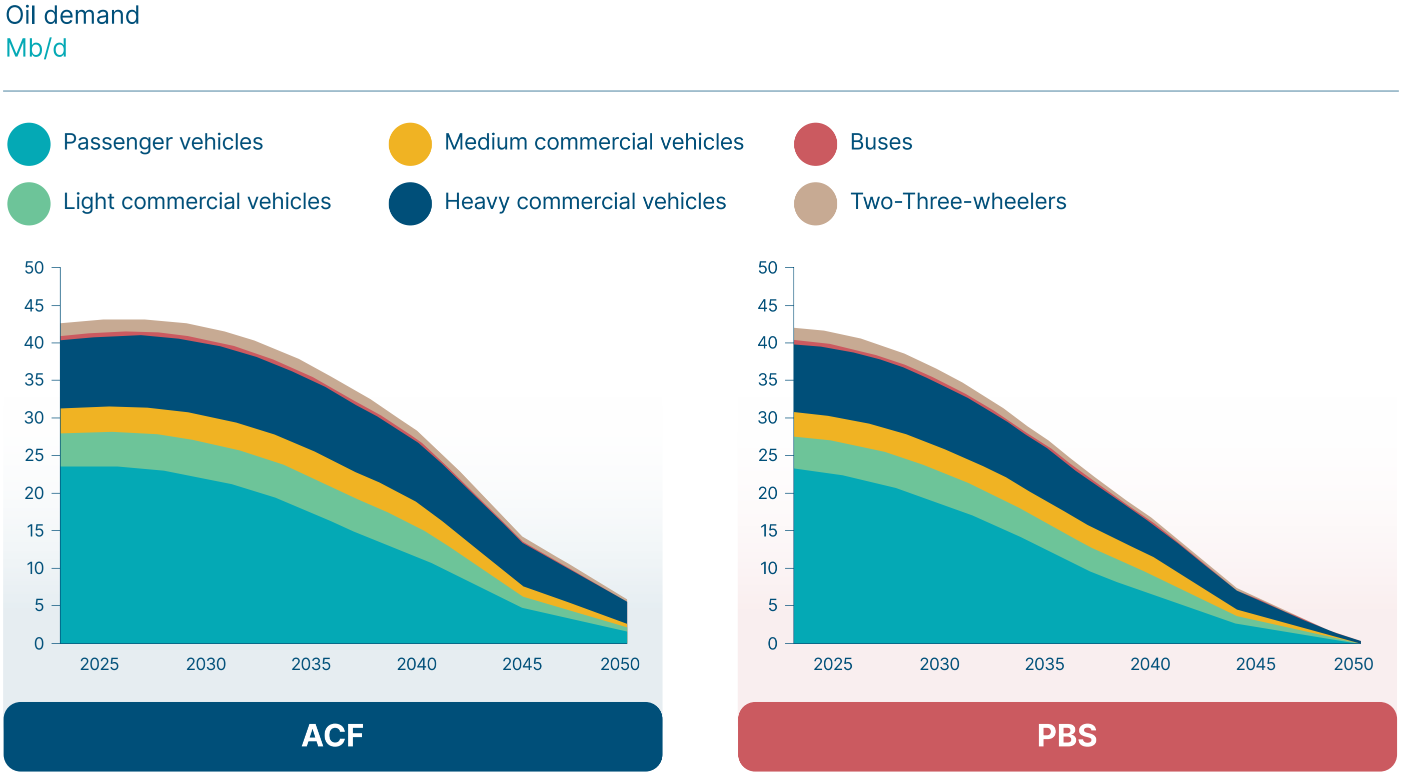
In our ACF scenario, we anticipate a deceleration in average annual fuel efficiency improvement, falling to 0.7% per year.[58]

Altogether, these assumptions create the two projections of oil demand from road transport presented in Exhibit 2.9. The ACF scenario suggest a roughly flat trend to 2030 (from 42.7 Mb/d in 2023 to 42 Mb/d), followed by a rapid decline to 28.4 Mb/d in 2040 and 5.8 Mb/d in 2050. In contrast, the PBS scenario suggests that a fall of 6 Mb/d could be realised by 2030, followed by a further decrease to 16.9 Mb/d in 2040 and 0.3 Mb/d in 2050.

Our assumptions relating to the much smaller rail transport sector are set out in Annex A.

EXHIBIT 2.9

## Aggregate oil demand in road transport in ACF and PBS




**NOTE:** Other vehicles, such as those used in construction or mining are not included. Aggregate oil demand figures exclude biofuels consumption for road transportation.

**SOURCE:** Systemiq analysis for the ETC; BNEF (2023), *Electric Vehicle Outlook*; MPP (2022), *Making Zero-Emissions Trucking Possible.*

57 IEA (2021), *Global Fuel Economy Initiative.*
58 The Truth about cars (2017), *Government intervention killing Japanese kei car.*

## Aviation

Around 5.9 Mb/d of oil was consumed in aviation 2022, with an expected rebound in demand as the sector recovers from the pandemic.[59]

Prospects for the deep decarbonisation of aviation have improved over the past five years. Until 2018, most industry projections assumed that aviation's emissions could only be partially reduced (e.g., by 50%) by 2050, and that any commitment to net-zero emissions would have to rely heavily on purchased offsets or removals.[60,61]

Since then, however, there has been a dramatic increase in ambition. Both the International Air Transport Association (IATA)[62] and the International Civil Aviation Organisation (ICAO)[63] have pledged to achieve net-zero sector emissions by 2050, and there is growing confidence that the majority of these reductions can be achieved via actions within the sector.[64]

Our trajectory for aviation, which is the same for both ACF and PBS, draws on the MPP's 2022 report *Making Net-Zero Aviation Possible*. This report assumes that demand for aviation will continue to grow strongly, so that emissions on a business-as-usual basis would almost triple from the 2019 figure of 1 $GtCO_2e$ per annum, and more than double even after significant improvements in fuel efficiency, as per Exhibit 2.10. That report then considers two scenarios, in both of which:

- Pure battery electric flight would play a slowly growing but still limited role. This reflects limits to the potential range of battery electric planes unless there are currently unanticipated breakthroughs in the energy density of batteries.
- There would be a significant role for hydrogen or hybrid planes, which could account for 10% of emissions reductions in the "prudent scenario" but for up to 25% if renewable energy and thus green hydrogen costs fell rapidly.
- Decarbonisation of medium- and long-distance flights would be achieved using sustainable aviation fuels (SAF) as a drop-in fuel in existing engines. This SAF could be produced either from bio-based resources or via the synthesis of hydrogen with $CO_2$ captured from the air (DAC).

These scenarios would result in near total elimination of emissions from aviation, with CDR used to offset any residuals. And it would imply the complete elimination of conventional jet fuel use by 2050, with oil demand for aviation therefore falling to zero compared to the increase to over 13 Mb/d which might occur in a business-as-usual scenario [Exhibit 2.11]. This would be offset by an increasing use of biofuels, or electricity to produce hydrogen and to capture $CO_2$.

As recognised in Chapter 3.1 on key uncertainties, our aviation scenario is subject to greater uncertainty than our road transport scenario since:

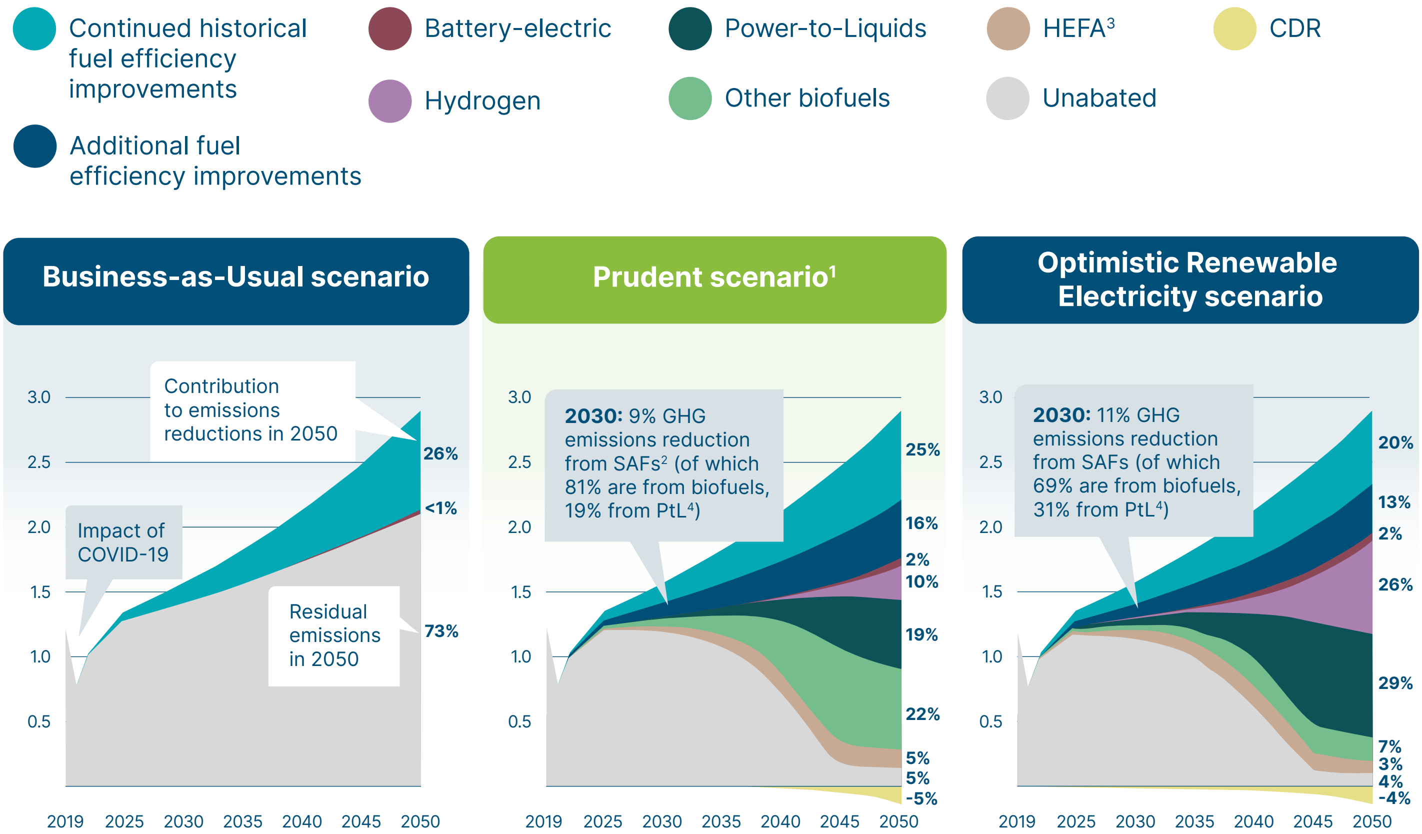
- Given the significant "green premium" involved in producing SAF and the increase in aviation ticket prices which will therefore result, this technically feasible transition will only occur if there are strong supporting policies, such as regulations to require a rising percentage of SAF in the fuel blend, and/or carbon taxes.
- Given that DAC[65] would be required to produce synthetic jet-fuel, an alternative decarbonisation route could be to continue to use conventional jet fuel and to offset the emissions via DACCS. This possibility is discussed in Chapter 4.
- And even in our scenario, aviation oil demand would increase by 1 Mb/d by 2030 before subsequent decline. This reflects limits to the pace at which SAF plans can be scaled up.

59 IATA (2022), *press-release: In 2021, overall traveller numbers were 47% of 2019 levels. This is expected to improve to 83% in 2022, 94% in 2023, 103% in 2024 and 111% in 2025.*
60 IEA (2017), *Energy technology perspectives.*
61 IATA (2016), *Offsetting $CO_2$ emissions with CORSIA.*
62 IATA (2021), *Fly Net-Zero initiative.*
63 ICAO (2022), *Long-term global aspirational goal of net-zero carbon emissions by 2050.*
64 MPP (2022), *Making Net-Zero Aviation Possible.*
65 Note that point source carbon capture and use (CCU) and bioenergy with CCU (BECCU) would also be suitable sources of carbon to produce SAF, but implies that SAF plants are collocated with point source of captured carbon.

EXHIBIT 2.10

# $CO_2$ emissions reduction levers in MPP decarbonisation scenarios for aviation

GHG emissions reduction
$GtCO_2e$

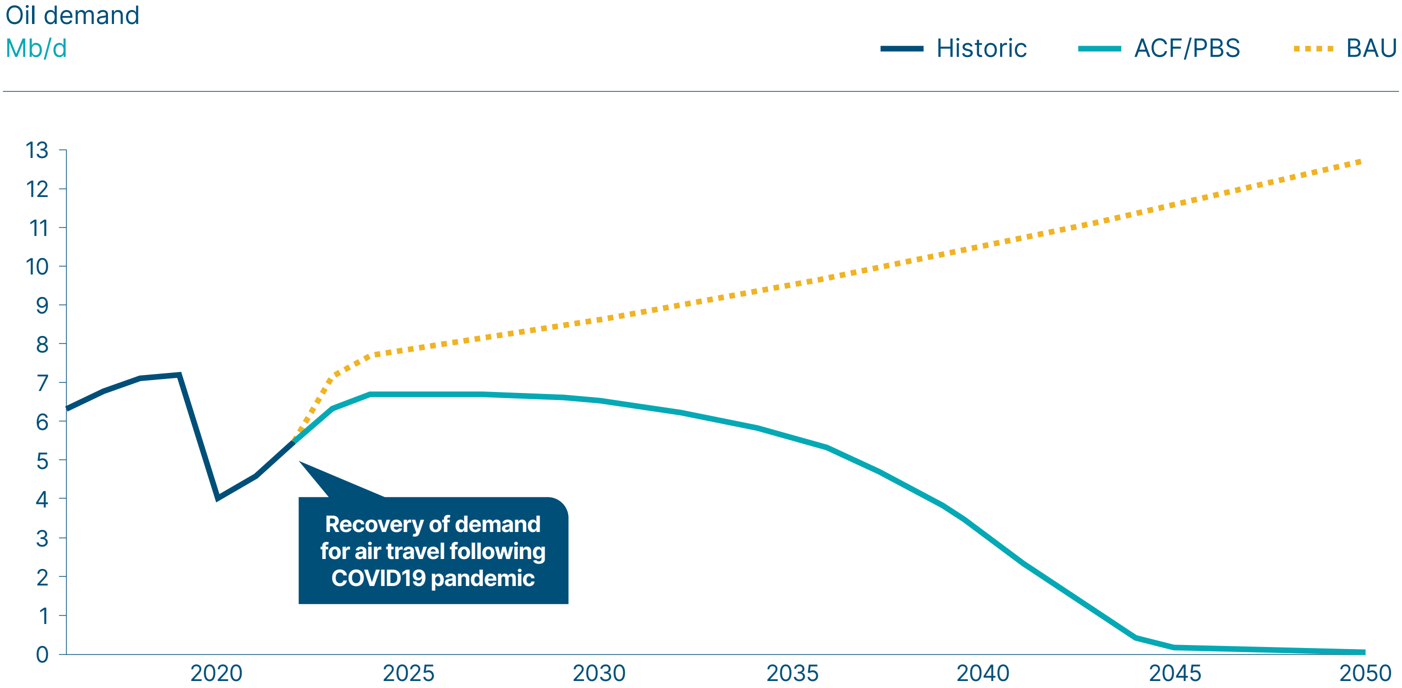



**NOTE:** [1] The Prudent Scenario is taken as reference for both the ACF and PBS; [2] Sustainable Aviation Fuel; [3] Hydroprocessed Esters and Fatty Acids; [4] Power to Liquids.

**SOURCE:** Systemiq analysis for the ETC; MPP (2022), *Making net-zero aviation possible.*

EXHIBIT 2.11

## Oil consumption in aviation for the ETC scenarios from today to 2050




**NOTE:** Both the ACF and PBS are aligned to the "Prudent scenario" from MPP. BAU refers to MPP's "business-as-usual" scenario for aviation, where only technologies which offer an economic advantage are implemented, and most mitigation comes from continued fuel efficiency improvements. Aviation includes air transport for both passenger and freight.

**SOURCE:** Systemiq analysis for the ETC; MPP (2022), *Making net-zero aviation possible.*

### Shipping

Around 5 Mb/d of oil (in the form of heavy fuel oil or marine diesel oil) is used in the shipping sector today.

The prospects for achieving deep decarbonisation in shipping have also progressed significantly over the past five years. Particularly noteworthy is the recent commitment of the International Maritime Organisation (IMO) to attain global net-zero shipping emissions by mid-century.[66] This is a substantial advancement compared to prior official policy stances, reflecting both:

- Growing confidence in the technical feasibility of decarbonising all categories of shipping.
- Growing understanding that, while the shift to zero-emissions will increase shipping costs, the very low typical share of shipping costs in the price of final goods means that the impact on the overall cost of traded goods would be negligible and easily absorbed by the global economy.[67]

Our scenarios for the shipping sector build on the MPP's 2022 report *A Strategy for the Transition to Net-Zero Emissions shipping* and on the 2021 report from the Maersk Mc-Kinney Moller Center for Zero Carbon Shipping, *We show the World It Is possible*. In our PBS scenario, we assume that total demand for shipping[68] grows at 1.3% per annum (a 44% increase between 2022 and 2050), in line with the assumptions in the Maersk Mc-Kinney Moller report,[69] this takes into account the decrease in fossil fuels trade (currently responsible for approximately 25% of shipping demand) which will occur as fossil fuel use declines.[70,71] Additional energy demand resulting from the growth in shipping demand is entirely offset by continued improvements in energy efficiency from the uptake of better designed and more fuel-efficient ships, improved onboard efficiency of existing ships, and more efficient

66 IMO (2023), *IMO GHG Strategy.*
67 For example, the IMF estimates that around 20% increase in shipping freight costs leads to on average less than 0.2% inflation – i.e. a 100x smaller impact. IMF (2022), *How soaring shipping costs raise prices around the world.*
68 Expressed in ton-kilometer of freight.
69 Maersk Mc-Kinney Moller Center for Zero Carbon Shipping (2021), *We show the world it is possible.*
70 Other outlooks also project annual increases in the range of 1.3%–1.4% per annum. to 2050, with faster growth to 2030 (> 3% per annum) and more limited growth from 2040 onwards (<1% per annum). DNV GL (2022), *Energy transition outlook 2022.*
71 DNV GL (2022), *Energy transition outlook 2022.*

management of logistics and ship routing.[72] As a result, total energy demand for shipping declines slightly by 2050 [Exhibit 2.12].

The resulting shipping activity could then be decarbonised via the use of four technologies:

- Over short distances, by electricity or hybrid solutions, but with this only accounting for around 5% of emissions reduction.
- The use of either e-methanol or ammonia as new low-carbon fuels, with e-methanol dominating in the earlier years given the potential for easier retrofit of existing engines, but with ammonia likely to play an increasing role over time.[73,74]
- LNG would also play a small role as a transition fuel in the short-term.

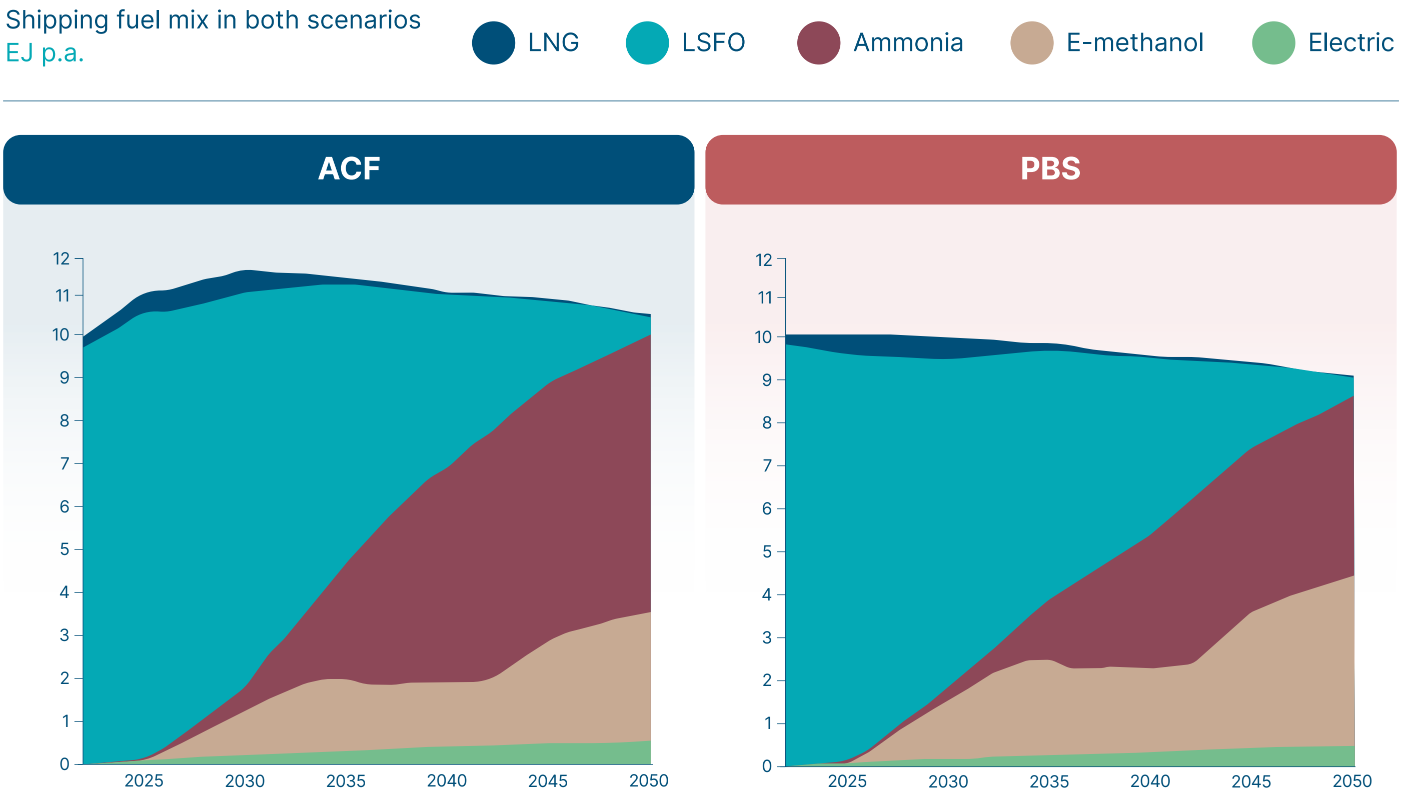
This would result in the PBS scenarios shown in Exhibit 2.13, with total oil demand for shipping falling slightly in the 2020s and then at an accelerating pace in the 2030s and 40s.

In the ACF, we have assumed that energy efficiency improvements to 2030 are more limited than in the PBS, resulting in a 15% increase in final energy demand for shipping, with oil demand in 2030 therefore higher than assumed in the PBS, but faster progress from 2030 onwards to reach zero by 2050.

As with aviation, this transition to zero-emissions shipping will only occur with strong policy support. But unlike aviation, the green premium involved in using sustainable fuel has minimal implications for consumer prices. This should reduce political opposition to the introduction of required policies.

**EXHIBIT 2.12**

## Fuel mix in shipping in both scenarios




**NOTE:** Total energy demand for shipping taken from Maersk Mc-Kinney and starting point rescaled to match total energy demand in 2022 from IEA, LSFO: Low Sulphur Fuel Oil, LNG: Liquefied Natural Gas

**SOURCES:** Systemiq analysis for ETC; MPP (2021), *A Strategy for the Transition to Zero-Emission Shipping;* Maersk Mc-Kinney Moller Center for Zero Carbon Shipping (2021), *We show the world it is possible.*

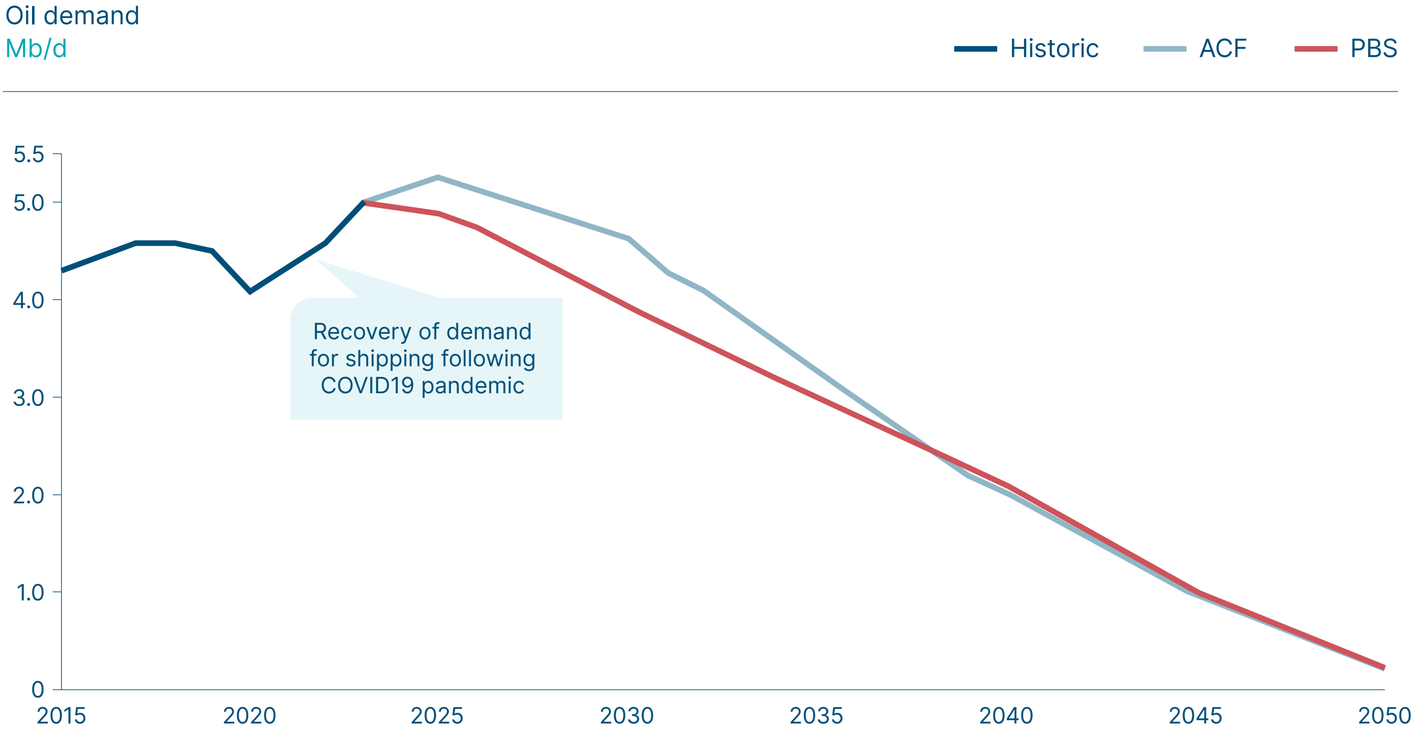
72 We assume 1.5% p.a. efficiency gains in the PBS scenario and 1.2% in the ACF scenario. These assumptions are in line with Maersk Mc-Kinney Moller Center for Zero Carbon Shipping (2021), *We show the world it is possible.* They are also within ranges from historical improvements of ~5% p.a. IRENA (2021), *A pathway to decarbonise the shipping sector by 2050.*

73 Capital investment for a methanol-fueled newbuild or retrofit is lower because there is no need for pressurisation or costly cryogenic fuel tanks and systems. DNV GL (2023), *Methanol as fuel heads for the mainstream in shipping.*

74 Ammonia is a toxic substance and can have significant adverse impacts on both humans or aquatic life if exposed. Compared to methane, ammonia has a lower but non negligeable risk of explosion. DNV GL (2022), *Ammonia as a marine fuel: Safety handbook.*

EXHIBIT 2.13

## Oil consumption in shipping in ACF and PBS




**NOTE:** Historic values are taken from the IEA. Despite identical demand for shipping, the ACF scenario assumes lower energy efficiency improvements to 2030 compared to the PBS, resulting in higher final energy demand, and thus increased oil demand, until the mid-2030s. In the ACF, the decarbonisation in shipping is faster than in the PBS after 2025 to still meet the net-zero target set by the IMO.

**SOURCE:** Systemiq analysis for the ETC; MPP (2021), *A Strategy for the Transition to Zero-Emission Shipping*; Maersk Mc-Kinney Moller Center for Zero Carbon Shipping (2021), *We show the World it is possible*; IEA (2023), *Energy consumption in international shipping by fuel in the Net Zero Scenario, 2010-2030*.

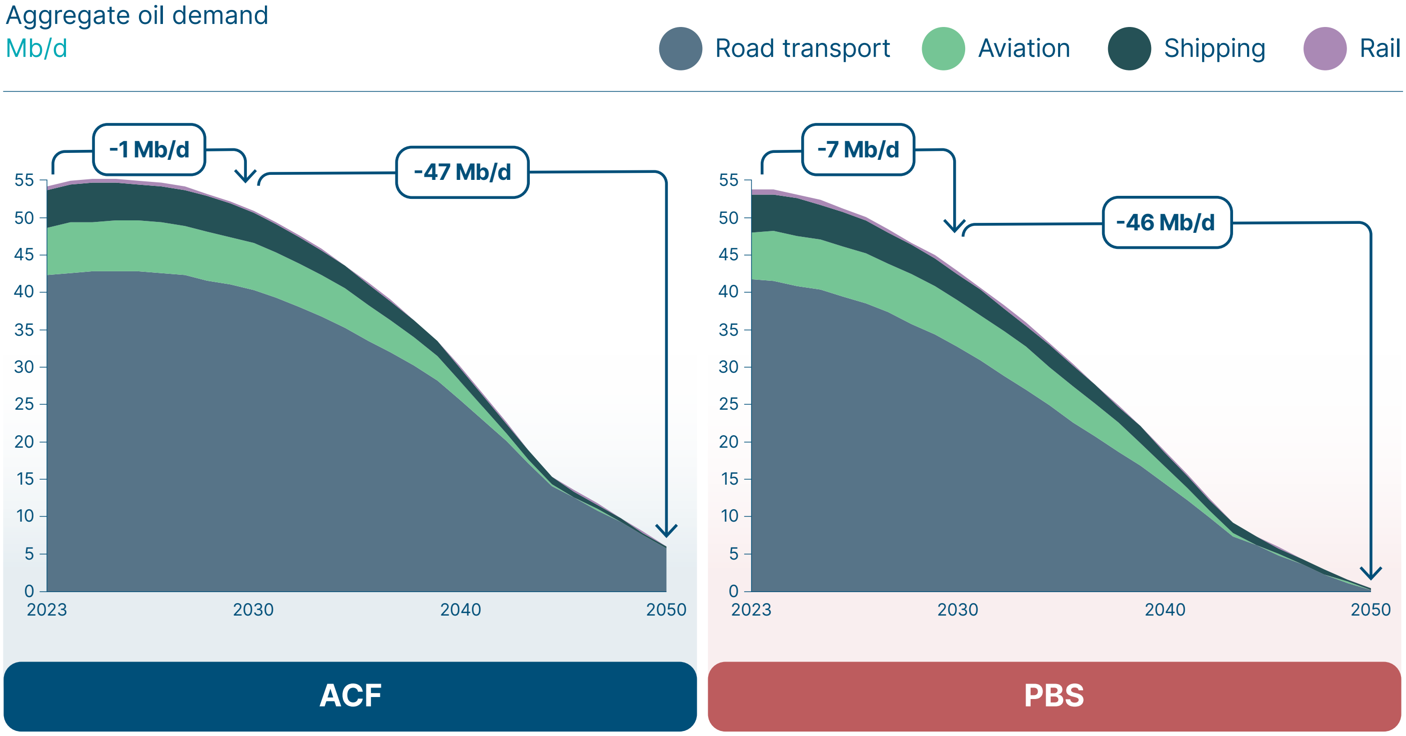
### Total transport sector scenarios

Combining road, shipping, aviation, and the relatively smaller rail sector, the overall oil demand for the transportation sector is depicted in Exhibit 2.14, with the following trends:

- In the ACF scenario, demand is roughly flat at around 53 Mb/d until 2030 but decreases to 34 Mb/d in 2040 and reaches 6 Mb/d in 2050.
- The PBS scenario shows a more rapid decline, reaching 47 Mb/d in 2030, 22 Mb/d in 2040, 0.5 Mb/d in 2050.

EXHIBIT 2.14

## Aggregate oil demand for transport in the ACF and the PBS scenarios




**NOTE:** Other vehicles, such as those used in construction or mining are not included. Aggregate oil demand figures exclude biofuels consumption for road transportation.

**SOURCE:** Systemiq analysis for the ETC; BNEF (2023), *Electric Vehicle Outlook*; MPP (2022), *Making Zero-Emissions Trucking Possible*; MPP (2021), *A Strategy for the Transition to Zero-Emission Shipping*; Maersk Mc-Kinney Moller Center for Zero Carbon Shipping (2021), *We show the World it is possible*; MPP (2022), *Making Net Zero Aviation possible.*

## 2.2.2 Industry

As illustrated in Exhibits 2.1 to 2.3, the industry sector is responsible for over a quarter of coal and natural gas consumption.

Within the total, five "heavy" industrial sectors – steel, cement, aluminium, petrochemicals and ammonia – account for over 83% of industrial coal use, 60% of gas use and 85% of oil use,[75] and as result, produce a large majority of total industry emissions. Until recently these were considered "hard to abate" sectors of the economy, which would have to rely on extensive use of offsets to achieve net-zero emissions. This was due to highly energy-intensive production processes, many of which require high-temperature heating, and in some cases like cement or chemicals, reactions that produce $CO_2$ as a by-product.

In 2018, however, the ETC's *Mission Possible* report showed that it is technically and economically feasible for all these heavy industry sectors to achieve near-total decarbonisation by 2050, and the MPP has subsequently detailed

75 Other transport not considered within other industry.

decarbonisation pathways for each. Our ACF and PBS scenarios for the heavy industry sectors are based on these MPP pathways as described below. In addition, we have conducted analysis of the options to decarbonise the other industrial sectors, which account for 17% of industrial coal demand, 15% of oil use in industry, but a significant 40% of gas.

### Steel

Steel accounts for 57% of coal consumption in industry, primarily in the form of coking/metallurgical coal used as both the energy source and the reduction agent in iron-making blast furnaces. Until recently, pathways for steel decarbonisation assumed a major role for CCS applied to blast furnaces, and therefore assumed a continued large-scale use of coking coal. But the Mission Possible Partnership's analysis, set out in their 2022 report *Making Net-Zero Emission Steel Possible*, shows that the optimal decarbonisation pathway will rely primarily on a mix of gas and hydrogen-based technologies, with carbon capture applied where gas is used. Exhibit 2.15 shows two MPP scenarios for the mix of technologies, with:

- *A Technology Moratorium scenario*, in which steel-making companies move to a new zero-carbon technology at the point where a major new asset investment needs to be made (e.g., when existing blast furnaces need to be relined). We have used this scenario as our ACF.
- *A Carbon Cost scenario* in which the pace of change is accelerated because of the imposition of a sector-wide carbon price – this becomes our PBS scenario (though we note that there are other means to achieve this scenario than a global carbon price).

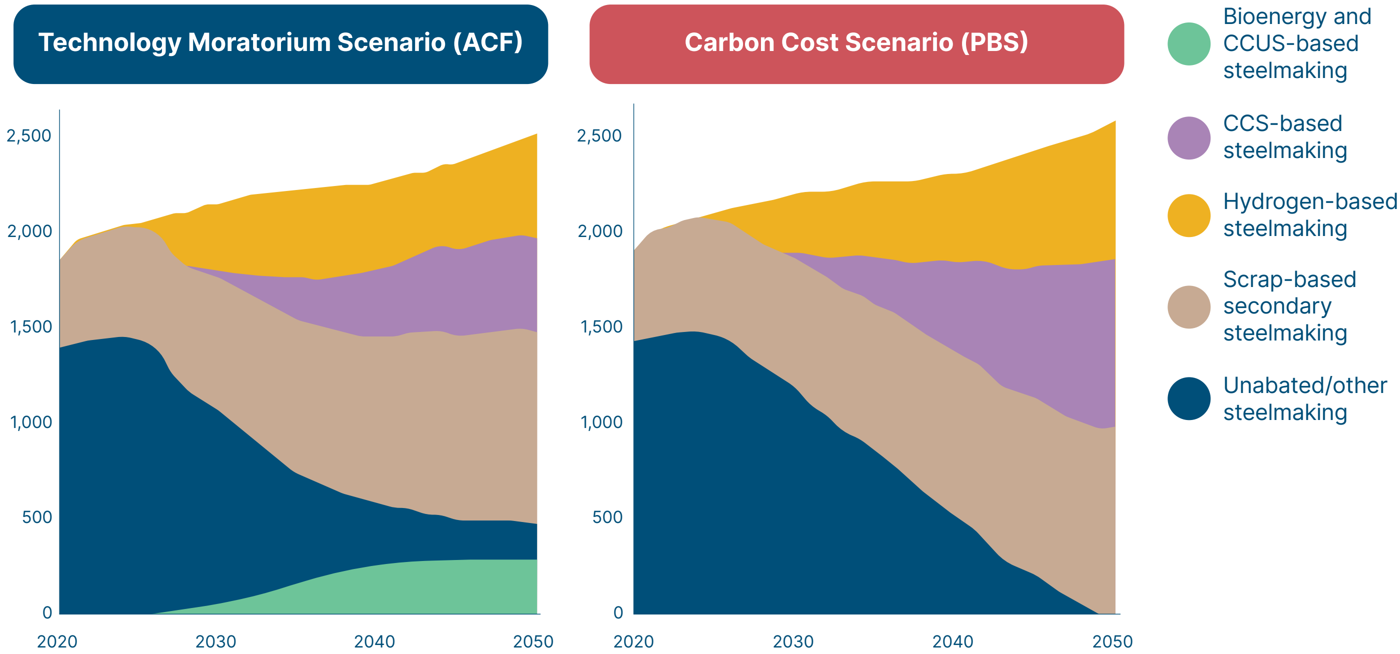
In both cases, blast furnace production and carbon capture plays only a minor role in 2050, and the use of coal falls by 80% in the ACF and a slightly bigger 82% in the PBS. However, gas use expands from 82 Bcm to 227 Bcm in the ACF and 198 Bcm in the PBS.

Hydrogen used by the steel industry increases dramatically, from minimal today to between 54–79 Mtpa in 2050.[76] This hydrogen could be derived either from electrolysis (green hydrogen) or natural gas reforming and CCS (blue hydrogen), and the total demand for gas therefore depends on the balance between these green and blue routes. This balance is considered in Chapter 2.2.5.

EXHIBIT 2.15

## Global steel production by technology for 2020–2050

Steel production
Million metric tonnes




**NOTE:** Specific technologies are regrouped across 5 main categories, Technology Moratorium scenario is used for the ACF pathway while the Carbon Cost scenario is used for the PBS.

**SOURCE:** MPP (2022), *Making net-zero steel possible.*

76 Million tonnes per annum.

## Cement

Cement production results in two forms of emissions: emissions from combustion, resulting from burning coal or gas to produce high-temperature heat for calcination, and process emissions which result from the calcination of calcium carbonate to lime (the chemical reaction which transforms $CaCO_3$ into CaO).

Alternative technologies for high-temperature heat production (e.g., bioenergy, electricity or hydrogen) are technically feasible and will likely be deployed in some locations. However, since CCS will almost certainly be required to capture process emissions, fossil fuels with CCS may also be applied on a large scale to provide zero-carbon heat.

As shown in Exhibit 2.16, the main MPP scenario for cement decarbonisation (which we use for both our ACF and PBS scenarios) therefore assumes that CCS will play a dominant role in decarbonising cement, alongside:

- Measures which reduce concrete demand via improved design or construction, and which improve the efficiency of concrete production.
- The reduction of the clinker-to-cement ratio, clinker being used as the primary strength-contributing ingredient to concrete, but which is highly carbon-intensive.
- Only a limited adoption of alternative energy sources.

As a result, the reduction in fossil fuel use is more limited in cement than in other sectors, with coal use falling from 231 Mtce today to 145 Mtce in 2050, while gas use grows from 41 Bcm to 81 Bcm by 2050.

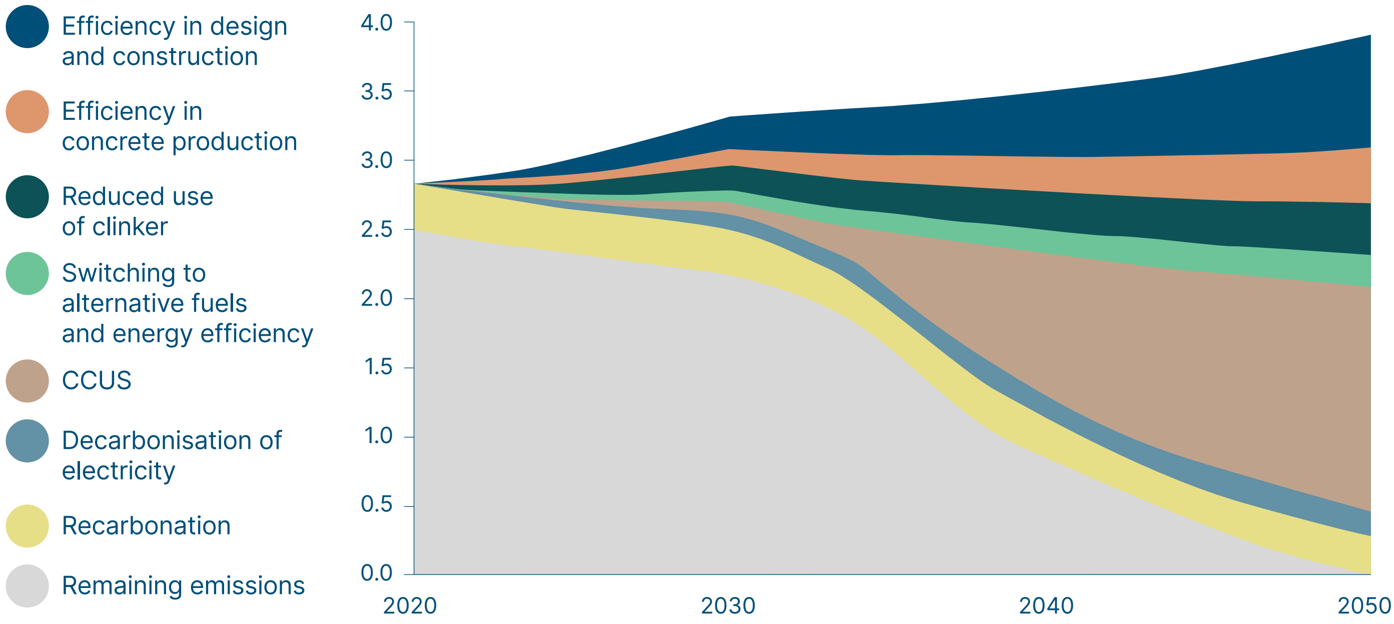
Coal demand for cement production will also be strongly influenced by the development of cement demand in China, which currently accounts for over 50% of the global total.[77] This demand reflects the huge bias of the Chinese economy towards construction (which also includes large quantities of steel), which accounts for 6.2% of its national GDP.[78] However, this construction must at some point decline in importance as the country already has a high urbanisation rate and stock of unoccupied apartments, and faces significant population decline.[79] The MPP cement decarbonisation pathway does not explicitly consider these implications for future demand developments in China, which may imply smaller fossil fuel needs in 2030 and 2040 than currently assumed.

77 Sustainability by numbers (2023), *China dominates global cement production.*
78 National Bureau of Statistics of China (2021).
79 Reuters (2023), *The climate upside of China's real estate downturns.*

EXHIBIT 2.16

## $CO_2$ emissions reduction by lever in MPP's decarbonisation scenarios for cement

Emissions from cement production (2020–2050)
$GtCO_2$




**NOTE:** Clinker is a nodular material produced in the kilning stage during the production of cement and is used as the binder in many cement products. Recarbonation is the uptake of $CO_2$ from the atmosphere by concrete during its operation and end-of-life stages through a chemical reaction that is the reverse of the chemical reaction that causes $CO_2$ emissions in the clinker-making process. Efficiency in concrete production is driven by increasing the effective strength of cement and industrialising the concrete production process.

**SOURCE:** Systemiq analysis for the ETC; MPP (Forthcoming), *Making net-zero concrete and cement possible*.

### Petrochemicals and plastics

The petrochemical sector uses gas and oil as both energy sources and feedstocks to produce plastics and other products.[80] And it produces emissions both during the production process (over 0.8 $GtCO_2$ per annum, including process emissions) and at end of life (over 0.4 $GtCO_2$), predominantly as a result of plastic incineration [Exhibit 2.17].

This reflects the fact that, in contrast to other sectors, carbon is an essential input for many chemical products. Today, chemical products containing around 710 Mt of embedded carbon are produced per year, 51% of which are polymers, with 90% of the carbon coming from fossil sources.[81]

In one sense, therefore, the chemical industry cannot be decarbonised, but only "defossilised" via a switch to one of five alternative carbon sources: recycled plastics or other waste, sustainable biomass, point-source or direct air captured carbon (including $CO_2$). Reduced use of plastics, mechanical or chemical recycling and reuse can also reduce demand for new plastics, and thus for feedstocks. And emissions involved in production processes can be reduced via electrification of process energy or the application of CCS.[82,83]

Analysis published in Systemiq's 2022 report *Planet Positive Chemicals* suggests that the least-cost pathway to decarbonise the petrochemicals industry is dominated by continued use of fossil fuels combined with CCS on production

80 IEA (2018), *The Future of Petrochemicals.*
81 RCI (2023), *RCI Carbon Flows Report: Compilation of supply and demand of fossil and renewable carbon on a global and European level.*
82 Systemiq (2022), *Planet Positive Chemicals.*
83 Agora Industry (2023), *Chemicals in transition.*

facilities and waste incinerators. This is due to a combination of low technology readiness level (TRL)[84] for low-carbon technologies, limited availability of alternative feedstock and high infrastructure costs. As a result, in the ACF pathway, over 70% of feedstock continues to come from fossil fuels. The PBS pathway assumes a more ambitious transition towards biogenic and carbon oxide-based feedstocks, with less than 20% fossil feedstock remaining by mid-century.

The electrification of road transportation will have a profound effect on the chemical industry, with the retirement of key oil refining processes such as catalytic reforming.[85] In these cases, new opportunities for low-emissions technologies open, such as methanol to aromatics, highlighting the important role that methanol could have as new intermediate for the industry [Exhibit 2.18].

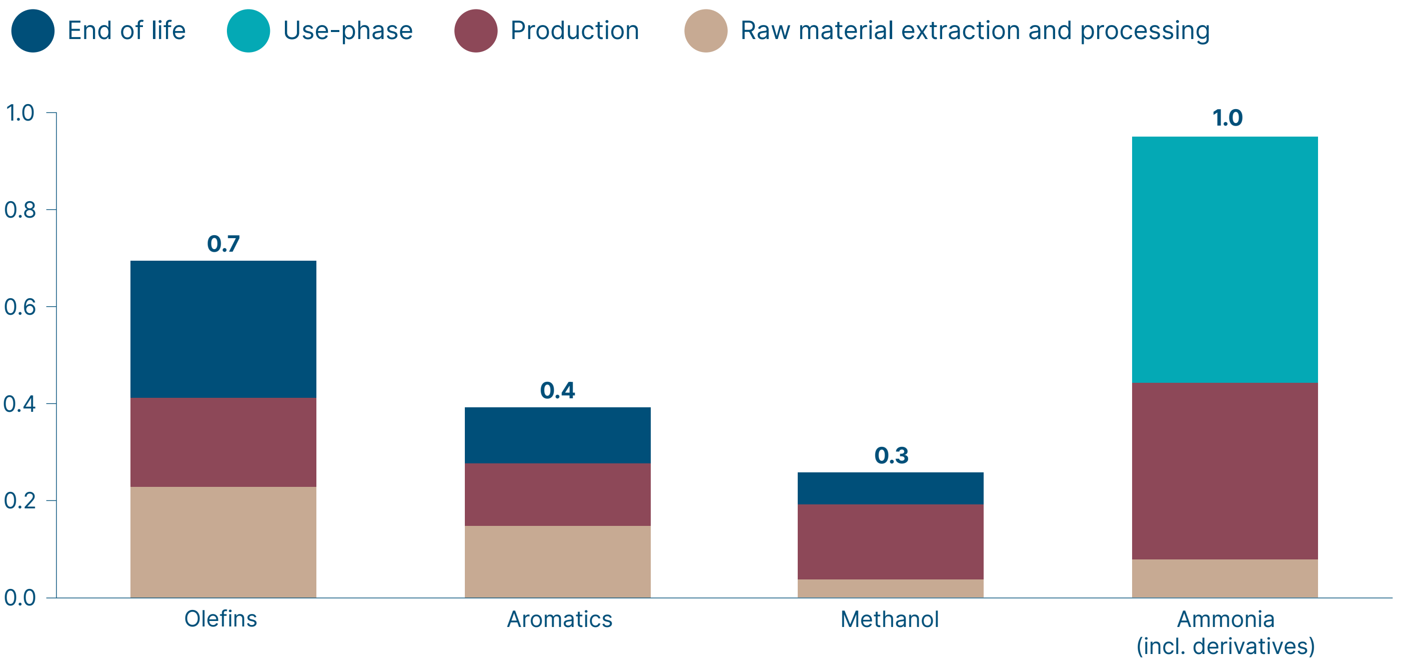
**The implications for fossil fuel use are that:**

- In the ACF scenario, oil use in petrochemicals falls only slightly from 15.5 Mb/d to 11 Mb/d in 2050, while gas consumption increases slightly from 329 Bcm to 548 Bcm.
- In the PBS scenario, oil use falls to just 1.7 Mb/d, and gas use to 98 Bcm.

**EXHIBIT 2.17**

## Emissions from petrochemicals in 2020

Emissions from petrochemicals in 2020 by lifecycle stage
$GtCO_2$




**NOTE:** Olefins are compounds commonly used as building blocks for plastics and include ethylene, propylene and butadiene. Aromatics include benzene, toluene and xylene (commonly referred to as BTX) and are used to manufacture a large array of chemical products. Methanol is most commonly used to make other chemical compounds to manufacture products (plastics, paints, etc.). Ammonia is the starting compound for all nitrogen-containing fertilisers, and derivatives include urea and ammonium nitrate.

**SOURCE:** Systemiq (2022), *Planet Positive Chemicals.*

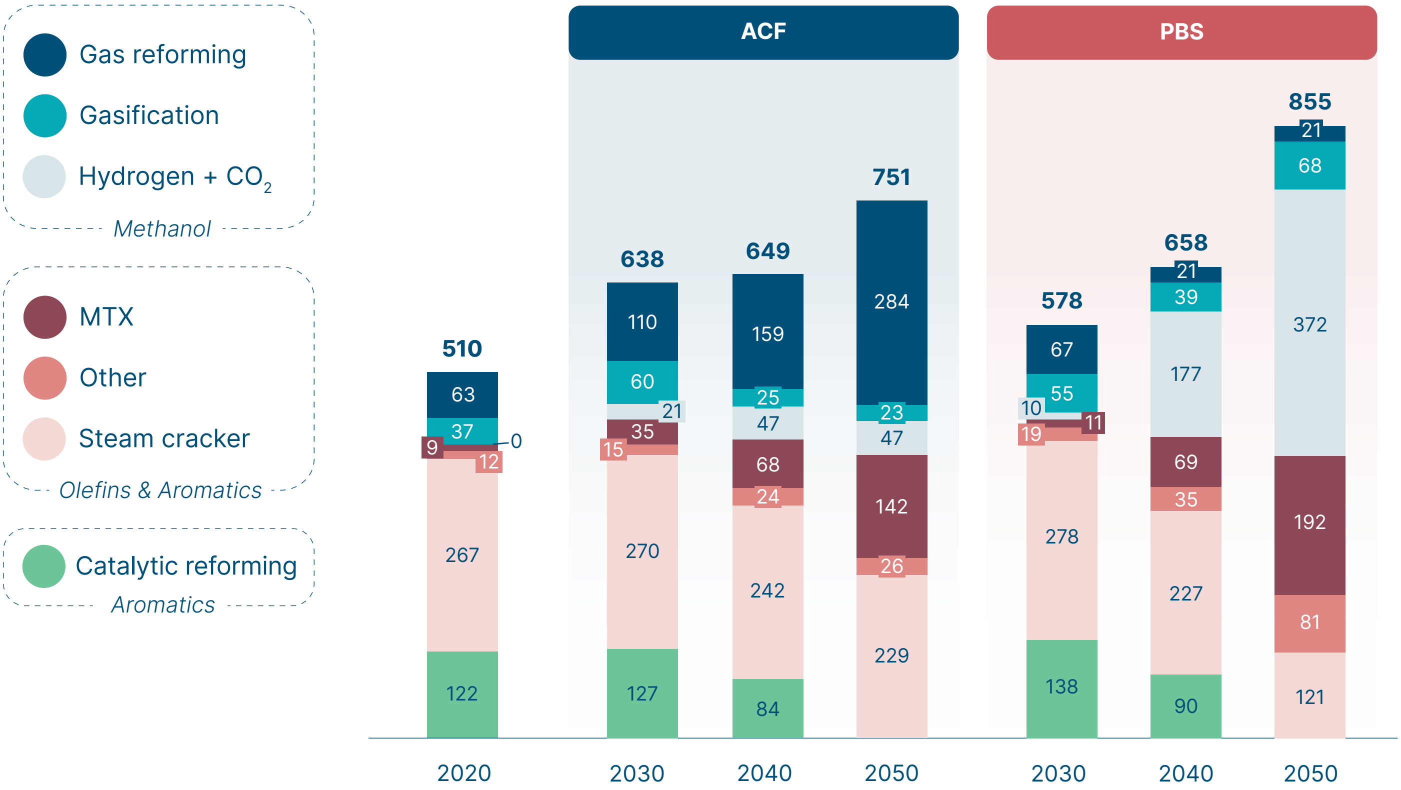
84 TRLs measure the maturity level of a technology throughout its research, development and deployment phase progression. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology.

85 Catalytic reforming is used to produce aromatic compounds (Benzene, Toluene, Xylene) which are used as premium road fuel blend but also form basis for many important chemicals and polymers (e.g., PET).

EXHIBIT 2.18

## Chemicals production by process

Chemicals production by chemicals and process (2020–2050)
Million tonnes of chemicals p.a.




**NOTE:** Methanol to X (MTX) refers to both Methanol to Olefins (MTO) and Methanol to Aromatics (MTA). MTO is a process of converting methanol to ethylene and propylene, while MTA is a method of producing aromatics (BTX) from methanol without the use of fossil fuels. Steam cracking is a petrochemicals process wherein long chain hydrocarbon molecules are mixed with steam and heated to break down into smaller hydrocarbon chains, like olefins and BTX. Catalytic reforming is a process used in refineries to upgrade fuel by converting naphtha into hydrocarbons with a high-octane rating. Gas Reforming is a process wherein hydrogen is produced through the heating of a methane source, like natural gas. Gasification is a process where mixed, end of life materials are heated in the presence of limited oxygen to produce syngas that can be converted into polymers again.

**SOURCE:** Systemiq (2022), *Planet Positive Chemicals.*

### Ammonia

Most ammonia is produced using natural gas, consuming 123 Bcm per annum today.[86] While ammonia production is often considered to be part of the chemicals sector, it is actually distinct from petrochemicals as it is not composed of carbon atoms, but instead involves the synthesis of nitrogen and hydrogen via the Haber-Bosch process.

Total ammonia demand will grow significantly both in existing uses and new,[87] but decarbonisation can be achieved as long as the input hydrogen produces no emissions. Therefore, the key question around ammonia-related fossil fuel demand is whether the hydrogen input is green or blue. This is further discussed in Chapter 5.

### Aluminium

Aluminium smelting relies primarily on electricity rather than direct fossil fuel use and can become a zero-carbon process if the electricity used is itself decarbonised. Alumina refining, a key process step before smelting, currently depends mainly on coal or gas to generate high-temperature heat but can be decarbonised through electrification or the use of hydrogen. Both our scenarios therefore assume that the direct use of fossil fuels by the aluminium industry is eliminated by 2050.[88]

86 MPP (2022), *Making net-zero ammonia possible.*
87 Existing uses mostly include fertiliser production, new uses will mostly come from use as a shipping fuel.
88 MPP (2022), *Making net-zero aluminium possible.*

### Other/light industry

Altogether, the heavy industry sectors account for two-thirds of all industrial energy use, while the other third is used by a wide variety of other “lighter” industrial sectors,[89] which comprise a wide range of activities ranging from glass making to large-scale food processing. As shown in Exhibit 2.19, these sectors use about 59 EJ of energy, of which approximately 50% is derived directly from fossil fuels, around 15% from bioenergy and over 30% from electricity.

The primary use of fossil fuels in these light industry sectors is to provide process heat at low or medium temperatures,[90] with the majority involving temperatures below 200°C.

There are multiple technically feasible routes to decarbonise this heat production, with electric heat pumps likely to be optimal in many applications below 200°C given higher efficiency than combustion-based processes.[91]

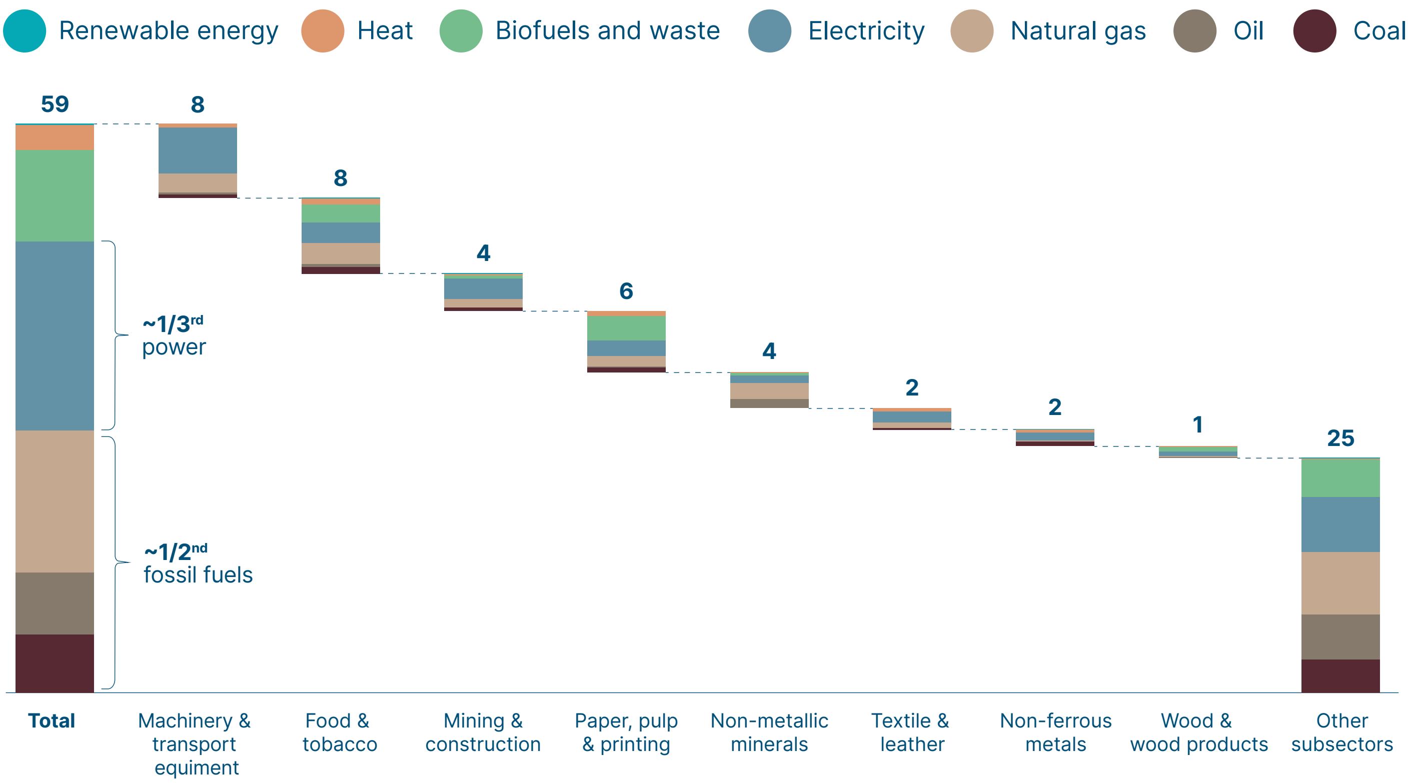
Given their higher energy-to-heat efficiency, using heat pumps instead of boilers will result in lower operating costs but higher upfront capital costs. These upfront costs mean that total economics will also depend on the cost of capital for companies of different sizes and types, and on the extent to which carbon prices increase, further increasing the operating cost advantage. In Annex A, we describe our assumptions on how these economics and policy incentives might evolve in different countries, with the implications for fossil fuel use shown in Exhibit 2.21. This analysis suggests that:

- By 2030, coal use in light industry sectors could already have fallen by 50–75%, but with much smaller reductions in oil and gas demand.
- But by 2050, demand for coal, gas and oil could all have fallen by over 85% in the ACF and by almost 95% in the PBS.

EXHIBIT 2.19

## Energy demand in “other industry” sectors by energy vector

Final Energy Demand for 2020
EJ




**NOTE:** Values shown in this exhibit are for 2020, a year with lower energy demand partly induced by the COVID-19 pandemic. Final energy demand in Other Industry was 65 EJ in 2022, and this is the value used as the starting point for ETC modelling of this sector. Other subsectors include but are not limited to pharmaceuticals, botanical products, furniture and any other subsectors not listed elsewhere.

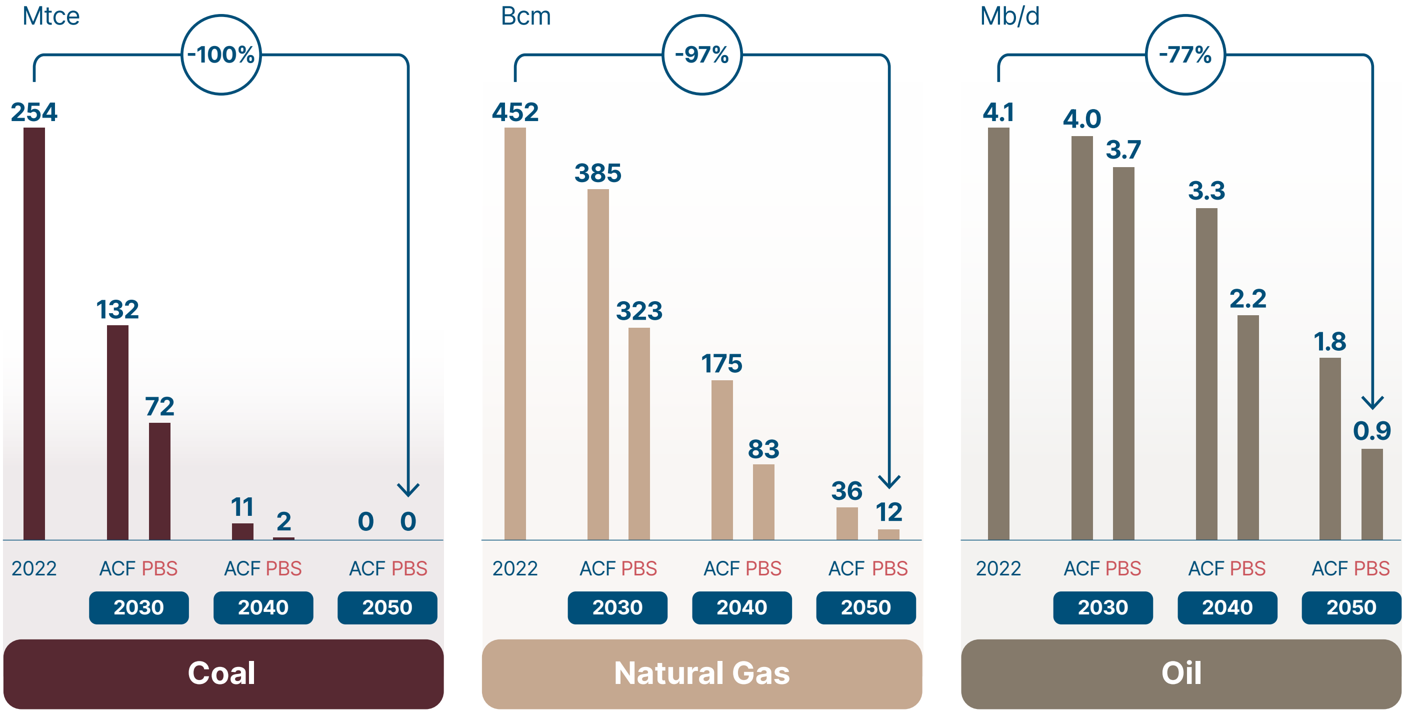
**SOURCE:** Systemiq analysis for the ETC; IEA (2022), *Energy Balance 2022*; IEA (2021), *Net Zero by 2050*.

89 IEA (2023), *Industrial energy consumption by fuel in the Net-Zero Scenario, 2000–2030.*
90 Around 100–400°C.
91 MAN Energy Solutions (2022), *Industrial heat pumps white paper.*

EXHIBIT 2.20

## Fossil Fuel demand in other industry in ACF and PBS

Fossil fuel demand projections
Specific units




**NOTE:** Figures include the allocation of fossil fuel consumption in energy own-use sector. Other industry includes machinery & transport equipment, food & tobacco, mining & construction, paper, pulp & printing, non-metals minerals, textile & leather, non-ferrous metals, wood & wood products and other subsectors not mentioned elsewhere.

**SOURCE:** Systemiq analysis for the ETC.

### Total industry sector scenarios

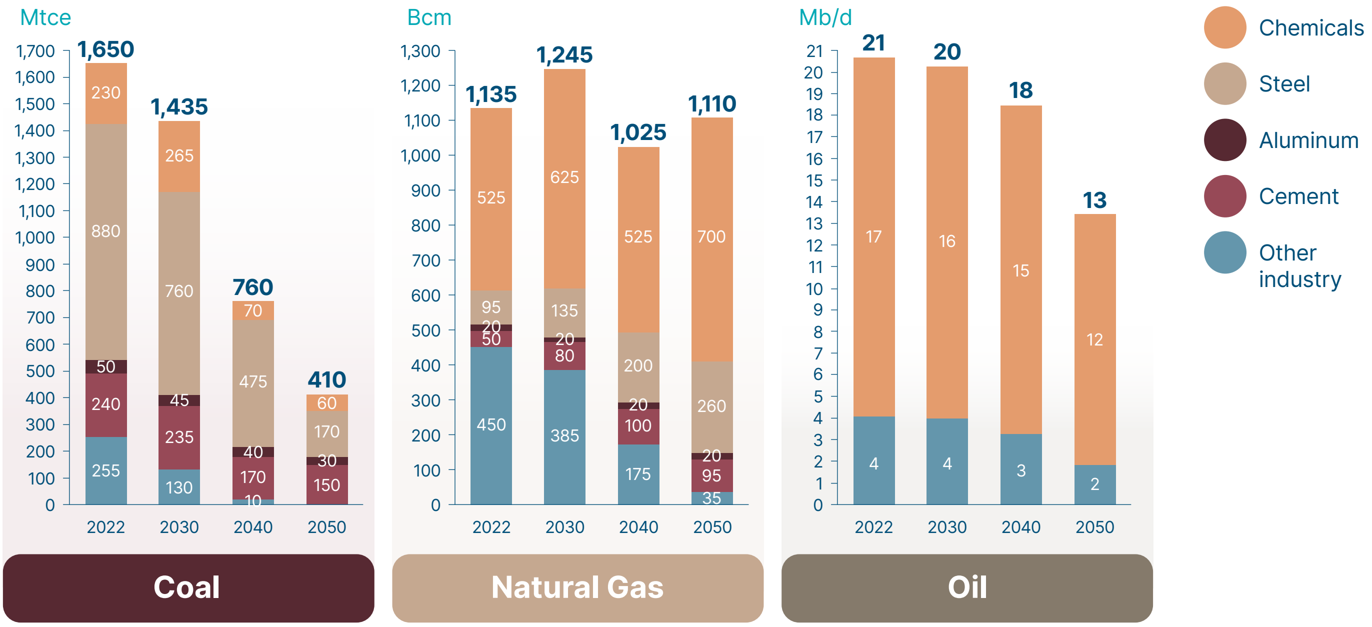
Exhibits 2.21 and 2.22 show the aggregate fossil fuel demand figures for industry in our ACF and PBS,[92] including:

- Industry coal demand is likely to fall dramatically by 2050, falling 75% in the ACF scenario and 80% in the PBS, but with only 13% reduction by 2030 in the ACF.
- Gas demand in the ACF stays roughly flat at around 1,100 Bcm per annum, as declining use in other/light industry is offset by increased use in steel. In the PBS it falls 55% as petrochemicals shifts strongly to non-fossil feedstock.
- Oil demand, which is concentrated in the petrochemical sector, falls only moderately in the ACF scenario from 21 Mb/d today to 13 Mb/d by 2050. In the PBS it falls much more dramatically to 3 Mb/d by 2050 as petrochemicals switches to non-fossil feedstocks. By 2030, however, there is very limited potential for reduced oil demand.

EXHIBIT 2.21

## Aggregate fossil fuel demand in heavy industries in the ACF scenario

Annual fossil fuel consumption by sector
Specific units




**NOTE:** All numbers are rounded. Figures include the allocation of fossil fuel consumption in energy own-use sector. Other industry includes machinery & transport equipment, food & tobacco, mining & construction, paper, pulp & printing, non-metals minerals, textile & leather, non-ferrous metals, wood & wood products and other subsectors not mentioned elsewhere.

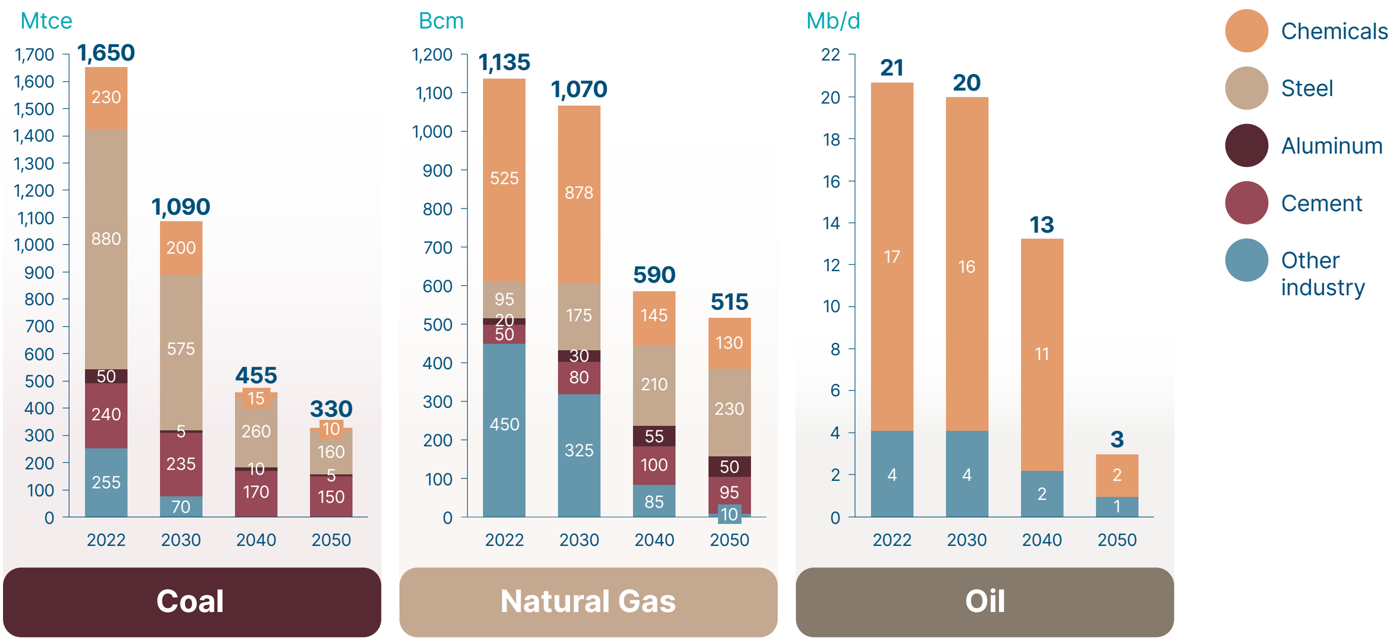
**SOURCE:** Systemiq analysis for the ETC.

92 Figures in exhibits 2.21 and 2.22 include the allocation of energy demand in refining.

EXHIBIT 2.22

# Aggregate fossil fuel demand in heavy industries in the PBS scenario

Annual fossil fuel consumption by sector
Specific units




**NOTE:** All numbers are rounded. Figures include the allocation of fossil fuel consumption in energy own-use sector. Other industry includes machinery & transport equipment, food & tobacco, mining & construction, paper, pulp & printing, non-metals minerals, textile & leather, non-ferrous metals, wood & wood products and other subsectors not mentioned elsewhere.

**SOURCE:** Systemiq analysis for the ETC.

### 2.2.3 Buildings

Total global energy use in buildings amounts to about 37,000 TWh or 130 EJ today.[93] Direct use of fossil fuels account for around 35–40% of this, providing 14,000 TWh in 2022. Within this total, gas accounts for 60%, oil for 30%, and coal for almost 10%.

Space and water heating account for 45% of all energy used in buildings (equivalent to 16,700 TWh) and 80% of all fossil fuel use in buildings (11,000 TWh).[94] Fossil fuels generate 65% of on-site building heating, and a further 10% is provided by district heating systems, which are 90% fossil fuel-based.[95] Today, a mere 15% of building heating is electrified.

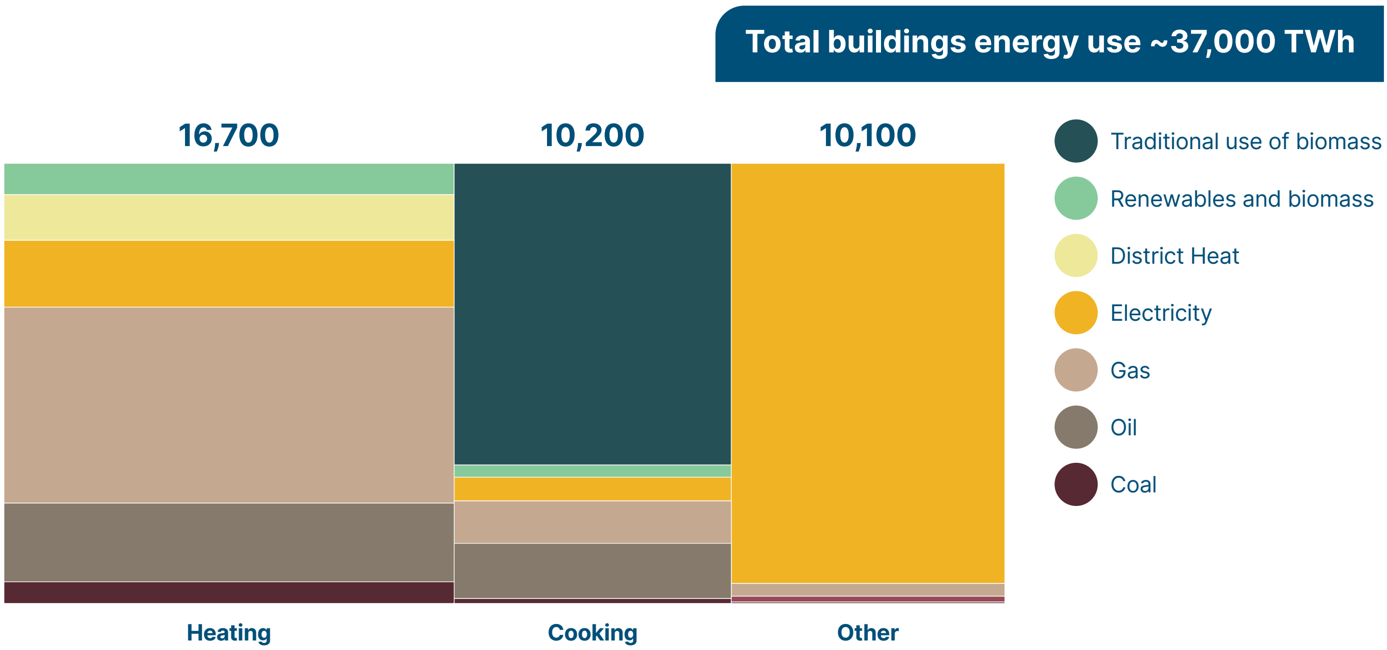
By contrast, the 10,200 TWh of energy used for cooking today primarily derives from Traditional Use of Biomass (TUOB) in low-income countries. This is extremely inefficient (as little as 10% of energy used is converted to useful heat) and has severe implications for human health.[96]

Finally, the remaining 10,100 TWh of energy used in buildings is over 95% electricity, driving electrical appliances, lighting and air-conditioning units [Exhibit 2.23].

EXHIBIT 2.23

## Breakdown of global energy use in buildings by source and end-use in 2022

Energy use in buildings
TWh




| Heating | Cooking | Other | |
|---|---|---|---|
| 45% | 30% | 25% | Share of total buildings **energy use** |
| 80% | 15% | <5% | Share of total buildings **fossil fuel use** |

**NOTE:** For cooking, renewables and biomass refers to biomass excluding traditional use of biomass, which is presented as a separate category. For heating, renewables and biomass includes all biomass.

**SOURCE:** Systemiq analysis for the ETC; IEA (2023), *World energy balances dataset*.

93 IEA (2023), *World Energy Outlook 2022*.
94 IEA (2022), *World Energy Outlook 2021*.
95 District heating involves generating heat in a centralised location and then distributing it to residences, businesses and industry in a local area. IEA (2023), *District Heating*.
96 IEA (2023), *A Vision for Clean Cooking Access for All*. TUOB refers to the use of solid biomass (e.g., wood, wood waste, and charcoal) with basic technologies (e.g., open fires and basic stoves).

The two key questions are therefore how to decarbonise **heating** and **cooking**.

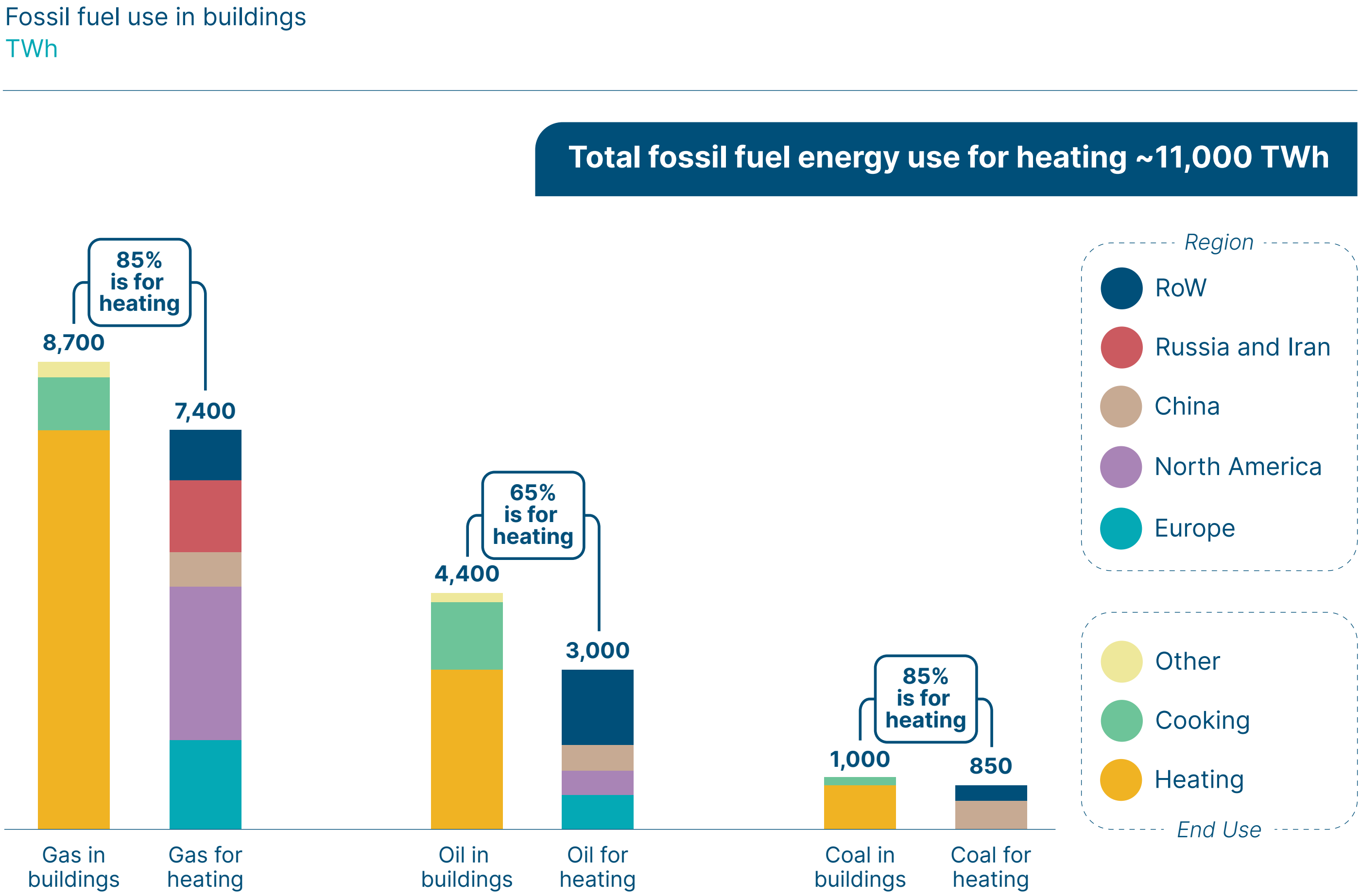
### Building Heating

Of the 11,000 TWh of fossil energy used directly to provide on-site heat, around 65% or 7,400 TWh is gas, 25% or 2,900 TWh is oil, and the remaining amount is coal. Coal is dominant in some district heating systems, particularly those in northern China.[97]

As shown in Exhibit 2.24, fossil-based heating is concentrated in higher latitude, northern hemisphere countries with relatively cold winters, and total gas use in buildings is therefore concentrated in those countries. Around 75% of total fossil fuel use for heating buildings, and over 60% of total gas use in buildings, is in the US and Canada, Europe, and China. Russia and Iran are also major users of gas in buildings, accounting for 10% and 7% respectively of total global gas use in buildings.[98]

EXHIBIT 2.24

## Breakdown of fossil fuel use in buildings by end-use and region




**NOTE:** Heating includes both space and water heating. Other includes building cooling, lighting and appliances. RoW = Rest of World.

**SOURCE:** Systemiq analysis for the ETC; IEA (2022), *World Energy Outlook 2022*; IEA (2023), *World Energy Outlook 2023*; IEA (2023), *World Energy Balances dataset*; IEA (2023), *Energy Efficiency dataset*; Tsinghua Building Energy Research Center, *Annual Report of Building Energy in China.*

97 IEA (2017), *Heating Chinese cities while enhancing air quality.*
98 IEA (2023), *World Energy Balances dataset.*

Outside of these and similar latitude countries (e.g., Japan, Korea, Turkey), demand for cooling far exceeds that of heating. Furthermore, without action to address energy efficiency, energy demand for space cooling could more than triple by 2050, as rising incomes enable people to afford air-conditioning and as the need for adaptation grows with the warming climate.[99] An increasing number of households in these other countries will therefore install air-conditioning, creating a natural and cost-effective solution for both space cooling and limited space heating needs via the installation of bidirectional air-source heat pumps. Water heating will increasingly be electrified or be provided by solar thermal panels in countries with significant potential for solar energy.

The open question is therefore **how to decarbonise space and water heating in colder and predominantly richer countries**, and at what pace this can be achieved. Over the longer term, the solution will be dominated by electrification, particularly with heat pumps and in particular in countries which also have significant cooling needs, such as southern Europe.

Several countries have already introduced policies to encourage or mandate the installation of heat pumps rather than gas or fuel oil boilers in new buildings (e.g., by 2026), and some are considering dates beyond which to ban the sale of fossil fuel boilers to replace existing assets (e.g., by 2035) [Exhibit 2.25]. To date, however, no major country has set timelines for when gas distribution networks to supply buildings could be switched off. Feasible trajectories shown in this report suggest this could be possible around 2045.

Transitioning fossil fuel heating to heat pumps faces significant implementation challenges, given the higher up-front capital costs compared to gas or oil boilers, even though their lifetime costs may be much lower. Policies to provide low-cost finance (e.g., subsidies and grants targeted at low-income households) for residential building retrofits will be critical and must be scaled up this decade.[100]

EXHIBIT 2.25

## Existing policies to phase out fossil fuel use in building heating

3 stages of policy to phase out fossil fuel boilers

<table>
<tr><th></th><th>EU</th><th>UK</th><th>US</th><th>China</th></tr>
<tr><td>Key targets for 2030</td><td>RePower EU targets the installation of 30m additional heat pumps from 2020, taking total installed stock to at least 50m.</td><td>UK government aims to reach 600,000 annual heat pump installations by 2028, up from around 55,000 today.</td><td>4 states currently have heat pump deployment targets (~12m additional by 2030); no federal target.</td><td>No official targets to date</td></tr>
<tr><td>1 Preventing new builds from having fossil fuel boilers</td><td>8 member states have introduced bans on gas boilers in new builds (e.g., Netherlands from 2018, Italy from 2022, France from 2023).</td><td>Plans to ban gas boilers in new builds from 2025; but there is political uncertainty surrounding this.</td><td>New York is the first state to ban fossil fuel heating and cooking in new builds from 2026 (short buildings) and 2029 (taller buildings).</td><td rowspan="2">• Main focus in China to date has been the transition away from coal heating, towards either district heat or heat pumps.<br>• Potential for heat pump subsidies to be introduced in 2026.</td></tr>
<tr><td>2 Preventing new fossil fuel boilers in existing homes</td><td>• Emissions Trading Scheme to be extended to buildings in 2025.<br>• 5 member states have bans on oil and gas boilers in all buildings (e.g., Ireland from 2025, Germany from 2026).</td><td>Exemption recently added to the 2035 ban of gas boilers for around a fifth of households that may require more extensive retrofitting.</td><td>• No timelines to date<br>• Inflation Reduction Act residential heat pump subsidies could lead to an additional 7m deployed.</td></tr>
<tr><td>3 Preventing buildings from running a fossil fuel boiler</td><td>Denmark plans to convert all remaining gas boilers to heat pumps or district heating by 2029.</td><td>No policies or indication to date.</td><td>No policies or indication to date.</td><td>No policies or indication to date.</td></tr>
</table>

**NOTE:** This exhibit refers to existing policies as of October 2023.

**SOURCE:** Systemiq analysis for the ETC; European Commission (2023), *Heat pumps*; European Heat Pump Association (2023), *Market data*; RMI (2022), *Millions of US homes are installing heat pumps. Will it be enough?*; UK Prime Minister's Office, *PM recommits UK to Net Zero by 2050 and pledges a "fairer" path to achieving target, 20 September 2023.*

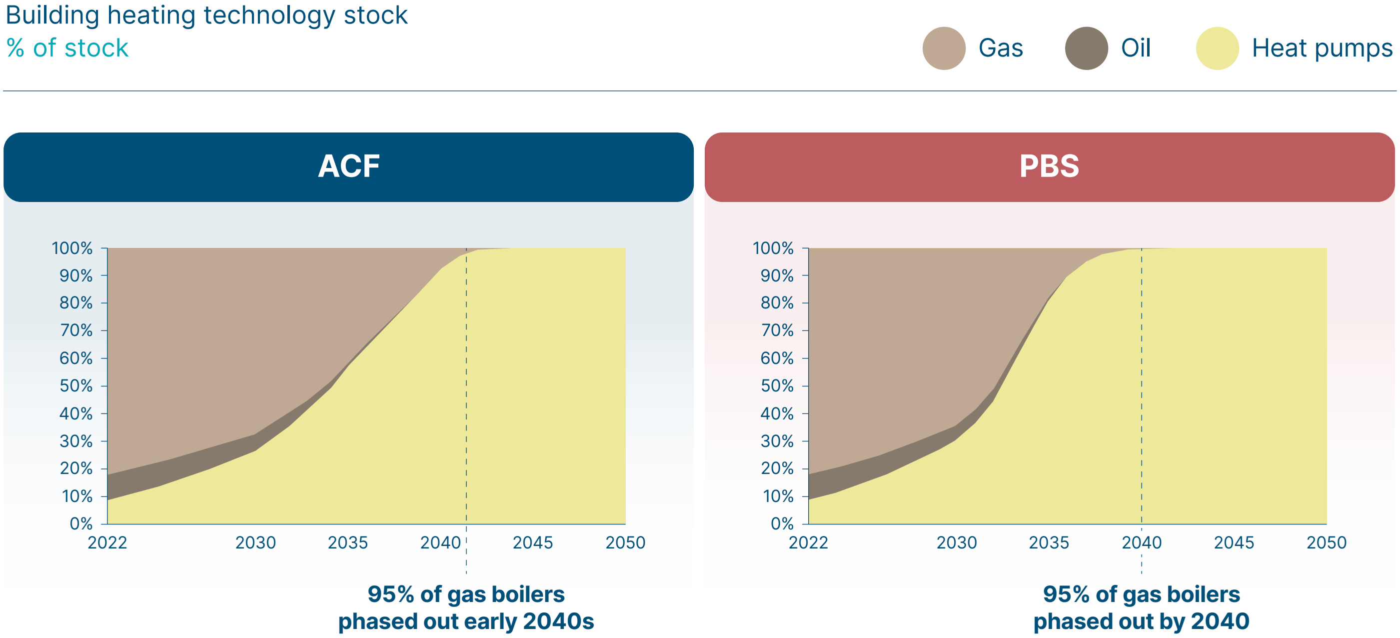
99 IEA (2020), *Is cooling the future of heating?*
100 ETC (2023), *Financing the Transition.*

Even once all new heating installations are electric rather than fossil-based, it will take considerable time before the share of the total stock electrified approaches 100%. Exhibit 2.26 sets out ACF and PBS assumptions on how rapidly the stock of European and US heating systems could shift from gas to electric boilers sales. In other countries the transition is likely to occur later. This results in the scenarios for fossil fuel use in building heating shown in Exhibit 2.27.

**EXHIBIT 2.26**

## Stock of building heating technologies in Europe and the US in ACF and PBS

Building heating technology stock
% of stock

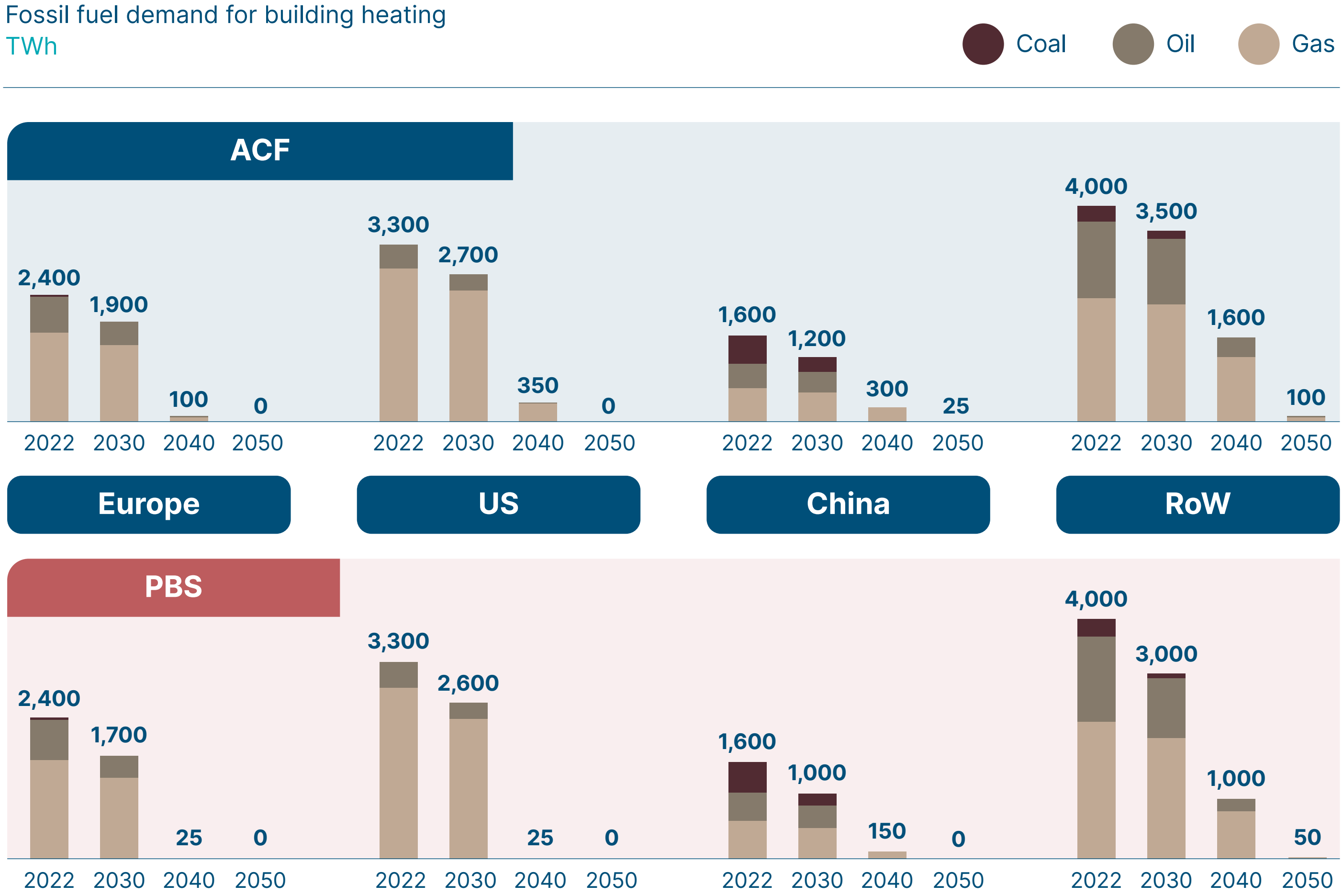



| | ACF | | PBS |
|---|---|---|---|
| **No new gas boiler installations** | 2035 in Europe<br>2037 in US | **No new gas boiler installations** | 2034 in Europe<br>2036 in US |
| **No gas boilers to run** | 2045 | **No gas boilers to run** | 2044 |

**SOURCE:** Systemiq analysis for the ETC; IEA (2022), *World Energy Outlook 2022*; IEA (2023), *World Energy Outlook 2023*; IEA (2023), *World Energy Balances dataset*; IEA (2023), *Energy Efficiency dataset*; Tsinghua Building Energy Research Center, *Annual Report of Building Energy in China.*

EXHIBIT 2.27

## Fossil fuel demand for building heating by region in ACF and PBS for 2022–2050




**NOTE:** Values are rounded.

**SOURCE:** Systemiq analysis for the ETC; IEA (2022), *World Energy Outlook 2022*; IEA (2023), *World Energy Outlook 2023*; IEA (2023), *World Energy Balances dataset*; IEA (2023), *Energy Efficiency dataset*; Tsinghua Building Energy Research Center, *Annual Report of Building Energy in China.*

### Cooking

Electricity is already an important energy source for cooking in high-income countries and will become dominant as gas is phased out of residential and commercial heating systems. But progress towards electrification will be much slower in many lower-income countries, given the higher cost of electricity relative to other fuel sources, and in some cases a lack of electricity supply and reliable grid infrastructure. Around 75% of the population in Sub-Saharan Africa currently lack any access to electricity, and while decentralised small-scale solar systems can provide adequate power for lighting, many appliances and refrigeration, they are often insufficient to support cooking applications as well.[101,102]

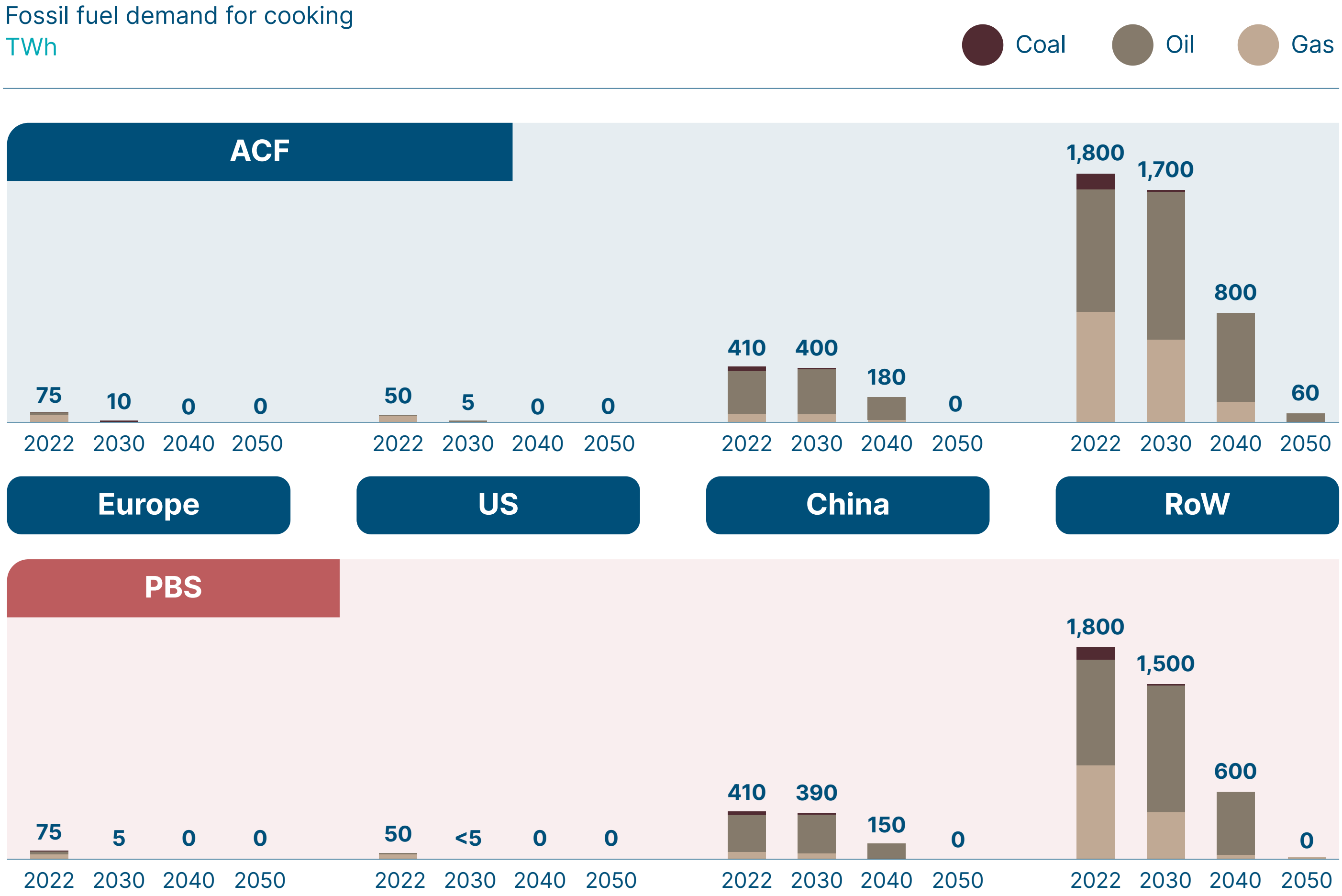
In many countries where cooking currently depends primarily on TUOB, the initial transition is more likely to be to fossil fuels in the form of Liquefied Petroleum Gas (LPG) (produced during oil refining or extracted from oil and gas reservoirs), or modern forms of bioenergy. As a result, fossil fuel use in cooking in our ACF shows oil use increasing slightly in the rest of the world (i.e. countries outside China, North America, and Europe) between now and 2030, as per Exhibit 2.28, before steeply declining to nearly zero by 2050.

101 IEA (2023), *SDG7: Access to electricity.*

102 Lighting, appliances, and refrigerators require steady amounts of electricity over time whereas cooking requires high amounts of energy for limited amounts of time.

EXHIBIT 2.28

## Fossil fuel demand for cooking by region in ACF and PBS for 2022–2050




**NOTE:** Values are rounded.

**SOURCE:** Systemiq analysis for the ETC; IEA (2022), *World Energy Outlook 2022*; IEA (2023), *World Energy Outlook 2023*; IEA (2023), *World Energy Balances dataset*; IEA (2023), *Energy Efficiency dataset*; Tsinghua Building Energy Research Center, *Annual Report of Building Energy in China*.

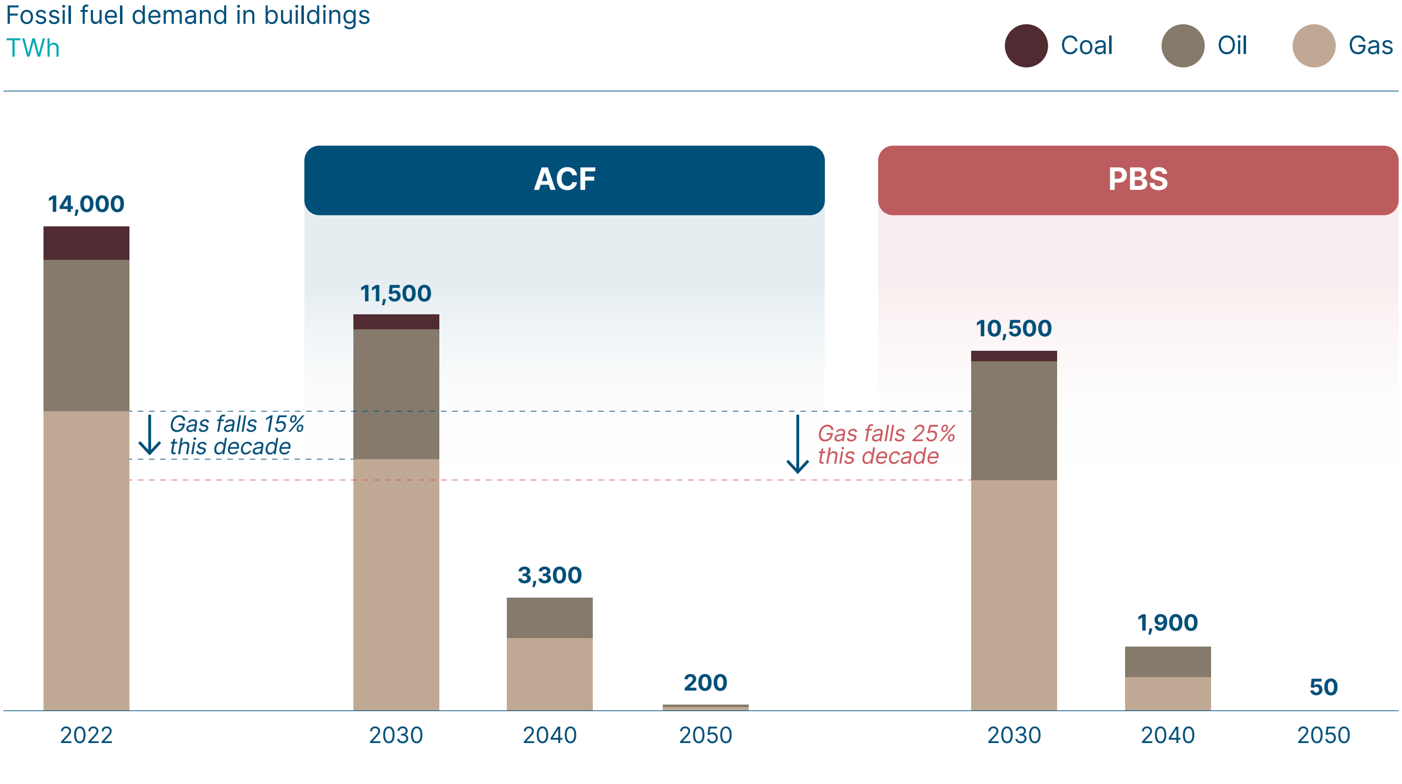
### Total building sector scenario

Combining the projections for heating and cooking, plus for other applications where fossil fuel use is already small, results in the overall building sector scenarios shown in Exhibit 2.29:

- Coal use is entirely eliminated by 2040 in both scenarios.
- Gas use also is almost entirely eliminated by 2050 but falls only 15–25% by 2030.
- Oil use in heating declines rapidly, but initially grows for cooking (in the form of LPG); however, since oil use for heating is currently around 2.5 times larger than for cooking, a material decline of 15–25% can still be achieved globally by 2030.

EXHIBIT 2.29

## Aggregate fossil fuel demand in buildings in ACF and PBS for 2022–2050




**NOTE:** Values are rounded.

**SOURCE:** Systemiq analysis for the ETC; IEA (2022), *World Energy Outlook 2022*; IEA (2023), *World Energy Outlook 2023*; IEA (2023), *World Energy Balances dataset*; IEA (2023), *Energy Efficiency dataset*; Tsinghua Building Energy Research Center, *Annual Report of Building Energy in China.*

### 2.2.4 Power sector decarbonisation

Electricity generation accounts for 67% of coal use and 46% of gas, and results in 13.8 $GtCO_2$ of emissions each year. Decarbonisation of energy using sectors e.g., via electrifying industrial processes, will moreover result in increasing demand for electricity. Decarbonising the world's power systems is therefore the most crucial priority in achieving a net-zero emissions economy.

As the ETC described in our 2021 report *Making Clean Electrification Possible*, **electricity generation can now be decarbonised more rapidly and at lower cost** than was believed 10 years ago. Two factors explain that conclusion:

- First, the very large declines in the cost of wind and solar power generation over the last 10–15 years, which have made renewable electricity competitive with fossil fuel generation in most locations.
- Second, there is a growing recognition that it is possible to balance power demand and supply in systems with much higher shares of intermittent generation than seemed possible 10–15 years ago (e.g., as much as 75 to 90%). This reflects the declining cost of batteries and coming declines in the cost of green hydrogen production, as well as greater understanding of the ability to balance systems with thermal dispatchable plant (burning either hydrogen or gas with CCUS) running only a limited hours per annum.

As a result, while CCS applied to flexible thermal plant may still play a significant role in power systems, latest analysis suggests a minimal role for baseload thermal generation plus CCS, and estimates of the total scale of carbon capture in power systems have been revised down dramatically.[103]

Across most of the world, the endpoint of decarbonisation is therefore increasingly clear and agreed, with a dominant role for wind and solar, plus hydro where resources are available, a possible role for nuclear, and some thermal dispatchable plant, either burning hydrogen or gas with CCS.

103 From 2000 to 2015, we assumed that renewables would remain uncompetitive, and that gas or coal coupled with CCS would be essential to decarbonise baseload power. But given that wind and solar now outcompete new thermal power generation for 82% global generation, and even existing thermal power generation in 57% of global generation, CCS is expected to play only a minor role. ETC (2022), *Carbon Capture Utilisation & Storage in the Energy Transition: Vital but Limited*; BNEF (2023), *Levelized cost of electricity 1H 2023.*

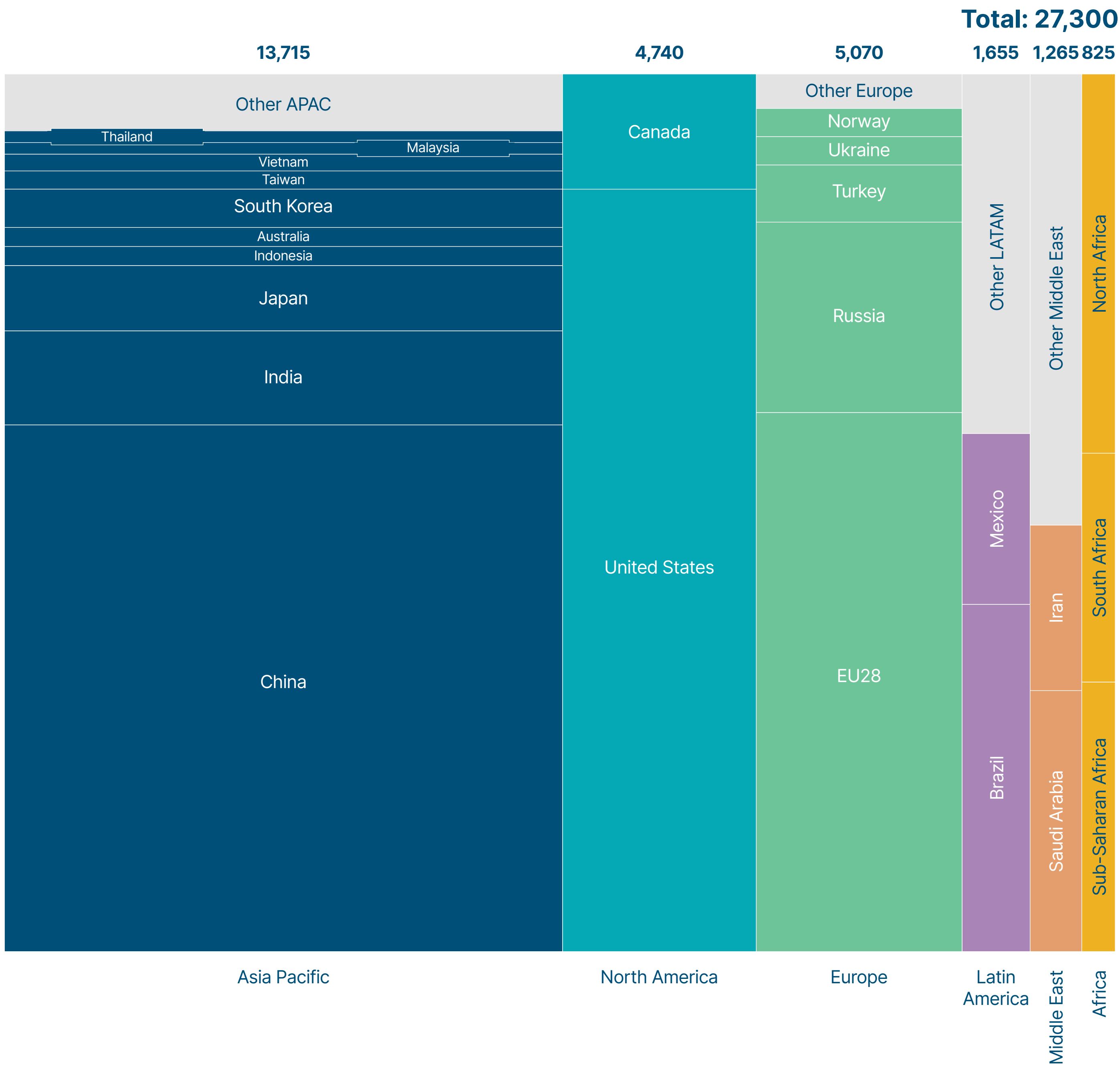
The crucial question is how rapidly progress can be made towards that endpoint. This will vary significantly by country, given differences in the growth rate of electricity demand, the installed base of generation capacity, availability and quality of wind, solar and hydro resources, and countries' ability and willingness to accept incremental costs during the initial stages of renewable deployment.

Our bottom-up projections for future fossil fuel use in power draw on detailed modelling of national power systems, developed by organisations whose assumptions about technology development and costs are similar to our own. Annex A describes these studies, which in total account for 90% of current global power generation, as illustrated in Exhibit 2.30, and the detailed assumptions from these studies used in the ACF and PBS pathways.

**EXHIBIT 2.30**

## Aggregate power generation in 2021 by region and country

Power generation by country in 2021
TWh




**NOTE:** Values are rounded, Countries highlighted are those covered in the bottom-up aggregation of regional power system models or for which proxy country mixes are used. APAC=Asia Pacific; LATAM=Latin America.

**SOURCE:** Systemiq analysis for the ETC; BNEF (2023), *Power generation data.*

China, the US and the EU account for about 15,500 TWh (equivalent to 55%) of total current power generation, and several major developing countries – in particular India and Indonesia – will become increasingly important as electricity demand increases with economic growth.[104] The shape of the transition to net-zero power systems will be very different between these major countries:

- The **EU** and the **US** are already well advanced in reducing coal use and are both committed to achieve close to zero emission power systems by 2035, and well-placed to achieve that objective.[105] In both, therefore, gas use will decline fairly rapidly, with gas power plants running for a declining number of hours per year as they provide flexible backup to a system dominated by intermittent renewables.

- **China** is leading the way in the installation of renewables, with 2023 capacity increases likely to reach around 65 GW for wind and 155 GW for solar.[106] But until 2022, rapid annual growth in electricity demand was slightly exceeding the growth in renewable generation, with particularly strong growth in peak electricity use as a result of rising demand for air conditioning. With hydro generation limited by droughts, coal generation has therefore continued to grow slightly.[107] As the 2020s progress, additional renewable generation will increasingly outpace demand, and coal-based power generation and plant utilisation will begin to fall, reducing total coal use. But even in our PBS scenario, we anticipate only a 17% reduction in thermal coal power generation by 2030. However, by 2050, coal use in China's power system is likely to fall by more than 80%.[108]

- For **India**, estimates produced by The Energy and Resources Institute (TERI) suggest that by 2050,[109] solar and wind could account for between 88% to 95% of electricity generation with coal use entirely eliminated in the PBS. But with electricity demand growing rapidly, coal generation could still rise in the 2030s before beginning a rapid decline in the 2040s. Indonesia is likely to follow a similar path.

Aggregating these and other country analysis produces the **global scenarios for fossil fuel use** in the global power system [Exhibit 2.31]:

- Coal use in the ACF scenario falls just 13% in the 2020s, but with an accelerating pace of reduction in the 2030s and 2040s, while the PBS scenario results in a particularly dramatic reduction in the 2030s.

- Natural gas use in global power generation declines at a steady pace in the ACF (28% by 2030 and 42% by 2040) but initially slightly more slowly in the PBS (20% by 2030 and 51% by 2040) because of coal-to-gas switching in some countries.

- Use of oil in the power sector, which is already limited to just 3 Mb/d, largely concentrated in legacy plants in the Middle East, is rapidly phased out and replaced by either gas or renewables.[110]

104 BNEF (2023), *Power generation data.*
105 The US has set an ambitious goal to achieve a carbon and pollution-free power sector by 2035. The EU has set a new legally binding renewable energy target for 2030 of at least 42.5% of final energy demand. The White House (2023) and European Commission (2023).
106 BNEF (2023), *China on track to blow past Xi's clean power goal five years early.*
107 IEA (2022), *Coal market report 2022.*
108 Relative to 2021, including both abated and unabated use of coal in power generation.
109 The Energy and Resources Institutes.
110 IEA (2023), *Oil market report 2023.*

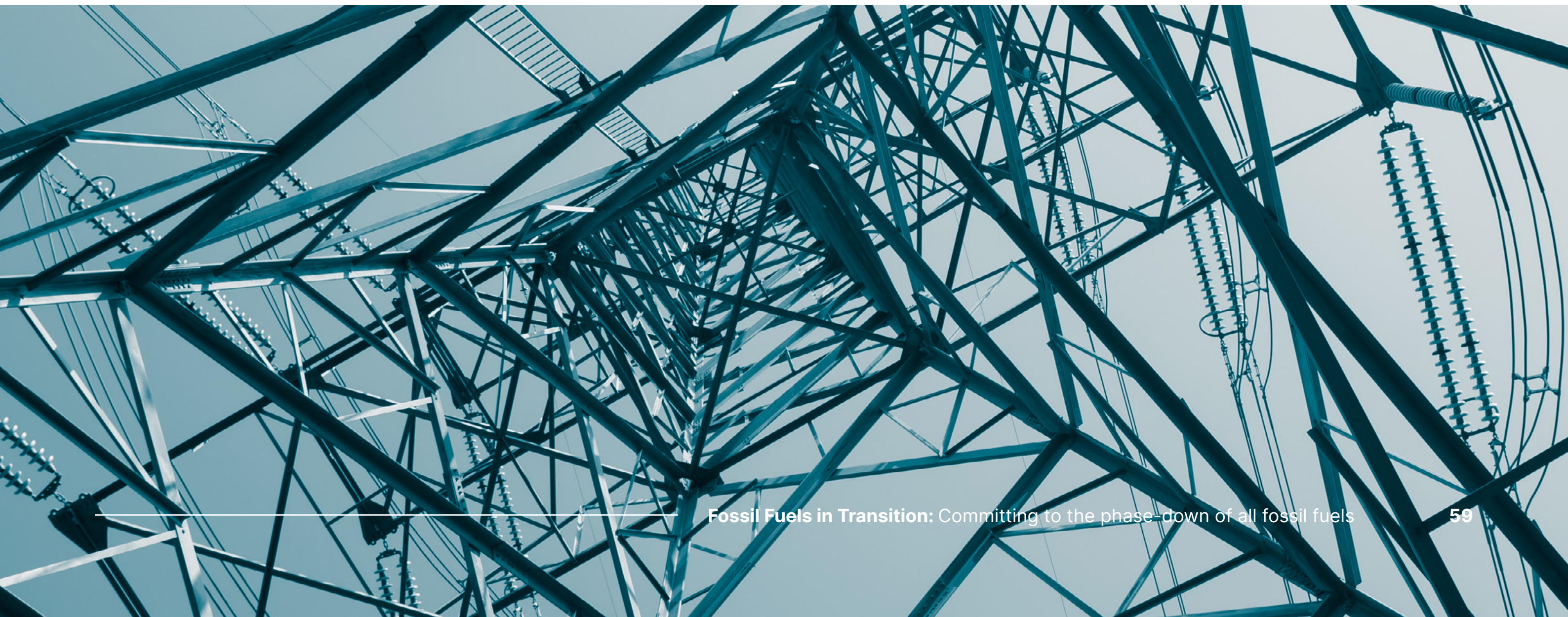
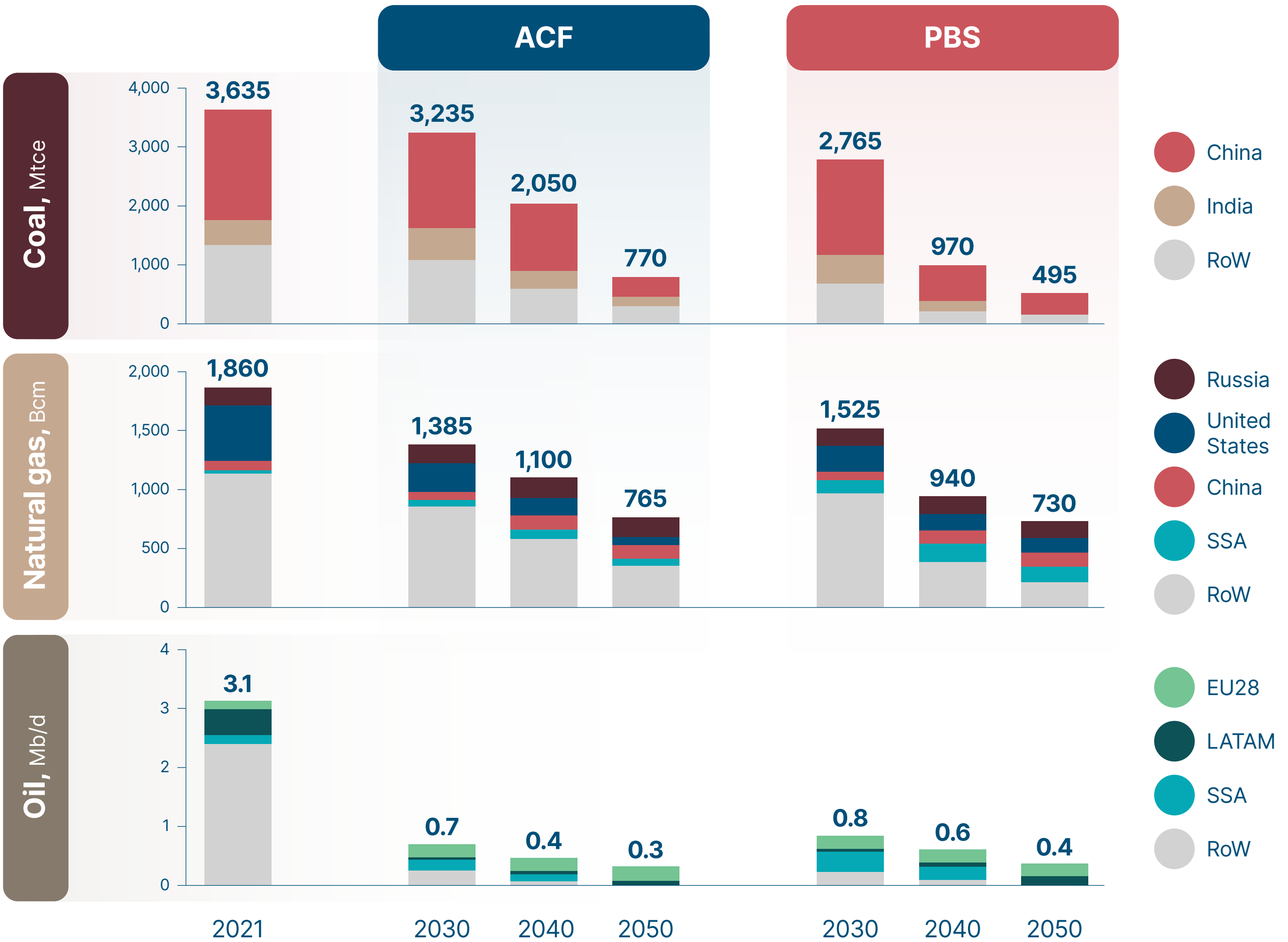


EXHIBIT 2.31

# Fossil fuel use in power generation in ACF and PBS by region

Fossil fuel use in power generation by region
Specific units




**NOTE:** Values for coal and gas are rounded. Numbers include both unabated and abated (coupled with CCS) fossil fuel use. LATAM = Latin America, SSA = Sub-Saharan African, RoW = Rest of World.

**SOURCE:** Systemiq analysis for the ETC.

In addition, the use of captive renewables to produce green hydrogen could reach 13,5000 – 22,500 TWh given our assumptions for total hydrogen and green hydrogen demand discussed in Chapter 2.2.5. Total global electricity generation in 2050 could therefore amount to 74,500 – 95,500 TWh.[111]

For direct power demand, the 61–73,000 TWh range is lower than the 75–90,000 TWh of direct electricity use projected in our 2021 *Making Clean Electrification Possible* report. Two factors explain the difference:

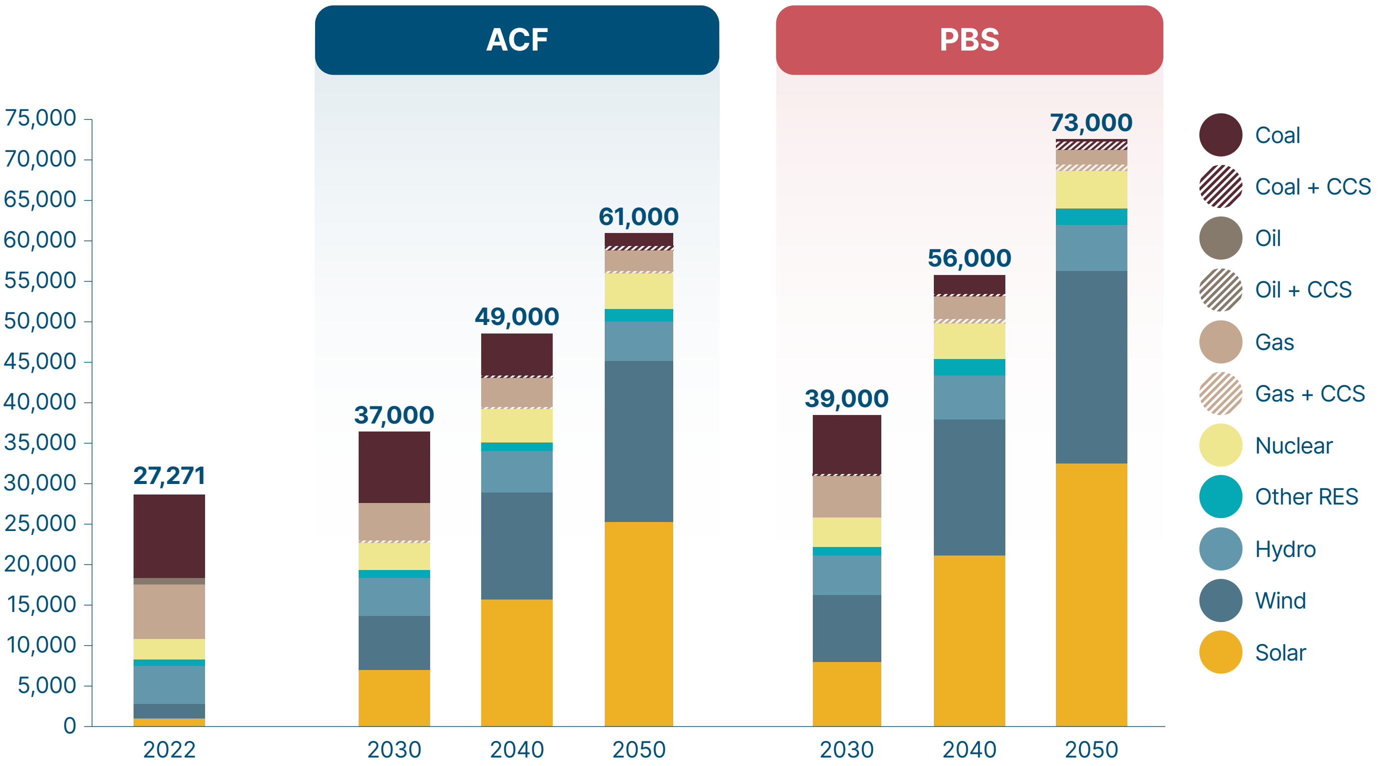
- We have refined our analysis of the impact of electrification on energy efficiency, with electrification of both road transport and of domestic heating (via heat pumps) delivering "energy services" in a far more efficient way. Our latest estimates are therefore more comparable with the 75,000 TWh figure of direct electricity use which was assumed in our previous "maximum productivity" scenario.
- Some of the national studies on which we have drawn make more cautious assumptions about the extent to which rising prosperity will increase electricity demand by 2050. TERI's analysis for India, for instance, assumes that Indian power consumption will grow three times by 2050, but this implies that even by then, India would be using about 25% less electricity per capita than China does today. The implication in India and in many other developing countries is that there will almost certainly be significant further growth in electricity demand beyond 2050. Total global electricity use could therefore meet or exceed our previous 75,000 TWh estimate sometime during the decades after 2050.

Building much greater and completely decarbonised electricity systems, primarily based on renewables, is therefore by far the most important priority to enable the world to achieve net-zero emissions, while delivering rising prosperity for all.

**EXHIBIT 2.32**

## Global power generation by source in ACF and PBS

Global power generation by source
TWh




**NOTE:** All values are rounded. RES = renewable energy sources. There could be a need for up to around 22,500 TWh of additional wind and solar generation for green hydrogen production implied in our projections, which may be underestimated in the regional power generation analyses we have aggregated.

**SOURCE:** Systemiq analysis for the ETC.

111 For instance, if 500 Mt of green hydrogen was produced from dedicated renewables, this could imply another 22,500 TWh of power supply, assuming an electrolyser efficiency of 45 kWh per $kgH_2$.

## 2.2.5 Cross cutting technologies – Hydrogen, CCUS and bioenergy

While massive clean electrification is the highest priority, both carbon capture storage or use and storage (CCUS) and the use of hydrogen will also need to play a role in achieving net-zero emissions. Bioenergy, with significant applicability to decarbonise existing fossil fuel uses but tightly constrained sustainable potential, will also play a limited role in reaching net-zero. Energy efficiency improvements also have a crucial role in reducing both the demand for fossil fuels during the transition to new technologies and total electricity demand in the long-term. This section therefore highlights the assumptions relating to carbon capture, hydrogen, bioenergy and energy efficiency, which are implicit within our sectoral projections of fossil fuel use. It also describes our assumptions on the non-energy uses of oil.

### Carbon capture and storage

Carbon capture and storage (CCS) cannot play a significant (if any) role in the direct decarbonisation of road transport, aviation, or shipping, nor in the decarbonisation of heat applications in hundreds of millions of residential and commercial buildings. But our analysis of industrial sectors and the power system suggests that CCUS will sometimes be the most economic route to decarbonisation, even if other low-carbon technologies play a dominant role. And Steam Methane Reforming (SMR) with CCUS will be used to produce blue hydrogen, which will in turn sometimes be used as an input to ammonia and methanol production and synthetic aviation fuel production.

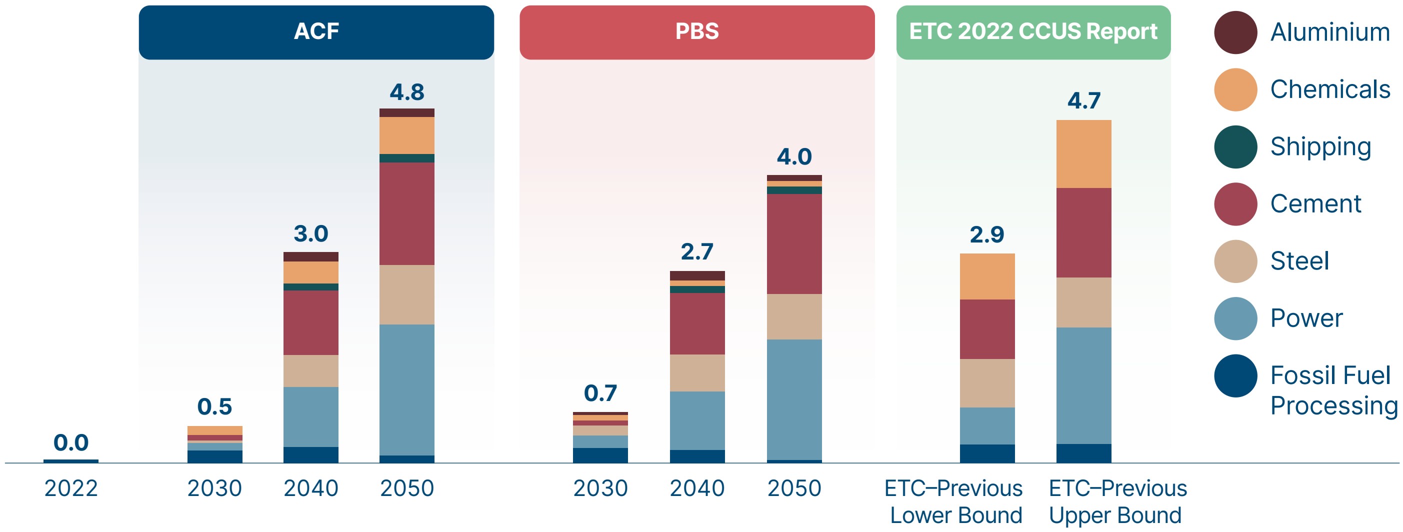
Exhibit 2.34 sets out the scale of point-source carbon capture which we assume by sector, reaching 4.0 $GtCO_2$ per annum by 2050 in the PBS scenario and 4.8 $GtCO_2$ in the ACF scenario. It also shows the rapid growth required in the 2020s from today's minimal level, to reach 0.5–0.7 $GtCO_2$ by 2030. In both scenarios, the use of carbon capture is dominated by:

- The power sector, where it is used to capture emissions from coal or gas plants running as flexible backup to renewables-dominated systems.
- Steel production where gas with CCUS will play a role alongside hydrogen-based direct reduction of iron ore ($H_2$ DRI).
- Cement, where carbon capture will be required to eliminate process emissions even if non-fossil fuel energy is used as a heat source.
- And chemicals where, particularly in the ACF scenario, CCUS could be used to capture emissions resulting from the continued use of oil or gas (with the potential to use the captured carbon as a feedstock).

EXHIBIT 2.33

## Point-source carbon capture by sector in ACF and PBS

CCS demand by sector
$GtCO_2$ per annum




More CCS in power, steel and shipping, as well as for fossil fuel processing.

Lower CCS use in chemicals sector vs. ACF, slightly less CCS in steel and power.

Previous ETC upper bound assumed less CCS for cement and chemicals.

**NOTE:** Total captured emissions include both utilised carbon and carbon that is permanently stored.

**SOURCE:** Systemiq analysis for the ETC; ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited.*

In total, the CCUS deployed by 2050 would capture the emissions generated by burning around 650–750 Mtce of coal (10–15% of current demand) and around 1,100 bcm of natural gas (around 25% of current demand), and point-source CCUS applied to just 2-4 Mb/d of oil demand.[112]

These estimates are towards the upper end of the range which we estimated in our previous ETC analysis, and in particular the 2022 ETC report *Carbon Capture and Storage or Utilisation: Vital but limited*. In that report, we argued that while the role of CCUS in achieving net-zero emissions was limited, it was also vital, and we highlighted the danger that the development of CCUS might not occur fast enough to meet even this limited role.

Chapter 4 assesses the latest information on the pace of development, and also considers the role of carbon dioxide removals, whether achieved via direct air capture (DACCS) or via nature-based removals (NBS).

### Hydrogen

Hydrogen will play a central role in the decarbonisation of many sectors, including:

- In shipping, where ammonia or methanol, both of which require a hydrogen input, will replace the use of heavy fuel oil and marine diesel.
- In the power sector, where hydrogen burned in gas turbines will compete with gas peaker plants with CCS to provide flexible supply in wind and solar-dominated systems.
- And in primary steelmaking, where $H_2$ DRI will play a crucial role.

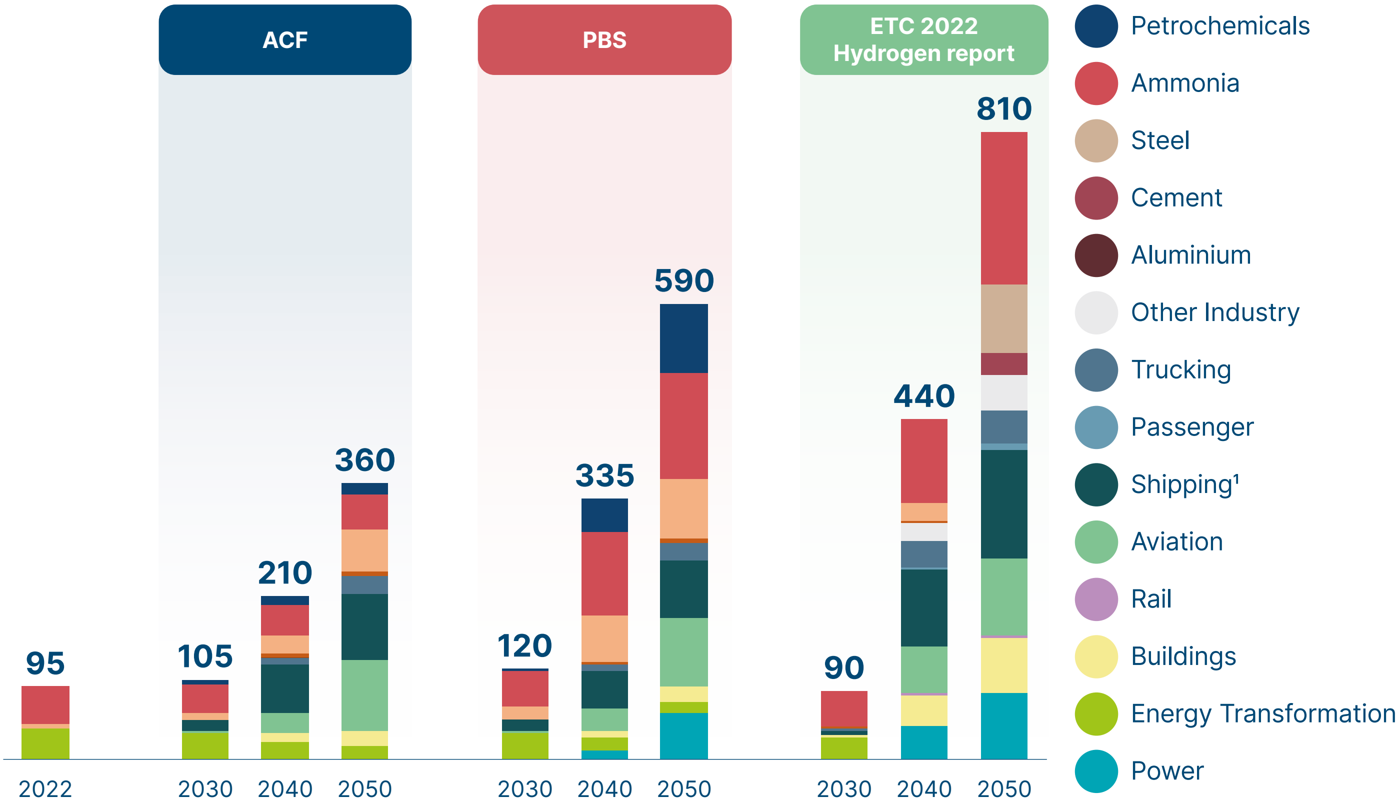
Exhibit 2.34 sets out the hydrogen demand implied in our decarbonisation pathways, reaching 350 $MtH_2$ per annum in the ACF scenario and 600 $MtH_2$ in the PBS scenario. This compares with the 500–800 $MtH_2$ which we estimated in the 2021 ETC report *Making the Hydrogen Economy Possible*.

112 This would amount to 3.5–4.1 $GtCO_2$ of fossil fuel emissions abated. The remainder of capture emissions shown in Exhibit 2.34 are due to process emissions from calcination in cement production.

EXHIBIT 2.34

# Hydrogen demand in the ACF and PBS

Hydrogen demand by sector
Million tons of hydrogen ($MtH_2$) per annum




**NOTE:** Values are rounded. ¹ Ammonia does not include ammonia/hydrogen used in shipping, which is accounted for separately under 'Shipping', hydrogen consumption from trucking comes from MPP (2022), *Making Zero-emissions trucking possible*, Energy transformation = energy consumed in processing raw fossil fuels into useable energy products, mostly to convert crude oil to refined oil products.

**SOURCE:** Systemiq analysis for the ETC; ETC (2021), *Making the hydrogen economy possible.*

Our latest estimates suggest:

- Somewhat lower levels of hydrogen use in buildings and light industry, where there is increasing confidence that electricity-based solutions will dominate.
- Lower levels in the power system, where the balance between hydrogen versus gas with CCS is difficult to predict.
- And slightly lower volume required for shipping fuel, where we now assume greater potential for energy efficiency improvement.[113]

But even our new figures still imply a significant increase in hydrogen production from today's 95 Mt per annum, and all the 350–600 Mt needed in 2050 must be produced in a zero-carbon way.

In our 2021 report, we assumed that in the long run and in most regions, green hydrogen produced via electrolysis would be cheaper than blue hydrogen produced via natural gas (SMR) or syngas (ATR) reforming coupled with CCS, and our latest analysis continues to make this assumption.[114] But it is important to note that even if the share of blue hydrogen is limited to 15% in 2050, this would still imply the need for 350 Bcm of natural gas in our PBS scenario, and around 200 Bcm in the ACF. This would be the equivalent to just below one-third of all natural gas use in 2050 in the PBS.

113 25% of current shipping demand is for the transport of fossil fuels. DNV GL (2022), *Energy transition outlook 2022.*

114 The assumptions behind feasible and realistic pathways for blue and green hydrogen production were set out in detail in Chapter 2 in the ETC's 2022 report, *Making the hydrogen economy possible.* These assumptions included both long-term cost reductions in green hydrogen production, and feasibility of retrofitting existing grey hydrogen production with CCS and building out new blue hydrogen production. More recent forecasts for hydrogen production costs still expect green hydrogen to be most cost-competitive from the mid-2030s, and we therefore keep the same shape of supply trajectory for future decades as we assumed in our previous report, with ~85% of supply from green hydrogen, and ~15% from blue. See also BNEF (2023), *Hydrogen levelised cost update.*

Future developments in the relative economics of hydrogen-based versus other decarbonisation options and in relative costs of green versus blue hydrogen will therefore have a significant influence on the precise level of future gas demand.

### Bioenergy

The ETC's report on sustainable bioresources set out clearly the potential, limited, role for sustainable bioenergy in the energy system by 2050.[115] It analysed what volume of bioresources could be safely and sustainably extracted given competing demands for food production and biodiversity preservation. This suggested that around 50 EJ could certainly be sustainably extracted, with potential for another 50-60 EJ if land use for food production could be reduced. The report then set out guidelines for prioritisation of scarce bioresources supply, focussing on those applications where alternative decarbonisation options were not available or likely to be very expensive.

Based on the sectoral analysis of decarbonisation options set out above, the ETC's updated view on bioenergy demand remains broadly consistent with our previous view. Revisions include smaller uses in aviation and chemicals, but slightly larger roles in carbon dioxide removal (whether via BECSS or biochar), and in cement steel and buildings:

- Direct use of bioresources in wood products and pulp and paper would remain a significant demand segment, reaching 20–25 EJ of final bioenergy demand by 2050.
- The use of biofuels in aviation would be the next largest sector, with around 10 EJ of final bioenergy demand in 2050, while use of bio-oils and other bio-based products in the chemicals sector would contribute a further 5 EJ of final bioenergy demand.
- Bioenergy used in either BECCS or for biochar, both for carbon removals, would correspond to 4–5 EJ of final energy demand.
- A small role for bioenergy in steel, cement and in buildings, in total around 5–6 EJ.
- Traditional use of bioenergy, typically used for cooking, is assumed to phase out gradually from current levels of ~24 EJ in 2022, halving by 2030 and reaching zero by 2050.

### Energy efficiency

Our 2020 *Making Mission Possible* report made top-down assumptions about the impact of energy efficiency improvements on total energy demand. Our latest projections, and the underpinning MPP sector analyses, include more granular assumptions.

The biggest driver of future efficiency improvement will be electrification, with for instance:

- Electric vehicles being 3–4 times more efficient than internal combustion engines at converting the energy stored in a vehicle's tank into kinetic energy to drive the wheels (tank-to-wheel efficiency).[116]
- Heat pumps potentially converting electricity into heat at 300–400% efficiency, while the most efficient condensing gas boilers reach efficiencies of around 95% but cannot exceed 100%.[117]

But many other types of energy efficiency improvement can play a vital role, both in reducing demand for fossil fuels where they are used (e.g., ICEs still on the road) and to reduce future electricity demand. Exhibit 2.35 sets out the efficiency improvements assumed in our scenarios.

These assumptions include multiple ways in which the same demand for services enabled by energy consumption (e.g., km travelled by plane, or kWh of heat within a house) could be delivered in a more efficient fashion. We have not however assumed any significant changes in behaviour (e.g., reductions in the level of air travel or turning down thermostats in homes) which would reduce demand for overall energy services. This is a major difference between our PBS scenario and the IEA's *Net-Zero Emissions scenario*,[118] which we discuss in Chapter 3.2 below.

115 ETC (2021), *Bioresources within a net-zero emissions economy.*
116 DNV GL (2022), *Energy Transition Outlook 2022.*
117 IEA (2022), *The future of heat pumps.*
118 IEA (2023), *Net-zero roadmap.*

EXHIBIT 2.35

# Energy efficiency assumptions by sector in ACF and PBS

| Sector | | Energy efficiency assumptions *(not comprehensive)*[1] |
|---|---|---|
| Transport | Road transport *(incl. trucking)* | • **ICE fuel economy improvements: -0.7% p.a. in ACF, -1.6% p.a. in PBS.**<br>• EV motor efficiency improvements: -1.6% p.a. in both scenarios.<br>• Conversion losses results in 5% additional electricity consumption for EVs. |
| | Other transport | • n.a. |
| | Shipping | • **Efficiency improvements:** ~1.2% p.a. in ACF, ~1.5% in PBS, thus entirely offsetting demand growth between 2020 and 2050. |
| | Aviation | • **Fuel efficiency improvements:** 1.5% p.a. from 2019-30, ramping up to 2% p.a. in 2030, then constant at 2% p.a. until 2050. |
| | Rail | • n.a. |
| Buildings | Heating, Cooking, Other | • **Average heat pumps efficiency of 300%**, dominant technology to decarbonise buildings.[2] |
| Industry | Steel | • **Material efficiency strategies:** material recirculation, productivity of use and material efficiency reduce demand by up to 40% in 2050 in the High Circularity Scenario vs. BAU, and 60% in a maximal scenario. |
| | Cement | • **Concrete demand reduction:** 22% by 2050 compared with BAU scenario<br>• Deploying electrical and thermal efficiency measures can decrease the energy intensity of concrete production by 12% by 2050. |
| | Aluminium | • **Scale of up secondary usage** can reduce emissions by up to -24% by 2050<br>• **Material and resource efficiency** by up to 17% by 2050. |
| | Petrochemicals | • **Materials circularity/recycling** can reduce total demand by 33% - 50% by 2050 for non-ammonia chemicals. |
| | Ammonia | • Demand for ammonia growing 1% p.a., offset by some efficiency improvements in fertiliser application.<br>• **Circularity measures:** 4% impact on scope 1 and 2 emissions intensity by 2050 in fastest abatement scenario. |
| | Light industry | • Assumes **industrial heat pump efficiency of 200%** for low-temperature process heating. |
| Other | Energy transformation & non-energy uses | • **Average heat pumps efficiency of 300%**, dominant technology to decarbonise buildings.[2] |

**NOTE:** [1] Energy efficiency improvements via continuing improvement in production efficiencies via e.g., digital / automation technologies are included across most sectors.
[2] Building envelope efficiency (such as insulation) not model explicitly but implied in the assumed heat pump efficiency that is held constant to 2050 and which also includes the fact that some resistive heating will displace fossil fuel use rather than heat pumps, with efficiencies of 100%.

**SOURCE:** Systemiq analysis for the ETC; MPP (2022), *Sector Transition Strategies*; Maersk Mc-Kinney Moller Center (2021), *We show the world it is possible.*

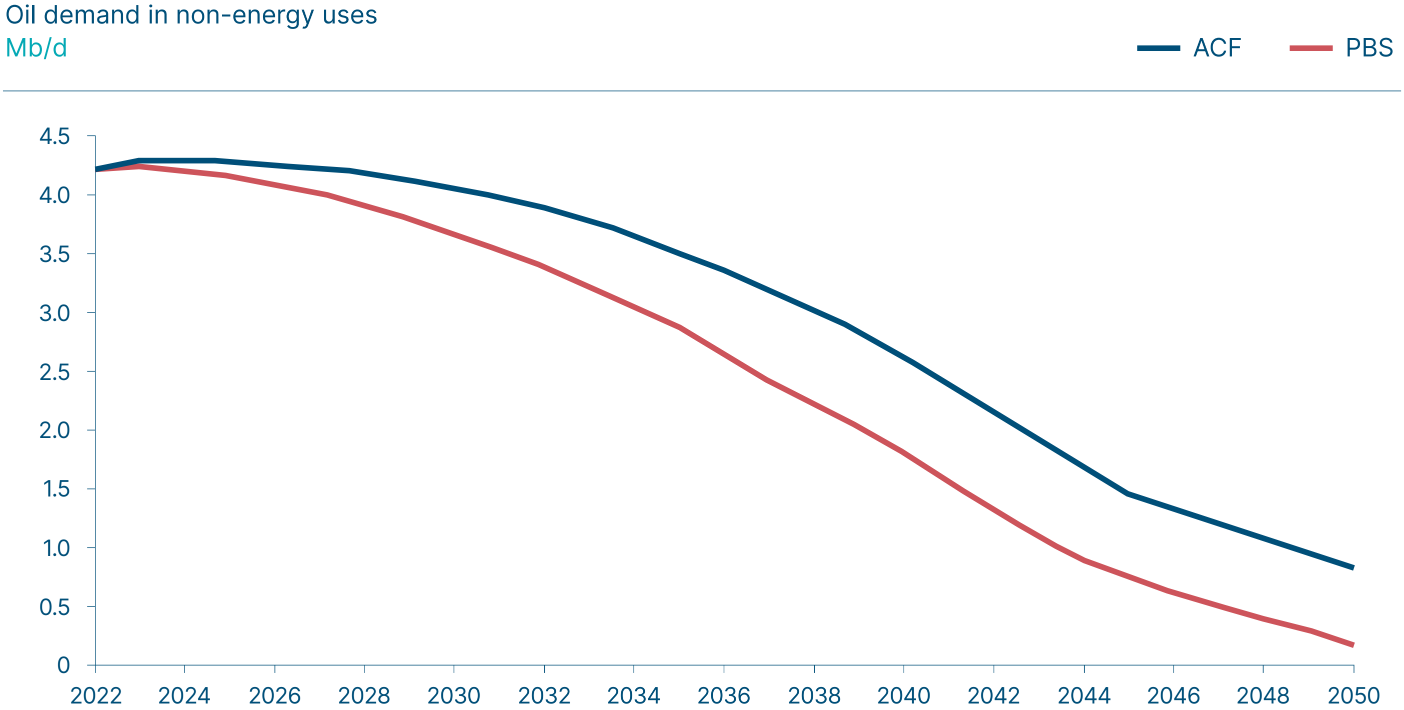
## Non-energy uses of oil

Apart from the primary uses of oil in transport and chemicals, and to a lesser extent in buildings and power, about 4 Mb/d are currently used not as an energy source but to make a range of products which include bitumen, paraffin waxes and white spirits.[119] Since these are co-products of refining, their supply will mechanically fall with the reduction in refining capacity, which will be mostly driven by the decarbonisation of road transport, shipping and aviation. Exhibit 2.36 sets out the implications for declining oil demand. While alternative products can be developed, the fall in supply must be anticipated, and will imply an increased demand for bioresources.[120]

119 RystadEnergy (2022), *Oil market transition report.*
120 We have not assessed the additional demand for bioresources that would result from the decarbonisation of non-energy uses of oil.

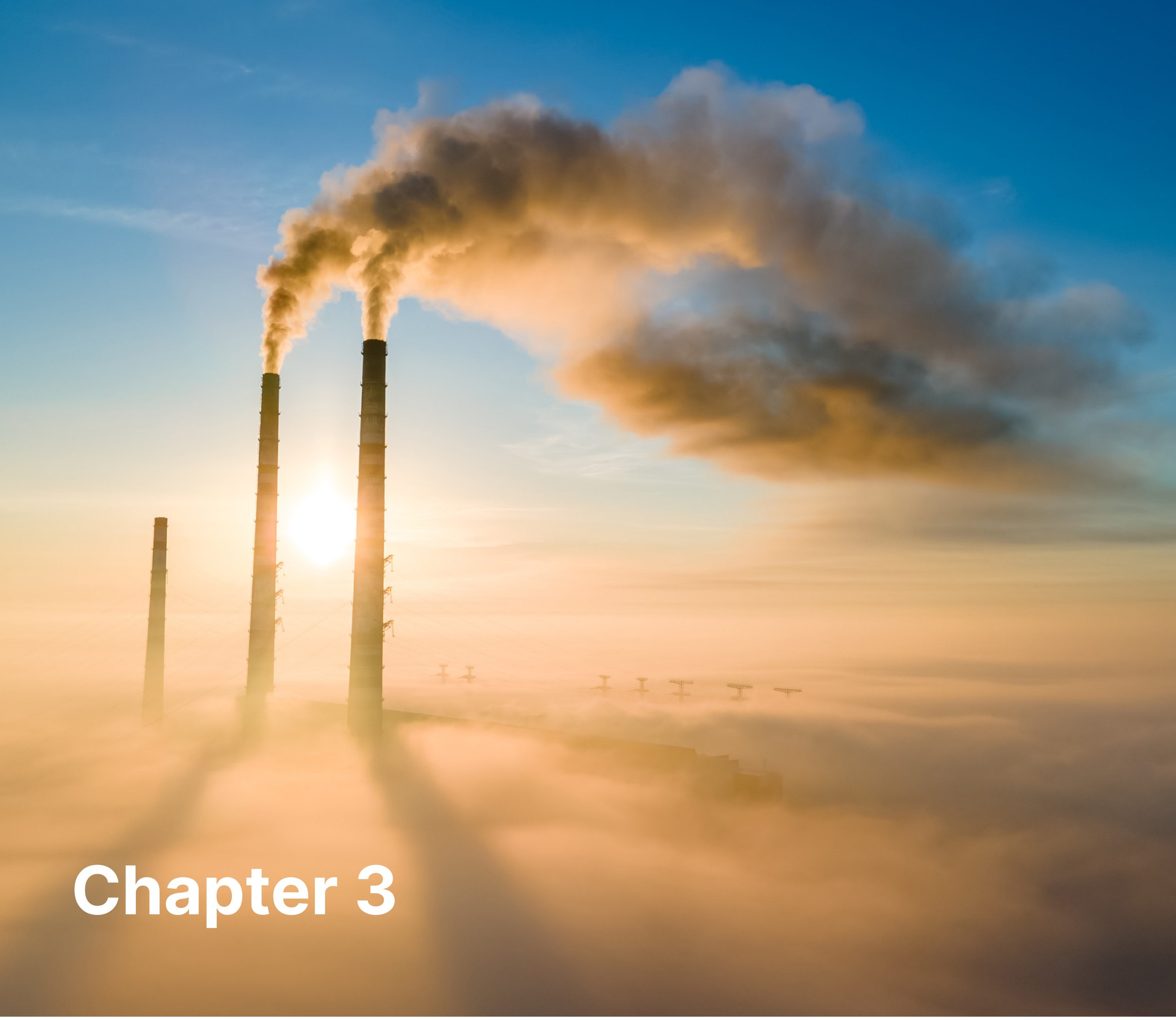
EXHIBIT 2.36

## Oil demand in non-energy applications in ACF and PBS for 2022–2050




**NOTE:** Non-energy uses of oil include bitumen, lubricants, paraffin waxes and white spirits.

**SOURCE:** Systemiq analysis for the ETC.




# Aggregate fossil fuel demand, uncertainties and comparisons with other scenarios

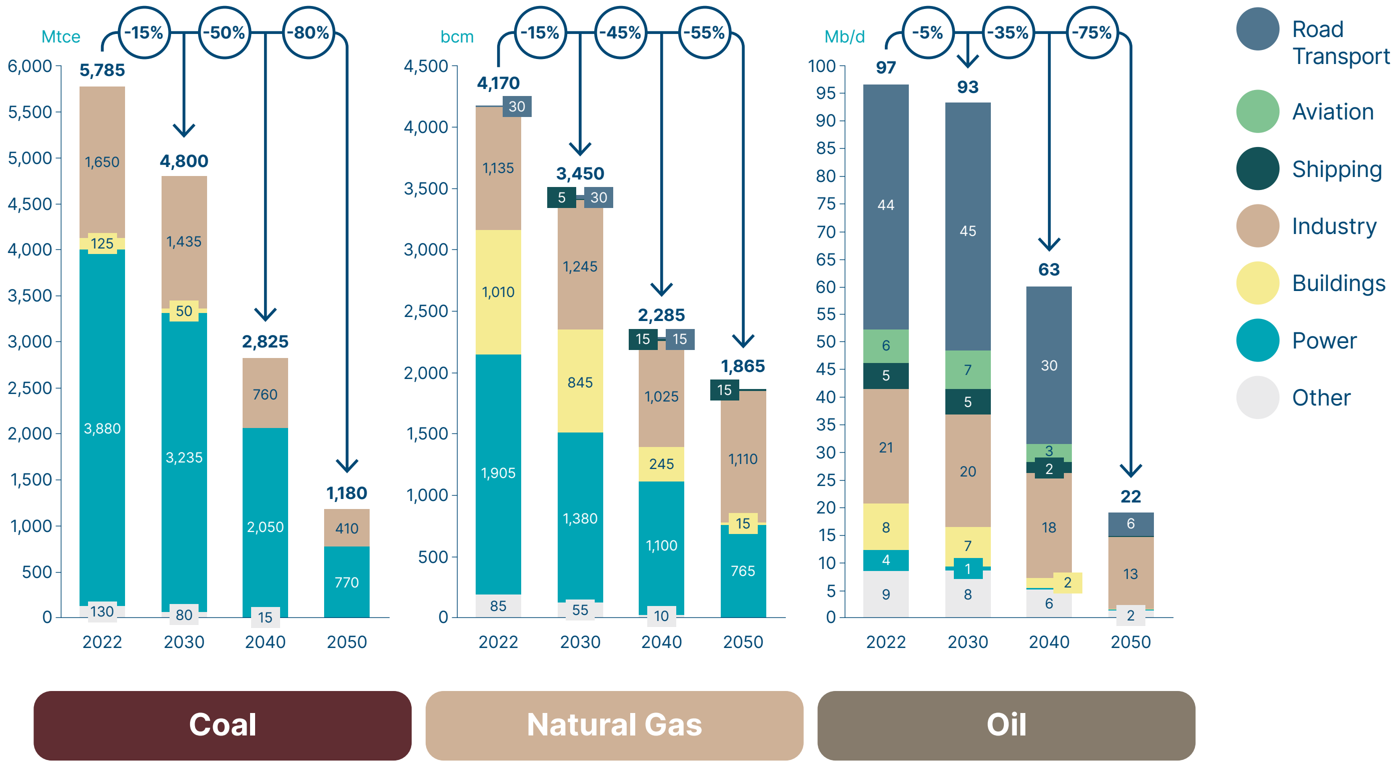
Aggregating our projections for all the sectors, Exhibits 3.1 and 3.2[121] show the resulting total fossil fuel use between now and 2050. Our scenarios suggest that:

- By mid-century, the use of all three fossil fuels could and should be dramatically reduced: coal consumption could fall by 80–86%, gas by 54–70%, and oil by 77–96%.
- There are limits to how far fossil fuel use can be reduced by 2030, with our scenarios suggesting reductions of 17–31% for coal, 15–17% for gas, and 4–13% for oil. This reflects inherent limits to the pace at which the existing capital stock can be replaced, the short time left until 2030, and the reality that fossil fuel use is currently still rising.
- However, by 2040, it would be feasible to achieve reductions of 51–75% for coal, 42–60% for gas, and 35–56% for oil. Commitments made by governments, fossil fuel companies, and financial institutions, and supporting policies and investments should include a strong focus on how to achieve significant reductions by that date.

EXHIBIT 3.1

## Total fossil fuel demand in ACF

Annual fossil fuel consumption by sector
Specific units




**NOTE:** Values are rounded. Allocating energy transformation, "Other" includes other transport (incl. agriculture, mining) and rail.

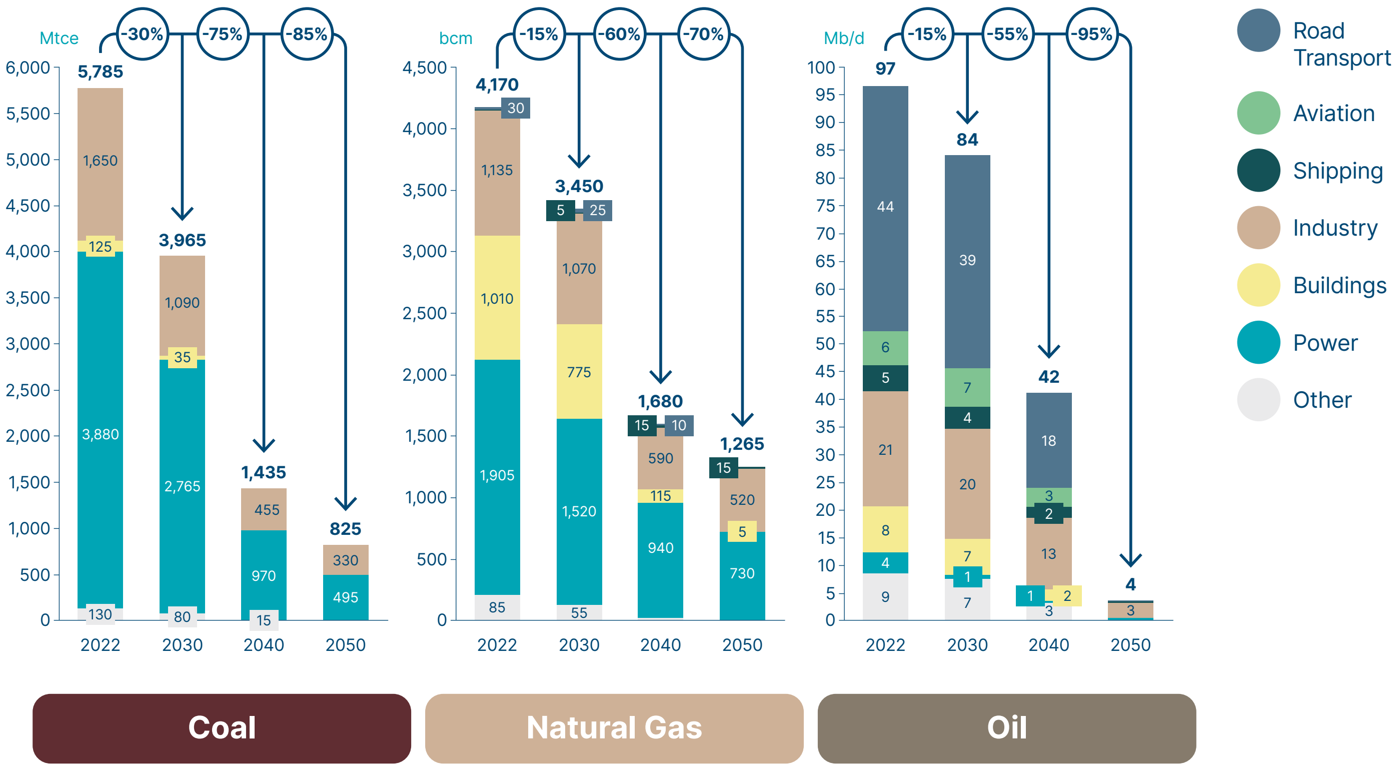
**SOURCE:** Systemiq analysis for the ETC.

121 Figures in exhibits 3.1 and 3.2 include the allocation of energy demand in refining.

EXHIBIT 3.2

# Total fossil fuel demand in PBS

Annual fossil fuel consumption by sector
Specific units




**NOTE:** Values are rounded. Allocating energy transformation, "Other" includes other transport (incl. agriculture, mining) and rail.

**SOURCE:** Systemiq analysis for the ETC.

Exhibit 3.3 shows the implications of this pattern of fossil fuel use, together with our assumptions on point source CCUS, for total emissions from the energy, building, industry and transport (EBIT) sectors of the economy. In the ACF scenario, these would fall from 36.9 to 6.0 $GtCO_2$ after CCUS, and in the PBS case from 36.9 to 2.4 $GtCO_2$.

Chapter 5 explores the implications of these declines in emissions for temperatures, given additional assumptions relating to emissions from AFOLU, and the possible scale-up of CDR.

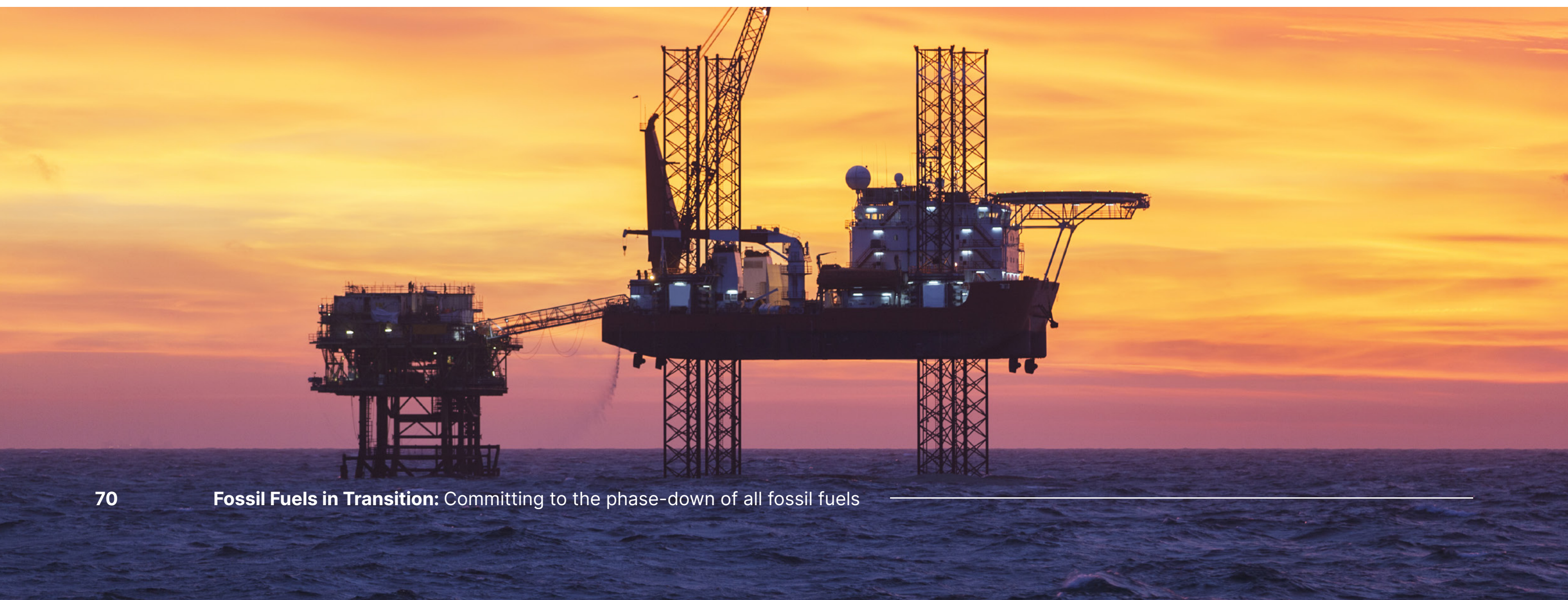
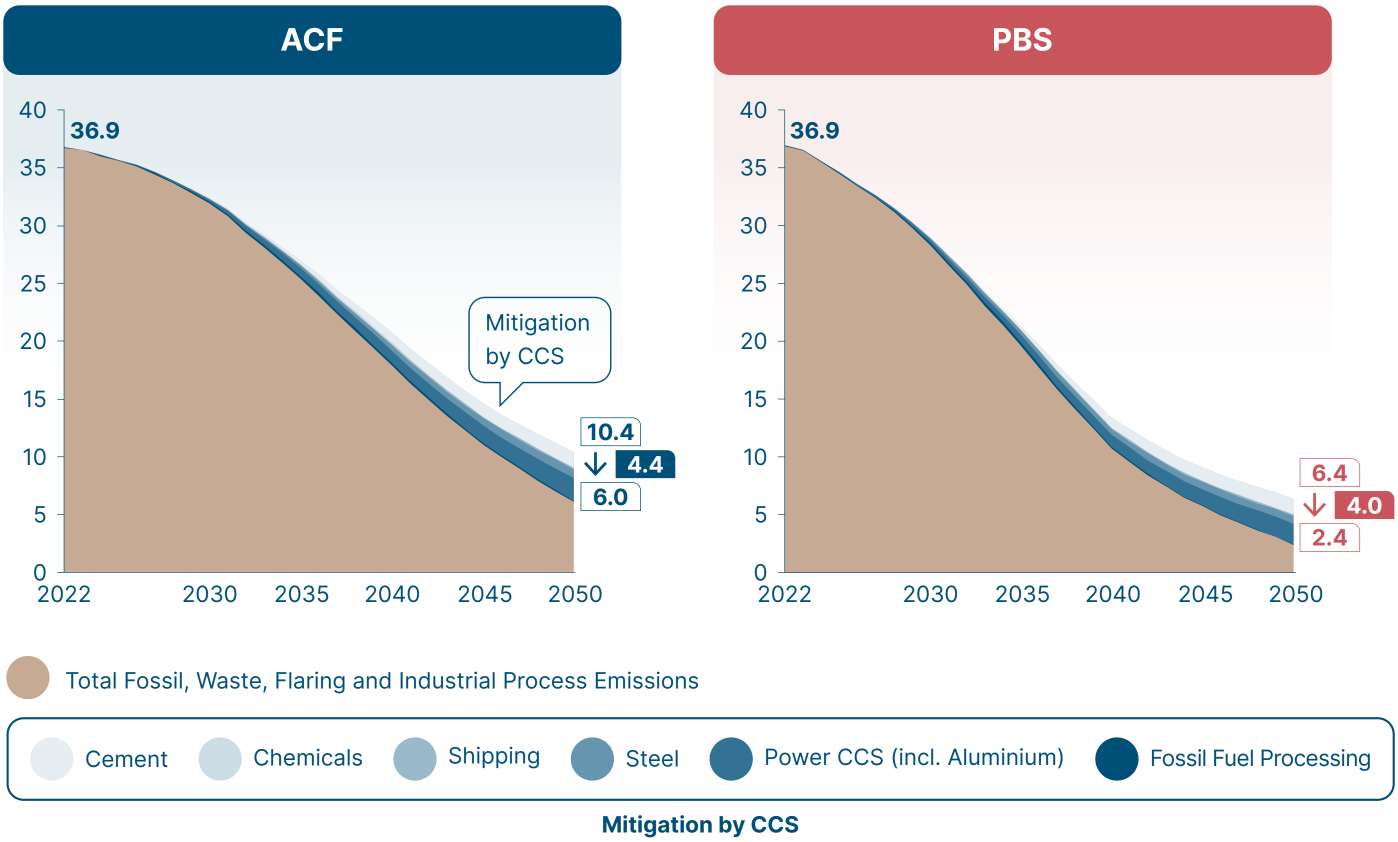


EXHIBIT 3.3

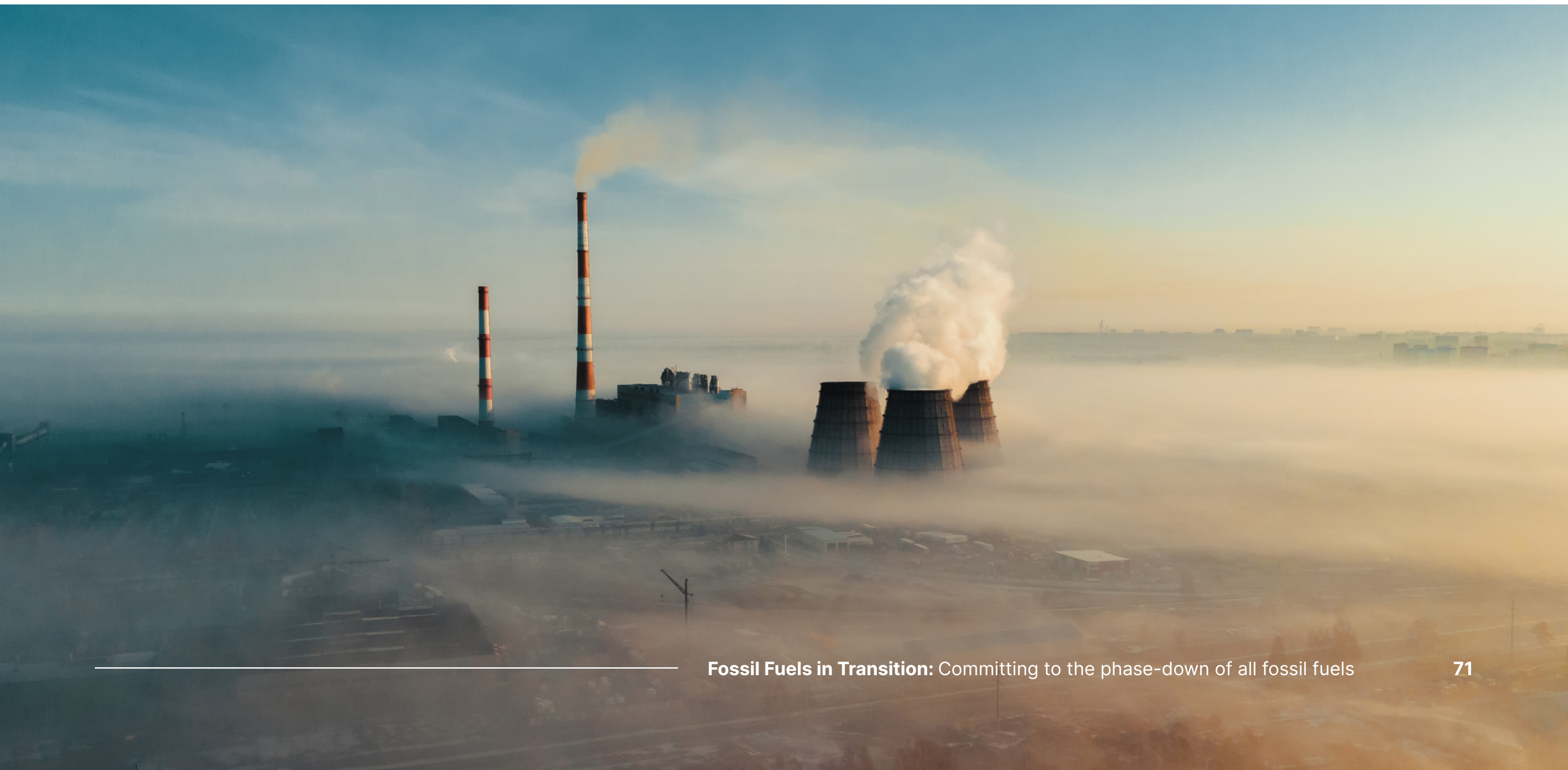
# Net emissions from the EBIT sector in ACF and PBS

Net emissions from fossil fuels and industry after carbon capture and storage
$GtCO_2$




**NOTE:** EBIT = Energy, Building, Industry and Transport, abatement of emissions via CCS excludes carbon captured for CCU.

**SOURCE:** Systemiq analysis for the ETC.



## 3.1 Key uncertainties

All scenarios are inherently uncertain since they are dependent on assumptions about the future path of technological development, relative costs, company investments, and government policies, as previously shown in Box B. At the aggregate level, we are confident that fossil fuel use can fall at the sort of pace indicated by our ACF and PBS scenarios, but with greater certainty in some sectors than others, and with potential for either significantly slower or faster progress in some.

Our assessment of the degree of certainty of our projections by sector is the following:

- For the **road transport sector**, we have high confidence that the endpoint, sometime around mid-century, will see the near complete elimination of ICE vehicles, replaced primarily by electric vehicles and some hydrogen-based vehicles in heavy trucking. The pace of progress could be slower than our scenarios suggest, particularly in trucking, if the required policy support is not strong enough, in particular to deploy enabling infrastructure. But it might also be faster if battery technology progresses faster than currently anticipated. Crucially, the certainty of the endpoint means that even if oil demand is somewhat higher in 2050 than our scenarios suggest, it will fall close to zero in the following decade.
- For **aviation** the uncertainty is greater. Commitments made by ICAO and the industry to achieve net-zero by 2050, together with fuel mandates and carbon pricing in Europe, mean that the use of SAF is bound to grow significantly. But as Chapter 4 discusses, it is possible that the optimal path might include some role for continued use of conventional jet fuel, offset by DACCS.
- For **shipping**, we are certain that the endpoint will see heavy fuel oil and marine diesel oil use eliminated, but with uncertainty over the pace of progress in the early years, and over the balance between methanol and ammonia as the replacement fuel.
- Within the **industry** sectors, the pace of progress in steel, cement, and ammonia will strongly depend on policy support, and in particular the introduction of regulations or carbon prices. Slower progress is possible, but as in the case of road transport, the endpoint is usually clear. For instance, if coking coal demand is higher in 2050 than our scenarios suggest, it will still disappear in the following decade.
- By contrast, **petrochemicals, in particular plastics**, remains an area of long-term uncertainty. It is possible that the sector will continue to use 15–20 Mb/d of oil in perpetuity, but it is also possible that shifts to new bio-based or recycled feedstock could eliminate oil use almost entirely.
- **Residential building heating** is a key area of policy uncertainty. While electrification via heat pumps is likely to become the dominant solution over time, progress towards the elimination of gas could be slowed by both (i) the upfront costs entailed, which vary significantly by specific circumstance (e.g., the quality of building insulation) and (ii) the need to build up a supply chain of skilled installers. Rapid progress will therefore only occur if governments implement strong policies, including subsidies or other mechanisms, to reduce financial barriers to low-income households. Slower progress than our ACF scenario is therefore possible, implying a "larger for longer" role for gas.
- In the **power** sector there are uncertainties in both directions, particularly in developing economies. It is possible that the decline in coal use will be slower than we anticipate, and/or that there will be a larger transitional role for gas.[122] But technological development and cost reduction may also make existing thermal capacity uncompetitive faster than our scenarios assume. In particular, faster cost reductions in solar PV and in batteries, combined with the massive scale up of solar PV manufacturing capacity now being put in place, could make the combination of solar plus batteries competitive versus existing coal plants in many locations with high quality solar resources. Almost all past projections for the growth of solar PV have fallen far short of what occurred, and it is possible that the same will be true in the coming years.

We will explore these uncertainties in greater detail in our 2024 supplementary report, with a particular focus on the wide degree of uncertainty about the future of petrochemical production.

These uncertainties imply that public policy and commitments from companies and financial institutions will play a crucial role in delivering the feasible and required fossil fuel demand reductions to meet climate objectives. Chapter 5.3 describes the policies required to drive these reductions in fossil fuel demand.

122 This could be driven in particular by the large expected oversupply of LNG once projects will come online in 2027–2028, with gas prices falling and developing left with the decision to lock-in demand through contracts or accelerate the deployment of renewables. Systemiq analysis for the ETC; BNEF (2023), *LNG project database.*

## 3.2 Comparison with IEA scenarios

As Chapter 1 described, scenarios can be designed for different purposes – some describe what **would** occur under a given set of policy assumptions, while others are normative scenarios, which describe what **must** occur to achieve specified climate objectives. And as Exhibit 1.3 showed, even among normative scenarios there are widely varying assumptions about the role which CCUS and removals can play in reaching net-zero emissions. The OPEC *Advanced Technologies* scenario for instance, is based on the assumption that sustained high oil and gas demand can be made compatible with limiting global warming to acceptable levels by assuming very high levels of CCUS and removals before and after 2050.

Both our ACF and PBS scenarios are designed to be normative in the long-term, but more descriptive in the early years. They are both:

- Clearly technically feasible since they rely on existing low-carbon solutions, most of which are already commercially mature (e.g., wind and solar, electric vehicles, heat pumps) or have already been demonstrated at scale (e.g., hydrogen DRI, point source and direct air carbon capture).
- Economically feasible, in the sense that any adverse impact on living standards relative to a business-as-usual growth path would be small enough to be politically feasible, with energy services growing to support rising prosperity in the developing world.
- Normative in the long term since they are designed to ensure climate objectives are achieved, limiting global warming to 1.7°C in the ACF and 1.5°C in the PBS.
- Only achievable with (i) commitments to reduce emissions which go beyond pledges already made, and with (ii) very significant strengthening of policies to achieve those commitments.
- But constrained by judgments about how rapidly fossil fuel demand can be reduced in the short-term (e.g., before 2030) given current trends and policy settings, and the short amount of time left to achieve major changes.

Given this design, it is not surprising that the emissions resulting from our scenarios lie within the range between the IEA's *Announced Pledges Scenario* (APS) and their *Net-Zero Emissions scenario* (NZE) [Exhibit 3.4], and that the pathways for individual fossil fuel use are similarly placed relative to these two IEA scenarios [Exhibit 3.5].

Both our two ETC scenarios lie far below the IEA STEPS scenario, which would result from unchanged policy settings. This shows that meeting our ACF scenario, and even more so our PBS scenario, will require very significant strengthening of many aspects of policy.

In the case of oil and gas moreover, and for coal after 2040, both our scenarios fall below the IEA APS. This implies that they will only be met if countries strengthen the commitments which they have made to reduce emissions whether in the short-term to 2030 or the long-term to mid-century.

For our PBS scenario, the most useful comparison is with the IEA NZE scenario, since both aim to describe paths compatible with limiting global warming to 1.5°C. This comparison reveals that:

- In the case of gas, our projection for 2030 is very similar to but very slightly below the IEA NZE, but slightly higher in the 2040s. This reflects the similar assumptions which we have made about the pace at which residential heating can and should be electrified, the minimal role for gas as a transition fuel in the power sector, and the potential to replace gas with various forms of electric heat generation in many industries. But it is important to recognise that these common assumptions about the pace of possible and required decline will only become reality if stronger policies are enforced.[123]
- In the case of oil, cumulative projected demand over the whole period to 2050 is almost exactly the same in the IEA NZE and the ETC PBS, but:
    - Our PBS is more cautious about the reduction which can be achieved by 2030, with the IEA suggesting a fall from 97 Mb/d in 2022 to 77 Mb/d in 2030, while we suggest a slightly less dramatic fall to 84 Mb/d by that date. This difference is in part explained by the fact that the IEA NZE includes the impact of a universal 100 km/h speed limit, while our PBS scenario does not allow for any such behavioural changes.
    - Conversely, we make more ambitious assumptions about the potential to replace oil use as petrochemical feedstock with bio, synthetic or recycled sources by 2050. This largely explains the difference between the 2050 figures, with the IEA NZE suggesting 22 Mb/d, while the ETC PBS suggests that a figure as low as 4 Mb/d may be possible.[124]

123 IEA (2023), *Net-Zero Roadmap: A global pathway to keep the 1.5°C goal in reach.*
124 Ibid.

- The biggest difference lies in our projections for coal use. Here, both the IEA NZE and the ETC PBS scenarios assume that coal use can and should begin immediate decline, and fall by 90% or more by 2050. This reflects the potential for renewables to replace thermal coal use in power generation and for hydrogen (or syngas derived from methane with CCUS) to replace coking coal as the reduction agent in ironmaking. But the country-by-country analyses of power system decarbonisation pathways on which we have drawn suggest that existing coal generation will exit power systems at a slightly slower pace than the IEA NZE indicates. This reflects the facts that:
    - While renewables are now cheaper than new-build coal power generation in most locations, closing existing coal still often imposes some cost, and may not occur as fast as needed to meet a 1.5°C pathway unless supported by a flow of finance from developed countries, as discussed in the ETC's 2023 *Financing the Transition* report.
    - Recent unexpectedly rapid growth in electricity demand in China and India (with particularly strong growth in peak demand) has meant that coal generation is still not yet falling, despite rapid growth in renewables deployment.

If, however, climate finance to support the closure of existing coal can be mobilised on a greater scale, more rapid reductions than indicated by our PBS scenario might be possible in the early years. And it is also possible that cost reductions of renewables (in particular solar) and batteries may be even faster than currently assumed, bringing forward the point at which renewables with storage can undercut even existing coal. As discussed in section 3.1, this is a key upside uncertainty which we will assess in our supplementary report in 2024.

Both IEA NZE and ETC PBS scenarios, however, make clear the severe challenge which the world faces if it is to limit global warming to 1.5°C:

- In the case of IEA's NZE, the significant reductions in fossil fuel use achieved by 2030, can only be achieved through a significant acceleration of energy intensity improvements (growing from 2.0% per annum today to 4.2% per annum in 2030), enabled by energy efficiency improvements, and behavioural changes.[125] Behavioural changes assumed include speed limits of 100 km/h on major roads, limiting indoor heating to 19°C and cooling to 24°C, and a progressive reduction in demand for aviation through modal shift, frequent flyer levies, and reduction in business flights [Box D].[126]
- By contrast, our PBS does not assume such behavioural changes. But unlike the IEA, we assume that it is possible, as well as necessary, to achieve a cumulative 120 $GtCO_2$ of nature-based removals before 2050, in addition to 30 $GtCO_2$ of engineering and hybrid removals (e.g., DACCS and BECSS), which the IEA also assumes.[127] Our 2022 report *Mind the Gap* set out why we believe removals of this scale are technically possible, and Chapter 4.2 and 4.3 restate key arguments from that report. However, the report made clear that removals on that scale will only occur if there is a large-scale mobilisation of finance from developed country governments, companies, and philanthropic institutions, together with tougher standards and management processes to improve confidence in the certainty and permanence of nature-based removals. Over the 18 months since we published that report, little if any progress has been made towards achieving those conditions. It is therefore clearly not credible to assume a level of removals any higher than we assumed in our *Mind the Gap* report, but even that level looks extremely challenging.

It is therefore important to face the reality that limiting global warming to 1.5°C will be extremely difficult, and will require either, or a combination of, the following:

- Reducing fossil fuel use as fast as the ETC's PBS scenario **and** financing removals on the scale which we described in our *Mind the Gap* report.
- Committing not only to the long-term pace of fossil fuel use decline which both the ETC's PBS and IEA's NZE describe, but also to the behavioural changes which must occur if fossil fuel use is to fall as rapidly in the early years as the IEA's NZE requires.

The implication of this for companies and financial institutions which have made or intend to make commitments to strategies compatible with a 1.5°C climate target are set out in Chapter 7.3.

125 IEA (2023), *Net-Zero Roadmap: A global pathway to keep the 1.5°C goal in reach.*

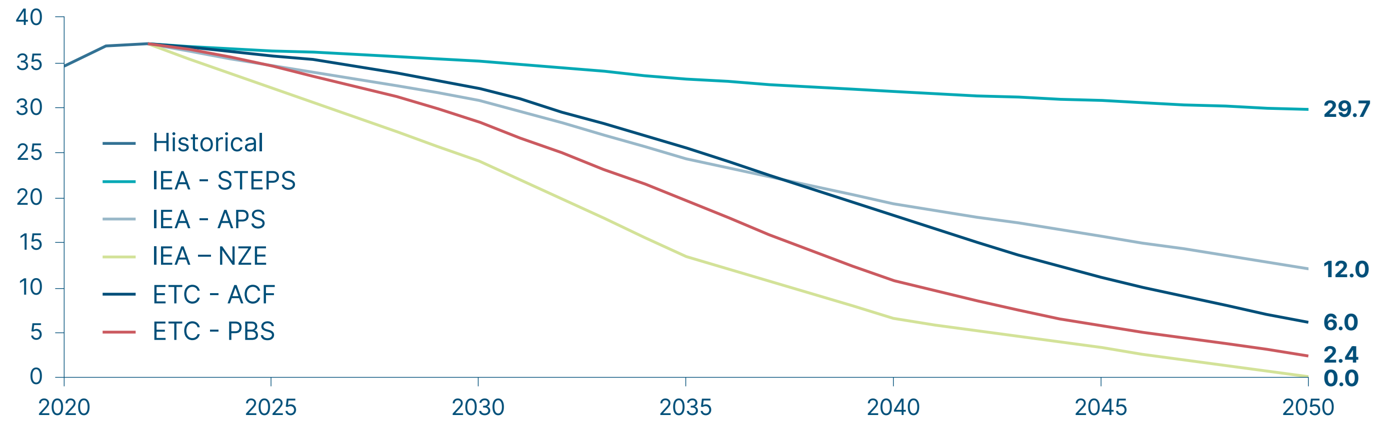
126 Ibid.

127 The IEA assumes ~22 Gt of cumulative carbon removals, through BECCS, biofuel production and DACCS, between 2022–2050.

EXHIBIT 3.4

## Net $CO_2$ emissions in IEA and ETC scenarios

Net emissions from fossil fuels, flaring, waste and industrial processes (excl. AFOLU) after carbon capture and storage
$GtCO_2$



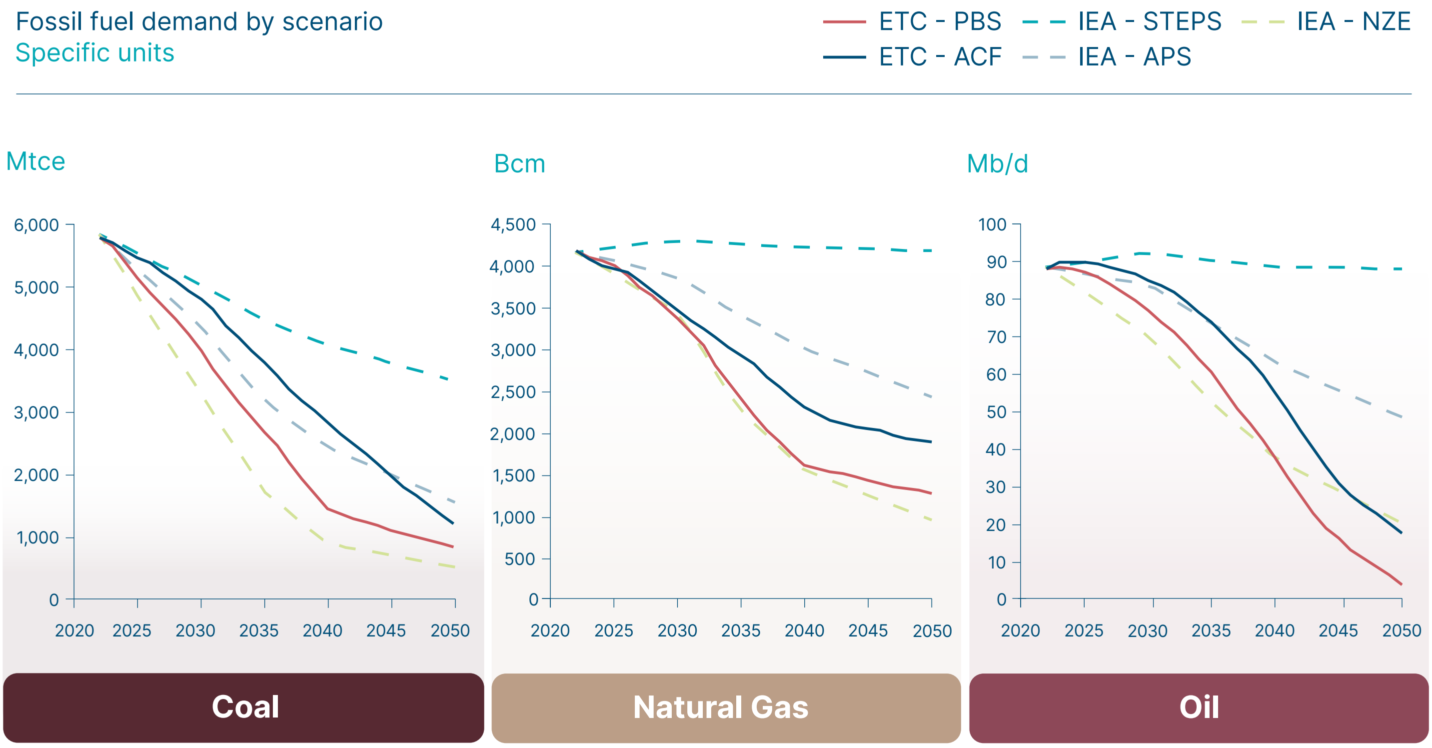

**NOTE:** STEPS = Stated Policies Scenario, APS = Announced Pledges Scenario, NZE = Net-Zero Emissions, ACF = Accelerated but Clearly Feasible Scenario, PBS = Possible But Stretching Scenario.

**SOURCE:** Systemiq analysis for the ETC (2023); IEA (2023), *World energy outlook 2023*.

EXHIBIT 3.5

## Fossil fuel demand in IEA and ETC scenarios to 2050

Fossil fuel demand by scenario
Specific units




**SOURCE:** Systemiq analysis for the ETC; IEA (2023), *World energy outlook 2023*.

## BOX D: BEHAVIOURAL CHANGES TO REDUCE FOSSIL FUEL DEMAND

The IEA defines behavioural changes as "actions that energy consumers can take to reduce or eliminate unnecessary or wasteful energy consumption".[1] Examples of behavioural changes include modal shift for transport – such as replacing car trips with walking, cycling or public transport, or short-haul flights with high-speed rail – or moderating the use of heating and air conditioning in homes.

Behavioural changes typically have no implications on the rate of economic growth, and some have no necessary impact on consumer welfare since, for example, consumers who switch from cars to bicycle may, once they have made the switch, be content with that choice. These changes can be implemented immediately and at little to no cost, since in most cases they do not require investment in new capital assets or technologies. This potential for immediate impact can be illustrated by the response to the 2022 energy crisis following Russia's invasion of Ukraine, with reduced building heating temperatures in the EU cutting natural gas demand by 7 Bcm compared to the previous year.[2]

In its Net-Zero Emissions scenario, the IEA assumes a number of behavioural changes, in particular in the transport and buildings sector [Exhibit 3.4]. These assumptions include tighter road speed limits, reduced vehicle use in cities and a consumer preference shift away from SUVs, increased modal shift and use of car sharing and public transport, and reduced heating temperature and increased cooling temperatures.[3]

As Exhibit 3.4 shows, the IEA estimates that these changes could deliver about 15% of emissions reductions between now and 2030, and about 10% of emissions reductions from 2030 to 2050.[4] Their contribution to the decline in fossil fuel use over those periods must be similar.

Behavioural changes could therefore in principle make a significant contribution to reducing emissions fast and could make it possible to limit global warming to 1.5°C without relying on significant nature-based removals. But achieving behavioural change rapidly will require a combination of policies to enforce change (e.g., speed limits) and strong encouragement to make voluntary changes (e.g., reducing building heating temperatures and reducing cooling temperatures), and either approach may generate political opposition, or in the case of encouragement, be ineffective.

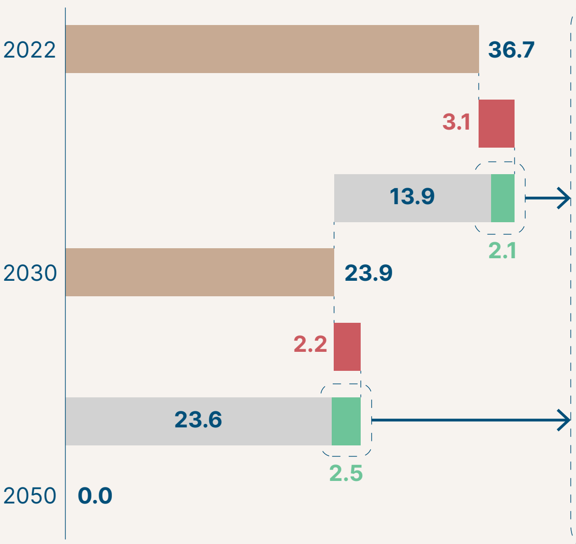
1 IEA (2023), *Behavioural changes.*
2 IEA (2023), *Europe's energy crisis: What factors drove the record fall in natural gas demand for 2022?*
3 IEA (2023), *Net Zero Roadmap: A global pathway to keep the 1.5°C goal in reach.*
4 Ibid.

EXHIBIT 3.6

## Impact of behavioural changes on $CO_2$ emissions in the IEA NZE scenario

$CO_2$ emissions reductions by mitigation measures
$GtCO_2$

Emissions
Activity
Behaviour and avoided demand
Other mitigation




| Sector | Behavioural change assumptions |
|---|---|
| Transport | **Road transport:**<br>• Eco-driving, including 100 km/h driving speed limits introduced by 2030<br>• Use of ICE phased out in large cities by 2030<br>• Modal shift from passenger cars to public transport in cities<br>• Increased vehicle sharing through carpooling<br>• Consumer preference shifts away from SUVs<br>**Aviation:**<br>• Modal shift from air travel to rail |
| Buildings | • Space heating temperatures moderated to 19-20°C by 2030<br>• Space cooling temperatures moderated to 24-25°C by 2030<br>• Eco-households, including line drying clothes, reducing laundry temperatures, switching off lights in unoccupied rooms, unplugging appliances, lowering water heating temperatures. |
| Industry | |

**SOURCE:** IEA (2023), *Net zero roadmap: A global pathway to keep the 1.5°C goal in reach.*

# The role of carbon capture and removals

Chapters 1–3 presented the ETC's scenarios for the pace at which fossil fuel use can and should decline over the next 30 years. The implications for greenhouse gas emissions also depend on the scope for:

- Carbon capture and utilisation or storage (CCUS) applied to energy using applications in any sector of the economy ("point-source CCUS").
- Carbon removals achieved via direct air carbon capture and storage (DACCS) or bioenergy coupled with CCS (BECCS). These could offset residual emissions from economic activities which cannot be abated either via elimination of fossil fuel use or via point source CCUS, and/or could be used to generate "negative emissions" once net emissions from all economic activities have been reduced to close to zero.
- Carbon removals via nature-based solutions (NBS) which can have the same effects as DACCS or BECCS.

Different assumptions about the scope for each of these can very significantly change the level of future fossil fuel use compatible with defined climate objectives. As discussed in Chapter 1, all scenarios which assume continued high fossil fuel use must either assume very high levels of carbon capture or removals, or imply global warming well above agreed limits.

This chapter therefore assesses the role that each of the different types of carbon capture or removal might play. It covers in turn:

- The different types of CCUS and removals, and previous ETC assessments of the potential scale of deployment.
- Our updated assessment of the need and potential for point-source CCUS, DACCS and nature-based removals.
- The implications for credible assessments of the role of CCUS and of different types of removal.

Our **key conclusions** are that:

- There is a "vital but limited" role for point source CCUS to capture and store about 4.0–4.8 $GtCO_2$, abating the continued use of about 750–950 Mtce of coal and 900–1,250 Bcm of gas.[128] But even this limited role will not be achieved without increased investment and stronger policy support.
- In principle, both engineered and nature-based removals could play a role in reducing net emissions and the temperature calculations presented in Chapter 5 retain our previous assumption, described in our 2022 report *Mind the Gap*, that a cumulative 150 $GtCO_2$ of removals could be achieved by 2050. But finance to support removals is not growing at required pace, and there is a major risk that actual carbon removals will fall far short of our previous assessment.
- It would therefore be incredible and imprudent to assume significantly higher levels of point source CCUS or removals than currently included within our temperature calculations.
- As a result, fossil fuel demand must fall at least as fast as in our ACF or PBS scenarios if global warming is to be limited to 1.7°C (in the ACF) or 1.5°C (in the PBS).

## 4.1 Types of carbon capture/removal and previous ETC assessments

In 2022, the ETC published two reports which assessed the technically feasible and economically optimal role of carbon capture and removals:

- In March 2022, our *Mind the Gap* report assessed the potential for carbon dioxide removals, whether achieved via nature-based solutions, BECCS or DACCS.
- In July 2022, our report *Carbon Capture Utilisation and Storage in the Energy Transition: Vital but Limited*, analysed the potential for carbon capture and storage technology, whether applied at point source, or involving DACCS.

The potential for DACCS was therefore covered in both reports. The July 2022 report analysed the different impacts that CCUS can have on emissions depending on where the $CO_2$ is captured from and where it ends up, as detailed in Box E. It concluded that CCUS technology must play a "*Vital but Limited*" role in achieving net-zero emissions, with total point source CCUS reaching 2.9–4.7 $GtCO_2$ per annum by 2050 [Exhibit 2.33].

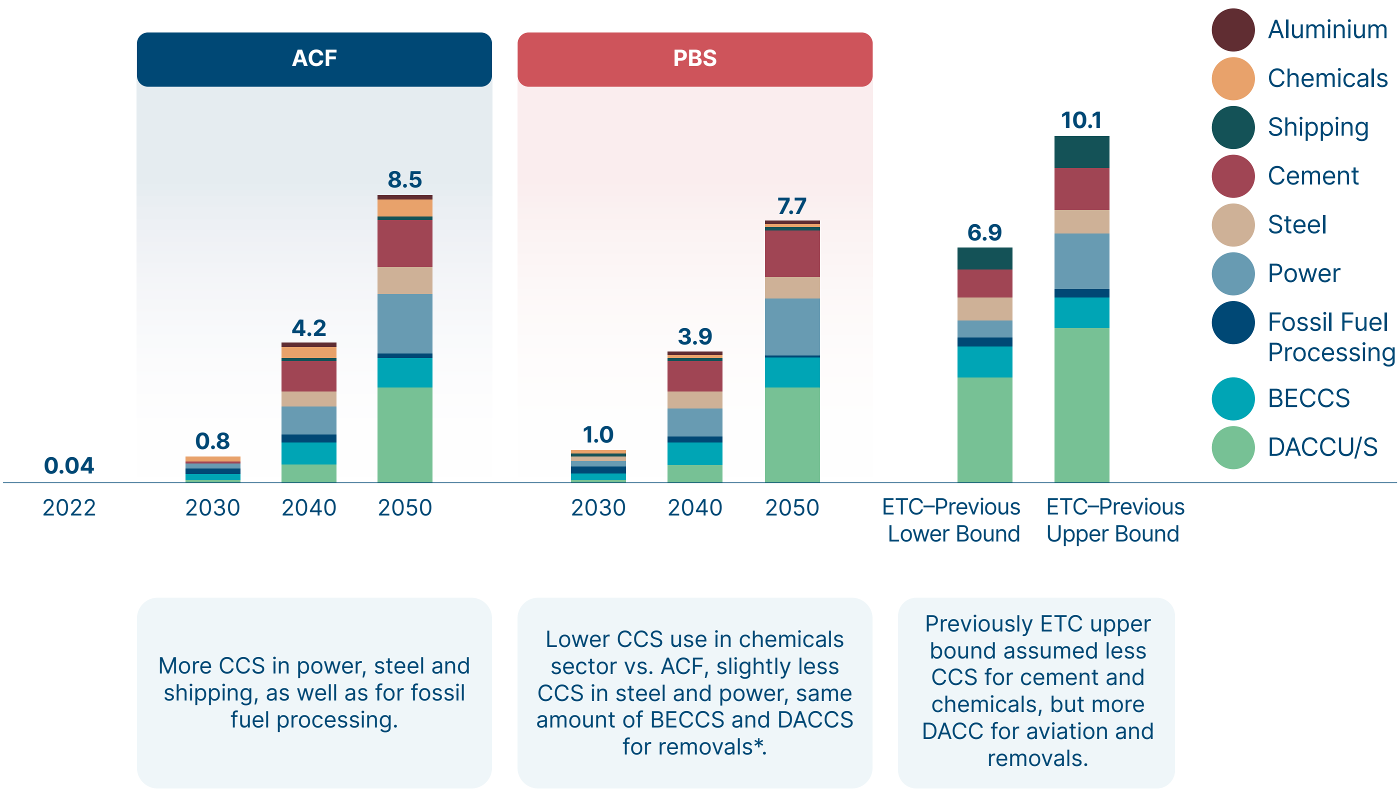
In addition, that report estimated that DACCS might reach 3.0–4.5 $GtCO_2$ per annum by 2050, with BECCS accounting for another 0.9 $GtCO_2$. In total, this amounted to 6.9–10.1 $GtCO_2$ of carbon capture across a range of sectors [Exhibit 4.1]. Of these captured quantities, our 2022 report assumed that the majority would be stored, but with 2.0–2.5 Gt per annum utilised in applications relating to construction aggregates, synthetic aviation fuel and enhanced oil recovery (EOR), as shown in Exhibit 4.3.

128 Additional fossil fuel use beyond this level leads to gross $CO_2$ emissions, and therefore will need to be neutralised by equivalent removals, as discussed in Chapter 4, Sections 4.3 and 4.4. In order to reach the 4.0–4.7 $GtCO_2$ of total point-source carbon capture in Exhibit 2.33, a further 0.9 $GtCO_2$ of carbon capture from bioenergy would need to be included on top of the emissions from gas and coal.

EXHIBIT 4.1

## Projected CCS capacity in ACF and PBS, and comparison with previous ETC estimate

CCUS demand by sector
$GtCO_2$




**NOTE:** Total captured emissions include both utilised carbon and carbon that is permanently stored. * Volumes in ACF and PBS are same as "ETC – Previous Lower Bound".

**SOURCE:** Systemiq analysis for the ETC; ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited.*

**BOX E: TYPES OF CCUS AND IMPACTS ON EMISSIONS.**

Exhibit 4.2 illustrates the different impact which CCUS can have on net emissions depending on where the carbon is captured from and where it ends up:[129]

- Carbon can be **captured** from three sources:
    - At the end of power generation and industrial processes. In these cases, carbon derives either from fossil fuel use or from the chemical reaction involved (e.g., from $CO_2$ embedded in calcium carbonate used in cement production). This category is known as point-source CCS.[130]
    - From combustion of bioresources, which draw $CO_2$ from the air via photosynthesis.
    - Directly from the air via DACC.
- Carbon can then be either **stored** in geographical formations or **used** in other end-use applications. Some of these – e.g., use within aggregates – are equivalent in their effect to permanent storage, but do not displace additional fossil fuel use. Others, such as sustainable aviation fuels or the production of urea from ammonia, result in the eventual re-emission of $CO_2$ when the fuel is used, but do displace additional fossil fuel use.
- Different combinations of source and either storage or use can result in either of below:
    - **Increased carbon efficiency**, with the same carbon molecule used to achieve more than one economic function and therefore leading to mitigation of emissions, but still leaving net positive emissions.
    - **Net-zero emissions**, with gross emissions either captured or neutralised by removals.
    - **Net carbon removal**, i.e. negative emissions, in cases where carbon is captured directly or indirectly from the air and then stored.

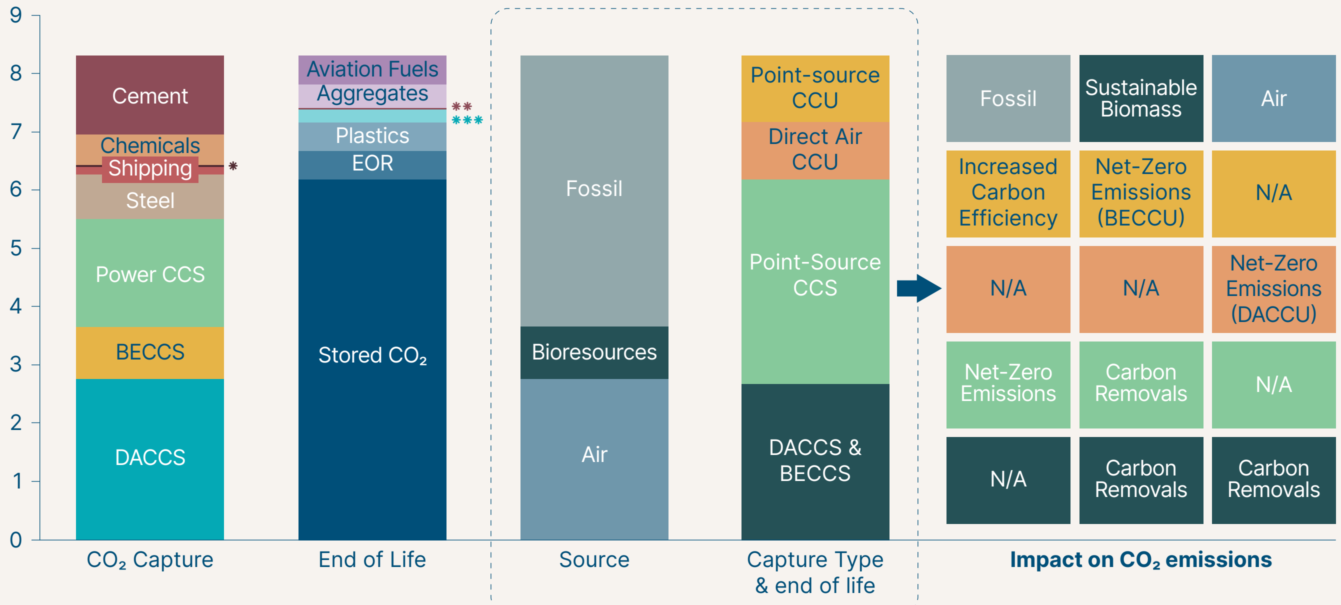
129 ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited*, Chapter 2.1 and Exhibit 19 for more discussion of this.

130 Point-source capture can also be applied to other carbon oxides, notably carbon monoxide (CO). This form of carbon capture can also play a significant role in certain industrial or chemical processes where flue gases include significant amounts of CO, such as in Steam Methane Reformation, a key step for current ("grey") hydrogen production.

EXHIBIT 4.2

## Combinations of $CO_2$ capture and end-of-life management and impact on emissions

CCUS volumes in 2050 under ACF Scenario
$GtCO_2$ p.a.




* Fossil Fuel Processing
** Cement
*** High Value Chemicals

**NOTE:** Volumes shown refer to Ambitious But Clearly Feasible Scenario. Fossil Fuel Processing includes natural gas processing, oil products refining and production of high value petrochemicals (methanol, ethylene, propylene, butadiene, benzene, toluene, xylene). EOR = enhanced oil recovery. CCU = carbon capture and utilisation. CCS = carbon capture and storage. DACCS = direct air carbon capture and storage. DACCU = direct air carbon capture and utilisation. BECCS = bioenergy with carbon capture and storage. Note that the majority of point source CCS emissions will come from fossil processes and combustion, and industrial processes.

**SOURCE:** Systemiq analysis for the ETC; ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited.*

EXHIBIT 4.3

## Carbon utilisation in ETC CCUS report (2022)

Carbon dioxide utilisation[1] volumes in 2050 under lower bound scenario
$GtCO_2$ p.a.


**Cement and Aggregates:** Mineralisation or recarbonation can lead to carbon dioxide utilisation over the long term. Depending on the source of $CO_2$, this can be either long-term utilisation or removals.

**Petrochemicals and Plastics:** $CO_2$ is used in chemical products, leading to carbon sequestration of multiple years (but does not count as long-term storage).

**Aviation Fuels[2]:** Captured $CO_2$ can be used to make synthetic fuels for aviation, in combination with low-carbon hydrogen.

**Enhanced Oil Recovery:** Captured $CO_2$ is used to increase output of oil and gas from existing wells.

**NOTE:** [1] Carbon utilisation can take place via a range of carbon compounds, notably carbon dioxide and carbon monoxide
[2] There is an open debate over whether DACC will be best used to provide $CO_2$ as an input to synthetic jet fuel production, or whether DACCS should be used to offset the continued use of conventional jet fuel. Our current assessment is that synthetic jet fuel will prove the most economic solution once account is taken of non-$CO_2$ climate forcing effects, but it is possible that future analysis will change this assessment. This might increase our estimate of likely 2050 oil demand by a few million barrels of oil per day.

**SOURCE:** ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited.*

Our March 2022 *Mind the Gap* report on removals began with the conclusion that it would be impossible to limit global warming to 1.5°C solely by reducing the use of fossil fuels. This was because cumulative emissions through to 2050 are likely to exceed the remaining "carbon budget" for such a temperature rise, even if fossil fuel demand fell as fast as we then assumed possible.

This implied that to meet agreed climate objectives, significant removals would be required both in the period to 2050 and thereafter. Our latest analysis of the temperature implications of different scenarios presented in Chapter 5 confirms this conclusion: even the faster reductions in fossil fuel use entailed in the PBS scenario would be insufficient to achieve a 1.5°C global average temperature increase without the use of large-scale carbon removals. Removals would also be needed to maintain net-zero emissions in future years, and neutralise any residual $CO_2$ and $N_2O$ emissions after mid-century.[131]

The *Mind the Gap* report analysed the potential to deploy at scale three different types of removals: nature-based solutions, hybrid solutions such as BECCS, and engineered solutions, in particular DACCS.

It concluded that with very strong policy support, large-scale financing and significant technological progress, it might be possible to achieve the removals shown in Exhibit 4.4 with:

- Total cumulative removals from all three categories reaching up to 150 $GtCO_2$ over the period of 2020 to 2050.[132]
- Nature-based solutions providing almost all the pre-2030 removals, and most removals up to 2040.
- But with BECCS and DACCS growing rapidly in the 2030s and 2040s, and with removals via DACCS reaching 2–3 $GtCO_2$ per annum by 2050.[133]

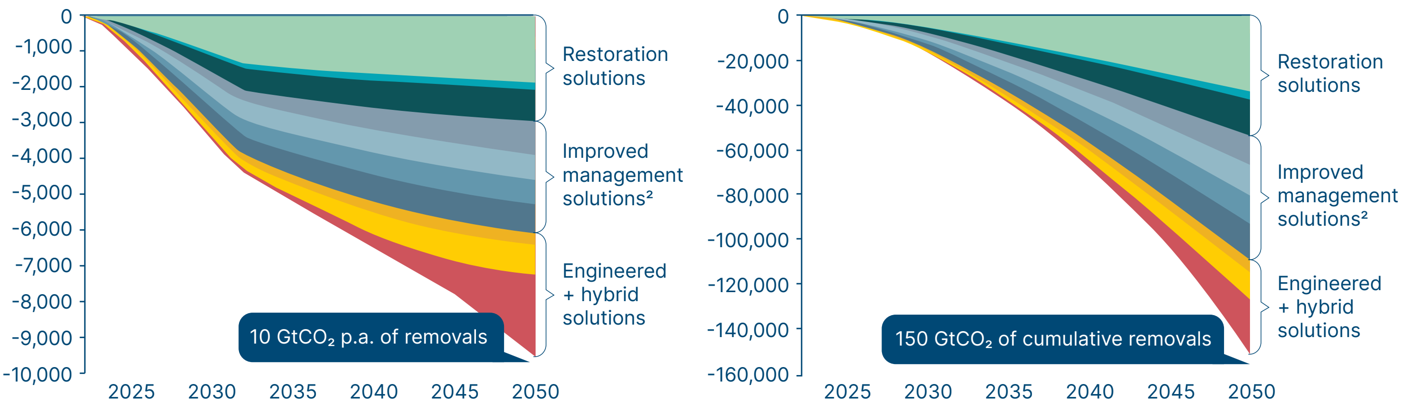
131 It may also be necessary to generate sufficient net negative emissions in the second half of the 21st-century to reverse the climate-warming effect of an overshoot of the cumulative budget. However any strategy which relies on removing $CO_2$ after the "budget" has already been overshot carries a danger of triggering earth system tipping points and self-reinforcing feedback loops that are potentially irreversible. Armstrong McKay et al. (2022), *Exceeding 1.5°C global warming could trigger multiple climate tipping points.*
132 This amount has been revised slightly downwards from the 165 $GtCO_2$ of cumulative removals originally included in the Mind the Gap report, to account for some carbon utilisation from $CO_2$ that is captured via DACC.
133 Consistent with ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited.*

EXHIBIT 4.4

## Ramp-up of Carbon Dioxide Removal in ACF and PBS

Potential ramp-up of CDR
Mt $CO_2$/year, global

Cumulative CDR 2022–2050
Mt $CO_2$, global




**NCS: Restore**
- Restore forests
- Restore blue carbon[1]
- Restore drained peatlands

**NCS: Manage**
- Improve forest management
- Agroforestry
- Enhance soil carbon sequestration in degraded croplands
- Enhance soil carbon sequestration in degraded grazing lands

**Hybrid and engineered approaches**
- Apply biochar
- BECCS
- DACCS

**NOTE:** [1] "Blue carbon" is defined as ocean-based biomass sequestration including mangroves, seagrasses, and tidal marshes.
[2] Improved management solutions have been adjusted for feasibility on a country-by-country basis. Overall average reduction is ~50%.

**SOURCE:** Systemiq analysis for the ETC; ETC (2022), *Mind the gap*; ETC (2021), *Bioresources for a Sustainable Net-Zero Economy*; Roe et al. (2021), *Land-based measures to mitigate climate change: potential and feasibility by country*; Hanna et al. (2021), *Emergency deployment of direct air capture as a response to the climate crisis*; Griscom et al. (2017), *Natural climate solutions*.

## 4.2 Updated assessment of point-source CCUS

Our July 2022 report assessed the potential role for point-source CCUS by sector. The key conclusions were the following:

**Minimal role in decentralised applications:** Carbon capture is very unlikely to play an economically feasible role in the many applications where fossil fuel is used in many relatively small items of equipment. This includes in particular:

- Transport applications which account for around 60% of oil use.[134]
- Residential heat applications which account for about 15% of gas use.

In these applications, the predominant way to reduce emissions (as against offsetting them) is simply to reduce the use of fossil fuels.

**Technically feasible in several large-scale applications:** Carbon capture is technically feasible in large-scale applications such as power generation, fossil fuel processing and production of iron, cement, petrochemicals and "blue" hydrogen. Capture rates achieved in many past large-scale projects have been disappointing,[135] and point-source CCS deployed has remained stagnant at around 40 Mt$CO_2$ for nearly a decade, partly due to a combination of uncertain incentives and changes in policy in key countries.[136]

134 Including shipping and aviation.
135 Three of the largest projects thus far (Boundary Dam, Gorgon and Petra Nova) faced multiple outages, challenges with geological $CO_2$ injection, and technical challenges with flue gases and CCS system integration. Chapter 2, Box 4 in ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited.*
136 BNEF (2022), *CCUS outlook*; ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited*; Grantham Research Institute (2021), *Seizing sustainable growth opportunities from carbon capture, usage and storage in the UK.*

However, high rates over 90% are technically feasible and have been achieved.[137] Such high capture rates should be required by regulations, and be carefully monitored, to enable large-scale deployment of point-source capture in these applications.[138]

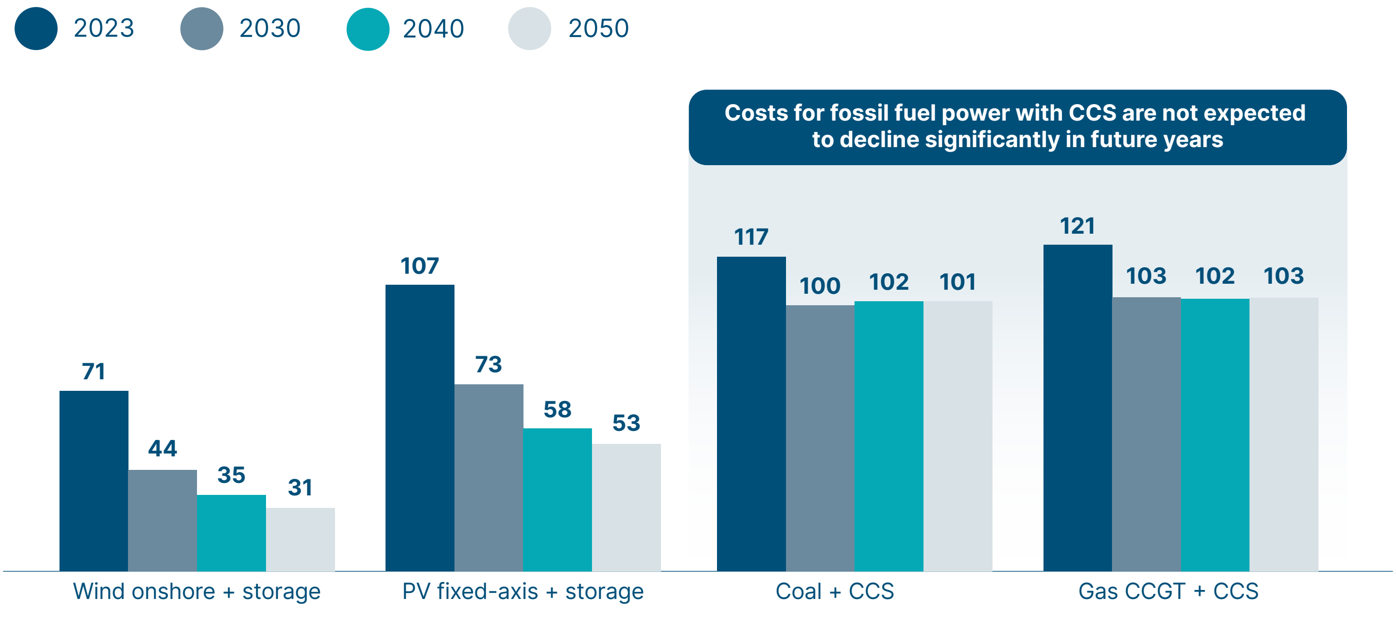
**Relative economic competitiveness has declined, but CCUS will still play a significant role in several hard-to-abate sectors.** In some applications however, the relative competitiveness of point-source CCS compared with other decarbonisation technologies has declined over the last 10–15 years, and is expected to remain less competitive in future years [Exhibit 4.5]. This reflects the facts that:

- While it is possible for non-CCS technologies to become cheaper than today's fossil fuel-based technologies, applying CCS to a fossil fuel-based process will always add costs.[139]
- The cost of several new energy technologies – most notably solar PV and batteries – has fallen dramatically over the last 10–15 years (by over 90%) because of economies of scale and learning curve effects.[140] Further significant cost reductions are likely in these technologies and others such as electrolysers for green hydrogen production.
- By contrast, the estimated cost of carbon capture and storage has decreased by much less over that period.[141] This reflects the inherent complexities of applying CCS in plants which require bespoke engineering design, with less opportunity to achieve economy of scale and learning curve effects,[142] and in many cases costs are therefore expected to remain relatively higher than clean alternatives.

EXHIBIT 4.5

## Global average LCOE outlooks for power production by energy source

Global average LCOE outlooks
$/MWh, real 2022




**NOTE:** LCOE = Levelised Cost of Electricity, based on average levelised cost of electricity for China, Germany, India, Japan, the United Kingdom and the United States. Storage assumes a four-hour duration Li-ion battery system with 50% capacity ratio. Capacity factors for wind gradually rise from ~28% up to ~46% by 2050. All LCOE calculations are unsubsidised.

**SOURCE:** BNEF (2023), *1H LCOE Data Viewer Tool.*

137 For example, the Petra Nova CCS project achieved an average capture rate of 92% across three years of demonstration. ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited;* Kennedy G. (2020), *Parish post-combustion $CO_2$ capture and sequestration demonstration project (final technical report).*

138 Chapter 2, Section 2.4, and Box 4 in ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited.*

139 For example, BloombergNEF estimate that adding CCS to coal-fired power generation increases the levelised cost of electricity from ~$74/MWh up to ~$123/MWh. BNEF (2023), *1H LCOE Update.*

140 The levelised cost of electricity generated by solar, onshore wind and batteries declined by 90%, 80% and 85%, respectively, between 2009–22 (2012–22 for batteries). BNEF (2023), *1H LCOE Update.*

141 For example, in 2012 the UK Committee on Climate Change/Poyry estimated a 2030 cost of electricity from a gas-fired power plant with CCS of around £100/MWh. In 2023, they estimated the 2035 cost to be £75–90/MWh – at most a 25% decrease (both values given in 2012 prices). Poyry (2012), *Technology supply curves for low-carbon generation – a report to the Committee on Climate Change*; Committee on Climate Change (2023), *Delivering a reliable decarbonised power system.*

142 The potential for cost declines for CCUS was discussed extensively in Chapter 2 in the ETC's 2022 report, *Carbon capture, utilisation and storage in the energy transition: Vital but limited*; Malhotra and Schmidt (2020), *Accelerating low-carbon innovation*; IEA (2021), *Is carbon capture too expensive?*

As a result, estimates of the optimal role of point-source CCUS in several sectors have been significantly reduced over the last decade:

- Less than a decade ago, many studies assumed that CCS would play a very major role in the power sector, with coal or gas with CCS thought to be potentially competitive with renewables, even on a greenfield new investment basis.[143] Latest estimates by contrast suggest that renewables plus storage could outcompete fossil fuel plus CCS, even in some cases where coal or gas plants already exist.[144]
- Only 6–7 years ago, many analyses of pathways for iron and steel decarbonisation assumed a significant role for CCS applied to existing blast furnaces, with this technology combination contributing up to 75% of total decarbonisation.[145] The latest analysis from the Mission Possible Partnership suggests a significantly smaller role for blast furnaces plus CCS and a much greater role for various forms of hydrogen-based reduction.[146]
- Point-source CCUS will still play a major role in blue hydrogen production, which in our scenarios accounts for a significant share of residual gas demand in 2050 and a significant share of point-source CCS.[147] However, techno-economic analysis suggests that green hydrogen will be the cheaper option in most regions from the mid-2030s onwards.[148]

Our latest analysis has broadly confirmed the conclusions we reached in our 2022 report and, as Exhibit 2.33 showed, our ACF and PBS scenarios assume a level of point-source CCUS deployment lying within the range indicated by that report. Specifically, we now assume that point-source CCUS might result in the capture, storage or utilisation of 4.0–4.8 $GtCO_2$ per annum. As a result, the total amount of fossil fuel emissions mitigated via point-source CCUS technology would be limited to:

- Around 1.8–1.9 $GtCO_2$ captured from coal and gas power plants: this would abate the gross emissions produced by 400–500 Mtce of coal and 400–500 Bcm of gas each year.[149]
- About 0.6–0.8 $GtCO_2$ captured from iron-making plants: this would capture emissions from the use of around 100 Mtce of coal and 200–250 Bcm of gas.[150]
- 0.2–0.7 Gt captured from the production of 50–85 Mt of blue hydrogen, using 250–350 Bcm of gas.
- Around 1.4 $GtCO_2$ captured from cement process emissions, and the use of 150 Mtce of coal and 100 Bcm of gas in cement plants.
- Around 0.1 $GtCO_2$ captured from fossil fuel processing plants, accounting for up to 50 Bcm of gas.

In total this amounts to 650–750 Mtce of coal and around 1,100 bcm of gas.

143 For example, in 2016 the IEA estimated that a future 2-degrees aligned power scenario would include around 5,000 TWh of fossil fuels with CCS in the power system by 2050 – and would cost around $3.5 trillion less than a scenario where CCS was not allowed. Instead, in its most recent *World Energy Outlook*, in both the Announced Pledges and Net-Zero Scenarios, which are broadly comparable, fossil fuels with CCS contribute less than 1,500 TWh by 2050. IEA (2016), *20 years of carbon capture and storage*; IEA (2022), *World energy outlook*.

144 For example, estimates for Germany give LCOE of $78 per MWh for onshore wind with storage, as opposed to $143 per MWh for combined-cycle gas turbines fitted with CCS. BNEF (2023), *1H LCOE Update*.

145 For example, the IEA's 2017 ETP assumed a significant share of blast-furnace based production in their Below 2 Degrees Scenario, with 75% of emissions from the steel sector being captured by CCS. IEA (2017), *Energy technology perspectives*.

146 MPP (2022), *Making net-zero steel possible*.

147 Up to 85 Mt of blue hydrogen could be needed by 2050, requiring around 350 Bcm of natural gas.

148 ETC (2021), *Making the hydrogen economy possible*; BNEF (2023), *Hydrogen levelized cost update*.

149 For power generation, CCS would likely be deployed in India and China, and potentially Russia, S. Korea and the USA, i.e. regions where fossil fuel costs are and may remain low without strong carbon pricing.

150 Roughly equivalent to 70 Mt of coal equivalent (Mtce).

## 4.2.1 Latest developments in CCUS deployment

Since January 2022, capture facilities with a total volume of around 125 $MtCO_2$ per annum have been announced,[151] and the US Inflation Reduction Act has provided generous deployment subsidies.[152]

But there is no evidence that costs are being reduced faster than assumed in our previous report, and latest projections for the growth in CCUS application suggests that volumes in place by 2030 will fall far below the level that is required in our ACF/PBS scenarios, and which must be achieved in order to be on target for the scale of deployment we foresee in 2050 [Exhibit 4.6].

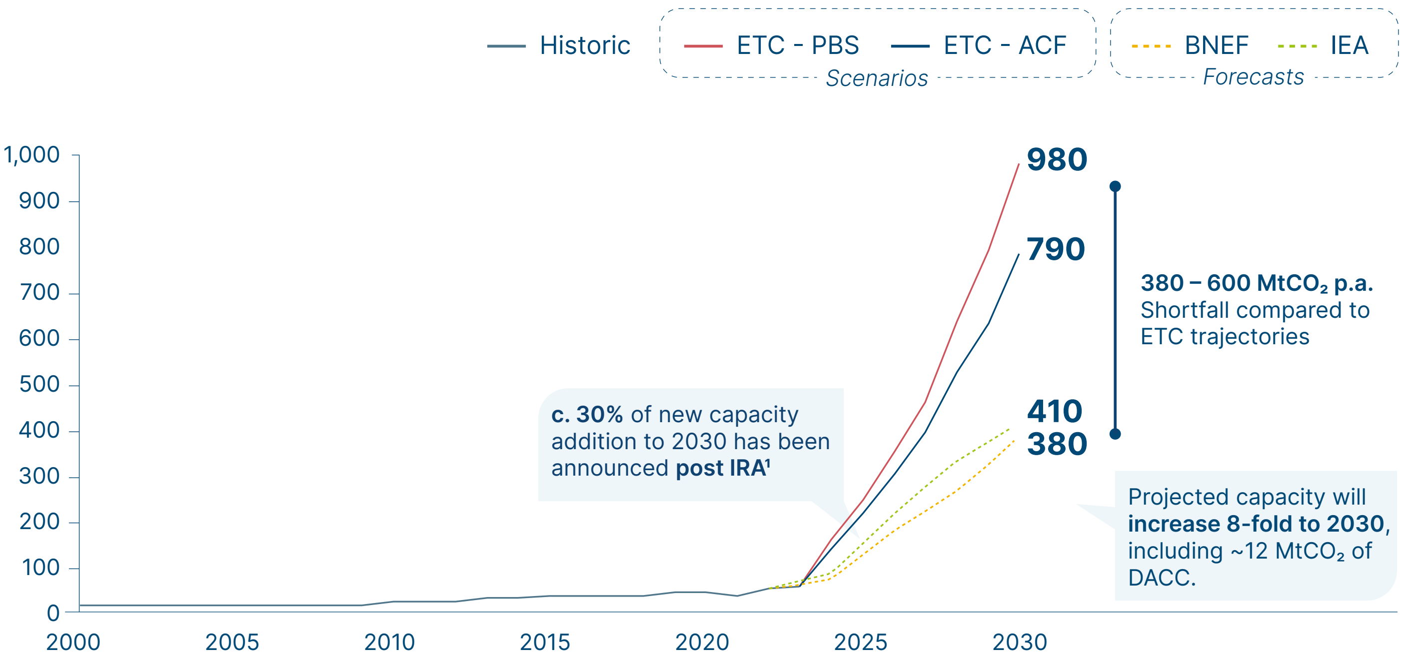
Our **updated assessment** is therefore that:

- Additional strong policy support and increased investment will be needed to ensure that point-source CCUS can play the vital but limited role which we continue to believe is technically possible and required to meet climate objectives.
- Any assumption that point-source CCUS could play a significantly larger role than we assume would be incredible and imprudent.

EXHIBIT 4.6

# Projected CCUS capacity to 2030 compared to requirements in ETC scenarios

Total Carbon Capture Utilisation and Storage (CCUS) capacity to 2030
$MtCO_2$ p.a.




**NOTE:** Values are rounded. ¹ IRA = Inflation Reduction Act. The values presented here from BNEF/IEA include direct air carbon capture (DACC) projects, but the volumes by 2030 are expected to be very low, 10-15 $MtCO_2$ p.a. of capacity.

**Source:** Systemiq analysis for the ETC; BNEF (2022) *CCUS Market Outlook*; IEA (2023), *Operational and planned capture capacity*, BCG (2023), *Impact of IRA, IIJA, CHIPS, and Energy Act of 2020 on Clean Technologies.*

151 IEA (2023), *Carbon capture, utilisation and storage - Tracking.*

152 The 45Q tax credit provides up to \$85/$tCO_2$ for CCS for industrial facilities and power plants with geological storage, and up to \$60/$tCO_2$ for utilisation of captured $CO_2$. Bipartisan Policy Center (2022), *Inflation Reduction Act Summary: Energy and Climate Provisions.*

## 4.3 Updated assessment of the role of DACCS

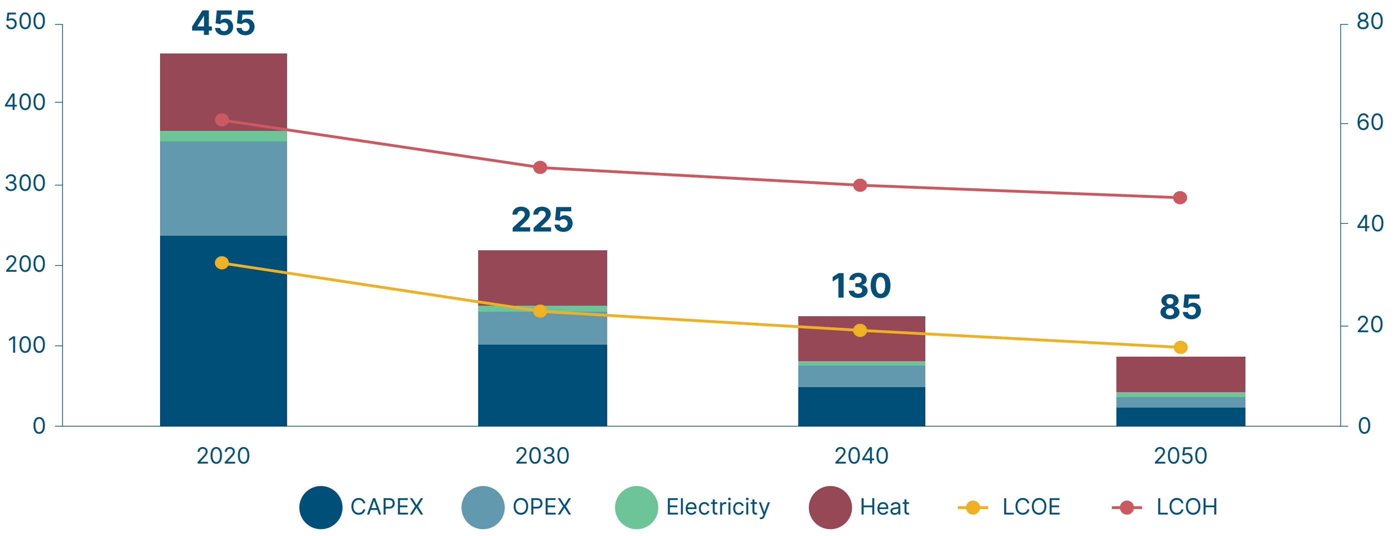
Both our March 2022 and July 2022 reports set out an assessment of the technological and economic feasibility of direct air carbon capture and storage. We concluded that:

- Direct air carbon capture and storage could, if long-term geological storage is tightly regulated, be a low-risk technology delivering certain and permanent removals.
- Current costs per tonne captured (over \$450/t$CO_2$) are far higher than those of alternative decarbonisation technologies, but could be reduced via improvements in energy efficiency and lower capital costs to reach \$250–300 per t$CO_2$ by 2030 and below \$100 per tonne by 2050, as per Exhibit 4.7.[153,154] Significant improvements in energy intensity and capital costs would be needed in order to drive down costs in the long-term, but these should be feasible.

**EXHIBIT 4.7**

### Projected levelised cost of Direct Air Capture (DAC) to 2050

Estimated levelised cost of direct air capture (LHS); energy costs for advantaged regions (RHS)
\$/t$CO_2$ (LHS); \$/MWh (RHS)




**NOTE:** LCOH/E = levelised cost of heat/electricity; Levelised Cost of $CO_2$ Direct Air Capture breakdown refers to a fully electrified high temperature DACC system for 5,000 Full Load Hours per annum. Assumes overnight cost of capital for 1Mt$CO_2$ plant in 2020 of \$1,470m, weighted average cost of capital of 7% and plant lifetime of 20 years, growing to 30 years by 2050. Capital, heat and electricity costs refer to an advantaged region with abundant wind and solar resources.

**SOURCE:** Systemiq analysis for the ETC; Fasihi et al. (2019), *Techno-economic assessment of $CO_2$ direct air capture plants*; Keith et al. (2018), *A Process for Capturing $CO_2$ from the Atmosphere.*

Our reports therefore assumed a limited short-term role but a significant and vital long-term role for DACC, with volumes captured reaching 70–80 Mt$CO_2$ per annum by 2030, 500–550 Mt$CO_2$ by 2040 and somewhere between 2–3 Gt$CO_2$ per annum by 2050. This would follow a similar increase to the IEA's NZE pathway through to 2040, but with a more ambitious trajectory from 2040 to 2050.[155] Of this total, the vast majority would be stored, and would thus generate negative emissions across the capture and storage cycle. But we also assumed that:

- About 0.5 Gt$CO_2$ per annum would be used in 2050 to make synthetic aviation fuel, in combination with zero-carbon hydrogen.
- And that up to 0.5 Gt per annum could be used in enhanced oil recovery, neutralising the emissions from around 3 Mb/d of oil.[156]

153 ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited.*
154 The technical annex of the ETC's CCUS report outlined in detail the key assumptions and drivers to reach a cost for DACC of below 100\$/t$CO_2$ by 2050. ETC (2022), *Carbon capture, utilisation and storage in the energy transition – Technical Annex.*
155 The IEA's updated NZE includes DACC deployment of 80/200/1040 Mt$CO_2$ in 2030/35/50. IEA (2023), *Net-zero roadmap – update.*
156 Using a carbon intensity of around 430 kg$CO_2$ per barrel of oil. Note that EOR could also be carried out using $CO_2$ captured from point-source emissions, in which case the life-cycle contribution to absolute emissions would be higher. ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited.*

These uses would result in net-zero emissions across the capture-to-use cycle but would not generate negative emissions.

Our ACF and PBS scenarios and our temperature calculations in Chapter 5.1 maintain the same assumptions for DACC which we made in our 2022 reports. Alternative assessments of the role of DACC in relation to both aviation fuel and to EOR could result in slightly higher estimates for total oil demand:

- In **aviation**, there is an open debate over whether DACC will be best used to provide $CO_2$ as an input to synthetic jet fuel production, or whether DACCS (i.e., DACC with storage) should be used to offset the continued use of conventional jet fuel. Our current assessment is that synthetic jet fuel will prove the most economic solution once account is taken of non-$CO_2$ climate forcing effects, but it is possible that future analysis will change this assessment. This might increase our estimate of likely 2050 oil demand by 5–6 Mb/d.[157]
- Meanwhile, the potential use of DACC with EOR is proposed by some oil and gas companies as a means to deliver "carbon-neutral oil" and thus make continued large-scale oil supply compatible with current climate objectives.[158] But our assessment in Chapter 2.6 of our CCUS report[159] argued that:
  - The net impact of **DACC with EOR** depends on the ratio of $CO_2$ injected to oil recovered, with positive net emissions still likely to occur in many proposed projects. Tight regulation to require high injection intensity is therefore essential.
  - The economic feasibility of projects which achieve a high injection intensity is unclear, and the economic role of DACC with EOR is therefore likely to be limited.
  - Assessment of the climate change impact of DACC with EOR must also take account of the upstream scope 1 and 2 emissions produced during oil and gas production (discussed further in Chapter 8); and once these are taken into account, the optimal role of DACC with EOR further declines.

No new information relating to EOR challenges has challenged this assessment and we therefore continue to believe that DACC for EOR can at most offset emissions produced from 3 Mb/d of oil.

## 4.3.1 Latest developments in direct air capture

Since our 2022 reports,[160] interest in DACCS has continued to grow, with important new announcements (e.g., the purchase of Carbon Engineering by Occidental Petroleum[161]), and significant support from the US government, both through the Inflation Reduction Act[162] and in the announcement of up to $1.2 billion of funding for two large-scale DACC demonstration projects.[163]

However:

- Current costs achieved continue to be far above an economically-viable level, in some cases reaching over $1,000/t$CO_2$, and recent projections of future cost (e.g., reaching $100 per ton by 2050) are no lower than we already assumed in our 2022 reports.[164]
- Volumes of $CO_2$ captured by announced projects are still trivial compared with our long-term projections. The largest planned DACC plant, DAC 1 in the Permian Basin, scheduled to come online in 2024, will initially capture just 1 Mt$CO_2$ per annum.[165] Further, the expected pipeline of DACC through to 2030 is just 12–14 Mt$CO_2$ per annum,[166] well below the ~75 Mt$CO_2$ per annum which we require in our ACF/PBS pathways, and which would be required to make our 2050 projected volumes credible.

It would therefore be **neither credible nor prudent to assume a future level of DACC deployment higher than assumed** in our 2022 reports (i.e. at most 4.5 Gt$CO_2$ per annum by 2050), and even the lower trajectory of 2.3 Gt$CO_2$ of DACC by 2050 used in the ACF and PBS scenarios will be challenging to achieve. Indeed, significantly stronger policy support, faster technological progress, and greatly increased private investment will be needed to deliver the DACC-based capture which we assume in our temperature calculations in Chapter 5.

157 Assuming 50% of 2050 aviation demand is met by conventional jet fuel, leading to ~275 Mt of jet fuel demand, or roughly 5.5 Mb/d. Note that likely oil production required to produce the jet fuel would likely be even higher than this value, as not all the hydrocarbon components of oil can be converted to jet fuel. MPP (2022), *Aviation net-zero explorer.*

158 Notably, the CEO of Occidental Petroleum stated that "direct capture technology is going to be the technology that helps to preserve our [the oil and gas] industry over time." The Energy Mix (2023), *Occidental seeks '60, 70, 80 years' of oil extraction with carbon engineering buyout.*

159 ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited.*

160 ETC (2022), *Carbon capture, utilisation and storage in the energy transition: Vital but limited;* ETC (2022), *Mind the Gap.*

161 Oxy (2023), *Occidental enter into agreement to acquire direct air capture technology innovator Carbon Engineering.*

162 The 45Q tax credit provides up to $180/t$CO_2$ for DACC with geological storage, and up to $135/t$CO_2$ for utilisation of captured $CO_2$ from DACC. Bipartisan Policy Center (2022), *Inflation Reduction Act Summary: Energy and Climate Provisions.*

163 US Department of Energy (2023), *Biden-Harris Administration announces up to $1.2 billion for nation's first direct air capture demonstrations in Texas and Louisiana.*

164 For example, BNEF have rough estimates of $59–186/t$CO_2$ for DACC in 2050, depending on current costs and future learning rates. BNEF (2023), *Direct air capture: Market and cost outlook.*

165 IEA (2023), *CCUS around the world – DAC 1.*

166 IEA (2023), *Operational and planned capture capacity*; BNEF (2023), *Direct air capture: Market and cost outlook.*

## 4.4 Updated assessment of nature-based removals

As Exhibit 2.4 showed, our 2022 *Mind the Gap* report assumed that nature-based solutions (NBS) would account for almost all removals achieved by 2030 and the vast majority up to 2040.

This reflected our assessment that NBS can, in principle, deliver removals at costs far lower than DACCS or BECCS and in most cases below $50 per tonne of $CO_2$ sequestered. In addition, NBS projects can bring significant co-benefits to local ecosystems and economic income to local communities. However, we also recognised that NBS projects, to a far greater extent than DACCS, face high risks relating to the certainty and permanence of sequestration which will require very careful management, regulation and monitoring.[167]

Relative to our expectations and projections, latest information over the last year has been extremely disappointing. The **volume of NBS credits is increasing far slower** than we projected, with the estimated volume of NBS credits purchased reaching only ~155 $MtCO_2$,[168] most of which have funded projects such as avoided deforestation, which deliver emissions reduction versus business as usual – but are not true removals.

In addition, there have been highly publicised **concerns about the credibility of some credits**,[169] alongside increasing concerns that climate change itself – especially via wildfires – threatens the permanence of some reforestation projects. Furthermore, rates of deforestation are not declining at the pace needed to rapidly reduce land-use emissions,[170] and there is some evidence that certain forested regions are becoming net sources of carbon, raising further concerns about the potential role of forests as “carbon sinks”.[171]

Very intensive policy support and increased investments would therefore be required to deliver even the level of NBS removals which we assumed in our 2022 report *Mind the Gap*. There can therefore be no reasonable case for projecting higher volumes of NBS removals than the 120 $GtCO_2$ cumulative which we assume can be achieved between now and 2050.

## 4.5 Implications for credible assumptions on CCS and removals

Given the challenges facing deployment of point-source CCUS, DACCS and NBS removals, there is **major risk** that the combined contribution of these technologies to emissions reductions will be significantly less than we previously assumed.

But as Chapter 5 describes, our ACF and PBS scenarios for fossil fuel use decline are only compatible with 1.7°C and 1.5°C global warming limits if combined with point-source CCUS growing to reach 4.0–4.8 Gt per annum by 2050, and cumulative removals of 150 Gt between now and 2050 .

The ETC’s judgement is therefore that:

- To have any chance of **limiting global warming to 1.5°C or 1.7°C**, it is essential to **reduce fossil fuel demand at least as fast as in our PBS or ACF scenarios**.
- In addition, it is essential to put in place the **investments and policies which can ensure the delivery of point-source CCUS** on the scale required, and to mobilise the finance needed to deliver significant DACCS and NBS removals.
- There is **no credible justification** for assuming that significantly higher levels of fossil fuel demand and supply can be made compatible with global climate objectives by assuming significantly higher future levels of CCUS, DACCS, BECCS or NBS removals.

167 ETC (2022), *Mind the gap.*
168 BNEF (2023), *Long-term carbon offsets outlook.*
169 For example, Patrick Greenfield/The Guardian (2023), *Revealed: More than 90% of rainforest carbon offsets by biggest certifier are worthless, analysis shows.*
170 ETC (2022), *Degree of urgency.*
171 Carbon Brief (2023), *Logged tropical forests are ‘substantial’ carbon source for at least 10 years*; Mills et al. (2023), *Tropical forests post-logging are a persistent net carbon source to the atmosphere.*

# Chapter 5

# Emissions, carbon budgets, implications for temperature and policy actions required to reduce fossil fuel demand

Chapters 1–3 presented our scenarios for reducing fossil fuel use; Chapter 4 considered the potential pace of development of both point-source CCUS and removals. The two combined imply a path for future temperature increases and define the scale of the challenge if we are to limit global warming to acceptable levels.

This chapter therefore:

- Sets out **estimates of the temperature increases** which would result from our scenarios.
- Explains **why policies to reduce fossil fuel demand are essential** to meet climate change objectives.
- Describes the **key demand-side policies** required to ensure as limited future temperature rise as possible.

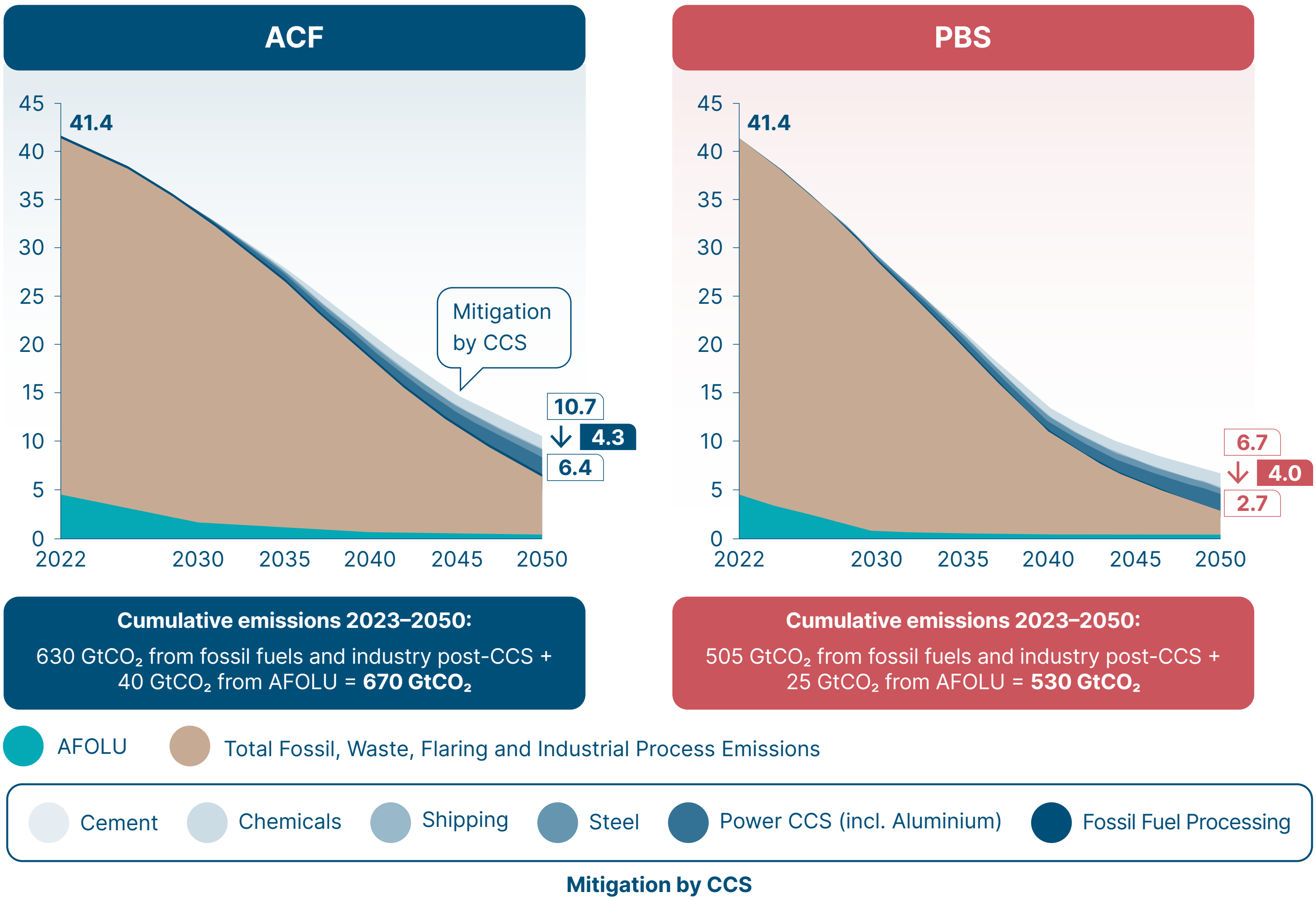
## 5.1 Temperature implications from cumulative emissions to 2050

Our ACF and PBS scenarios for fossil fuel decline, combined with our assumptions on the scale of mitigation from point-source CCUS, would result in cumulative emissions from fossil fuels and industry (including $CO_2$ from flaring and waste) of 630 $GtCO_2$ in the case of ACF, and 505 $GtCO_2$ if the PBS scenario could be achieved [Exhibit 5.1].

**EXHIBIT 5.1**

### Net cumulative $CO_2$ emissions from EBIT and AFOLU sectors to 2050 in ACF and PBS

Net emissions from fossil fuels, industry and AFOLU after carbon capture and storage
$GtCO_2$




**NOTE:** AFOLU = Agriculture, Forestry, and Other Land Use. Abatement of emissions via CCS excludes carbon captured for CCU.

**SOURCE:** Systemiq analysis for the ETC.

The implications of this for temperature will also depend on:

- Assumptions about the scale of $CO_2$ emissions from the agriculture, food and land use sectors (AFOLU), which are currently running at about 5 $GtCO_2$ per annum. In the ETC's past reports on actions required to achieve a 1.5°C warming limit[172] and on removals[173] we have assumed that these emissions can be very significantly reduced by 2030, primarily by putting an end to deforestation, with further decline of AFOLU $CO_2$ emissions to almost zero by 2050.
    - In our ACF scenario we assume total future cumulative $CO_2$ emissions from the AFOLU sector of around 40 $GtCO_2$ and 25 $GtCO_2$ in the PBS scenario.
    - But while this is possible, it will not occur without strong policies and significant financial flows from developed to developing countries, and these are not yet in place: despite commitments made at COP26 in Glasgow, minimal progress in ending deforestation has been made over the last few years.[174]
    - There is therefore a significant risk that future cumulative AFOLU $CO_2$ emissions will be significantly higher than the 25–40 $GtCO_2$ assumed in Exhibit 5.1.
- Assumptions about future levels of other greenhouse gas emissions, in particular methane and nitrous oxide ($N_2O$). Methane emissions derive primarily from two sources – the production, processing and transportation of fossil fuels, and from livestock because of enteric fermentation. The former can and must be radically reduced via the actions discussed in Chapter 8; radically reducing the latter will likely only be possible if a significant shift away from animal dairy and red meat consumption can be achieved. $N_2O$ emissions arise primarily in agriculture and can be significantly reduced, but complete elimination is unlikely to possible.[175]

To estimate the remaining "carbon budgets" of $CO_2$ emissions which would be compatible with limiting global warming to any specific temperature, the IPCC assumes reductions in methane emissions of 50% by 2050 and reductions in $N_2O$ emissions of 30%.[176]

Given these assumptions for other GHGs, the IPCC estimates the "carbon budget" of cumulative additional $CO_2$ emissions which would be compatible with a given likelihood of staying within either a 1.5°C or a 2°C temperature limit [Exhibit 3.2].[177] This carbon budget starting in 2020 was estimated at 500 $GtCO_2$ for a 50% chance of staying within a 1.5°C limit, and 1,350 $GtCO_2$ for a 50% chance of staying within a 2°C increase. But reasonable estimates are now lower for two reasons [Exhibit 5.2]:

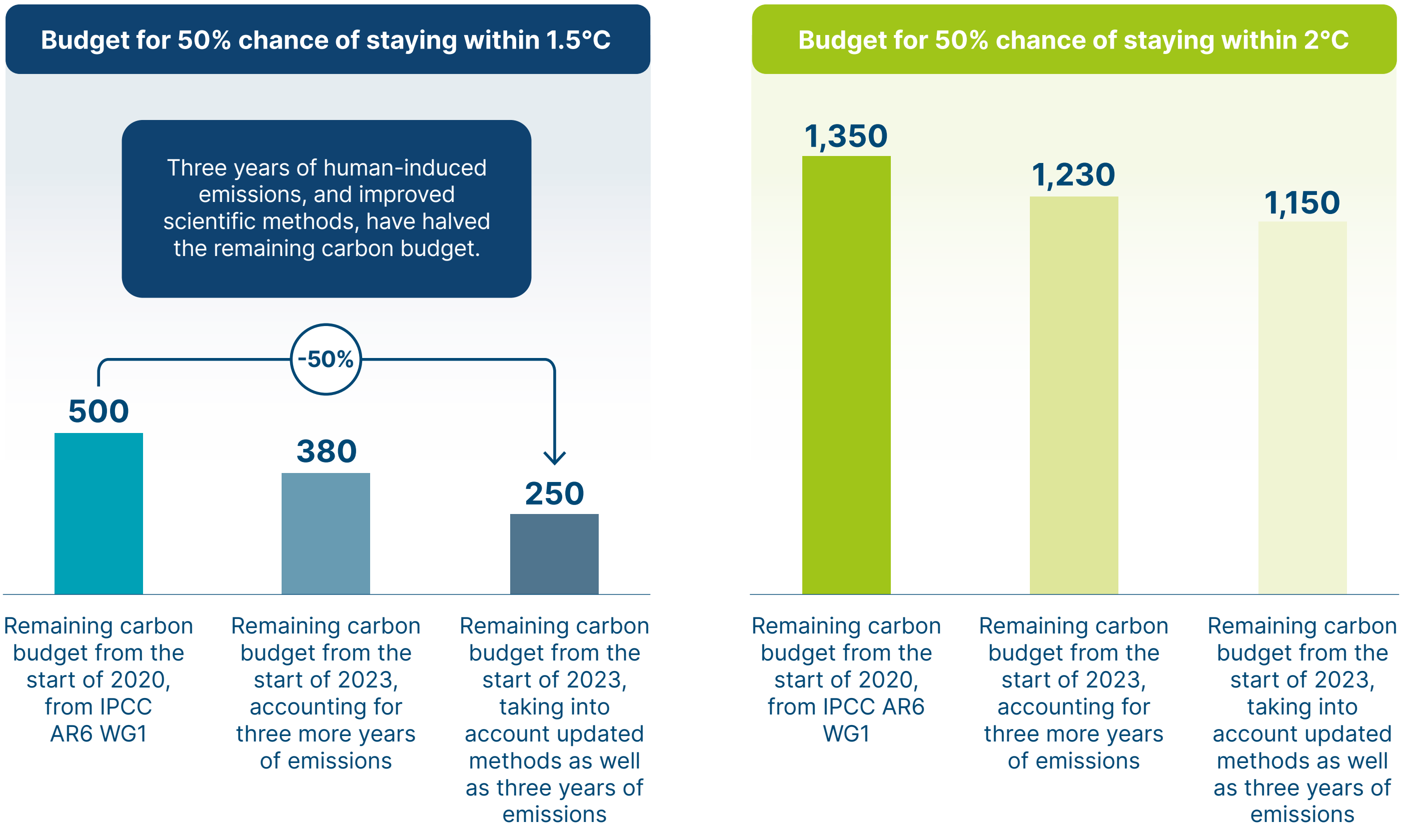
- First, because we are now in 2023 and since 2020 the world has already experienced three years of further $CO_2$ emissions running at around 40 $GtCO_2$ per annum. This reduces the estimated budgets to 380 $GtCO_2$ and 1,230 $GtCO_2$ respectively.
- Second, because new scientific evidence and analysis suggests a further reduction in the reasonably estimated carbon budgets – to 250 Gt for a 1.5°C limit and 1,150 Gt for a 2°C limit.[178]

172 ETC (2021), *Keeping 1.5°C Alive*; ETC (2022), *Degree of Urgency.*
173 ETC (2022), *Mind the Gap.*
174 ETC (2023), *Financing the Transition: The Costs of Avoiding Deforestation.*
175 This topic is discussed further in ETC (2022), *Mind the Gap.*
176 ETC (2022), *Mind the Gap*; IPCC, (2021), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.*
177 IPCC (2021), *Sixth Assessment Report - Working Group 1: The Physical Science Basis.*
178 The key drivers for this change are the increased warming impact of historical $CO_2$ emissions up to 2019, the increased warming impact of non-$CO_2$ greenhouse gases, and a reduction in the estimated cooling impact of aerosols. Forster et al. (2023), *Indicators of global climate change 2022: annual update of large-scale indicators of the state the climate system and human influence.*

EXHIBIT 5.2

## Carbon budgets to limit global average temperature increase to 1.5°C and 2°C

Carbon budgets for a given temperature rise
$GtCO_2$




**SOURCE:** Carbon Brief (2022), *What the tiny remaining 1.5°C carbon budget means for climate policy*; Forster et al. (2023), *Indicators of global climate change 2022: annual update of large-scale indicators of the state the climate system and human influence*; IPCC (2021), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.*

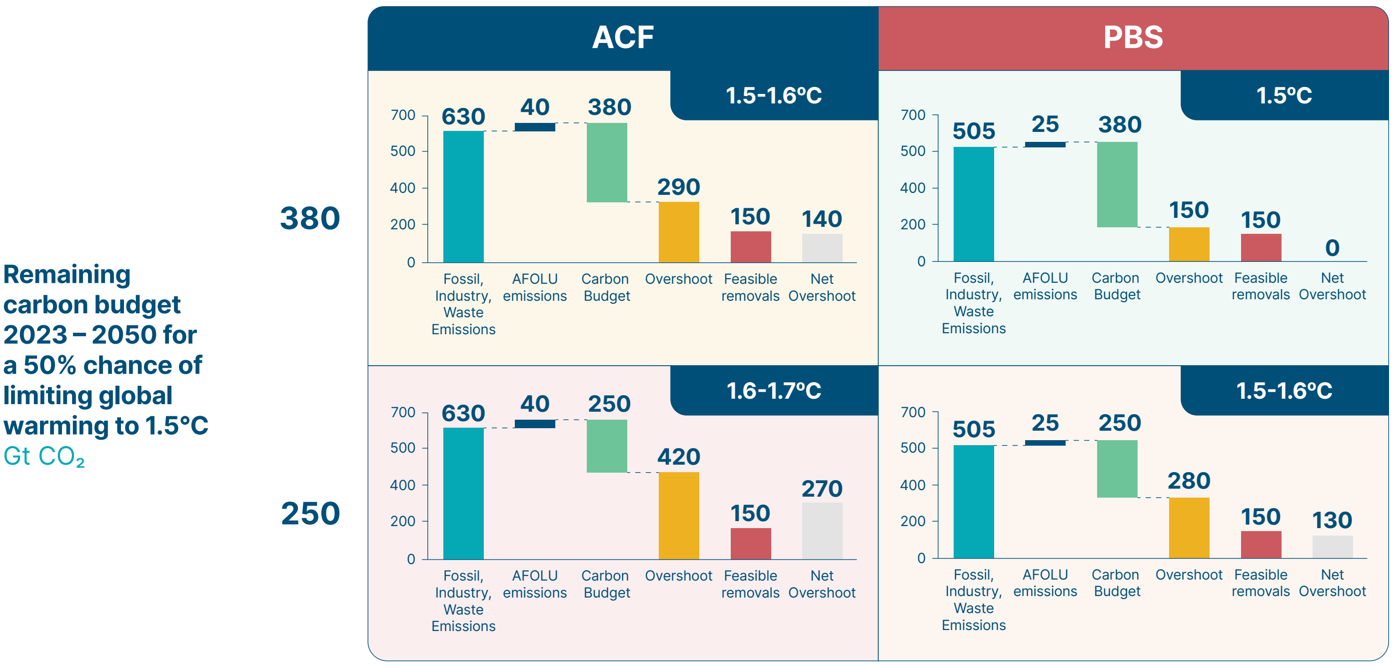
Exhibit 5.3 shows, for the 1.5°C limit, how our estimates of cumulative emissions compare with the remaining budgets, and the net overshoot after potential impact of removals, with:

- The ACF scenario implying an overshoot of 420 $GtCO_2$ versus a 250 $GtCO_2$ budget, and a 270 $GtCO_2$ "net overshoot" if we assume that 150 $GtCO_2$ of removals can be achieved.
- The PBS scenario implying a net overshoot of 130 $GtCO_2$ even after removals if the remaining carbon budget is 250 $GtCO_2$, but with no net overshoot if a 380 $GtCO_2$ budget is still available.

EXHIBIT 5.3

## Cumulative net emissions, removals and carbon budget overshoot

Net emissions overshoot and implied temperature rise, by scenario




**NOTE:** Estimates calculated using values for the Transient Climate Response to Cumulative Emissions of Carbon Dioxide (TCRE), using a value range of 0.27–0.63°C per 1,000 $GtCO_2$. Note that the temperature estimates calculated here will likely underestimate future warming, as these do not account for the warming impact of other greenhouse gases, notably methane and nitrous oxide.

**SOURCE:** Systemiq analysis for the ETC; IPCC (2021), *Climate Change 2021: The Physical Science Basis*; Forster et al. (2023), *Indicators of global climate change 2022: annual update of large-scale indicators of the state the climate system and human influence.*

An approximate estimate of implied temperature rise based on these emissions overshoots is also shown in Exhibit 5.3:[179]

- Under our ACF scenario, the global average temperature would be +1.5–1.6°C above preindustrial levels if the remaining carbon budget was 380 $GtCO_2$ but it would be +1.6–1.7°C if the remaining budget was only 250 $GtCO_2$.
- Under our PBS scenario, the temperature increase would be +1.5°C with a 380 $GtCO_2$ budget, and +1.5–1.6°C if the remaining budget is 250 $GtCO_2$.

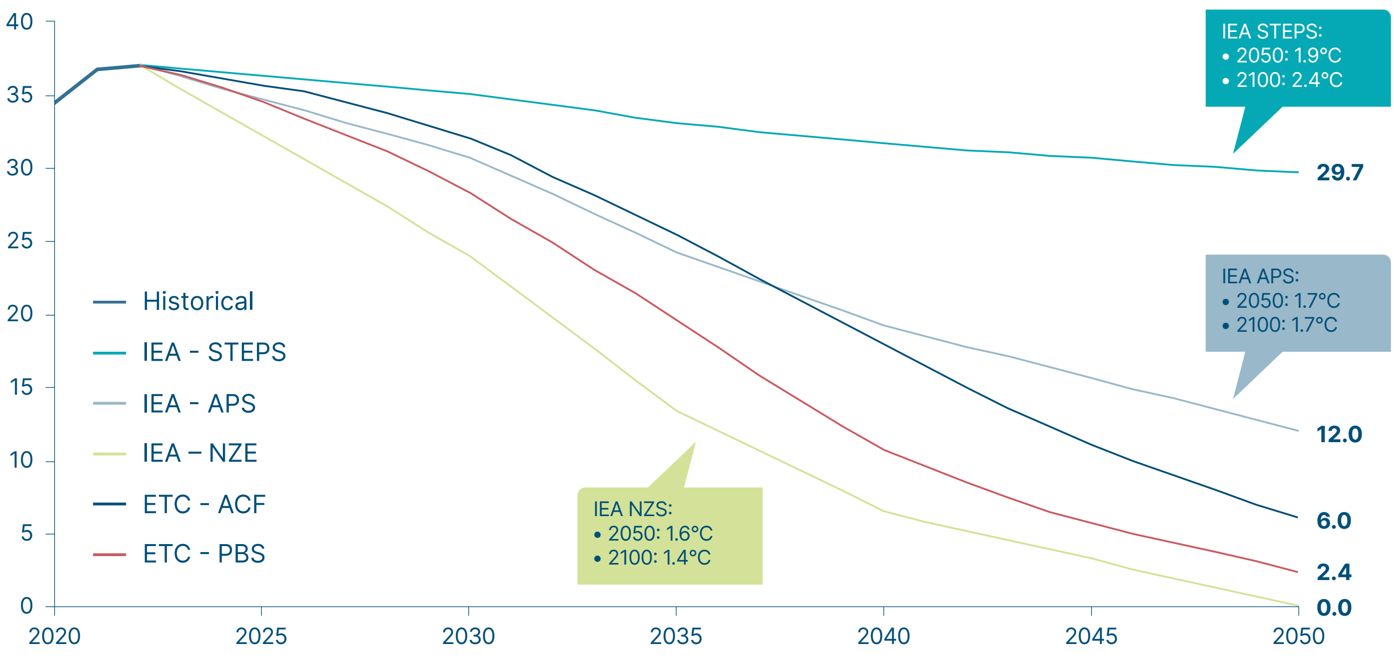
More cautious assumptions on removals and AFOLU cumulative emissions would increase these temperature results. For instance, if cumulative removals to 2050 were 80 $GtCO_2$ (rather than the 150 $GtCO_2$ assumed), and if cumulative AFOLU emissions amounted to 80 $GtCO_2$ (rather than 40 $GtCO_2$ assumed) this would increase the temperatures implied by our scenarios by another 0.03ºC–0.07ºC; combined with the more cautious estimate of remaining carbon budget, this could result in a temperature rise under the ACF scenario of well over 1.7°C.

These temperature results can be compared with the IEA estimates which result from their own scenarios for fossil fuel use [Exhibit 5.4]. They estimate that their APS scenario would result in a temperature rise of 1.7°C by 2050, while their NZE scenario would result in 1.5–1.6°C by that date.[180] As discussed in Chapter 3.2, our ACF and PBS scenarios lie between the IEA's APS and NZE scenarios, but the NZE scenario does not allow for the approximately 120 $GtCO_2$ of removals from nature-based solutions which we assume could be achieved by 2050. The IEA NZE and the ETC PBS scenarios thus produce roughly the same temperature increase by 2050.

EXHIBIT 5.4

## Net emissions from EBIT sectors in ETC and IEA scenarios

Net emissions from fossil fuels, flaring, waste and industrial processes after carbon capture and storage
$GtCO_2$




**NOTE:** STEPS = Stated Policies Scenario, APS = Announced Pledges Scenario, NZE = Net-Zero Emissions, ACF = Accelerated but Clearly Feasible Scenario, PBS = Possible But Stretching Scenario.

**SOURCE:** Systemiq analysis for the ETC; IEA (2023), *World energy outlook 2023*.

179 Note that the temperature estimates calculated here using the Transient Climate Response to Cumulative Emissions of Carbon Dioxide (TCRE), using a value range of 0.27–0.63°C per 1,000 $GtCO_2$, based on the IPCC's *Sixth Assessment Report*. Temperature estimates calculated in this way will likely underestimate future warming, as these do not account for the warming impact of other greenhouse gases, notably methane and nitrous oxide. As a sense-check, estimates of temperature rises were also carried out using the open-source MAGICC model, which provided pathways with ranges of temperature increases by 2050 that included the values calculated approximately here using the TCRE. See live.magicc.org

180 IEA (2023), *Peak temperature rises in the WEO-2022 scenarios*; IEA (2023), *Net-zero roadmap – update*.

The IEA also provides estimates of the temperature impact of their scenarios in 2100, with the APS scenario still producing a 1.7°C increase in that year, but the NZE scenario implying that temperatures, having increased by 1.6°C in mid-century, will fall back to 1.4°C by 2100.

We have not explicitly estimated the 2100 temperature impact of our scenarios, which would depend on assumptions about the path of emissions and of removals post-2050, alongside estimates of the impacts of other greenhouse gases. But if the significant annual removals which we have assumed is possible by 2050 [Exhibit 4.4] could be maintained in the subsequent decades, the temperature under our PBS scenario would follow a similar path to the IEA NZE , and likely fall below 1.5°C by 2100.[181]

It is therefore reasonable to characterise our scenarios, including their ambitious assumptions for the deployment of CCUS and of carbon removals, as being:[182]

- In the case of the ACF, compatible with a 1.7°C temperature limit but not a 1.5°C temperature limit.
- In the case of PBS, broadly compatible with a 1.5°C limit.

## 5.2 Meeting the climate challenge: phasing down fossil fuel use is essential

Given the temperature implications explored above, any credible strategy to limit global warming to 1.7°C or ideally to 1.5°C, must involve a commitment to reduce fossil fuel use at something like the pace indicated by our ACF and PBS scenarios.

This is essential because:

- Chapter 4 concluded that it is not prudent to assume that the rate of growth of point-source CCUS, DACCS or nature-based removals, is faster than we have assumed. Indeed, without strong policy support and large-scale investment, our assumed levels of removals will not be achieved, and there is a significant danger that actual removals may fall well short of our assumptions.
- Our assumption that future cumulative AFOLU emissions can be limited to 40 $GtCO_2$ is also ambitious and will not be achieved without strong policy support. Actual cumulative AFOLU emissions may turn out significantly higher than projected.
- Even if our removal and AFOLU assumptions are achieved, and even if the remaining carbon budget is 380 rather than 250 $GtCO_2$, our PBS scenario would only just meet the 1.5°C target. Our ACF scenario is clearly not consistent with limiting global warming to 1.5°C, but would deliver a temperature limit of 1.7°C.

Achieving our ACF scenario for the reduction of fossil fuel use should therefore be considered the minimal acceptable level of ambition, and the ideal objective should be to achieve reductions in line with or greater than our PBS scenario.

## 5.3 Commitments and policies required to limit global warming to 1.5°C

If the required reductions in fossil fuel use and emissions are to be achieved, the primary means will be through policies, investments and company actions which reduce demand for coal, oil and gas. Chapter 7 considers the potential supporting role of commitments to constrain future supply, but without strong action to reduce demand, those actions will be ineffective.

Over the last seven years, the ETC's reports have each set out the policy actions and investments required to drive decarbonisation of both energy-using sectors and of power supply. A non-exhaustive list of key policy recommendations arising from this work is presented in Exhibit 5.5.

181 Modelling of temperature rises implied by the $CO_2$ emissions pathways in the ACF and PBS scenarios, alongside other greenhouse gas emissions aligned with the IPCC's SSP1-2.6 pathways (which are compatible with "well below 2°C" scenarios, would yield temperature rises by 2100 of 1.4–1.6°C across the two scenarios.

182 Close but likely to overshoot, as our estimates of temperature rise here are *underestimates* as they have only been calculated accounting for $CO_2$-induced warming. Additional warming from other greenhouse gases would increase these estimates further.

EXHIBIT 5.5

## Key policies by sector

| | |
|---|---|
| **Road transport** | • Restricting or ending the use of internal combustion engine vehicles<br>• ICE sales bans<br>• Rollout of charging infrastructure<br>• Fuel efficiency standards<br>• ICE vehicle retirements |
| **Aviation and shipping** | • Fuel blending mandates<br>• Carbon taxes |
| **Buildings** | • Strong building codes & regulations<br>• Bans on the sales of fossil boilers<br>• Subsidies for heat pumps<br>• Switching to clean cooking<br>• Subsidies (and associated infrastructure development) for clean cooking |
| **Industry** | • Switching to low-carbon fuels<br>• Carbon pricing<br>• Additional de-risking support (purchase agreements, long-term contracts, associated $H_2$/CCS infrastructure development) |
| **Power** | • Scaling wind and solar<br>• Long-term contracts for renewables driven through competitive auctions<br>• Removing barriers to clean electrification (such as grid blockages, inefficient permitting, supply chain issues) |

**SOURCE:** Systemiq analysis for the ETC; ETC (2020), *Making Mission Possible;* ETC (2021), *Making Clean Electrification Possible;* ETC (2023), *Financing the Transition.*

In particular, public policy and private action should aim to achieve four objectives:

- **Speed up the deployment** of zero-carbon power and other proven emissions reduction technologies and business models.
- **Create the right policy and investment environment** to enable technology diffusion in all sectors where technologies are market-ready, but still not cost-competitive.
- Ensure the **technologies** that are still at the emergence phase are brought to market by the end of the 2020s at the latest.
- Deliver the scale up required in associated **low-carbon infrastructure** such as electricity grids, hydrogen or $CO_2$ networks.

Across all sectors, businesses will play a key role in developing low-carbon processes and products which reduce both their own fossil fuel use and that of their customers. But this must be enabled and supported by a combination of:

- **Public policy** creating greater market certainty through quantitative targets and appropriate market design, driving the development of necessary infrastructure, and using regulation, initial subsidies or carbon pricing to overcome the "green cost premium" in applications where zero-carbon solutions are not yet cost-competitive.
- **Financial institutions**, both private and public, which have a crucial role to play in supporting investment in new low-carbon technologies and restricting investment in assets which could lock-in fossil fuel demand.
- **Buyer commitments**, to purchase low-carbon goods and services in place of fossil fuel equivalents.

### 5.3.1 Public policy: further strengthening needed

In many regions of the world, but in particular in Europe, the US and China, strong policies are already driving the uptake of clean energy technologies and the reduction of fossil fuel use in the electricity sector and surface transport, and are expected to extend this progress to heavy industry. Key policies include:

- **Support for renewables deployment**, reflected in varying combinations of clear planning targets (e.g., as in China) and regulations, long-term contracts awarded via auctions (in many countries), and tax credits or other financial support (e.g., in the US via the Inflation Reduction Act (IRA)). As a result, wind and solar installations are already projected to increase from 295 GW per annum in 2022[183] to close to 900 GW per year by 2030.[184]

- **Support for EVs** via a combination of initial purchase subsidies (in many countries), specified dates for bans on the sale of ICEs (primarily in Europe), restrictions on the use of ICEs in cities (primarily in China and Europe) and automotive company commitments to phase out ICE sales beyond specified dates. As a result, the share of EVs in global passenger vehicle sales reached 14% in 2022,[185] and could rise to 44% by 2026 in our ACF scenario.

- **Carbon pricing** which both directly (most prominently via prices of around €90/t$CO_2$ in the EU's Emissions Trading Scheme (ETS)) and indirectly, via the inclusion of heavy industrial sectors in the EU's Carbon Border Adjustment Mechanism (CBAM) is incentivising the decarbonisation of heavy industrial sectors in particular. Additional policy support, such as tax credits under the IRA, or similar incentives in Europe, have seen around 500 large-scale low-carbon industrial facilities announced, many of which are expected to come online by the end of this decade.[186]

Together, this gives us confidence that much of the fossil fuel reductions in our ACF scenario are already being driven through strong policy.

However, stronger policies will be required in some sectors to meet even the ACF scenario, and much stronger policies across many sectors to achieve the PBS scenario. The most impactful of these are likely to be:

- Extending **ICE bans** to a wider set of markets, ideally setting 2035 as the date for passenger EVs and 2040 for heavy vehicles and ensuring that charging infrastructure enables such pace of deployment.

- Policies to encourage **early retirements of ICEs**, e.g., through the use of scrappage subsidies, particularly in regions with long vehicle usage lifetimes, such as India, and sub-Saharan Africa.

- Policies to **further accelerate renewables deployment**, aiming for at least a tripling of new wind and solar installations from around 400 GW in 2023 to over 1,200 GW in 2030. This requires the extension to other countries of the targets and policy supports already in place in the US, China and EU, and action to remove barriers to deployment (e.g., by streamlining permitting and grid connection processes, and proactively investing in grid capacity).[187] It also requires a massive increase in **flows of finance to low-income countries**, where a limited supply and high cost of finance is currently a major impediment to the deployment of renewables.

- **Bans on the sales of new fossil fuel boilers**, particularly in the northern hemisphere (and primarily richer) countries which account for the vast majority of residential heating demand.

- **Subsidies for clean cooking**, in particular to incentivise a switch away from traditional use of biomass in cooking in Sub-Saharan Africa, with associated health benefits.

- Ensuring that robust building **codes for low-carbon buildings** already being imposed in some countries are fully implemented and extended as best practice to all other markets, in particular in developing economies where most growth in floorspace is expected.[188]

- **Incentivising a rapid shift away from the use of coal in power generation**, particularly in China, but also through the use of JET-P[189] type financial support in India, South Africa, Indonesia, and other countries whose power generation is heavily coal-reliant. In the ETC's 2023 report *Financing the Transition,* we estimated that this could require an annual financial flow from developed to developing economies of $25-50 bn per annum, reducing gradually over the next 15 years.

- Policies to **incentivise a switch away from fossil fuel feedstocks** in the chemicals sector, which are particularly important for the oil demand reductions required in our PBS scenario.

- **Carbon pricing** applied as widely as possible, and in particular in all heavy industry sectors, shipping and aviation, with public support also for the deployment of first-of-a-kind projects based on low-carbon technologies.

183 IRENA (2023), *Record Growth in Renewables Achieved Despite Energy Crisis.*
184 For example, BNEF's median short-term outlooks include forecast capacity additions of 170 GW for wind, and 710 GW for solar, by 2030. BNEF (2023), *Interactive data tool – Global installed capacity.*
185 IEA (2023), *Electric car sales, 2016–2023.*
186 MPP project tracker.
187 IEA (2023), *Executive Summary, Renewable Energy Market Update*.
188 Around 80% of floor area growth is expected to be in emerging market and developing economies. IEA (2023), *Buildings.*
189 Just Energy Transition Partnerships.

Policy and regulation will also have to ensure that enabling infrastructure such as electricity grids, EV charging capacity (including in particular for heavy-duty electric vehicles), and hydrogen and $CO_2$ networks, are built at the pace and scale required. In many cases this is likely to require significant changes to and strengthening of policy and regulation, and overcoming of planning and permitting hurdles. These issues are covered in more detail in the ETC's *Barriers to Clean Electrification* series.

Most of these policies – such as switching from fossil fuel-based to renewable electricity generation or from ICE to electric vehicles – can be introduced with limited impact on consumer lifestyles. In some cases, more substantial changes might be required – such as switching to a heat pump rather than a gas boiler. And as discussed in Chapter 1, neither of our ETC scenarios assumes the more substantial "behavioural changes" which are required to meet the IEA's NZE scenario, especially in the period to 2030.

Even without such changes, we believe that our scenarios would be compatible with a global temperature increase around 1.5–1.7°C provided that cumulative carbon dioxide removals of around 150 $GtCO_2$ can be achieved. Policies to ensure that those removals occur are therefore also essential.[190]

If such removals cannot be achieved, credible policies to limit global warming to 1.5°C will also have to include the behaviour changes previously described in Box E.

## 5.3.2 The role of the financial sector

The financial sector will be critical to scale the deployment of low-carbon technologies, and reducing fossil fuel consumption. The ETC's work on finance shows that a **tripling of low-carbon finance is required between now and 2030**, from $1 trillion per year to around $3.5 trillion per year, with around 70% of those investment required in the power sector (generation, networks and storage).[191] While there are no material barriers to financing this in higher-income countries, provided well-designed real economy policies are in place, the ETC's work on finance highlights the challenges in rapidly scaling up finance for lower-income countries.[192]

This reflects the fact that the levelised cost of renewable electricity is higher in lower-income countries, which face a higher cost of capital than higher-income countries (e.g., due to both real and perceived economic and political risks).[193] Alongside the crucial role of MDBs, a dramatic increase in both external and domestic savings, and private finance, is required to deliver the flows of investment needed.

As highlighted in the ETC's 2023 report *Financing the Transition*, multilateral development banks have a critical role to play, both in increasing their lending capacity and in improving the effectiveness of that money in catalysing private capital (e.g., through the use of de-risking mechanisms like guarantees and an expanded role in technical assistance and policy development).[194]

Alongside investing in new technologies, financial institutions should also restrict investment in long-lived fossil fuel consuming assets, reducing the risk of locking-in fossil fuel use for decades to come.

Operationalising net-zero commitments from financial institutions should therefore include rules and guidance to constrain investment in carbon-intensive energy-using assets, including for example, commitments to limit or refuse finance for:

- Relining of steel blast furnaces, unless there is a clear date-specific plan to retrofit CCS.
- New oil-based ships.
- New ICE passenger vehicles (and later heavy-duty vehicles) in countries which do not yet have public policy prohibitions.
- New gas boilers in residential and commercial buildings.
- New real estate with energy efficiency ratings below minimum defined levels.

These considerations should form key elements of overall financial institutions' transition policies and be used to assess clients' transition plans.

190 These policies are discussed further in ETC (2022), *Mind the Gap*.
191 ETC (2023), *Financing the transition*.
192 Ibid.
193 Required returns from solar projects in low- and middle-income countries are in the range of 12-52%, compared to 7-10% for developed and high-income countries. Songwe & al. (2022), *Finance for climate action: Scaling up investment for climate and development*.
194 Whilst crucial, increased financial flows and reduced cost of capital alone are unlikely to be sufficient to enable the required scale up in low-carbon energy and technologies in low- and middle-income countries. The political economy effects of fossil fuels must be addressed, in particular through financial and governance innovations, to enable the required diffusion of low-carbon technologies. WRI (2023), *A path across the rift: Informing African energy transitions by unearthing crucial questions and data needs*.

### 5.3.3 The role of buyer commitments

Commitments to buy green products and reduce purchases of fossil-fuelled products can complement the policies and financial institution commitments listed above.

Commitments from buyers, both private and public, to purchase green goods and services can increase the scale of clean energy demand and drive learning curve effects, which in turn would then make zero-emissions products and services increasingly cost-competitive and accessible to a broader range of consumers. In some cases, (e.g., many power purchase agreements) these commitments may entail no cost increase but are still valuable since they provide renewable power developers with more certain revenue. In other cases, buyers need to accept a green premium in the absence of carbon pricing (e.g., for synthetic aviation fuel or green steel). Commitments already in place include:

- Widespread corporate purchases of renewable Power Purchase Agreements (PPAs), including 37 GW of clean power contracted in 2022.[195]
- Commitments from over 100 large purchasers to contract green steel, concrete and aluminium and sustainable aviation fuel under the First Movers Coalition.[196]
- Commitments to phase out fossil fuel consumption by 2040, as is called for in We Mean Business Coalition's *Fossil to Clean* principles.[197]

195 Statista (2023), *Renewable capacity contracted through corporate power purchase agreements (PPAs) worldwide from 2012 to 2022.*
196 WEF (2023), *First Movers Coalition: Introduction and Overview of Commitments (April 2023).*
197 See principles and campaign here.

# Chapter 6

# The need for clear mid-century commitments

Our ACF and PBS scenarios indicate that by 2050 it would be technically and economically feasible to reduce coal use by 80–86%, gas use by 55–70 % and oil use by 80–96%, with the upper end of the range likely to be achieved during the 2050s even if not by 2050 itself. They also describe the pathways of declining use from now to 2050.

Chapter 7 analyses the implications of those declining paths for the commitments which governments, fossil fuel companies and financial institutions should make to constrain fossil fuel supply in line with declining demand. The shape of these declining pathways is vital, since global warming results from cumulative emissions rather than annual emissions at any specific future date.

But it is still useful to start by defining the endpoint which has to be reached, and the implications for the minimum commitments which governments and companies should make.

Whatever the shape of the decline curve from today to mid-century, limiting global warming to 1.5°C (or even to 1.7°C) will only be possible if, by mid-century, all remaining fossil fuel emissions are either abated by the application of point-source CCUS or offset by removals. In other words, net-zero is always the goal.

This implies that aggregate scope 1, 2 and 3 emissions from all coal, oil and gas-producing companies must reach net-zero by mid-century. Net scope 3 emissions of all fossil fuel companies are mathematically equal to the net global emissions from using fossil fuels – the latter cannot be reduced to net-zero unless the former are too.

To ensure that the climate objectives agreed at COP21 in Paris and reiterated at subsequent COPs are met, all fossil fuel producing companies should therefore commit to reducing their net scope 1, 2 and 3 emissions to zero by mid-century. Achieving those targets will require a combination of:

- **Absolute reductions** in the production of coal, oil and gas.
- Actions to monitor that the coal, gas or oil produced and sold is used in applications where CCS is applied. This will require **effective measurement** of the application of point-source capture and storage, including the monitoring of capture rates.
- The purchase of **high-quality carbon removal credits** equal to residual GHG emissions after CCS, including offsets for any fugitive emissions released in the production and transportation of the associated fossil fuels.

The precise appropriate date for reaching this target can be debated, as climate models suggest some scope for limited net emissions after 2050 while still meeting climate targets.[198] And it is largely accepted that appropriate developing country targets to reach net-zero emissions can entail a later date than that of developed countries. The ETC believes that all developed countries should reach net-zero emissions by 2050 at the latest, and all developing countries by 2060 at the latest. A broad commitment for all fossil fuel companies to reach net-zero emissions "by mid-century" would therefore be an appropriate step towards more detailed commitments.

In addition, however, there is a strong case for fossil fuel companies to make commitments to reduce coal, oil and gas production by mid-century, limiting their assumed reliance on carbon capture and removals to achieve net-zero emissions. This reflects the analysis in Chapter 4, which showed that:

- Point-source **CCUS applications will be limited** to specific sectors, and in particular will play almost no role in offsetting continued use of oil.
- The **relative economics of point-source CCUS** have become less favourable in many applications over the last 10–15 years, limiting its economically optimal role compared to other decarbonisation solutions.
- The volume of nature-based and engineered carbon removals (e.g., DACCS) is still trivial today, and by 2030 will likely be well below our projected requirements. As a result, there is **no credible case for assuming that removals can play a greater role than assumed in our previous work.**[199]
- **Fossil fuel production is highly methane-intensive**, as explained in Chapter 8, and emissions are still increasing despite the Global Methane Pledge launched at COP26.[200]

198 Based on $CO_2$ emissions from C1 and C2 climate scenarios (scenarios which have a 50% chance of limiting global temperature increase to 1.5°C with no or limited overshoot) assessed by the IPCC AR6 WGIII. Systemiq analysis of IIASA (2023), *AR6 scenario explorer;* Jenkins et al. (2022), *The Multi-Decadal Response to Net-Zero $CO_2$ Emissions and Implications for Emissions Policy.*

199 ETC (2022), *Mind the Gap.*

200 IEA (2023), *Global methane tracker 2023.*

Given these facts, the ETC believes that:

- COP28 should reiterate the COP26 commitment to **phase down the use of coal** and should in addition gain commitment from all countries to **phase down the use, and therefore the production, of oil and gas.**
- Irrespective of different scenarios for the level of fossil fuel demand in 2050, COP28 should therefore seek commitments from **all fossil fuel-producing companies to reach net-zero scope 1, 2 and 3 emissions by mid-century.**
- Fossil fuel producers which purport to be playing a leading role in combating climate change should commit to not only achieving net-zero scope 1, 2, and 3 emissions by mid-century, but to doing so in a way which entails **significant reductions in fossil fuel production by 2050.**
- Standard setters such as SBTi should **only endorse fossil fuel company targets which include commitments to significantly reduce coal, oil and gas supply in 2050**, as well as to achieve net-zero scope 1, 2 and 3 emissions by that date.

Long-term commitments focused on the mid-century destination are often criticised as ineffective since:

- Mid-century commitments can in many cases can be combined with minimal immediate action.
- The global temperature increase will be determined not by the annual flow of net emissions in 2050, but by the cumulative net emissions between now and then.[201]

But while such targets alone are clearly insufficient to prevent harmful impacts of climate change, they are a crucial first step in establishing a widely shared consensus on the direction of travel, and a pre-requisite for setting strong intermediate targets.

The experience of the last five years has shown that when countries set net-zero emissions targets by a specific date, these become powerful forcing devices for earlier policy implementation and action, and influence private sector investment and technology development.

Gaining country and fossil fuel company commitments to achieve net-zero scope 1, 2 and 3 emissions by mid-century will establish a framework within which to debate the required balance between absolute reductions in fossil fuel supply and carbon capture and removals.

And gaining agreement that fossil fuel demand and supply must fall significantly by 2050 will establish a strong sense of direction within which to debate the precise pace of reductions.

The mid-century commitments proposed in this chapter thus provide a crucial context within which Chapter 7 assesses the implications of feasible reduction pathways over the next three decades.

201 IPCC (2021), *Sixth assessment report – working group I: The physical science basis.*

# Chapter 7

# Implications of the pathway to 2030 and 2040: investment needs, supply constraints, and required commitments

Chapter 1–3 set out our scenarios for the reductions in fossil fuel demand which could be achieved by 2030, 2040 and 2050, and which must be achieved if the world is to limit global warming to well below 2°C.

These scenarios showed that it is feasible and necessary to achieve dramatic reductions in the use of all fossil fuels by 2050, with major reductions achieved by 2040. Reductions achieved by 2030 are inevitably more limited, but essential to put the world on a path compatible with agreed climate objectives.

The primary levers to achieve required reductions are the demand-side policies described in Chapter 5.3.1, and COP28 should seek to gain government commitments to enforce such policies.

But there is also a case for governments, companies and financial institutions to enact policies and make commitments which seek to ensure that fossil fuel supply develops in line with the required demand reduction (hereafter referred to as "supply-side policies" or "supply-side constraints", as explained in Box F).

This chapter therefore:

- Assesses the **investment needed** to provide supply equivalent to our fossil fuel demand projections.
- Sets out the case for **supply-side constraints** to be applied alongside the crucial priority of demand-side policies.
- Considers the **implications for fossil fuel companies, financial institutions, and governments**.

**BOX F: POLICIES TO ACHIEVE A PHASE DOWN OF FOSSIL FUELS**

Multiple policy instruments can be used to achieve the decline in fossil fuels use shown in our ACF and PBS scenarios. Many of these do not explicitly seek to reduce fossil fuel use, but rather to reduce the cost and increase the deployment rate of alternative energy sources – in particular zero-carbon electricity supply.

Policies which more directly seek to reduce fossil fuel use can operate either on demand-side or supply-side [Exhibit 7.1].

Both alternative energy-related policies and demand-side policies specifically focused on fossil fuel use were discussed in Chapter 5.3. This chapter discusses the role of supply-side constraints.

But it should be noted that the distinction between demand and supply policies is not absolute. Indeed, any policy which constrains supply is likely (if all other circumstances and policy settings are unchanged) to produce a price increase, which will in itself create incentives to reduce demand.

EXHIBIT 7.1

## Types of climate policies

| | Demand-side | Supply-side |
|---|---|---|
| **Restrictions on fossil fuels** | **Economic instruments:**<br>• Carbon or fuel use taxes.<br>• Border carbon price adjustment.<br>• Removal of fossil fuel consumption subsidies.<br>• Cap and trade for consumption rights.<br>• Emission reduction credits or offsets.<br><br>**Regulatory approaches:**<br>• Emissions standards for thermal power plants.<br>• Building codes.<br><br>**Government provision of goods and services:**<br>• Policies to restrict export credit agency or multilateral development finance for thermal power plants.<br><br>**Information programmes, voluntary actions and others:**<br>• Energy audits.<br>• Vehicle or appliance labelling. | **Economic instruments:**<br>• Resource production or export tax.<br>• Removal of production subsidies.<br>• Cap and trade for production rights.<br>• Payments for leaving fossil resources unextracted.<br><br>**Regulatory approaches:**<br>• Prohibiting the development of certain resources or use of certain technologies.<br>• Limiting production or exports (via quotas).<br>• Assessment of emissions of new fossil fuel supply projects.<br><br>**Government provision of goods and services:**<br>• Restricted leasing of state-owned land for fossil fuel developments.<br>• Decision to not develop specific resource or infrastructure.<br>• Funding to compensate resource owners for leaving resources unextracted.<br>• Policies to restrict export credit agency or multilateral development finance for fossil fuel supply.<br><br>**Information programmes, voluntary actions and others:**<br>• Divestment by institutions and individuals from fossil fuel companies. |
| **Support for low-carbon alternatives** | See Chapter 5.3.1 | |

**SOURCE:** Green et al. (2018), *Cutting with both arms of the scissors: the economic and political case for restrictive supply-side climate policies*; Stockholm Environment Institute (2015), *Supply-side climate policy: the road less taken.*

## 7.1 Investment required to balance supply and falling demand

Our ACF and PBS scenarios set out how rapidly demand for fossil fuels can and must fall if we are to meet climate objectives.

This section compares the resulting cumulative demand with fossil fuel resources and reserves, and the falling annual demand with the annual supply which might be provided from existing fields and mines and from financially sanctioned projects currently under development.[202] It also considers the level of investment needed to ensure that supply is neither inadequate to meet demand nor so excessive as to undermine demand reductions.

202 Fossil fuel resources are the total estimated quantities of underground resources based on geological assessment of potential reservoirs. Proven reserves are the subset of resources that have been proven to be both technically and economically recoverable from reservoirs. EIA (2014), *Oil and natural gas resource categories reflect varying degrees of certainty.*

### 7.1.1 Resources and reserves

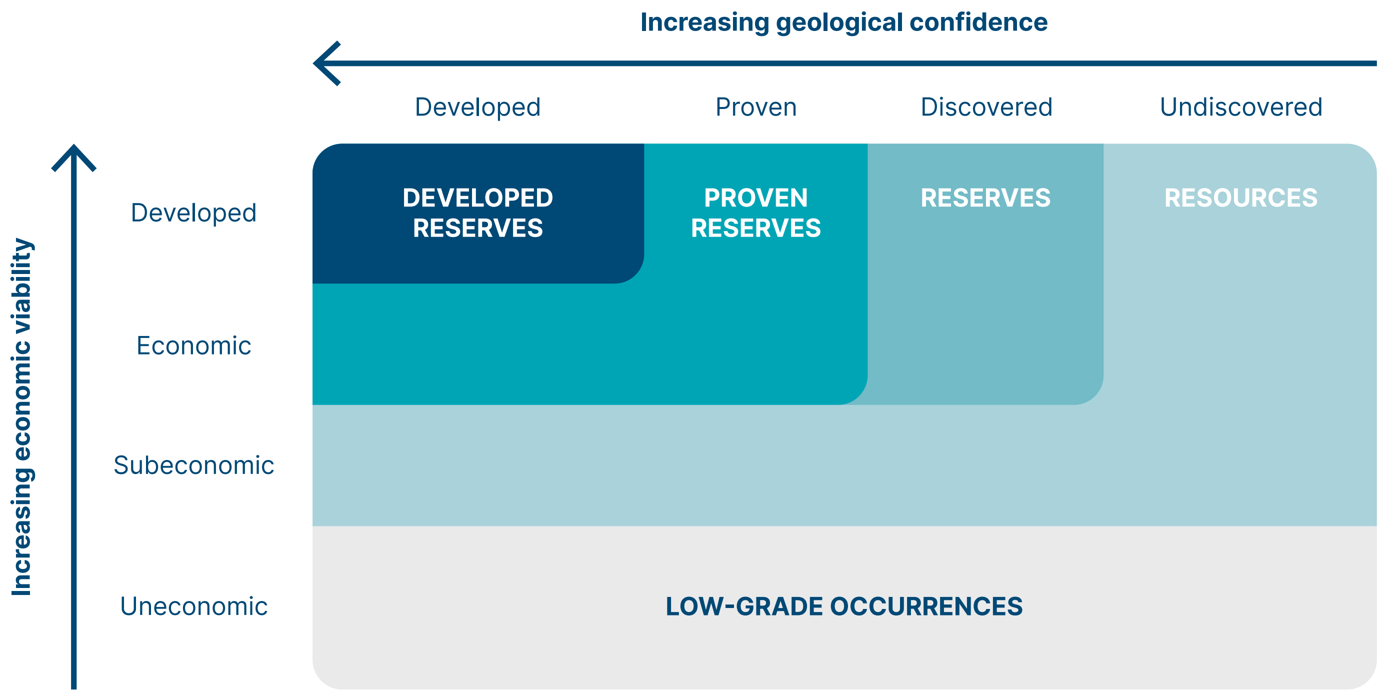
Exhibit 7.2 shows the definitions used in estimating fossil fuel "resources" and "reserves". Resources and reserves are classified based on the confidence in their geological presence and economic viability, and this classification only applies at specific points in time. Over time, as existing fields are depleted, production methods improve and costs and prices evolve, parts of what were previously defined as resources can become economically exploitable and proven reserves.[203]

Looking at either resources or reserves however, the key message is clear:

- The carbon content of all estimated fossil fuel resources – for all three fuels – massively exceeds any carbon budget compatible with limiting global warming to 1.5°C [Exhibit 7.3]. This implies that that 90–92% of oil resources, 87–89% of gas resources and 87–90% of coal resources must be left in the ground.
- Total proven and developed reserves of oil and gas also exceed the cumulative demand implied by our scenarios. Exhibit 7.4 suggests that 57–65%, 57–63% and 87–90% of proven reserves of oil, gas and coal respectively must remain unextracted.

EXHIBIT 7.2

## Definition of fossil fuel resources




**NOTE:** Proven reserves are quantities of hydrocarbon that are considered as commercially and technically recoverable from known reservoirs. "Economic" viability is met when project presents a positive undiscounted cumulative net cash flow over its lifetime. "Subeconomic" limit is any production below, or continued past, the economic limit of a project. "Uneconomic" means that undiscounted cumulative net project cash flow is negative over the project's lifetime. Low-grade occurrences refers to hydrocarbon deposits of low quality, that impacts both the confidence in subsurface resources and the economic viability of extraction.

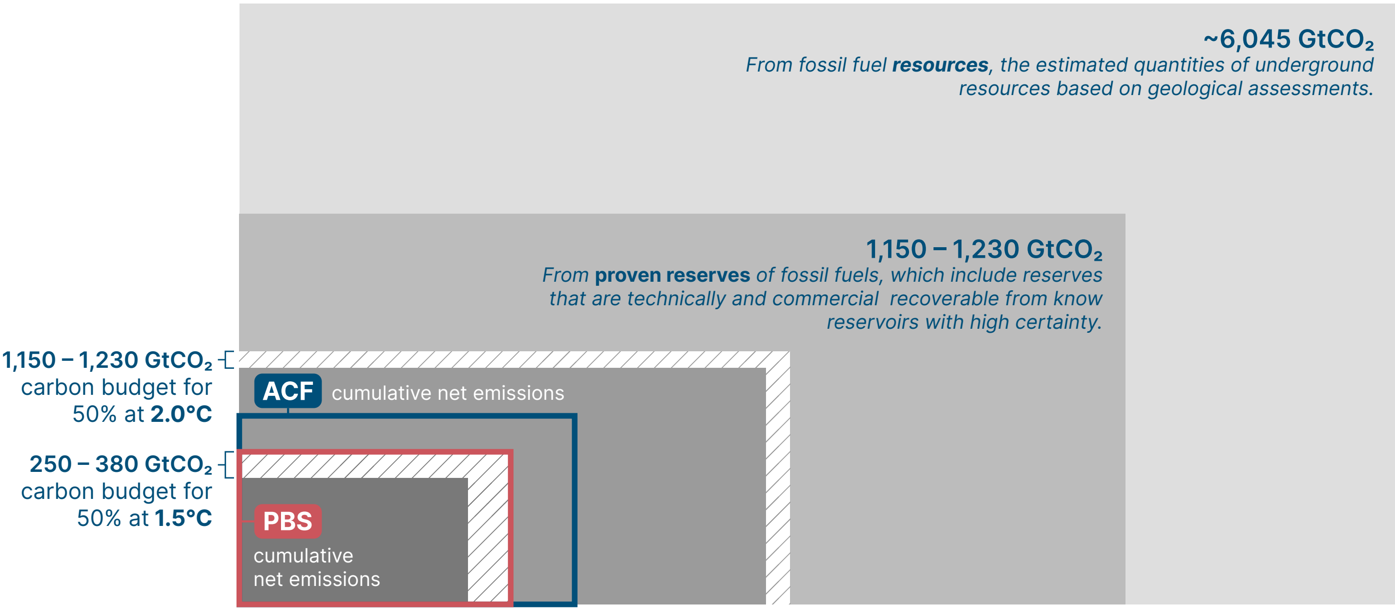
**SOURCE:** Trout et al. (2022), *Existing fossil fuel extraction would warm the world beyond 1.5°C*; Petroleum Resources Management System (2018); H. Rogner (1997), *An assessment of world hydrocarbon resources.*

203 While the criteria to establish such classification are clearly defined, whether or not certain resources or reserves meet these criteria rely on the best available information and assumptions from companies and countries. Petroleum Resources Management System (2018), *Version 1.03.*

EXHIBIT 7.3

# Carbon budgets, $CO_2$ emissions in ACF and PBS and potential emissions from fossil fuel resources

Cumulative $CO_2$ emissions from fossil fuels
$GtCO_2$




**NOTE:** Values are rounded. Cumulative net emissions for ACF (520 $GtCO_2$) and PBS (380 $GtCO_2$) include all emissions from EBIT and AFOLU sectors, minus captured emissions from fossil fuel combustion or process emissions and carbon removals (incl. nature-based, engineered and hybrid solutions). Emissions estimates from fossil fuels (reserves and resources) include $CO_2$ emissions during production and combustion, using emissions factors of 1.93 $tCO_2$/tonne of coal, 0.39 $tCO_2$/bbl of crude oil and 2.06 $tCO_2$/thousand cm of natural gas. Carbon budget ranges are estimates of the remaining carbon budget for limiting warming to 1.5°C and 2°C with a probability of 50%. The upper bound corresponds to the 2020 IPCC figure of 500 $GtCO_2$, to which 120 $GtCO_2$ have been subtracted to account for emissions from 2020-2022. The lower bound corresponds to revised estimates from Forster & al. (2022).

**SOURCE:** Systemiq analysis for the ETC; Energy Institute (2023), *Statistical Review of World Energy 2022;* WRI (2016), *Methodology for estimating and reporting the potential GHG emissions from fossil fuel reserves;* Welsby & al. (2021), *Unextractable resources in a 1.5°C world;* ETC (2022), *Mind the gap;* IPCC (2021), *Sixth Assessment Report;* Forster & al. (2022), *Indicators of global climate change 2022.*

EXHIBIT 7.4

## Cumulative oil and gas demand in ACF & PBS as a function of reserves

Cumulative oil and gas demand in ACF & PBS, and comparison with resources & reserves


**NOTE: ALL NUMBERS ARE ROUNDED.**"Resources under development & field evaluation" displays Estimated Ultimate Recovery (EUR) figures associated with assets that were in the two asset life cycle stages which precede production as of September 2022; assets under Field Evaluation are assets in which a company has already made considerable investments: Front-End Engineering and Design (FEED) has been confirmed. Assets under Development are oil & gas assets, which will soon enter production since all necessary permits are in place and a Final Investment Decision (FID) has been made. This includes the construction of wells and related infrastructure. GOGEL covers all companies that intend to add ≥ 20 Mmboe of resources to their production portfolio in the near future. The figures in this column depict economically recoverable hydrocarbons, which a company is extremely likely to add to its production portfolio in the "short term" (approx. 1-7 years depending on the type of asset).

**SOURCE:** Systemiq analysis for the ETC; GOGEL (2023), *Global Oil and Gas Exit List 2022*, Trout et al. (2022), *Existing fossil fuel extraction would warm the world beyond 1.5°C.*

## 7.1.2 Supply and demand over time

Many proven reserves are however not yet being exploited. So the crucial question is whether any further development of already proven reserves will be required to meet future demand, or whether that demand can be met from fields and mines already in operation. The answer is different for oil and gas versus coal.

### Oil and gas

For oil and gas, we have drawn on a detailed database[204] of existing fields and current developments, as well as the literature on production decline curves to estimate:

- How much supply can come from existing fields under a zero or minimal investment strategy.[205] For both oil and gas, supply would fall faster than any feasible reduction in demand across net-zero outlooks, with average annual decline rates of about 9% percent for oil and 8.5% for gas.
- How much supply would result from continued investments in already producing fields to increase resource recovery.[206]
- How much supply might result from new developments of proven reserves which have already received final investment decision (referred to as "sanctioned developments").

204 RystadEnergy's UCube solution.

205 Oil and gas producers systematically maintain investments in existing production to at least ensure operational efficiency, uptime and safety of production sites (e.g., well refurbishments). The "no investment case" would not occur in real world conditions.

206 Additional capital investments can be deployed to develop the infrastructure necessary for enhanced recovery of subsurface resources, as primary recovery of oil only allows for the extraction of ~30% of underground resources (~80% for natural gas), which is almost systematically insufficient to guarantee targeted returns from producers. Enhanced recovery methods can help reach extraction rates of ~70–80%. Hafner et al. (2022), *Economics of oil and gas production.*

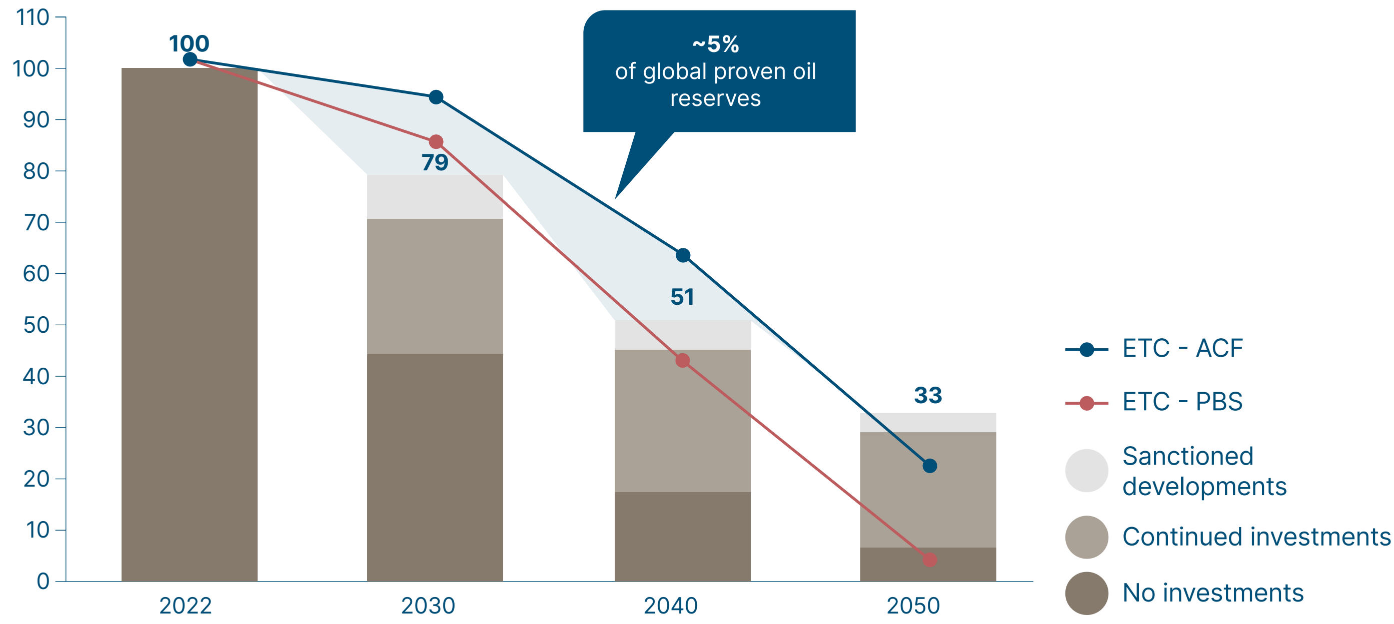
Exhibits 7.6 and 7.7 show the results for oil and gas respectively.

- **In the case of oil,** our demand scenario would slightly exceed supply from existing and sanctioned projects in 2030, implying the need for some limited new developments of proven reserves. But existing and already sanctioned development could meet demand in 2040 and significantly exceed it in 2050. This implies that investment in any assets which takes significant time to develop would not help to meet the short-term gap between demand and supply, and assets which will produce for a lengthy period of time could result in excess supply in the medium- to long-term.
- **In the case of gas**, the comparison implies a need for new developments in 2040 and 2050, as well as 2030, but with total demand and supply still falling rapidly.[207] For gas however, it is important to note that future supply would also be increased by successful action to reduce scope 1 & 2 emissions, since this will entail eliminating the loss of gas via flaring, venting or leaks (see Chapter 8.2). In addition, about ~20% of global natural gas supply is produced as "associated gas" in oil-dominated wells.[208] Exhibit 7.8 illustrates how future natural gas supply could evolve given these factors. After allowing for these factors, it still seems likely that supply from already operating or sanctioned fields will fall short of demand in 2040 and 2050, as well as in 2030. This might imply that some very limited development of long lead time conventional fields might be acceptable. But if the demand and supply gap in 2040 and 2050 does materialise, this could also be closed by sanctioning short lead time, short payback projects closer to that specific time.

EXHIBIT 7.5

## Comparison of projected oil supply and demand to 2050

Oil supply vs. demand outlook
Mb/d




**NOTE:** All decline curves are assumed exponential, reserves under development are taken from Rystad's Ucube database, assumes peak development by 2030 with linear ramp up from 2022, decline curve applied starting in 2031.

**SOURCE:** Systemiq analysis for the ETC; IEA (2020), *The Oil and Gas Industry in Energy Transitions;* bp (2022), *Energy Outlook 2022;* Kleinberg & al. (2016), *Tight Oil Development Economics: Benchmarks, Breakeven Points and Inelasticities;* IHS (n.a.), *Decline Analysis Theory;* Rystad Energy (2022), *Ucube database;* OCI (2023), *Oil and Gas Emissions Database;* EIA (2013), *Shale oil and shale gas resources are globally abundant.*

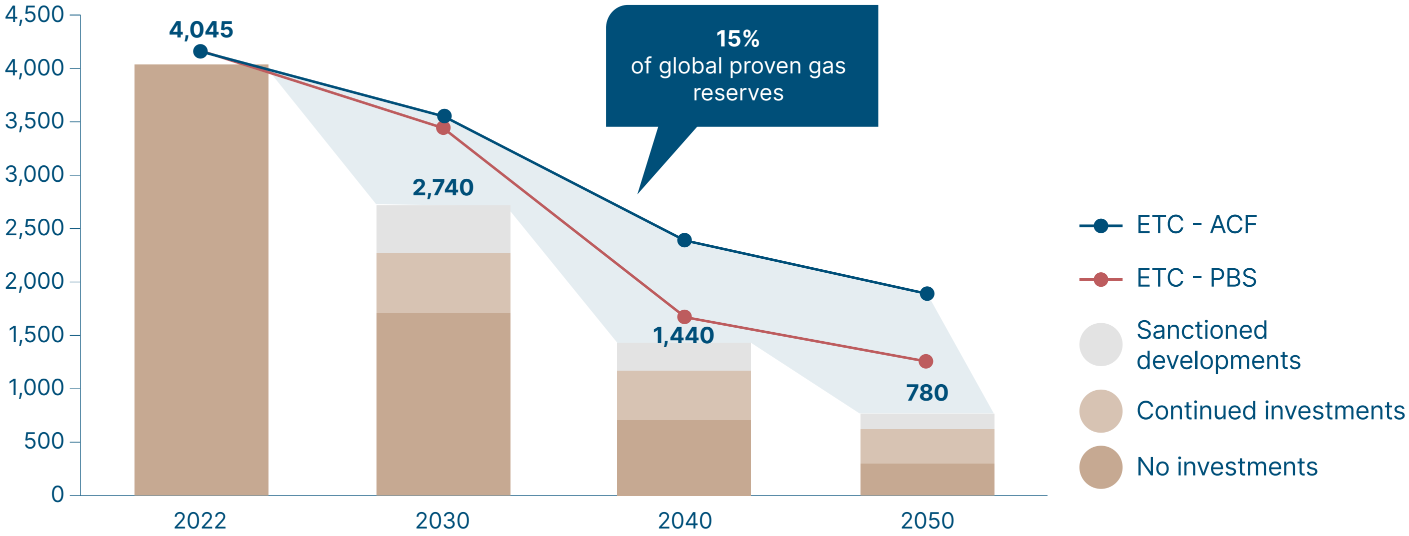
207 In the IEA's NZE scenario, projected oil and natural gas demand can be met without approving any new development of new long lead time projects. This is made possible through considerable behaviour change from energy consumers, which enables to curb oil and gas demand in the short-term, and ideally demand would fall fast enough to avoid any investment in new developments. Given our ACF and PBS scenario assume limited behaviour change in the short-term, demand projections on our scenarios require some limited new oil and gas developments. IEA (2022), *World Energy Outlook 2022.*

208 Systemiq analysis for the ETC; OCI+ (2023), *Oil and gas emissions database* and IEA (2020), *The oil and gas industry in energy transitions.*

EXHIBIT 7.6

## Comparison of projected natural gas supply and demand to 2050

Natural gas supply vs. demand outlook
bcm



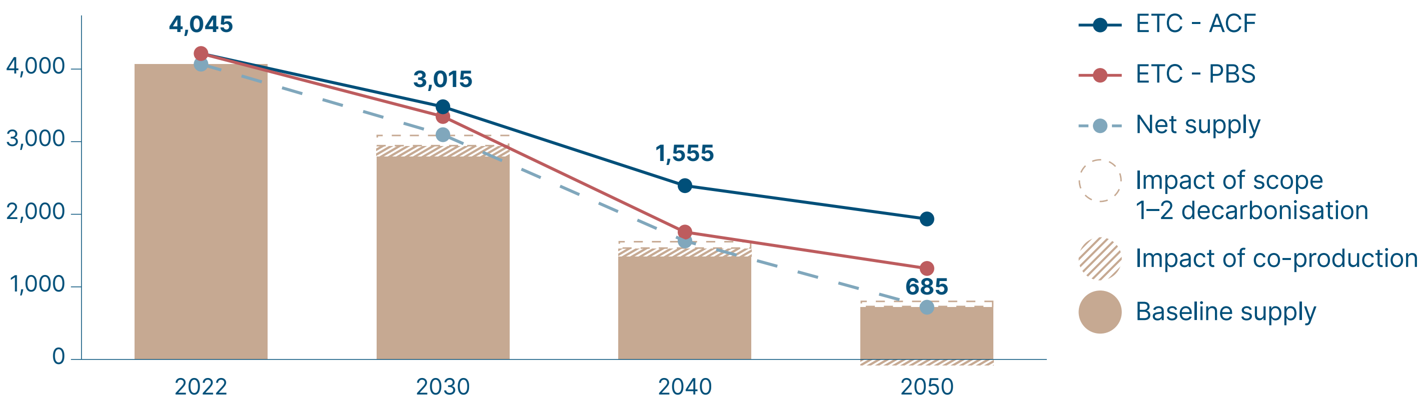

**NOTE:** All decline curves are assumed exponential, reserves under development are taken from Rystad's Ucube database, assumes peak development by 2030 with linear ramp up from 2022, decline curve applied starting in 2031, starting point has been adjusted to compensate ~300 bcm difference with Rystad data.

**SOURCE:** Systemiq analysis for the ETC ; IEA (2020), *The Oil and Gas Industry in Energy Transitions*, bp (2022), *Energy Outlook 2022*, Kleinberg & al. (2016), *Tight Oil Development Economics: Benchmarks, Breakeven Points and Inelasticities*, IHS (n.a.), *Decline Analysis Theory*, Rystad Energy (2022), *Ucube database*, OCI (2023), *Oil and Gas Emissions Database*.

EXHIBIT 7.7

## Impact of methane emissions abatement and evolution of oil supply on natural gas supply

Natural gas supply vs. demand outlook
bcm




**NOTE:** All numbers are rounded. Baseline supply is all supply from continued investment in existing production and capacity under development. Scope 1 & 2 decarbonisation is for coal, oil and gas, based on best view of underlying IEA NZE assumptions, considers NZE decline of demand over time, all abated methane emissions are assumed as being marketed, only coal mine methane emissions that are recovered (not destroyed) are assumed marketed. Co-production is determined based on the difference between baseline oil supply and demand in ACF scenario, assumes any supply shortage is compensated by new developments with average historical GOR (16 bcm/Mbpd) and any excess capacity is closed down, assuming 60% of associated gas is marketed (historical). Co-production in 2050 is negative as projected oil supply from all existing production will be in excess of projected demand, and stranded assets are assumed to close, resulting in a decrease in associated gas production.

**SOURCE:** Systemiq analysis for the ETC; IEA (2020), *The Oil and Gas Industry in Energy Transitions*; Capterio (2023), *Why COP28 is right to prioritise global methane and flaring reduction*; OCI (2023), *Oil and Gas Emissions Database*; IEA (2023), *Methane tracker* 2023; IEA (2023), *Emissions from oil and gas operations in net-zero transitions.*

However, it is important to note that this analysis is based on a rigorous assessment of whether new development projects have already received final investment decision (FID), and a somewhat different picture emerges from the analysis of the stated strategies of the 19 major fossil fuel-producing countries, which account for 80% of global supply:[209]

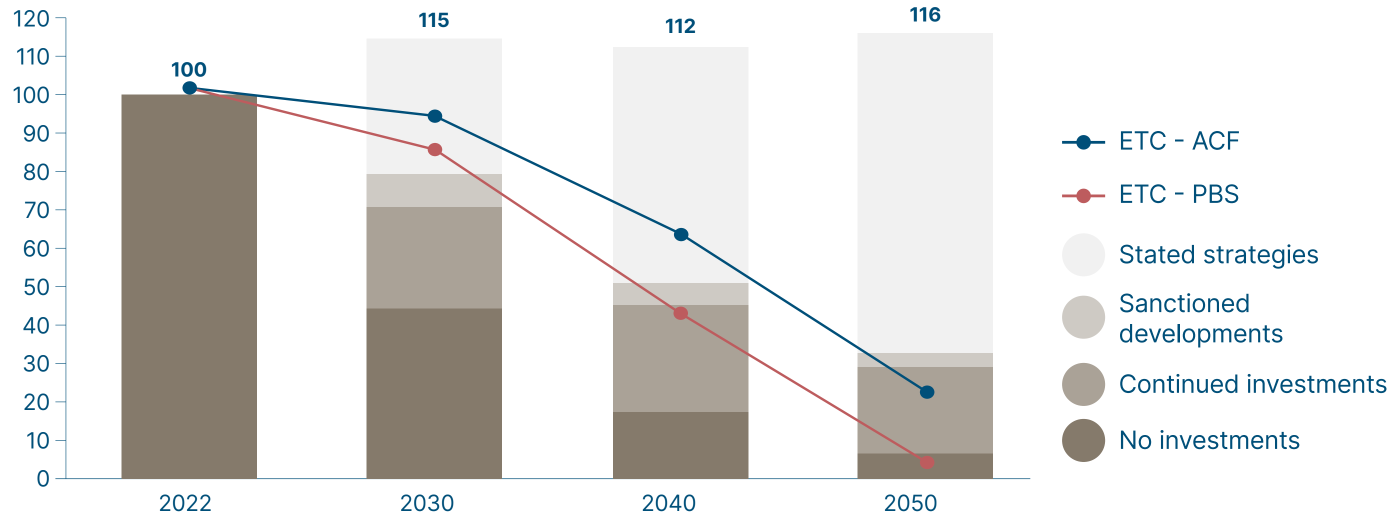
- For oil, this analysis suggests that supply could be as large as 115 mb/d in 2030, and up to 2050, resulting in supply well in excess of the projected demand of 84 – 93 Mb/d in 2030 and 4-22 Mb/d in 2050 in our ACF and PBS, as per Exhibit 7.8.
- For gas, stated strategies imply an additional 900 bcm of additional gas supply in 2030, reaching a total of 4,900 bcm, again well in excess of the 3,450 – 3,550 bcm of projected demand in ACF and PBS. By 2050, his would result in an excess supply of 3,600 – 4,250 bcm compared to our projections, as per Exhibit 7.9.

Thus, while some investment in new oil and gas developments is required, it is also the case that oil and gas supply implied by companies and governments' plans would result in a significant amount of excess supply relative to demand. Accounting for continued investments in oil and gas production that has already received FID, supply needed to bridge the supply and demand gap would represent just 5% of total proven oil reserves and 10-15% of proven gas reserves.[210] Aggregate country strategies imply a far larger increase in oil and gas reserve exploitation, and significant oversupply up to 2050.

**EXHIBIT 7.8**

## Increase in oil supply to 2050 implied by stated expansion plans

Oil supply vs. demand outlook
Mb/d




**NOTE:** All decline curves are assumed exponential, reserves under development are taken from Rystad's Ucube database, assumes peak development by 2030 with linear ramp up from 2022, decline curve applied starting in 2031. Supply from stated strategies comes from the compilation of government plans and projections for future fossil fuel production, featuring the most recent national outlooks from 19 of the 20 major fossil fuel-producer-countries (eq. to 80% of global production) as of August 2023. See UNEP (2023), *Production gap report*.

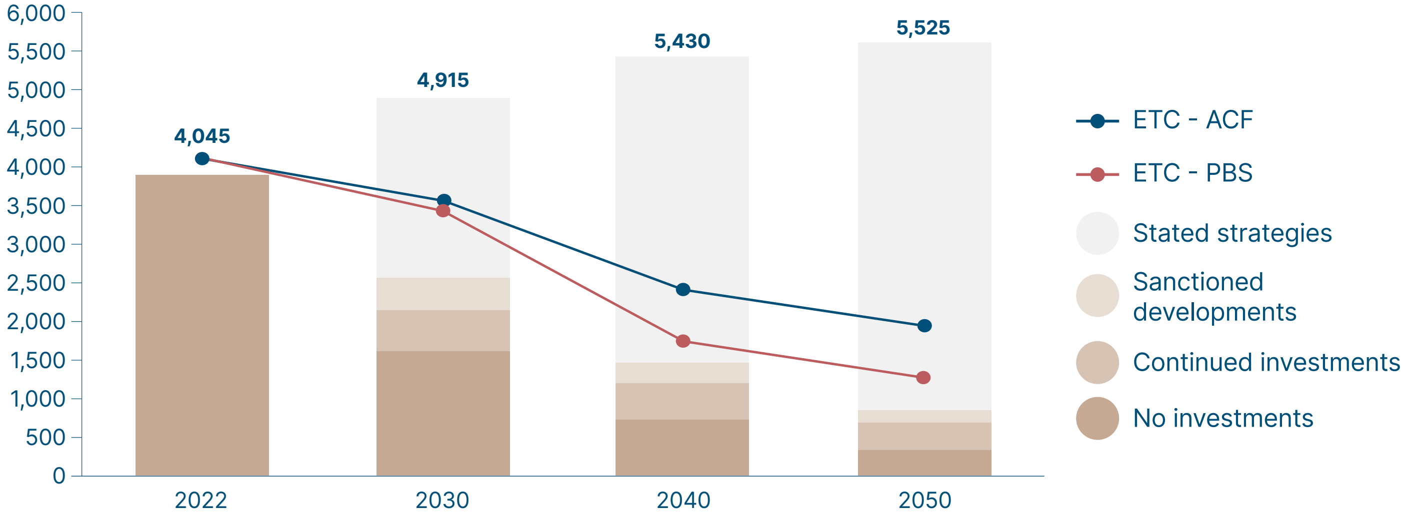
**SOURCE:** UNEP (2023), *Production Gap Report;* IEA (2020), *The Oil and Gas Industry in Energy Transitions;* BP (2022), *Energy Outlook 2022;* Kleinberg & al. (2016), *Tight Oil Development Economics: Benchmarks, Breakeven Points and Inelasticities;* IHS (n.a.), *Decline Analysis Theory;* Rystad Energy (2022), *Ucube database;* OCI (2023), *Oil and Gas Emissions Database;* EIA (2013), *Shale oil and shale gas resources are globally abundant.*

209 UNEP (2023), *Production gap report 2023.*
210 Cumulative difference between demand in ACF and PBS and projected annual supply from current production and production that has received FID between 2022 and 2050 as a function of total proven oil and gas reserves. Systemiq modelling for ETC (2023) based on RystadEnergy.

EXHIBIT 7.9

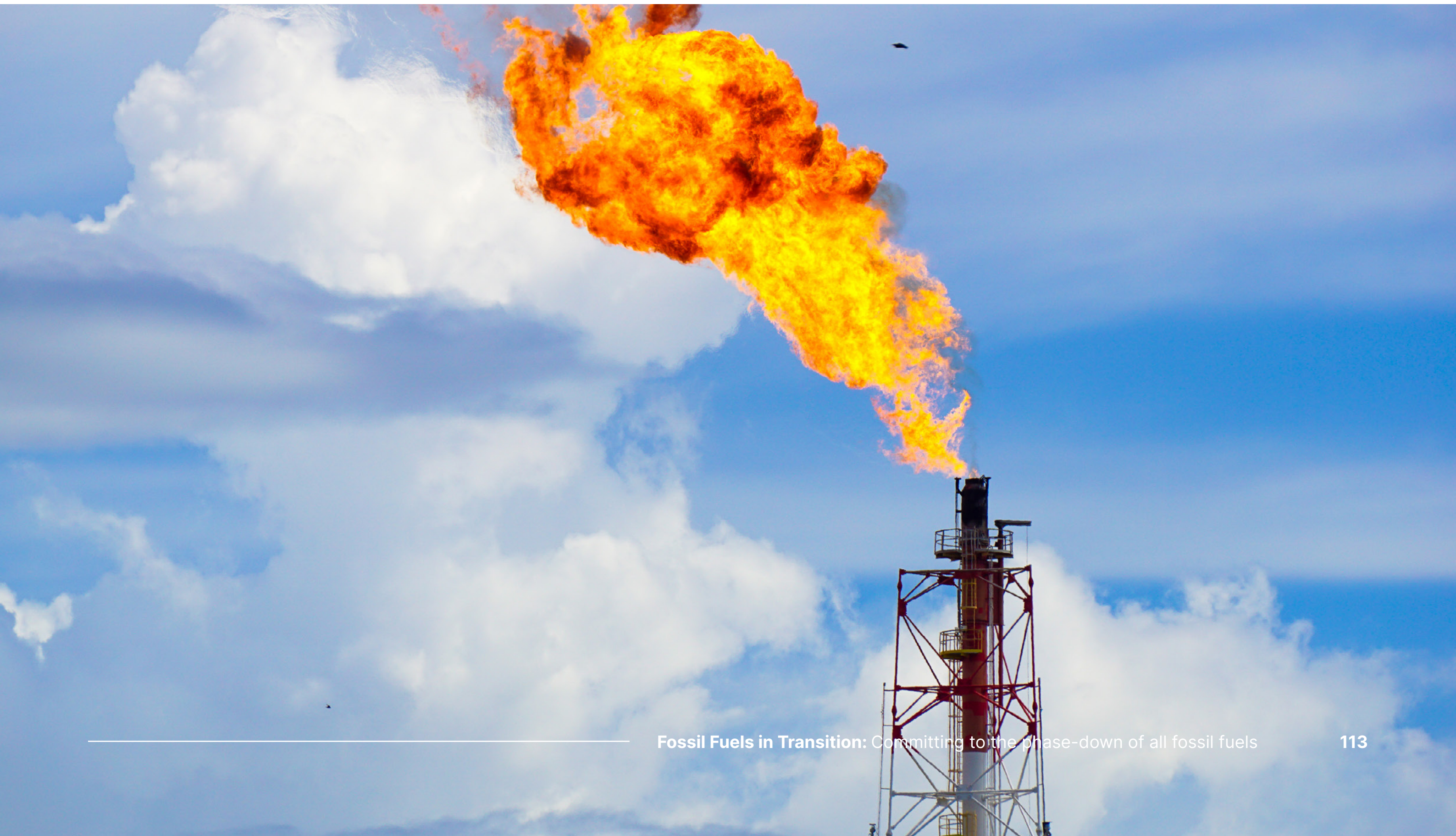
## Increase in natural gas supply to 2050 implied by stated expansion plans

Natural gas supply vs. demand outlook
bcm




**NOTE:** All decline curves are assumed exponential, reserves under development are taken from Rystad's Ucube database, assumes peak development by 2030 with linear ramp up from 2022, decline curve applied starting in 2031. Supply from stated strategies comes from the compilation of government plans and projections for future fossil fuel production, featuring the most recent national outlooks from 19 of the 20 major fossil fuel-producer-countries (eq. to 80% of global production) as of August 2023. See UNEP (2023), *Production gap report.*

**SOURCE:** UNEP (2023), *Production Gap Report;* IEA (2020), *The Oil and Gas Industry in Energy Transitions;* BP (2022), *Energy Outlook 2022;* Kleinberg & al. (2016), *Tight Oil Development Economics: Benchmarks, Breakeven Points and Inelasticities;* IHS (n.a.), *Decline Analysis Theory;* Rystad Energy (2022), *Ucube database;* OCI (2023), *Oil and Gas Emissions Database;* EIA (2013), *Shale oil and shale gas resources are globally abundant.*



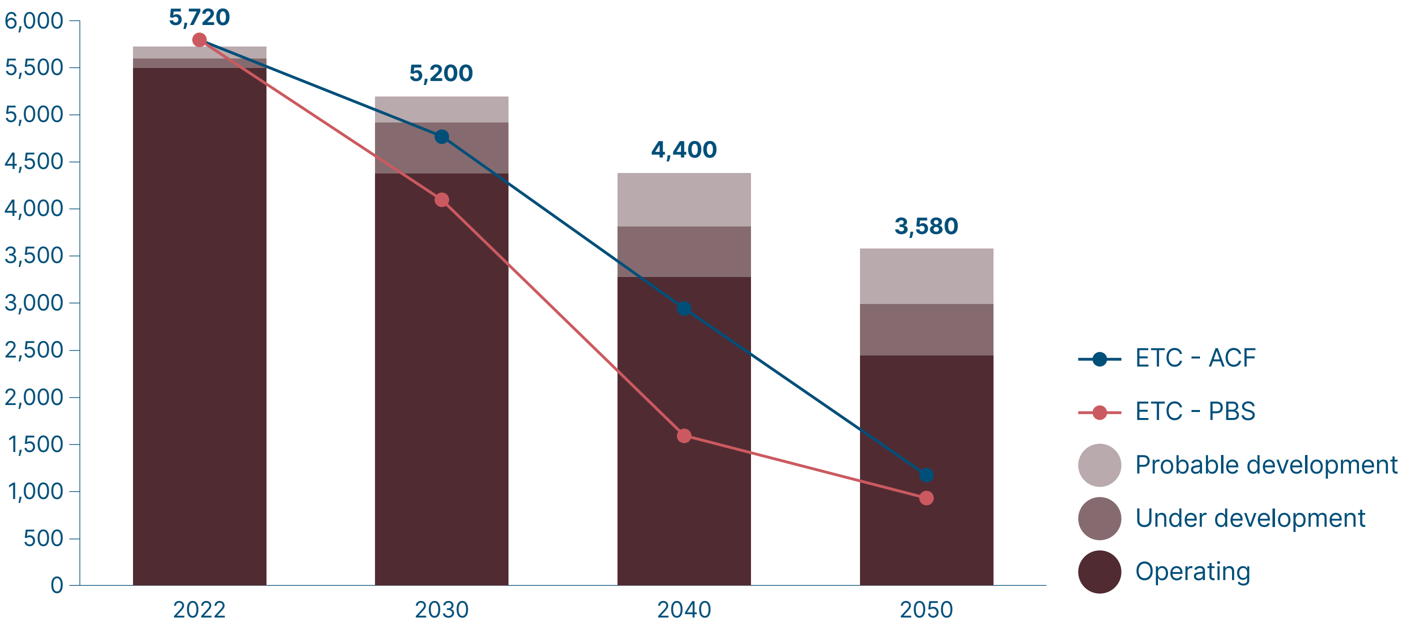
### Coal

For coal, the picture is far clearer [Exhibit 7.10]. Under both our scenarios, and almost all other organisations' scenarios, potential coal supply from mines already operating or under development exceeds demand, and greatly so by 2040. There is therefore no case for developing new coal mining capacity, nor for new projects to increase the capacity of existing mines.

EXHIBIT 7.10

## Comparison of projected coal supply and demand to 2050

Projected coal demand and supply
Mtce




**NOTE:** Values are rounded. 2022 demand figures have been adjusted to most recent IEA estimate, decline in operating capacity is determined by applying a standard 35-year lifetime to coal mines, assumed linear year-on-year decrease of production by 1/35, expansion refers to all capacity that is in pre-permit, permitted or construction stages, when production start date is unknown, it is computed using average development times for each lifecycle stage, taking 2022 as reference. Capacity under development refers to both new mines and extension of existing mines.

**SOURCE:** Systemiq analysis for the ETC; Global Energy Monitor (2022), *Coal Mine Tracker*; IEA (2022), *Coal 2022*, expert interview.

### 7.1.3 Required investment levels

Given this analysis, it is clear that investment in fossil fuel production cannot immediately stop since:

- Continued investments in existing production are required to limit the natural decline in output and increase recovery of resources.
- Incremental investments are necessary to bring fields currently already under development into production.
- Some investment in new projects is probably required, particularly in gas, to deliver the supply required to meet declining demand in our ACF and PBS scenarios.

Reflecting this, the IEA's 2023 updated *Net-Zero Roadmap* notes that continued investment is required in existing oil and gas assets and already approved projects.[211]

But total investment in fossil fuel production, transport and processing must be on a strongly declining trend, and far below levels currently being planned by both countries and companies.

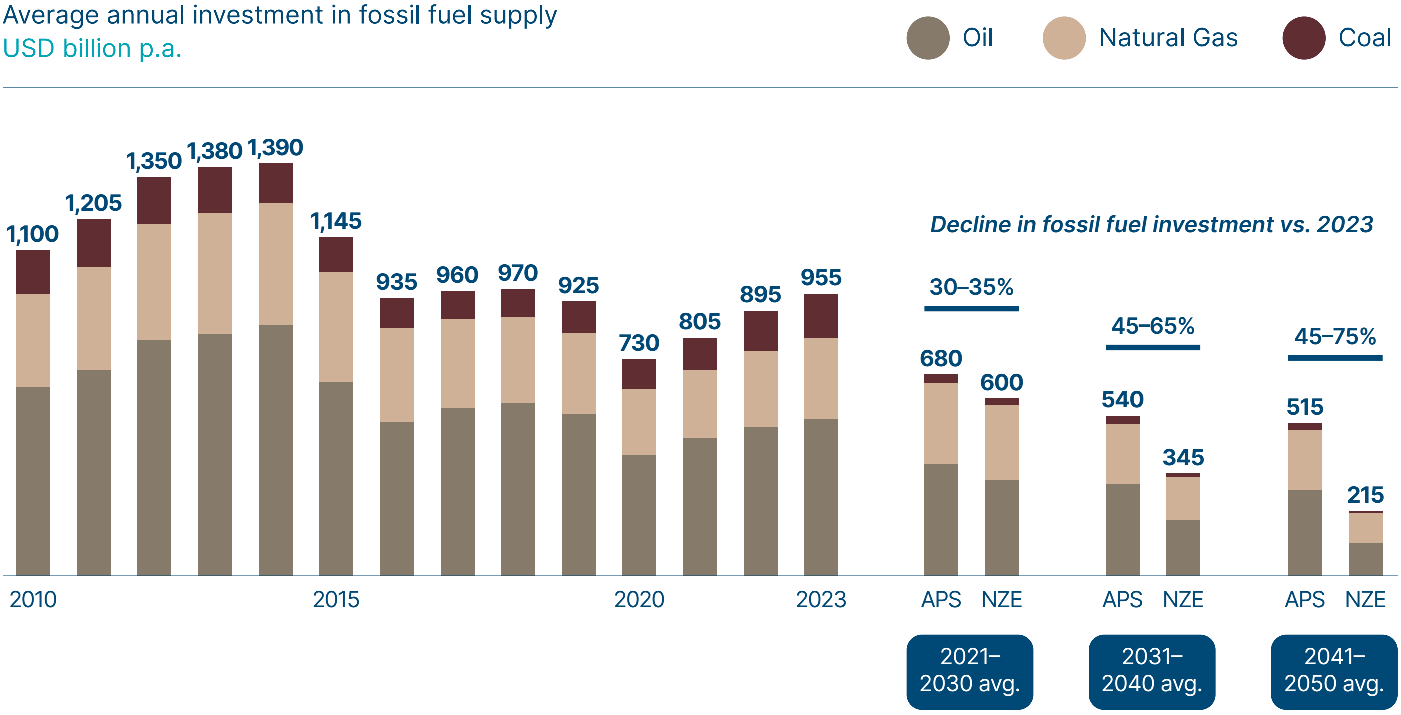
211 The IEA, in the 2021 edition of its Net-Zero scenario suggest that no new investment in new fossil production was required. In the 2023 edition this was changed to no new long-lead time upstream oil and gas projects. The recommendation on no new investment in coal was unchanged.

Figures from the IEA's World Energy Investment report suggest that in its NZE scenario, total fossil fuel investment would need to fall from around $1,100 billion per annum during 2010–2020,[212] to $600 billion per annum in the 2020s, $350 billion per annum in the 2030s and $200 billion per annum in the 2040s [Exhibit 7.11]. Investment in fossil fuel supply in the ACF and PBS would be of similar order of magnitudes given similar demand trajectories.

EXHIBIT 7.11

## Investments required in fossil fuel supply in IEA scenarios

Average annual investment in fossil fuel supply
USD billion p.a.




**NOTE:** All values are rounded. Investments projections for APS have been calculated by triangulating investment in fossil fuel supply and fossil fuel supply in NZE, applying that ratio to APS fossil fuel supply figures. APS = Announced Pledges Scenario, NZE = Net-Zero Emissions scenario.

**SOURCE:** Systemiq analysis for the ETC; BNEF (2022), *Investment needs of a 1.5°C world*; IEA (2022), *World Energy Outlook 2022;* IEA (2023), *World energy investment 2023.*

## 7.2 The in-principle case for supply-side constraints

As discussed in Chapter 5.3, it is essential that governments, companies, and financial institutions put in place policies and strategies which will ensure that fossil fuel demand falls in line with our scenarios, reducing at least as fast as our ACF scenario and ideally as fast as our PBS.

Indeed, some organisations, including fossil fuel companies, argue that such demand-side policies should be the only ones deployed, with no useful role for supply constraints. Two arguments are put forward for this point of view:

- First, that if effective demand-side policies and strategies are put in place, supply-side constraints are unnecessary and therefore redundant, since:
  - At the macroeconomic level, investment and resulting supply will develop broadly in line with the expectations of future demand generated by the policies enacted.
  - And if some individual companies and countries do invest in excessive supply, they will face the consequences of owning stranded assets, but with limited impact on the overall pace of the energy transition.[213]

212 In USD real 2022. IEA (2023), *World Energy Investments 2023.*

213 Issues relating to "stranded assets" and their potential implications on the pace of the energy transition will be addressed in the ETC's forthcoming supplementary discussion paper in 2024.

- Second, that if appropriate demand-side policies are not put in place, supply-side constraints can only limit demand by inducing high prices which could have disruptive socio-economic and harmful distributional effects, potentially producing a political backlash which might undermine the pace of the energy transition.

But several counter arguments establish **a strong case in principle** for imposing some supply-side policies, alongside and in support of those which seek directly to reduce demand. The arguments for and against depend on complex issues relating to the shape of cost curves for the different fossil fuels, and the elasticity of demand and supply in both the short and long-term. And even if in principle supply-side constraints could play a useful role, multiple implementation complexities may limit their effectiveness.[214]

But in essence, the key arguments for supply-side policies are that:

- In some circumstances, investment in excessive supply can, via lower induced prices, stimulate additional demand.
- Supply-side constraints which moderately, and progressively, increase expected future fossil fuel prices act similarly to a carbon price and can therefore usefully contribute to demand reduction.

### 7.2.1 Supply effects on demand

Additional supply could stimulate demand and thus make it more difficult to achieve required fossil fuel use reductions via both a "marginal cost" and a "political economy" effect.

**Marginal cost effect:** Once new supply has been developed, it will be economic to keep producing in the long run at any price greater than the marginal cost of production, even if a higher price was assumed when the investment was made. This lower-priced supply will, in turn, stimulate higher future demand than would otherwise arise. If, therefore, some fossil fuel companies and investors believe that the trajectory of fossil fuel demand will be higher than in the required reduction scenarios, these expectations can themselves undermine the ability to achieve those demand reductions.[215]

The strength of this effect will depend on multiple factors. These include in particular:

**The speed with which supply can adjust to lower demand.** This is likely to vary between different fuel sources and between the short and long-term.

- For oil and gas, the literature suggests that supply is largely inelastic in the short-term.[216,217] But in a context of where supply is developed in excess of demand, it is likely that this excess can be shaved off given the speed with which shale/tight oil and gas supply can be reduced, the ability of OPEC and OPEC+ to control supply to prevent price falls, and the impact of commercial or public stockpiles.[218, 219, 220]
- But over the long-term, beyond the natural rate of decline of oil and gas production, supply is largely inelastic, given the long timelines and significant specialised investments required to develop new supply.[221, 222] The very steep supply cost curves for both oil and gas [Exhibits 7.12 and 7.13] imply that for many suppliers, marginal production costs ("extraction" or "lifting" costs) are far below average market prices.[223]
- By contrast, coal supply is likely to be fairly elastic in both the short and long-term, given a much flatter supply cost curve, reflecting higher fixed marginal production costs [Exhibit 7.14].[224]

214 In particular, there currently exists no governing body that could regulate global fossil fuel production, and attribute production quotas to specific producers.

215 Assuming no counter-cyclical carbon pricing regime. Labandeira et al. (2016), *A meta-analysis on the price elasticity of energy demand.*

216 The reported short-term elasticity of oil supply is ~0.1. Source: Caldera & al. (2016), *Oil price elasticities and oil price fluctuations.*

217 Note: short-term denotes a span of 0–2 years, while long-term refers to any duration exceeding 2 years.

218 Shale and tight resources account for 15% and 26% of global oil and gas supply respectively, and production from such resources can decline by approximately 75% within a year without continued drilling. Systemiq analysis for the ETC; Rystad (2023), *Ucube data explorer.*

219 OPEC and OPEC+ countries account for 30% and 17% of global oil supply respectively (47% combined). OPEC possesses spare oil production capacity, defined as production that can enter production within 30 days and be sustained for 90 days, of 3 Mb/d on average since 2015. Systemiq analysis for the ETC; EIA (2023), *What is OPEC+ and how is it different from OPEC?* and EIA (2023), *OPEC spare production capacity and WTI crude oil prices.*

220 IEA members alone hold energy oil stockpiles of 1.5 billion barrels, or around 4 Mb/d assuming constant stock release over a year. IEA (2022), *IEA member countries to make 60 million barrels of oil available following Russia's invasion of Ukraine.*

221 Global oil and gas decline rates vary depending on the share of post-peak fields in production, and the assumption around the level of investment for enhanced oil recovery. Under standard industry conditions, oil and gas decline rates range from 4–8% per annum. Systemiq analysis for the ETC; RystadEnergy (2023), *Oil and gas supply cost curves*; bp (2023), *Energy outlook 2023*; IEA (2020), *The oil and gas industry in energy transitions.*

222 Lead time between exploration and production for oil and gas resources (excluding tight/shale resources) can range from 7–21 years, with most projects coming only within 13 years). Systemiq analysis for the ETC; Wachtmeister et Hook (2020), *Investment and production dynamics of conventional oil and unconventional tight oil: Implications for oil markets and climate strategies*; MIT CEEPR (2016), *Tight Oil development Economics: Benchmarks, Breakeven Points, and Inelasticities*; E. Darko (2014), *Short guide summarizing the oil and gas industry lifecycle for a non-technical audience*; IEA (2015), *World Energy Outlook.*

223 D. Caldara et al. (2018), *Oil price elasticities and oil price fluctuations.*

224 IEA (2020), *Coal 2020 report.*

**The elasticity of demand in the face of falling prices.** Here too, the short and long-term responses of demand must be distinguished:

- In the short-term, demand for key applications (e.g., gasoline use for driving) has historically tended to display relatively low price elasticity, with drivers facing a gasoline price spike often initially maintaining their driving habits.[225, 226]
- But long-term demand elasticity has tended to be higher with for instance differences in the average size of ICE passenger cars bought in different markets correlated with gasoline prices at the pump.[227] Moreover, the long-term elasticity of demand is likely to increase as the energy transition makes available to consumers non-fossil-based alternatives to meet any given consumer need. Drivers who expect to see sustained higher gasoline prices are likely to purchase electric vehicles earlier than they would if prices were expected to remain low.

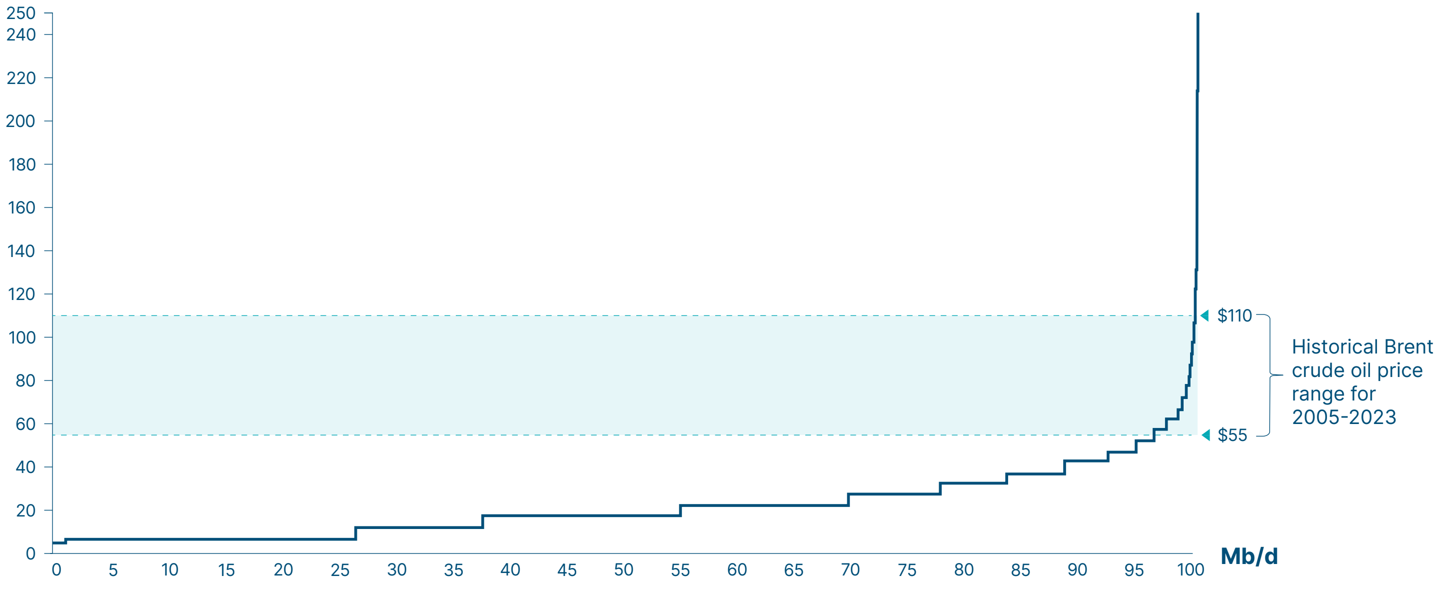
**Political economy effect:** Once supply capacity is in place jobs, profits and, in some cases, fiscal and trade revenues will depend on continued operation. Faced with falling prices, multiple stakeholders in governments, companies and financial institutions will therefore argue against required demand-side policies, undermining progress in demand reduction.[228]

Given both the arguments in principle and empirical elasticities, we believe that supply-side constraints could play a useful role in reinforcing demand-side policies.

EXHIBIT 7.12

## Global oil supply cost curve for 2022

Supply cost curve for oil
$/bbl




**NOTE:** Supply cost curves are technical breakeven costs and not lifting costs (or marginal cost of production), exclude financing costs and implicit costs from balancing government and trade budgets, include CAPEX depreciation for the current year.

**SOURCE:** Systemiq analysis for the ETC; Rystad Energy (2022), *Rystad Energy Ucube database.*

225 Note: demand and supply are considered elastic or inelastic when response to price is more or less than unity (1 or -1). Given energy is considered as a necessity, demand will tend to be inelastic, and maximum reported average price elasticities for different types of energy are between -0.2 in the short-term and -0.6 in the long-term. X. Labandeira et al. (2017), *A meta-analysis on the price elasticity of energy demand.*

226 Ibid.

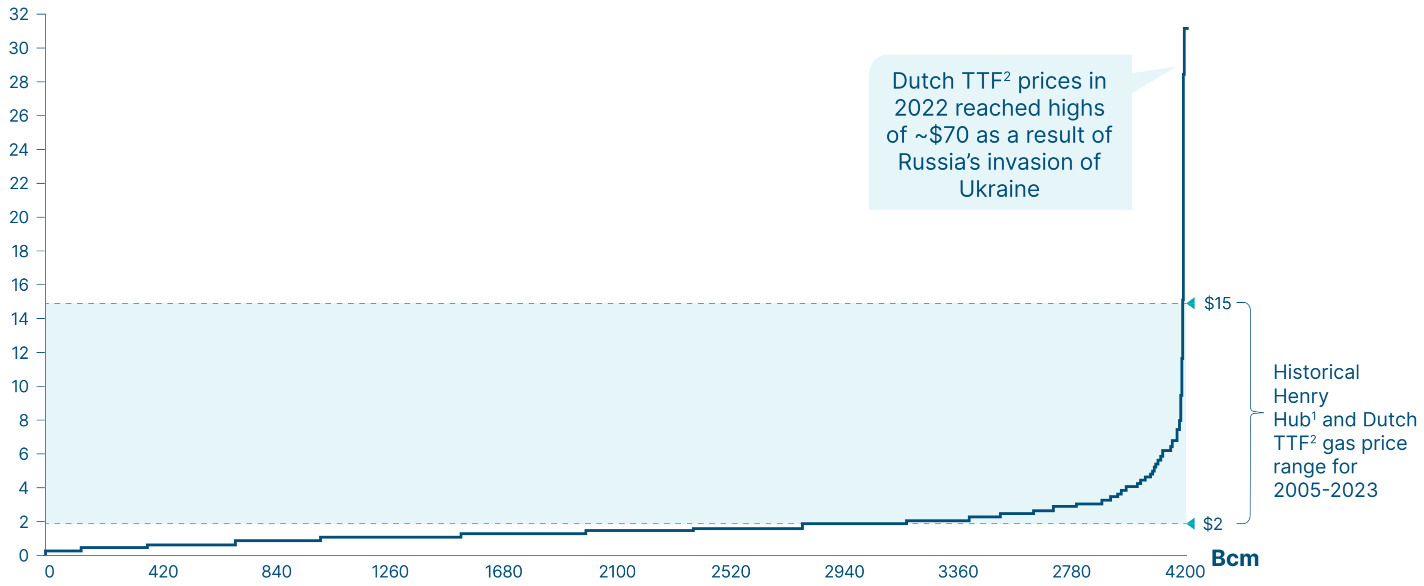
227 Ibid.

228 IMF (2021), *Managing the political economy of climate change policies.*

EXHIBIT 7.13

# Global natural gas supply cost curve for 2022

Supply cost curve for natural gas
$/MMBtu



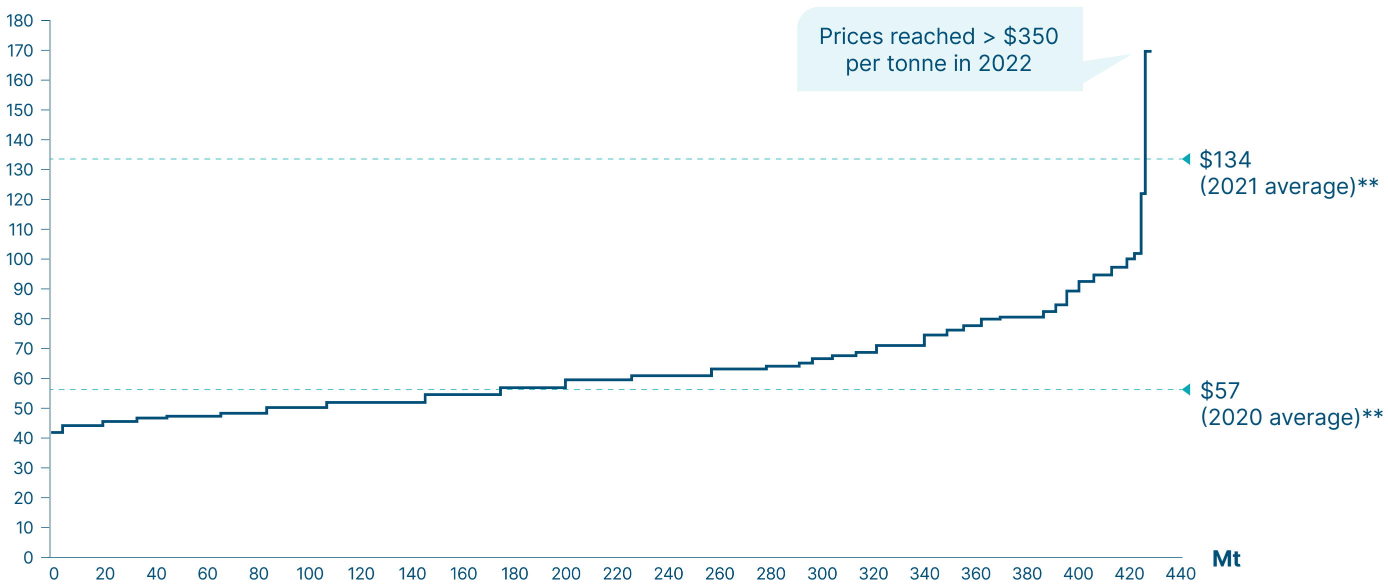

**NOTE:** Supply cost curves are technical breakeven costs and not lifting costs (or marginal cost of production), exclude financing costs and implicit costs from balancing government and trade budgets, include CAPEX depreciation for the current year. MMBtu=1 million British Thermal Units (a measure of heat).
[1] Henry Hub is the main pricing point for natural gas in North America, [2] Dutch TTF (title transfer facility) serves as the price benchmark for natural gas in European Markets.

**SOURCE:** Systemiq analysis for the ETC; Rystad Energy (2022), *Rystad Energy Ucube database*.

EXHIBIT 7.14

# Global coal supply cost curve for 2022

High calorific* thermal coal FOB[1] supply cost curve
$/tonne




**NOTE:** Coal mining is an inherently local market, with only ~20% of global coal supply being traded. Cost curve shown above is only for the 430 Mt of high calorific thermal coal that are being traded. Other categories of exports include low calorific thermal coal and hard coking coal.
* All thermal coal with calorific value higher than 5,700 kcal/kg; ** Newcastle (6,000 kcal/kg, FOB) price marker.
[1] Free On Board: coal mine sale price, excludes insurance or transportation charges for which the buyer would be liable.

**SOURCE:** Systemiq analysis for the ETC; IEA (2022), *Coal 2022 report*.

## 7.2.2 Supply constraints and price effects

Supply-side constraints can only affect demand via their impact on future prices or current expectations of future prices. Indeed, that fact is one of the arguments deployed against supply-side constraints on the grounds that sudden higher prices could undermine the pace of the energy transition.[229]

But supply-side constraints that generate moderately higher future fossil fuel prices could have a beneficial effect, which is closely analogous to the impact of carefully designed carbon pricing regimes:

- Carbon prices, whether generated via carbon taxes or via auctioning of emission rights within an emissions trading scheme, are widely and rightly recognised – including by a growing number of governments around the world, and many fossil fuel companies – as potentially very efficient policy levers, increasing the price for using fossil fuels in all sectors of the economy to which the scheme applies.

- Supply-side constraints have, in principle, the same effect. Indeed, if it were possible to devise a global auction for fossil fuel production licenses, with the quantities available each year declining in line with required emission reductions, this would have an economic effect almost the same as a global emissions trading scheme with allowable emissions falling at the same pace.[230]

In both cases, abrupt and dramatic changes in policy could have a harmful effect, which can be illustrated by considering the energy price volatility experienced over the last two years, as described in Box G.

While this volatility was not caused by climate change-related policies, it had an economic impact equivalent to imposing a $140–420 per tonne carbon price immediately [Exhibit 7.18].[231] Such volatility induced severe socio-economic harm which created a risk of a slowdown in the energy transition, though one which in this event did not actually crystallise.

The implication is that it would not be sensible to introduce dramatic supply-side constraints immediately and without warning (e.g., an immediate closedown of existing operations). But it does not in any way undermine the case for carefully calibrated supply constraints, whose impact can be anticipated well in advance.

**BOX G: DRIVERS OF ENERGY PRICE VOLATILITY FOR 2021–2022**

2021 and 2022 saw a fossil fuel price surge which was distinctive as it entailed simultaneous large increases in coal, gas and oil prices [Exhibit 7.15]. These price increases were largely unrelated to climate change policies, but rather induced by Russia's invasion of Ukraine:

European **gas** prices increased five to 10-fold in 2022 as a result of significant cuts in Russian imports, which accounted for 40% of Europe's supply.[232] This in turn led to a bidding competition for LNG supply between Europe and Asia, which also pushed Asian prices to similar levels. This price increase was, at its peak, equivalent to raising the price of carbon by $420 per tonne, dwarfing the $64 increase which resulted from tightening of the EU-ETS [Exhibit 7.17].

- Global thermal **coal** prices increased three-fold as gas-to-coal switching put further pressure on an already tight market, given the restart of the Chinese industry following the lift of pandemic lockdowns.[233,234]

- While they remained well within historical range, crude **oil** prices increased as a result of European sanctions on Russian oil exports and the restart of global transport following the pandemic.

- These higher energy prices have in some ways helped the energy transition, with the European Union taking policy actions that will accelerate the deployment of electric vehicles, heat pumps, and renewables, as shown in Exhibit 7.16.

But abrupt increases in energy prices had significant adverse socio-economic and distributional effects globally, impacting the poorest households the most.[235] Governments in developed economies, in particular Europe, shielded consumers from high energy prices, with subsidies for fossil fuel consumption doubling from $530 billion in 2021 to $1,100 billion in 2022.[236]

229 Production subsidies for fossil fuels were estimated at $[50]bn in 2022, measured through direct incentives as well as instruments like tax breaks. A discussion of wider fossil fuel subsidies will be including in our forthcoming supplementary discussion paper.

230 The key difference being that global emissions trading scheme would allow price-based market discovery of the optimal balance between fossil fuels and carbon capture and storage, whereas a constraint on new licenses would decide of this arbitrage in advance.

231 Systemiq analysis for the ETC; OCI+ (2023), *Lifecycle emissions from oil and gas production database*; Nasdaq (2023), *Dutch TTF natural gas forward day ahead.*

232 Systemiq analysis for the ETC; Bruegel (2023), *European natural gas imports* and Eurostat data.

233 IEA (2022), *Coal market report 2022.*

234 C. René (2023), *Gas to coal switching hits new milestone.*

235 Allianz Economic Research (2022), *The (energy) price of war for European households.*

236 IEA (2023), *World energy investment 2023.*

But governments from EMDEs had little capabilities to provide such relief to consumers, and could not compete with Europe and large Asian economies to secure LNG supplies, with households and industries forced to reduce energy consumption and output.[237]

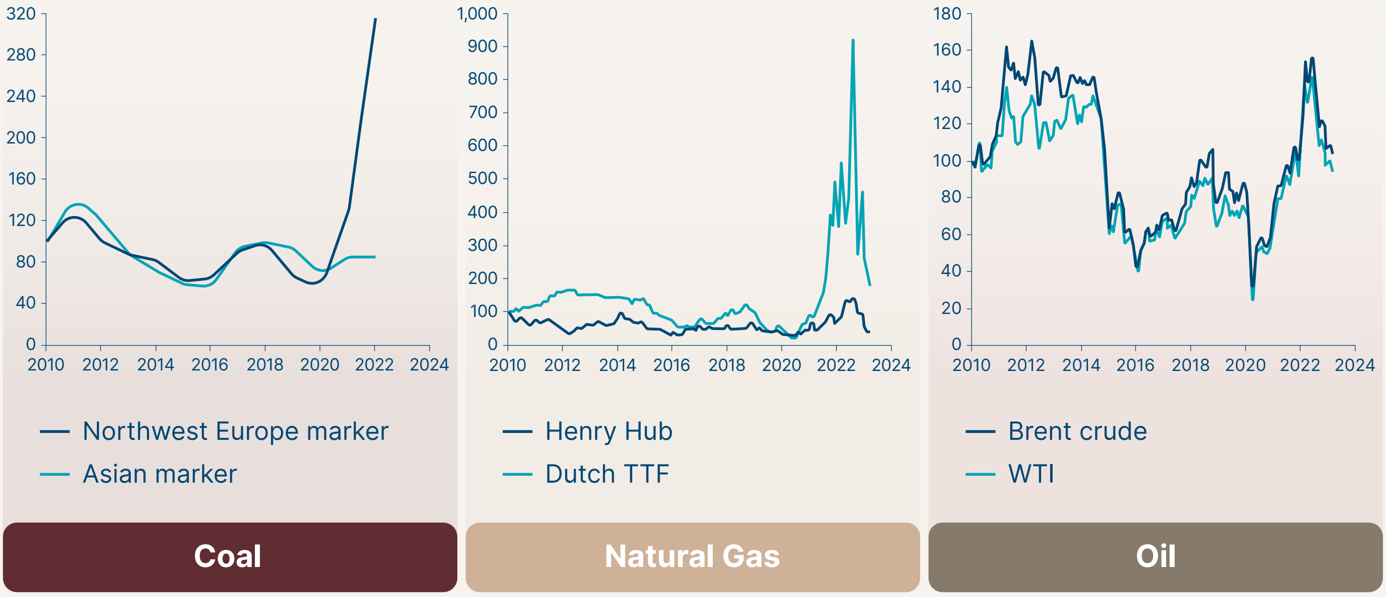
Even in developed countries and despite record subsidies, higher energy prices have helped provoke a political backlash against green policies, such as Germany's proposed policies to phase out fossil fuel boilers.[238]

The implication for supply-side policies is that while supply constraints can, via their impact on prices, play a positive role in accelerating the energy transition, they need to be introduced well in advance of their likely impact, and in a carefully calibrated fashion to avoid sudden, large and unexpected supply shortages of the sort provoked by Russia's invasion of Ukraine.

EXHIBIT 7.15

## Global fossil fuel prices from 2010 to 2023

Evolution of price markers for coal, natural gas and crude oil from 2010–2023
Index, 2010 = 100 values




**NOTE:** Yearly data is used for coal prices as monthly datasets are not publicly available. Henry Hub is the pricing point for natural gas futures on the New York Mercantile Exchange (NYMEX); Dutch TTF is a pricing location within the Netherlands that serves as a pricing proxy for the overall European LNG import market; Brent crude is the benchmark used for the light oil market in Europe, Africa and the Middle East. West Texas Intermediate (WTI) is the benchmark for the US light oil market. TTF = Title Transfer Facility; WTI = West Texas Intermediate.

**SOURCE:** Systemiq analysis for the ETC; *Henry Hub Natural Gas Spot Price*; EIA (2023), *Europe Brent Spot Price FOB*; Nasdaq (2023), *Dutch TTF Natural Gas Forward Day Ahead;* Nasdaq (2023), *Coal Marker Prices*; EIA (2023), *Cushing, OK WTI Spot Price FOB.*

237 Financial Times (2022), *Europe's appetite for LNG leaves developing nations starved of gas.*
238 Reuters (2023), *German parliament passes law to phase out gas and oil heating.*

EXHIBIT 7.16

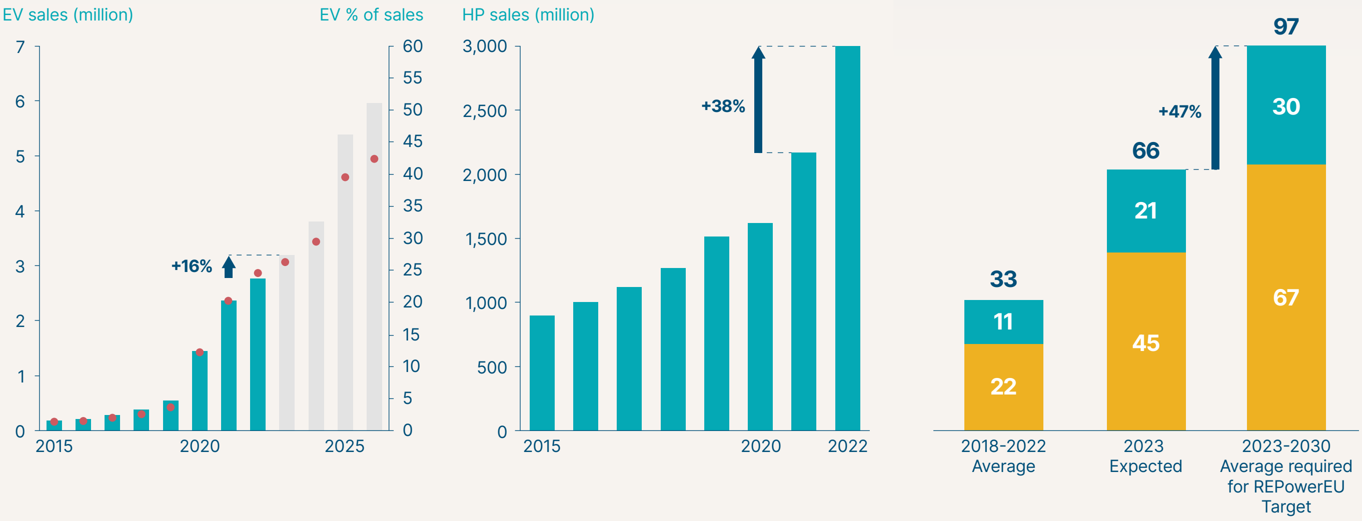
## Europe's response to the 2022 energy crisis – impact on electric vehicles, heat pumps and wind and solar capacity

### Energy demand

Electric vehicles (EVs) and heat pump (HP) sales in Europe

### Energy supply

Installed wind and solar capacity in the EU
GW p.a.



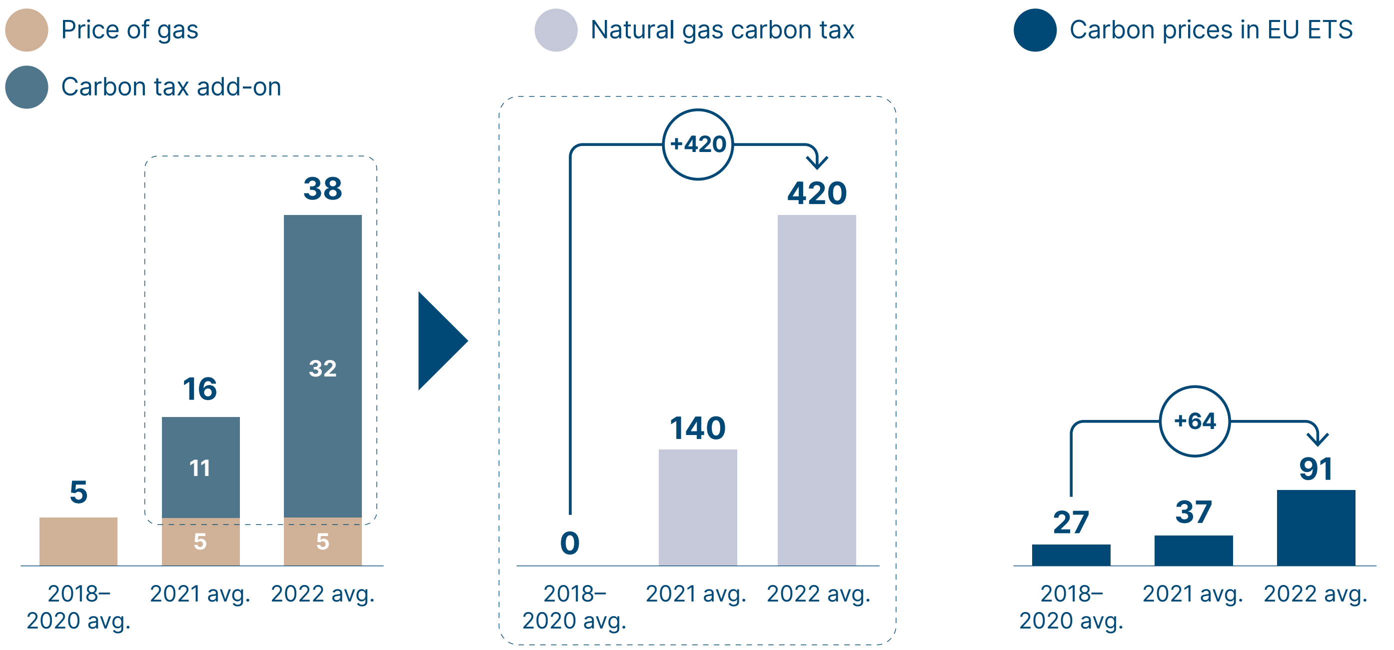

**SOURCE:** Systemiq analysis for the ETC; BNEF (2023), *Long-term electric vehicle outlook 2023*; EHPA (2023), *European heat pump market and statistics report 2022*; BNEF (2023), *Interactive data tool – global installed capacity*; Ember (2023), *Wind and solar deployment in the EU.*

EXHIBIT 7.17

## Increase in natural gas prices in 2021–2022 and equivalent carbon tax

Dutch TTF prices and equivalent carbon tax
$/MMBtu

Comparison of carbon tax imposed on natural gas vs. price of emissions allowance under the EU ETS
$/tCO$_2$




Gas prices rose steeply in 2021 and 2022. Relative to 2018–20 prices, the price rises are equivalent to carbon taxes of 11 and 32 $/MMBtu.

These "effective carbon prices" would correspond to actual carbon prices of $140 and $420/tCO$_2$ applied to natural gas.

However, the actual carbon price applied in the EU ETS was only $37-91/tCO$_2$ in those years.

**NOTE:** Some values are rounded. Carbon tax is assumed as being the difference in TTF prices for 2020, 2021 and 2022, taking lifecycle emissions of natural gas (including methane emissions, $GWP_{100}$ =30). EUR to USD conversion rate taken for 18/09/2023: 1.07 US$/€. EU ETS = The EU's Emissions Trading Scheme.

**SOURCE:** Systemiq analysis for the ETC; Ember (2023), *Price of emissions allowances in the EU and UK*; Nasdaq (2023), *Dutch TTF Natural Gas Forward Day Ahead*; OCI+ (2023), *Lifecycle emissions from oil and gas production database.*

## 7.3 Implications for policies, strategies and commitments

If the world is to meet agreed climate objectives, it is essential to reduce fossil fuel use at a pace at least as ambitious as our ACF scenario, and ideally as quickly as our PBS scenario. The crucial priority is to design and implement policies that reduce demand, as discussed in Chapter 5.3.

But there is a risk that these policies alone might be insufficient, and/or that they could be undermined by the development of excessive supply. As described above, there is therefore a case in principle for supply-side constraints to reduce the dangers of excess supply relative to demand, and to provide some price pressure which, in itself, will drive reductions in demand.

The question addressed in this section is whether pragmatically effective forms of supply constraint can be designed, and the respective role of governments, international institutions, fossil fuel companies and financial institutions in implementing those constraints.

## 7.3.1 International agreements and authoritative analysis: narrowing the range of beliefs

The energy transition will unfold in the most efficient and least disruptive fashion possible if plans for fossil fuel supply are broadly aligned with the feasible and required pace of demand reduction. But today, as illustrated by Exhibit 0.1, there is a very wide range of projections for how fossil fuel demand could evolve.

If there were a growing global consensus that the feasible and required path must lie somewhere around our ACF and PBS scenarios, that would, in itself, motivate a combination of actions – from energy producers, users, and financiers – which would increase the likelihood of achieving the required path.

Internationally agreed commitments to the phase-down of fossil fuels, supported by scenarios published by trusted organisations, can therefore in themselves play an important role in driving an effective energy transition.

The IEA's reports and scenarios establish an authoritative benchmark for what needs to be achieved, and our ACF and PBS scenarios lie in the range between the IEA's APS and NZE scenarios. But reports and scenarios will have maximum impact when endorsed by globally agreed commitments.

**COP28 should therefore commit to the phase-down of oil and gas supply and demand** and should begin the debate on how rapid a phase-down is feasible and required, and on credible limits to the role which CCUS, DACCS and NBS removals can play in achieving net emissions reductions. **This would build on the COP26 commitment to phase down coal use**.

Future COPs should aim to gain commitments which narrow the range of uncertainty about how fast fossil fuel use can, and must, decline.

## 7.3.2 Types of projects: new versus existing, short versus long developments and paybacks

Broad consensus around, and high-level commitments to future scenarios for fossil fuel decline can themselves play an important role. But they cannot by themselves prevent specific projects or company strategies which are incompatible with future climate objectives.

Firm rules to limit specific types of project therefore seem desirable. One proposal is that governments, companies and financiers should commit to no development of **new** oil and gas fields or mines.[239]

Such a rule would reflect the crucial fact that the vast majority of known fossil fuel reserves and resources must be left in the ground, and that unless at some point in time we commit to cease new developments, we will inevitably exceed any reasonable carbon budget. In addition, such a rule is clear and therefore enforceable.

In two respects, this clarity is possible and desirable:

- No new oil and gas exploration is required at the global level – oil and gas companies should cease exploration of undiscovered fields and basins,[240] financial institutions should cease all lending to finance exploration,[241] and governments should cease to issue new exploration licenses.
- And no new coal development is appropriate – financial institutions, whether private or public, should refuse to finance new coal mines or any expansion of capacity at existing mines, and governments should refuse to approve new mines.

239 Note that the IEA mentioned in 2021 and again in 2022 that fossil fuel demand in its Net-Zero Emissions scenario could be met without the approval of new long lead times projects, through continued investments in existing production. IEA (2022), *World energy outlook 2022*.

240 Including greenfield or frontier oil and gas exploration, or exploration activities where estimated reserves are still undiscovered, or where previous exploration activities have not led to commercial discoveries.

241 Noting that due to the inherent uncertainty and risk of exploration not leading to any commercial discoveries, exploration activities are almost systematically equity-financed. N. Bret-Rouzaut (2022), *The Economics of oil and gas production*.

But greater complexities arise in relation to new developments of already proven oil and gas reserves, since in particular:

- Reasonable estimates of feasible and required demand reduction pathways, as shown on Exhibits 7.5 and 7.6, imply the need for some development of proven oil and gas reserves. This required "new" supply may already be planned under the stated plans shown in Exhibits 7.8 and 7.9, but since specific projects will often not yet have reached final investment decision, a blanket ban on all new field development may not be feasible.
- The differentiation of a new and an existing oil and/or gas field is often not straightforward, particularly in relation to supply from tight oil and shale gas reserves, as detailed in Box F. Some complexity also arises in the definition of exploration.
- A blanket ban on any "new" field development, while accepting continued investment to extract more production from already developed fields, could conflict with climate justice considerations. New fields could be located in developing countries, while existing production mostly lies in developed countries which have been responsible for the vast majority of cumulative emissions to date and who have used the proceeds of the industry to fuel their development.
- In some cases, developing new fields might be preferable to lower scope 1 and 2 emissions, by targeting less emissions-intensive resources, but also to increase the bankability of investment projects to decarbonise production – this topic is covered in greater depth in Chapter 8.2.

As a result, while it is important to recognise that there is only limited need for new developments – in particular for oil – and that excessive new developments will result in either increased emissions or stranded assets, it is not possible to propose an absolute hard and fast ban on all new oil and gas developments.[242]

### BOX F: COMPLEXITIES OF "NEW" OIL AND GAS EXPLORATION AND DEVELOPMENTS

**New exploration**

Exhibit 7.4 showed that at the aggregate level, no new exploration of oil and gas is required, with current proven reserves already much greater than cumulative demand implied in the ACF and PBS to 2050.

But proven reserves are classified based on the certainty that underground resources are present, and that they are economically viable, as shown in Exhibit 7.18. Within these, reserves classified as '2PCX' would technically require new exploration as they are yet to be discovered, although they can be excluded on the basis that they are not required to meet cumulative demand in our scenarios.

But because of the inherent uncertainty around the precise amount of underground, economically-viable reserves, oil and gas companies must continuously "appraise" those 1P, 2P and 2PC reserves that result from successful exploration campaigns. Such appraisal activities are often carried out on the periphery of already developed fields or basins (i.e. where infrastructure already exists), or on fields that have been explored but which have not yet been developed.

A guideline that only allows for appraisal of already discovered resources is therefore suitable for conventional oil and gas formations and would prevent any non-required greenfield or frontier exploration. But such distinction between exploration, appraisal and production is much less clear in the case of tight oil and gas projects, as explained below.

**New production or developments**

Restricting the development of "new supply" could be difficult both to impose and monitor given ambiguities in the definition of "new", and the complexity of clearly delimitating subsurface geological formations. "New supply" could refer to new geological formations, different fields or basins, or a different bench or zone of a shale reservoir.[243]

Defining "new supply" should include considerations around infill wells, which are drilled during EOR. Oil producers almost systematically resort to enhanced oil recovery (EOR) given that solely relying on the reservoir's pressure (called "primary recovery") only enables to recover ~30% of underground oil resources, insufficient for producers to reach profitability.[244]

For conventional projects, such enhanced recovery technique can include the drilling of infill, or "child" wells, whose purpose is to increase the sweep efficiency to target pockets of hydrocarbons left behind from the "parent" wells, or original development plans.[245] To some, infill wells are argued as being "new production", despite being developed on already producing fields.

242 The IEA can enforce such blanket ban on all new developments given its Net-Zero Emissions scenario relies on significant consumer behaviour change and efficiency improvements in the short-term, which enables to rapidly displace oil and gas demand in particular by 2030.

243 Based on interviews of experts.

244 Hafner et al. (2022), *Economics of oil and gas production.*

245 B. N. Ghosh et al. (2004), *Improved oil recovery by infill drilling in a mature field: A success story.*

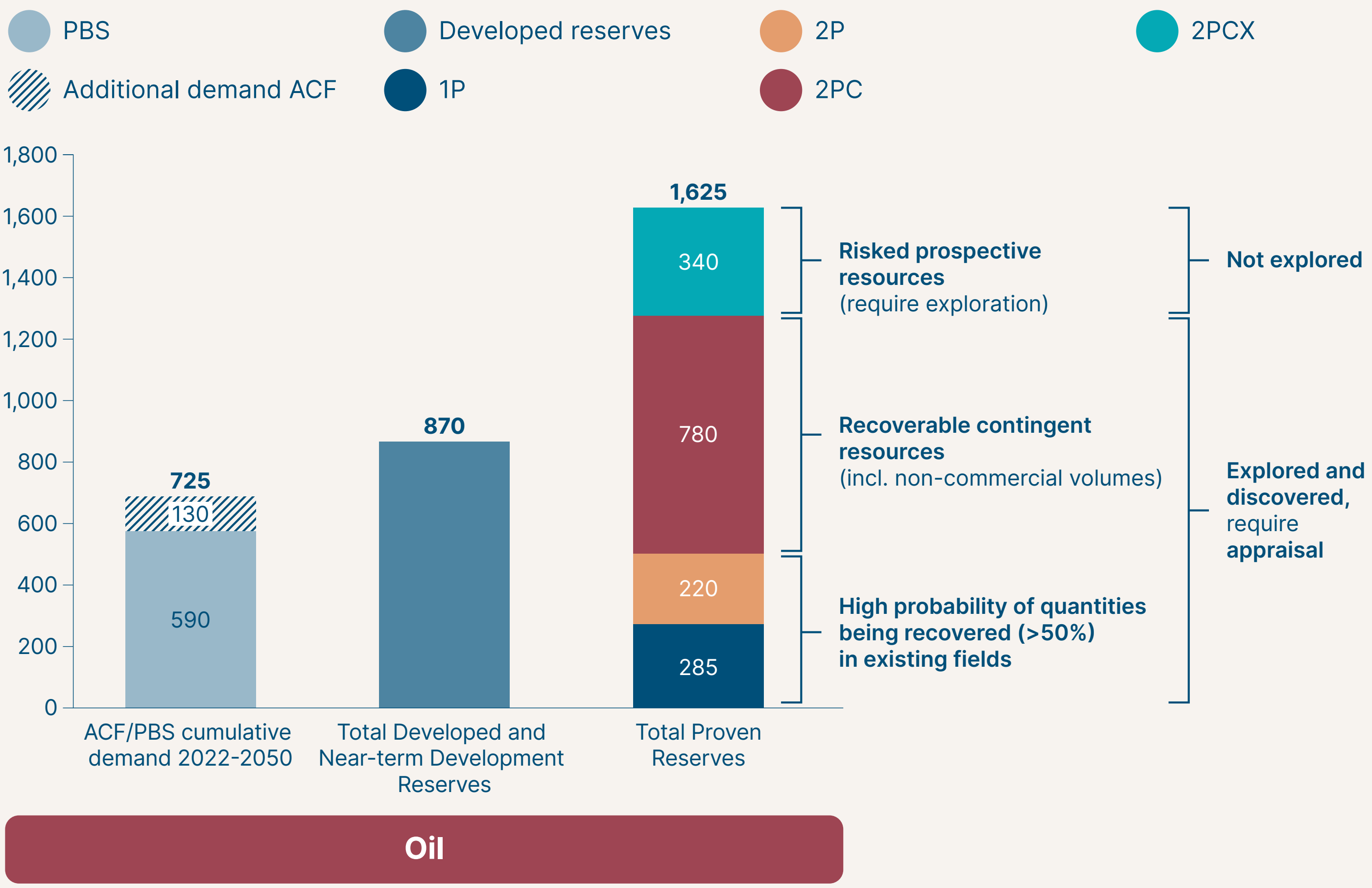
Another complexity comes from tight oil formations, which can be viewed as small hydrocarbon pockets distributed over a large area of land. It is hard to precisely delimit these "pockets" given their dispersion over large areas. Furthermore, tight oil extraction techniques consists in the continuous development of horizontal wells to fracture and release oil and gas formations trapped in bedrock.[246] There are no clear exploration or appraisal wells in the case of tight oil and gas, and every new well developed aims to increase production rather than confirm the presence of underground resources. Furthermore, horizontal wells can cover distances of over 5 km;[247] it is therefore hard to assess and monitor whether such wells are deployed on already exploited tight oil formations, or if they extend to "new" formations, even if the wells are connected to existing surface infrastructure.

Thus while it would be possible to precisely define what "new" oil and gas supply could refer to, infill wells and horizontal wells create inherent complexities for monitoring that they are indeed only deployed on formations which are already developed or in production.

**EXHIBIT 7.18**

## Breakdown of global proven oil reserves by PRMS classification

Proven oil reserves by classification and comparison with demand in ACF & PBS
Billion barrels




**NOTE:** Proven reserves are taken from Energy Institute (2023), *Statistical review of world energy*, and are defined as "those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions. The data series for total proved oil reserves does not necessarily meet the definitions, guidelines and practices used for determining proved reserves at company level, for instance as published by the US Securities and Exchange Commission". PRMS = The Petroleum Resources Management System (PRMS) is a system developed for consistent and reliable definition, classification, and estimation of hydrocarbon resources. 1P = Proved reserves from existing fields (> 90% certainty), 2P = Probable reserves from existing fields (> 50% certainty), 2PC = Probable reserves in existing fields and mean contingent recoverable resource in unsanctioned projects / discoveries, including non-commercial volumes, 2PCX = most likely estimate from existing fields, plus contingent resources in discoveries, plus risked prospective resources in undiscovered fields.

**SOURCE:** Systemiq analysis for the ETC; Energy Institute (2023), *Statistical review of world energy*, GOGEL (2023), *Global Oil and Gas Exit List* 2022, Trout et al. (2022), *Existing fossil fuel extraction would warm the world beyond 1.5 °C*, RystadEnergy (2023), *Recoverable oil reserves top 1,600 billion barrels, capable of warming the planet an extra 0.2°C by 2100*, PRMS (2018), *Version 1.03*

246 McKinsey Energy Insights (2023), *Light tight oil.*
247 Journal of Petroleum Technology (2022), *The trend in drilling horizontal wells is longer, faster, cheaper.*

An alternative approach would be to focus on the length of time required for new project development. It is clear from Exhibits 7.5 and 7.6 that any project which does not bring production online until the early 2030s, or which relies on extended production through the late 2030s and 2040s to be economically viable, would be in danger of being stranded and of creating supply in excess of declining demand. There is therefore a case in principle for ceasing all new projects which require long development times, while continuing to approve and finance some new projects which have short development and payback times.

One potential consequence of such a rule would tend to favour shale oil and gas developments, many of which have in the past produced larger upstream methane emissions per barrel or cubic metre than large conventional fields.[248,249,250] This reflects both the inherent features of production methods and the fact that many tight oil/shale gas fields have been operated by smaller companies with less stringent operating approaches than the major IOCs. Any guidance or rule to favour short payback projects must therefore be combined with tightly enforced standards on scope 1 and 2 methane emissions (see Chapter 8).

Additionally, favouring short payback projects inherently favours new tight oil developments in the US, with similar climate justice considerations to those stated earlier.[251] While the US only accounts for ~25% of global proven tight oil reserves, developing shale reserves outside of the US would require a critical mass of activity, as continued drilling and well completion would be required to sustain production over several years. To date, few other countries have achieved success in developing tight oil production.[252]

Therefore overall, while there is a role for project type-based rules for new supply development, it is likely that general rules and guidance relating to overall volumes will play a more powerful role.

### 7.3.3 Fossil fuel company commitments and guidelines

As Chapter 6 made clear, all fossil fuel companies should commit to net-zero scope 1, 2 and 3 emissions by mid-century. Any lesser objective is incompatible with limiting global warming to 1.5°C.

In addition, all major fossil fuel companies, whether private or state-owned, should set out transition plans to net-zero emissions which are compatible with the global emissions decline required to meet climate objectives, and the associated decline in fossil fuel use this implies.

There are complexities involved in turning this into a quantitative rule which can apply to each specific company. This is because the globally optimal path of emissions and supply reduction is likely to imply faster reductions for some countries and companies than others. This globally optimal path will be determined by multiple potentially competing factors – including least-cost operation, least emissions intensity, and climate justice considerations. These will be considered in the ETC's supplementary report on fossil fuels in 2024.

But all fossil fuel company commitments and strategies should include:

- No new exploration to discover new oil and gas basins/fields.
- Specified pathways for the decline of scope 1, 2 and 3 emissions to reach net-zero by mid-century, with clear justifications for any significant divergence between the proposed company pathway and the overall global pace of emissions reduction required to meet climate objectives.[253]
- Specific targets for the decline in coal, oil and gas production over time, with transparent justification for any significant divergence from the reduction range indicated by our ACF and PBS scenarios.
- Credible assessments of the role which CCS, DACCS, and NBS removals could play in reducing net emissions, with any strategy based on figures significantly above those outlined in Chapter 4 neither credible nor prudent.

In some cases, this may imply quantitative reduction pathways which are more or less aggressive than required in aggregate at the global level. Financial institutions will therefore need to play a crucial role in assessing the credibility of transition plans and deciding whether they should be supported by debt and equity investment.

248 Since 2015, shale/tight resources have resulted on 7.5% less emissions-intensity (using a $GWP_{100}$ = 30 for methane) per unit produced compared to other resources, but 4.7% more methane-intensive. Systemiq analysis of OCI+ (2023), *Oil and gas emissions dataset*.
249 Note: payback periods of projects would be impacted by the investments required to abate scope 1 & 2 emissions.
250 Best in class technical mitigation option can be applied to tight/shale oil and gas production to reduce methane emissions-intensity of production to 0.2–0.6%, These would likely fall short of best-in-class emissions intensity for conventional projects. CCC (2016), *The compatibility of UK onshore petroleum with meeting the UK's carbon budgets.*
251 IEA (2019), *Could tight oil go global?*
252 Ibid.
253 Such justifications include the recognition of common but differentiated responsibilities in meeting the goals of the Paris Agreement, with developing economies reaching net-zero at a later date than developed economies. Any divergences on the role or scale of carbon capture or removals with our scenarios are not valid justifications.

**BOX G: HOW OIL AND GAS COMPANIES CAN OPERATIONALISE NET-ZERO TARGETS**

**Scope 3 emissions:**

All companies should commit to absolute reduction targets for emissions from the use of sold production, including absolute reduction targets for the production of hydrocarbons and derived products. Intensity-based targets, usually measured as a ratio of emissions to energy produced (e.g., $kgCO_2e/MJ$), are insufficient as intensity could be reduced while absolute emissions do not if companies increase production, and can be further offset by the increase in the sale of low-carbon energy. Because the global carbon budget is measured in absolute value, measuring performance against set budget similarly requires absolute reductions.[254]

Furthermore, all companies should set specific pathways for the decline in coal, oil and gas production over time to reach net-zero by mid-century, with transparent justification for any significant divergence from the reduction range indicated by our ACF and PBS scenarios. Interim targets should also be set, and under gold standard commitments should align to at least the reductions implied by our ACF scenario, and ideally those implied by the PBS (see Chapter 3).

In developing these pathways, companies should undertake credible assessments of the role of carbon capture and removals in meeting their net-zero targets. These assessments should quantify the role these technologies will play towards meeting interim and long-term targets. Companies should also provide evidence, through 3rd party verification and certification, that sold products, where used in applications where carbon capture is applied, reach at least 90% capture rates.

All companies should purchase and retire only high quality carbon removals to offset residual emissions, including from production, transport and processing, on the path to 2050 to avoid overshooting the carbon budget for 1.5°C. Our 2022 *Mind the Gap* report highlights what criteria high quality removals must meet.

**Scope 1 & 2 emissions:**

All companies should set intensity-based targets for both $CO_2$ and methane emissions from operated assets. Intensity-based targets are usually less desirable than absolute targets, but if combined with absolute scope 3 targets avoid the risk of increasing absolute emissions explained in the section on Scope 3 emissions above (i.e. by lowering intensity but increasing overall production, resulting in increased absolute emissions). Furthermore, as companies commit to absolute reductions in production, intensity targets enable companies to appropriately measure true progress on reducing scope 1 & 2 emissions, as absolute targets would be influenced by the mechanical reductions from production ramp down, rather than actual progress on reducing scope 1 & 2 emissions.

**All emissions:**

Net-zero targets should include all emissions from operations and use of sold products, but also all emissions released from all activities that the company profits from (e.g., 3rd party refining and transportation).[255]

Divestments and asset sell-offs should not count towards meeting net-zero targets under gold standard commitments if the transfer of assets does not occur between companies that have committed to gold standard targets, as explained in this chapter.

At present, very few major oil and gas companies have made explicit commitments of any sort to reduce scope 3 emissions, with most companies committing only to scope 1 and 2 emission reductions, as shown in Exhibit 7.19.

254 Carbon Tracker (2023), *Absolute impact 2023*.
255 Ibid.

EXHIBIT 7.19

# Oil and gas company targets

| Company Type | Company | Hallmark commitments: Net-zero scope 1 & 2 emissions by 2050 | Hallmark commitments: Net-zero scope 3 emissions by 2050/ mid-century | Hallmark commitments: Interim scope 1 & 2 emissions targets | Hallmark commitments: Interim scope 3 emissions targets | Hallmark commitments: Production reduction targets | Gold Standards: Divestments included to reach targets | Gold Standards: Operational or equity | Gold Standards: Production decline aligned to ACF |
|---|---|---|---|---|---|---|---|---|---|
| IOC | Eni | Yes | Absolute | Absolute | Absolute | No | Yes | Equity | No |
| | Total Energies | Yes | Intensity | Intensity | Absolute | Yes | Yes | Operational | No |
| | Repsol | Yes | Absolute | Intensity | Absolute | No | Yes | Partial equity | No |
| | BP | Yes | Absolute | Absolute | Absolute | Yes | Yes | Operational | Yes |
| | Shell | Yes | Intensity | Absolute | Intensity | Yes | Yes | Equity | No |
| | Chevron | Yes | No | Intensity | Intensity | No | Yes | Partial equity | No |
| | Conoco Philips | Yes | No | Intensity | No | No | Yes | Equity | No |
| | Exxon Mobil | Yes | No | Intensity | No | No | Yes | Operational | No |
| NOC | Equinor | Yes | Intensity | Absolute | Intensity | No | Yes | Partial equity | No |
| | Saudi Aramco | Yes | No | Intensity | No | No | Yes | Operational | No |
| | CNOOC | No | No | Absolute | No | No | Yes | Operational | No |
| | Petro China | No ('near-zero') | No | No | No | No | Yes | Operational | No |
| | Sinopec | No | No | Absolute | No | No | Yes | Operational | No |
| | Petrobras | Yes | No | Absolute | No | No | Yes | Operational | No |
| | Petronas | Yes | No | Absolute | No | No | Yes | Operational | No |
| Independents | Occidental Petroleum | Yes | Yes, undisclosed | Intensity (& absolute) | No | No | Yes | Operational | No |
| | Suncor | Yes | No | No | No | No | Yes | Operational | No |
| | Pioneer | Yes | No | Intensity | No | No | Yes | Operational | No |

**NOTE:** Partial equity-share basis means operational emissions are on an operated-asset basis and scope 3 emissions on a full equity-share basis, or vice versa.
IOC = International Oil Company; NOC = National Oil Company.

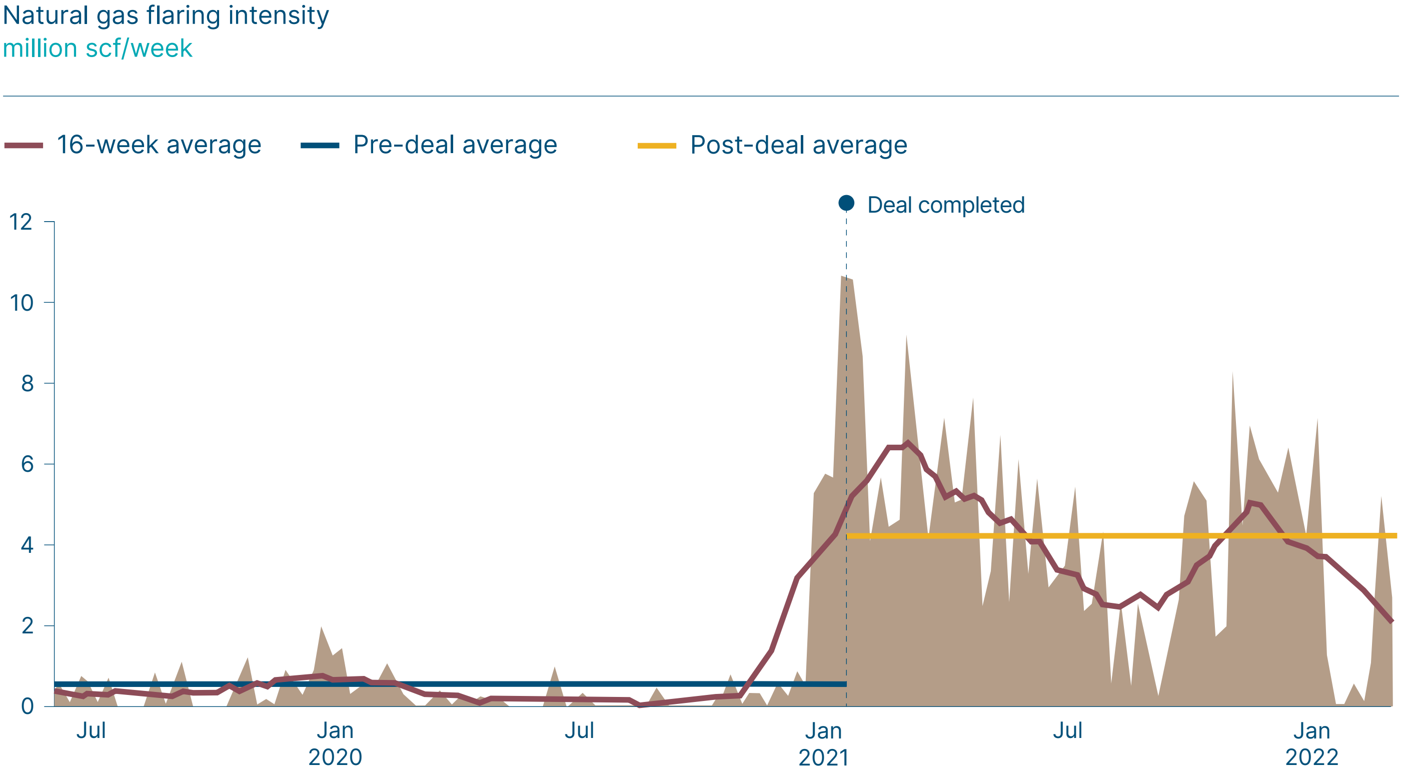
**SOURCE:** Carbon Tracker (2023), *Absolute impact 2023: Progress on oil and gas emissions targets has stalled*, Petronas (2022), *Sustainability report 2022.*

Beyond the commitments which all companies should make, gold standards for clearly climate-compatible pathways – such as any future SBTi endorsement – should only be awarded to those companies which commit to pathways for the reduction in emissions and fossil fuel production in line with the globally required trend, i.e. at least in line with the ACF and ideally in line with the PBS. In addition, gold standard commitments must:

- Exclude any new exploration of oil and gas basins/fields.
- Not count divestments and asset sell-offs as a mechanism by which to meet commitments to reduce emissions or fossil fuel production. Exhibit 7.20 suggests that asset sell-offs do not result in absolute emissions reduction but rather in a transfer of emissions, which in some cases can increase.
- Account for the emissions and production deriving from non-operated joint ventures (NOJV) over which the companies have significant influence; these must be accounted for on an equity-basis.

EXHIBIT 7.20

## Evolution of flaring intensity at Umuechem oil field after asset sell-off




**NOTE:** TNOG means Trans-Niger Oil & Gas. TNOG, owned by Heirs Holdings, has stated that it aims to triple the oil production from the Umuechem block.
Scf = standard cubic feet.

**SOURCE:** Systemiq analysis for the ETC; EDF (2022), *Transferred Emissions: How risks in O&G M&A could hamper the energy transition, based on Capterio data.*

Separate to the question of how rapidly fossil fuel companies should reduce their emissions and their fossil fuel production, is what role they should play in building the new energy system. In principle, two opposite positions could be justified:

- One in which fossil fuel companies use their cash flows, human capital, and complex project management expertise to invest in renewable energy and other clean technologies, transforming themselves over time into "energy companies".
- One in which fossil fuel companies deliberately pay out their cash flows – whether via dividends to private or public shareholders, or in taxes and royalties to governments and ultimate asset owners – leaving it to capital markets and governments to reallocate capital to clean technology investments.

Several oil and gas companies have made statements which commit to the first strategy, but despite record profits in 2022, actual investments made so far fall well short of those needed if they are to play a major role in the energy transition [Exhibit 7.21]. Clean energy investment by oil and gas companies was just 2% of overall low-carbon expenditure in 2022, with considerable variations across regions.[256]

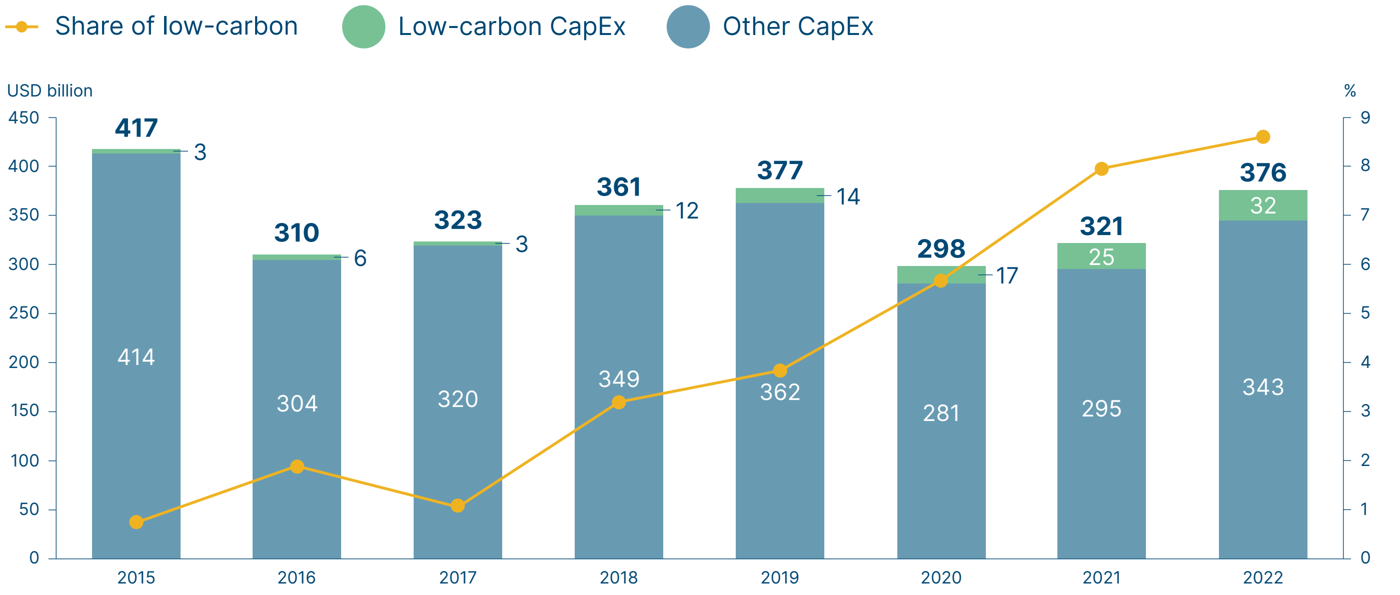
The ETC's supplementary fossil fuel report (2024) will consider in detail the relative merits of the different strategies, and the metrics which fossil fuel companies should meet if they are to significantly contribute to the energy transition.

256 Clean energy investment by oil and gas companies was $20–32 bn in 2022, compared to $1.7 trn in overall low-carbon expenditure. Systemiq analysis for the ETC; BNEF (2023), *Oil and gas: Energy transition investment trends 2022*; IEA (2023), *World energy investment 2023.*

EXHIBIT 7.21

## Capital expenditure from the oil and gas industry

Capital expenditure from oil and gas companies from 2015–2022
USD billion (left) and % of low-carbon CapEx (right)




**SOURCE:** BNEF (2023), *Oil and gas: Energy transition investment trends 2022.*

### 7.3.4 Financial institutions – a crucial role

Financial institutions – whether ultimate investors, asset owners, asset managers or lending banks, and whether private or public (e.g., MDBs) – must play a vital role in ensuring that fossil fuel demand and supply falls in line with feasible scenarios. As Chapter 5.3 described, this should include policies and commitments to reduce, and eventually eliminate, funding of energy-using assets which contribute to locking-in fossil fuel use and carbon emissions.

Supply side-related policies should include two hard firm commitments to provide:

- No finance for new oil and gas exploration.
- No finance for any new coal mine development or for capacity expansion at existing mines.

In addition, financial institutions can and must play a crucial role in ensuring that oil and gas investment falls at the required pace, and it is possible to define appropriate quantitative rules for financial institutions even if they cannot be applied at the level of each individual oil and gas company.

This is because:

- While some individual oil and gas companies may experience a slower or faster pace of emissions or production decline than the global trend, large financial institutions will likely hold a broadly diversified portfolio of investments and loans, whose emissions intensity should move in line with the globally required trend.
- And while some fossil fuel companies may choose not to play a major role in scaling up the clean technology investment required to drive the energy transition, all financial institutions should play a central role in the development of the new energy system and economy, as well as the decline and phase-out of the existing energy system.

This implies that financial institutions must play a major role in assessing the credibility of fossil fuel companies' transition plans, and should only be willing to finance companies with credible strategies for reaching net-zero scope 1, 2 and 3 emissions by mid-century, and with justifiable pathways to that destination.

As Box H explains, assessments of transition plans is inherently difficult, and should therefore be underpinned by two key quantitative measures:

- Portfolio-level **"financed emissions"** commitments, with financed emissions falling in line with the pace of emissions reduction required to limit global warming to 1.5°C. These targets should, however, be accompanied by other metrics to avoid the risk that they incentivise financial institutions to withdraw capital away from high-emitting sectors which must finance their transition.[257]

- Financial institutions should also commit to achieve a steadily rising **ratio of investments in new clean technology to those in fossil fuels**, in line with estimates of investment balance needed to drive a global transition in line with agreed climate objectives. These estimates suggest that the ratio of investment in low-carbon energy to fossil fuel supply needs to rise from about 1 today to 4 for 2021–30, 6 for 2031–40 and 10 for 2041–50, as shown in Exhibit 7.22.[258]

To provide clear discipline in the setting of financed emissions targets and in the assessment of client transition plans, financial institutions will typically want and need to adopt a benchmark scenario which defines how rapidly global emissions and fossil fuel use can and should decline. Several financial institutions which have joined GFANZ and committed to make their strategies compatible with limiting global warming to 1.5°C have adopted the IEA NZE as their benchmark scenario.

Chapter 3.2 compared the ETC's PBS scenario for future fossil fuel use and for total emissions with the IEA NZE, and noted that:

- In the case of gas, the projected pathway to 2030 is almost identical, but with the ETC PBS suggesting slightly more gas use in the 2040s.

- For oil, cumulative demand and supply from 2023-2050 is almost identical, and the ETC PBS suggests a significantly lower oil demand in 2050. But in the period before 2030, the ETC PBS suggests a slightly slower pace demand decline (to 84 Mb/d versus 77 Mb/d the IEA NZE). This is partly because the IEA NZE assumes that adoption of new technologies and a dramatic acceleration of energy efficiency improvements can be combined with changes in behaviour which look extremely challenging over just seven years. By contrast the ETC PBS is constrained by a judgment about what can be achieved before 2030 given current trends and policy settings.

- The biggest difference relates to coal, where both the IEA NZE and the ETC PBS project a rapid fall in coal use, but with the ETC PBS a bit more cautious about the pace at which existing coal generation can be retired.

- The ETC PBS scenario, however, is only compatible with limiting global warming to 1.5°C if rapid reductions in fossil fuel use can be combined with a cumulative 150 Gt of carbon removals before 2050, a scale which looks extremely challenging to achieve given latest disappointing trends.

Both scenarios thus illustrate how extremely difficult it will be to limit global warming to 1.5°C. But it remains highly desirable that major financial institutions, as members of GFANZ, remain committed to that temperature objective. We therefore believe that financial institutions which have made, or in future make, commitments to be 1.5°C-compatible should either:

- Treat the IEA NZE scenario as their benchmark scenario, and argue not only for the new technology deployments which underpin both the IEA and ETC projections, but also for the policies which can deliver the assumed behaviour changes.

- Treat the ETC PBS as their benchmark scenario for fossil fuel reduction but recognise that this is only 1.5°C-compatible if combined with carbon removals on the scale indicated in Chapter 4. This means that they should in their adoption of appropriate financed emission targets either:
    - Require that clients commit to finance removals on the scale required to compensate for a fossil fuel reduction path less severe than IEA NZE; these removals must be in addition to, and not instead of, clear commitments to reduce own emissions to net-zero by 2050.[253]
    - Or themselves commit to finance removals on the required scale.

257 ETC (2023), *Financing the transition: How to make the money flow for a net-zero economy*. See also GFANZ (2023), *Defining transition finance and considerations for decarbonisation contribution methodology*.

258 Ratio is based on investments in energy supply only, and excludes investments in end-uses, energy efficiency and biomass liquids. The IEA states that investment ratio of 1.7 will be reached this year, but includes investments in energy efficiency and end-uses. Systemiq analysis of BNEF (2022), *Investment requirements of a low-carbon world: Energy supply investment ratios;* IEA (2023), *World energy investments 2023*.

253 It is crucial that clients commit to true removals on the scale required and not to "offsets" which do not entail permanent removal of $CO_2$ emissions. ETC (2022), *Mind the Gap*.

**BOX H: FINANCIAL INSTITUTIONS' ASSESSMENT OF FOSSIL FUEL COMPANY TRANSITION PLANS**

Financial institutions must assess the credibility of their clients' transition plans and adjust their financing decisions accordingly. This assessment requires financial institutions to a) assess whether fossil fuel companies have a credible strategy for reducing their scope 1, 2 and 3 emissions fast enough to be compatible with a 1.5°C pathway, and b) assess the implications of their financed emissions for their own net-zero commitments.

There are **two core challenges** for financial institutions in making these assessments:

- They may not have the necessary data and information from fossil fuel companies regarding their transition plans.
- There is a lack of consensus on what actions from fossil fuel companies are and are not compatible with a 1.5°C-aligned transition.

**1. Transition planning**

A significant body of work is currently underway to develop clear and comprehensive guidance on how real economy companies, including fossil fuel companies, should develop their transition plans and disclose information in a way that enables financial institutions to make a robust assessment. The next step is for this guidance to be made more specific to the fossil fuel sector and for best practices to be sharpened.

Key examples include:

- **International Sustainability Standards Board's sustainability disclosure standards** serve as a global baseline for sustainability disclosure for capital markets.[259]
- **GFANZ** has set out the key elements of a credible transition plan (e.g., how will the company align business activities with its climate objectives, and how will it will influence others to support its transition strategy).[260] GFANZ also have guidance on the managed phase-out of high-emitting assets, including the tools to identify those assets that may need to be retired early.[261]
- **The Transition Plan Taskforce:** the UK has developed a globally-applicable, sector-neutral disclosure framework for best-practice transition plan disclosures, alongside implementation and sector guidance (including upcoming fossil fuel guidance in late 2023).[262]

**2. Alignment and assessment**

This second stage is where additional work is still needed. As outlined in this report, there is no global consensus on how and how fast fossil fuel use should fall. Climate modelling within financial institutions is in its infancy and faces many challenges, including a disconnect between climate scientists, economists and financiers and a significant underestimation of climate risk.[263]

A number of initiatives are underway to address these challenges; however in general, the outputs are currently too high-level (e.g., global and sector-generic) to be useful. Further work and guidance is needed, especially in the case of the fossil fuel sector. Key areas of work include:

- **1.5°C-aligned scenarios:** these form the basis of any assessment of credibility and alignment. Examples include the IEA's Net-Zero scenarios and the ETC's PBS scenario PBS scenario outlined in this report, both of which can serve as a baseline global scenario for financial institutions.
- **Target-setting methodologies and validation:** provide guidance for companies to estimate, set and disclose GHG emission targets, as well as validation of targets. Examples include the Science-Based Targets Initiative (note: the SBTi's validation of fossil fuel sector targets is currently paused while they further develop their methodology) and the Transition Pathway Initiative.
- **Transition plan assessment tools:** evaluate and assess the credibility and comprehensiveness of a company's transition and GHG emission targets. Examples include the Transition Pathway Initiative, Climate Action 100+ and ACT.

259 ISSB IFRS S1 General Requirements for Disclosure of Sustainability-related Financial Information, and IFRS S2 Climate-related Disclosures.

260 GFANZ (2022), *Expectations for Real Economy Transition Plans*.

261 GFANZ (2022), *Managed Phase-Out of High-Emitting Assets*.

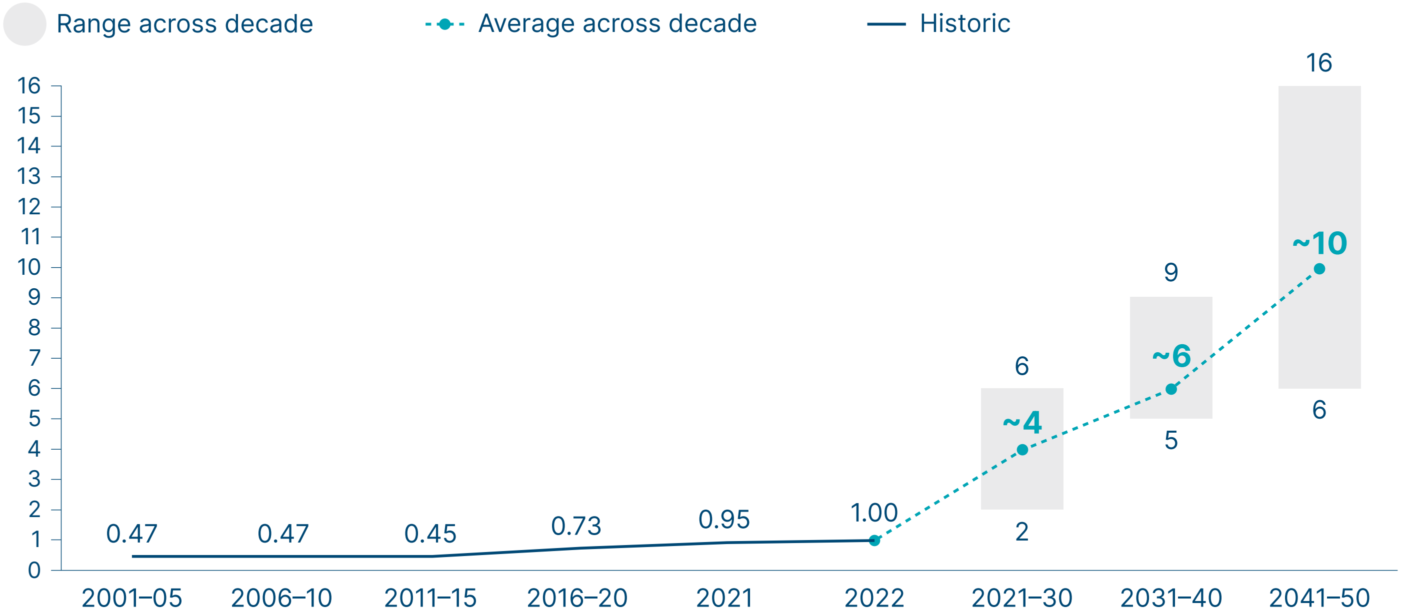
262 The TPT Disclosure Framework is designed to be available for voluntary and mandatory use internationally, purposefully supporting regulatory implementation in a manner consistent with reporting under ISSB Standards. TPT (2023), Disclosure framework: https://transitiontaskforce.net/wp-content/uploads/2023/10/TPT_Disclosure-framework-2023.pdf.

263 Trust et al. (2023), *The Emperor's New Climate Scenarios*; University of Exeter (2023), *New Scenario Narratives for Action on Climate Change*.

EXHIBIT 7.22

## Ratio of investment in low-carbon energy vs. fossil fuel supply

Low-carbon energy to fossil fuel supply investment ratio up to 2050
Unitless




**NOTE:** Ratios for 2021 and 2022 have been determined based on BNEF (2023), *Energy transition investments trends 2023*. Ratios shown only include investments in low-carbon and fossil fuel energy supply, and exclude investments in end-uses, energy efficiency and biomass liquids.

**SOURCE:** BNEF (2022), *Investment Requirements of a Low-Carbon World: Energy Supply Investment Ratios.*

### 7.3.5 Governments

Government strategies for the development or rundown of their fossil fuel production will inevitably vary by country, and will reflect energy security and economic development objectives alongside policies required to meet both mid-century zero-emission goals and medium-term NDCs. The ETC's supplementary 2024 report on fossil fuels will explore the complexities introduced by these competing objectives, and how to manage them while ensuring that climate objectives are achieved.

But some clear implications follow from the analysis in this report. In particular, governments should:

- Commit to no further issuance of new exploration licenses to discover oil or gas.
- Explicitly reject the idea that all their own fossil fuel reserves must be exploited. Any such assertion is incompatible with stated commitments to play a responsible role in limiting climate change, since – if applied by all countries – would result in global emissions massively in excess of any acceptable carbon budget.
- Remove any subsidies or tax breaks that incentivise the production of fossil fuels.

In addition, there is a good case for developed country governments to refuse the development of new oil or gas fields on their territory as a signal to developing countries of their determination to address the climate challenge to which their past emissions have made an outsized contribution. This and other climate justice-related considerations will be assessed in more detail in the ETC's subsequent fossil fuel discussion paper.

Governments around the world also have a crucial role to play in mobilising significant low-cost finance to scale-up clean energy supply in developing economies, including via their role in multilateral development banks.[264]

264 ETC (2023), *Financing the transition.*

# Chapter 8

# Reducing scope 1 and scope 2 emissions

As Exhibit 1.1 showed, 6.5 $GtCO_2e$ of emissions today – around 15% of all fossil emissions – result from the production, processing, transport and refining of fossil fuels, rather than from combustion in end-use applications.[265,266]

Of these, 2.9 Gt are $CO_2$ emissions, while 120 Mt of methane emissions ($CH_4$) are estimated to have a global warming effect equivalent to another 3.6 $GtCO_2e$ if a global warming potential (GWP) of 30 is used to establish equivalent effect.[267] There are arguments, however, for using a GWP of 82.5, which would suggest that 120 Mt of methane has an equivalent effect to 9.9 $GtCO_2$, as discussed in Box I.[268]

Of the total, coal accounts for only 7% of the $CO_2$ emissions, but for 33% of methane emissions [Exhibit 8.1].

### BOX I: METHANE AND GLOBAL WARMING

Methane is a relatively short-lived greenhouse gas, with a half-life in the atmosphere of about 10–12 years, compared to decades and centuries for $CO_2$ or $N_2O$.[269] This indicates that the concentration of methane produced by a one-off emission (or "pulse") takes around 10 years to halve, as methane is converted (via a complex set of oxidisation reactions) into $CO_2$ and $H_2O$, eventually leaving around 2.75 tonnes of $CO_2$ per tonne of methane emitted.[270]

Estimates suggest that increasing concentrations of methane have been responsible for about 30% of global average temperature increase to date.[271] Given the short-lived nature of methane, methane concentrations and the associated forcing effect would stabilise if the flow of new methane emissions ceased to rise. But this does not mean, as some interest groups suggest, that the appropriate objective should be simply to stabilise rather than reduce methane emissions for **two reasons**:

- First, because $CO_2$ concentrations and temperatures will continue to rise as long as net $CO_2$ flows are above zero, unless methane emissions are cut.[272]
- Second, because the very fact of methane's high but short-lived GWP means that reducing methane emissions is the most powerful lever to limit short-term temperature forcing, and thus reduce the risk that feedback loops will take the climate beyond potential tipping points. Objectives for methane emissions are therefore expressed in terms of how fast annual flows should fall over time.[273,274]

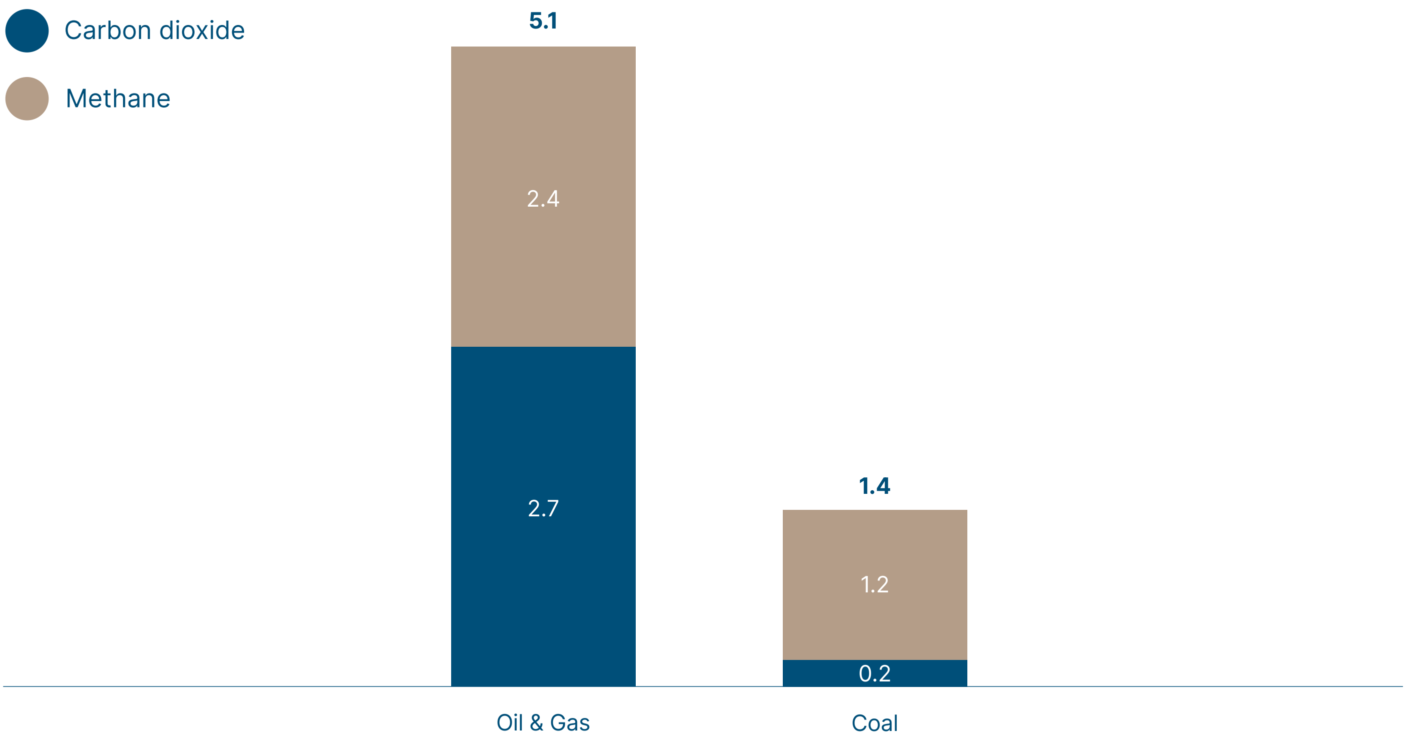
Given the different nature of short and long-lived greenhouse gases, estimates of the "carbon equivalent" effect of methane emissions depends on the timescale assumed. Over a 100-year period, a ton of methane emitted has a forcing effect of about 27–30 times more than a ton of $CO_2$ emitted today. Over a 20-year period, methane's impact is 81–83 times greater per ton emitted.[275]

265 IEA (2023), *Scope 1 & 2 GHG emissions from oil and gas operations on the Net-Zero Scenario.*
266 IEA (2023), *Coal mine methane emissions and abatement potential.*
267 IPCC (2013), *Climate change 2013: The physical science basis. Contribution of working group I to the 5th assessment report of the IPCC.*
268 Methane is a short-lived climate pollutant (SLCP), meaning that it disappears from the atmosphere faster than other gases (12 years vs. 300–1,000 years for $CO_2$). As such, a 20-year GWP for methane better reflects its sharp but temporary pulse on warming, rather than a constant agent like $CO_2$. Allen et al. (2018), *A solution to the misrepresentations of $CO_2$-equivalent emissions of short-lived climate pollutants under ambitious mitigation.*
269 Saunois, M. et al. (2020), *The Global Carbon Budget 2000–2017.*
270 As methane in the atmosphere degrades into carbon.
271 IEA (2023), *Global methane tracker.*
272 Referring to $CO_2$ only, not $CO_2$ equivalent emissions.
273 Saunois, M. et al. (2020), *The Global Methane Budget 2000–2017.*
274 It is assumed that IPCC carbon budgets take the long-lasting products of tropospheric oxidation of $CH_4$ into account; "Collins, M. et al. (2018), applied a process-based approach to assess the importance of $CH_4$ reductions for the 1.5°C target. Their modelling approach included indirect effects of CH4 on tropospheric ozone, stratospheric water vapour and the carbon cycle." IPCC (2018), *Global warming of 1.5°C: An IPCC Special Report.*
275 IPCC (2021), *Climate change 2021: The physical science basis.*

EXHIBIT 8.1

## Scope 1 & 2 emissions for coal, oil and natural gas

Emission from fossil fuels production, processing, transport and refining (scope 1 and 2) for 2022
$GtCO_2e$




**NOTE:** Methane $CO_2$ equivalence is expressed using a $GWP_{100}$ = 30, coal production and transport emissions are estimated as ~1.4% of life-cycle emissions, based on US Congressional Research Service (2015), emissions from oil and natural gas cannot be dissociated as they are systematically co-produced and cannot be precisely allocated.

**SOURCE:** Systemiq analysis for the ETC; IEA (2023), *Scope 1 and 2 GHG emission from oil and gas operations in the Net Zero Scenario*; IEA (2023), *Global Methane Tracker*; IEA (2023), *$CO_2$ Emissions in 2022*; UNEP (2022), *Emissions gap report 2022*; US Congressional Research Service (2015).

These scope 1 and 2 emissions would disappear in a world with no fossil fuel use and will mechanically fall by 80 to 90% by 2050 if the pathways described in Chapter 2 were achieved.[276,277] But it is also possible to abate these emissions by reducing the amount of scope 1 and 2 emissions per tonne of coal, cubic metre of gas or barrel of oil produced and consumed - and given the projections set out in Chapter 2, which indicates still very significant fossil fuel use in 2030 and 2040, it is essential that scope 1 and 2 emissions are addressed as fast and comprehensively as possible.

If emissions intensity (i.e. scope 1 & 2 emissions per quantity of fossil fuel used) is not reduced, our projections for fossil fuel use in 2040 would imply continued scope 1 & 2 emissions of 2.5–3.8 $GtCO_2e$ in that year. This would be equivalent to ~20% of all unabated emissions.[278]

We describe in turn below:

- Coal-related emissions, actions to drive reductions and appropriate policies.
- Oil and gas-related emissions, actions and policies - these are considered together given oil and gas are co-produced from the same fields.[279]

276 Note that additional emissions reduction could be achieved by focusing on closing down fields and mines with highest emissions-intensity, as there is a 2.5x and 5x variation in lifecycle emissions from oil and gas fields. Systemiq analysis for the ETC; OCI (2023), *Oil and gas emissions database.*

277 Such reductions are unlikely to apply to methane emissions from coal mining due to continued leakage of methane after mine closure, see Chapter 8.1.2.

278 Taking into account both scope 1 & 2 $CO_2$ and methane emissions, relative to net emissions (including CCUS) from fossil fuels, flaring, waste and industrial processes, excluding AFOLU).

279 RMI (2022), *Know your oil and gas.*

## 8.1 Emissions from coal mining

85% of scope 1 and 2 emissions from coal production are fugitive methane emissions - this is the equivalent of 40.5 $MtCH_4$, and accounts for 10% of total anthropogenic methane emissions.[280] Coal seams naturally contain methane that is released during mining operations, directly to the atmosphere for surface or open pit mines, or from safety venting in underground mine ventilation systems.[281] Methane emissions from underground coal mines are the most material, but they are also the easiest to mitigate.[282,283] Other methane emissions are produced during the processing, transport and storage of coal, when trapped methane seeps out, and from abandoned mines – the latter are currently poorly quantified and accounted for.[284,285]

Scope 1 and 2 $CO_2$ emissions for coal mostly arise from the diesel used by machinery and equipment required for site preparation, mine drilling and casing, as well as for onsite power generation.[286]

The main priority for coal is therefore to mitigate methane emissions from both active and abandoned coal mines.

### 8.1.1 Methane emissions from active coal mines

Many opportunities exist to reduce coal mine methane (CMM) from active mines. The IEA estimates that around half of methane emissions from active coal mines could be avoided using existing technologies.[287] As shown in Exhibit 8.2, levers to reduce CMM include capturing and eliminating fugitive methane emissions (circa 8.3 $MtCH_4$), or using them to meet onsite heat and power demand (circa 12.8 $MtCH_4$, though this would result in some $CO_2$ emissions).[288]

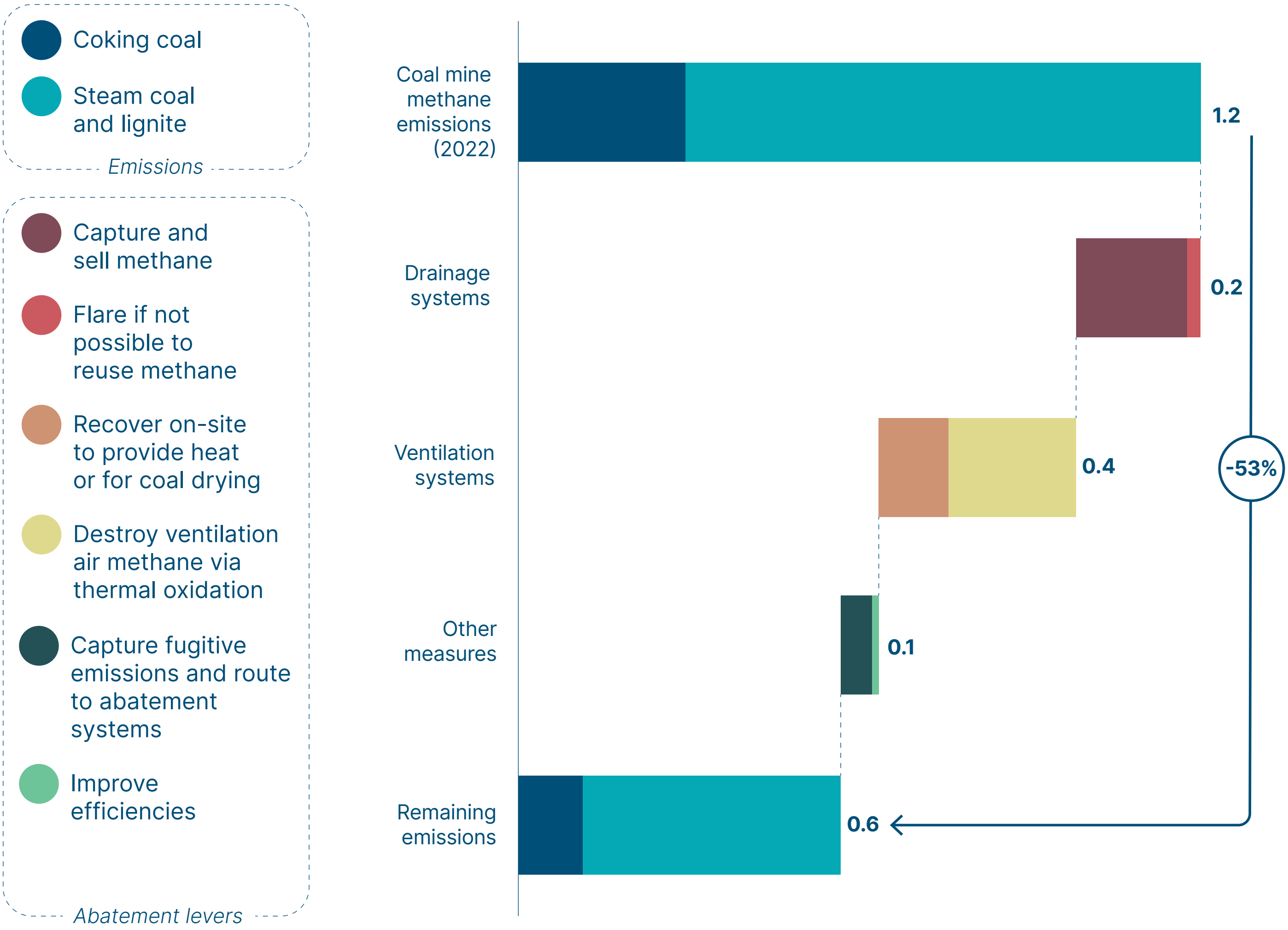
The economics for valorising captured methane depend largely on the structure of mines and the concentration of methane in the captured flux, as well as regional coal and power prices.[289] The IEA estimates that around 6 $MtCH_4$ (equivalent to 15%) can be abated at no or negative costs [Exhibit 8.3].[290]

280 Note: excluding methane emissions from abandoned coal mines. IEA (2023), *Driving down coal mine methane emissions.*
281 IEA (2023), *Global methane tracker 2023.*
282 IEA (2023), *Driving down coal mine methane emissions: A regulatory roadmap and toolkit.*
283 Ember (2023), *Major loopholes for coal mines in EU methane regulation.*
284 Ibid.
285 UNECE (2019), *Best practice guidance for effective methane recovery and use from abandoned coal mines.*
286 Liu et al. (2022), *Managing methane emissions in abandoned coal mines.*
287 Ibid.
288 Ibid.
289 Air from ventilation systems of underground mines often contains less than 1% methane.
290 Ibid, based on average regional coal and power prices for 2017–2021.

EXHIBIT 8.2

## Breakdown of coal mine methane emissions for 2022 and abatement potential

Coal mine methane emissions and mitigation levers
$GtCO_2e$



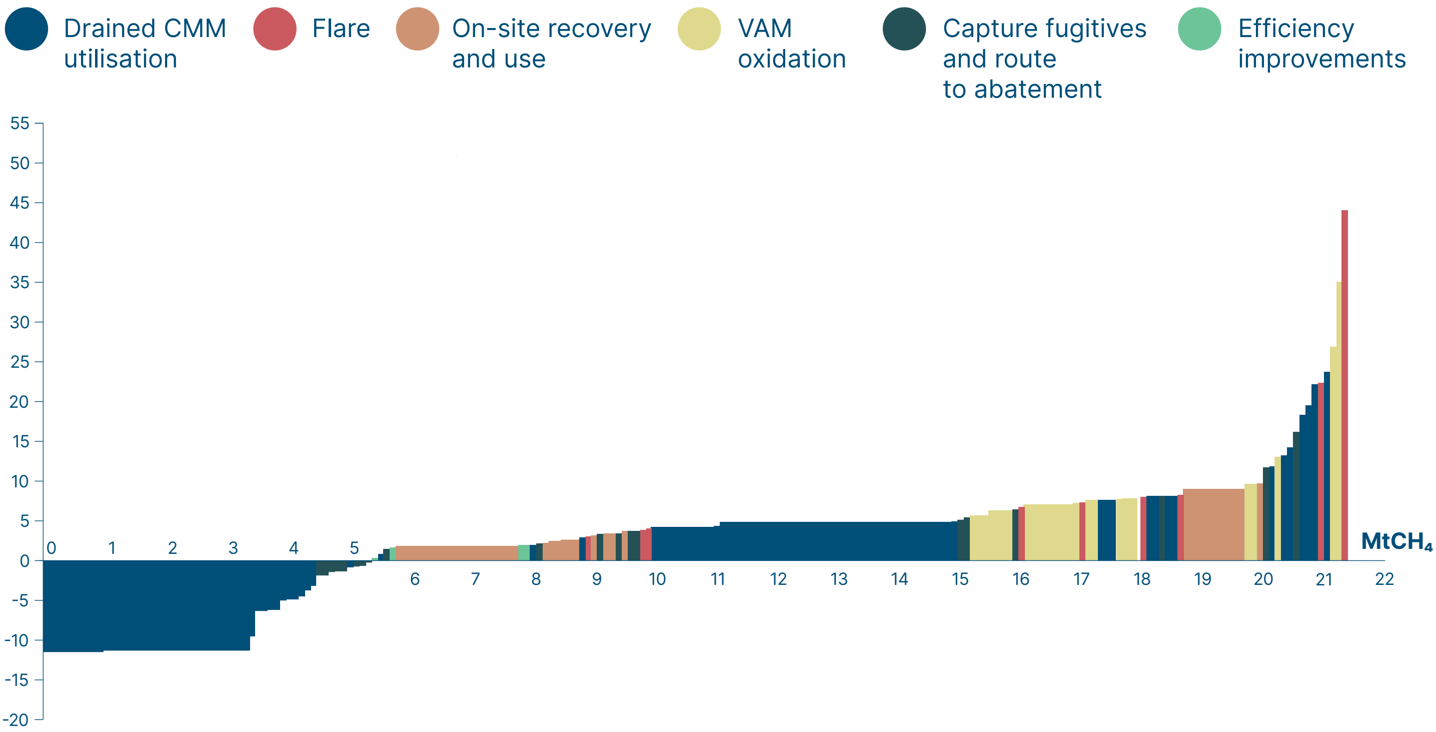

**NOTE:** Methane $CO_2$ equivalence is expressed using a $GWP_{100}$ = 30. Emissions from abandoned coal mines are not included in these estimates but could represent a significant source of emissions.

**SOURCE:** Systemiq analysis for the ETC; IEA (2023), *Coal mine methane emissions and abatement potentials.*

EXHIBIT 8.3

## Marginal abatement cost curve for coal mine methane emissions

Marginal abatement cost curve
$/MMBtu




**NOTE:** Abatement measures with MAC > $53/MMBtu are not displayed.
CMM = Coal Mine Methane; VAM = Ventilation Air Methane.

**SOURCE:** Systemiq analysis for the ETC; IEA (2023), *Coal mine methane emissions and abatement potentials, 2022.*

## 8.1.2 Methane emissions from abandoned coal mines

Although poorly quantified today, there is high certainty that methane emissions from abandoned coal mines are material, estimated at around 25–30% that of CMM, and can explain gaps between estimated values and on-the-ground measurements.[291,292]

As Exhibit 7.10 illustrated, a large share of the existing 4,300 coal mines today will close in the upcoming years, with supply from existing mines more than sufficient to meet projected demand in the scenarios described in Chapter 2.[293] It is therefore crucial to minimise emissions from abandoned mines.

While levers to abate abandoned mine methane (AMM) emissions exist, it's unlikely that all can be mitigated. AMM emissions can be reduced by flooding abandoned mines or capturing and using, or eliminating, residual methane.[294] Mine flooding is efficient but takes 8 to 20 years to complete, and is highly location-specific.[295] Additionally, flooding of abandoned coal mines can also have adverse environmental impacts, including underground water pollution due to heavy metals or others pollutants.[296] When flooding is not an option, AMM can be captured by sealing abandoned mines and then flared, but not all mines are suited for this solution.[297] Alternatively, the captured AMM can be used to generate power and heat, but the applicability of such solution depends on the local energy needs, infrastructure availability and methane concentration in the trapped gas.[298]

291 Kholod et al. (2020), *Global methane emissions from coal mining to continue growing even with declining coal production.*
292 A recent study in China estimated that methane emissions from abandoned coal mines reached approximately 5 $MtCH_4$ in 2020, equivalent to 4% of energy-related methane emissions that year. Chen et al. (2022), *Substantial methane emissions from abandoned coal mines in China.*
293 Global Energy Monitor (2023), *Global coal mine tracker.*
294 World Bank (2022), *Tackling methane emissions from abandoned and active coal mines.*
295 Ibid.
296 Environment Agency (2008), *Abandoned mines and the water environment.*
297 Ember (2023), *Major loopholes for coal mines in EU methane regulation.*
298 Chen et al. (2022), *Substantial methane emissions from abandoned coal mines in China.*

## 8.1.3 Policies and regulations to address scope 1 and 2 emissions from coal

Unlike scope 1 & 2 $CO_2$ emissions, which are relatively small and will mechanically fall as coal demand is phased out, methane emissions from coal mining will not decline in a similar fashion and will continue well beyond the closure of existing mines.[299] It is therefore crucial to take action to reduce methane emissions from active mines, abandoned mines, and future abandoned mines.

**Commitments** from responsible coal mining companies should include:

- Targets to reduce scope 1 and 2 methane intensity from operating coal mines by 30% by 2030,[300] and by at least 50% by 2040,[301] reaching near-zero by 2050.
- Systematic flooding of abandoned mines where possible.
- Targets to reach zero methane venting from abandoned coal mines, while reaching a minimum flaring efficiency threshold of 98%.

Policies and regulations have a major role to play to create the incentives for producers to exploit opportunities and deliver on commitments. And governments are at the forefront to deliver on these targets given that around 60% of global coal mines are owned by governments or are state-owned enterprises.[302]

Policies should reinforce emissions monitoring and report transparency from all producers, supported and enabled by progress in satellite technologies.[303] Policies should help overcome technical barriers to mitigating coal mine methane emissions by sharing best operational practices across the industry. Most importantly, policies should focus on pricing externalities appropriately to create the required financial incentives for coal producers to act on abating methane emissions.

299 A growing body of work suggests that there exists a gap between top-down estimates of global coal mine methane emissions from authoritative bodies (e.g., the IEA or the World Bank) and bottom-up estimates using on-the-ground methane emissions data from coal mines, transposed at the global level. Many sources suggest that most of this discrepancy could be explained by the methane emitted from inactive or abandoned coal mines. Analysis suggests that methane emissions from abandoned, non-flooded coal mines can still be ~40% of initial emissions 20 years after abandonment. Kholod et al. (2020), *Global methane emissions from coal mining to continue growing even with declining coal production.*

300 Relative to 2020 levels, in line with the Global Methane Pledge.

301 In line with the IEA's assessment of technically feasible methane emissions reductions.

302 Nelson et al. (2014), *Moving to a low-carbon economy: The impact of policy pathways on fossil fuel asset values.*

303 Environmental Defense Fund (2023), *Methane satellites usher in new era of emissions visibility and transparency.*

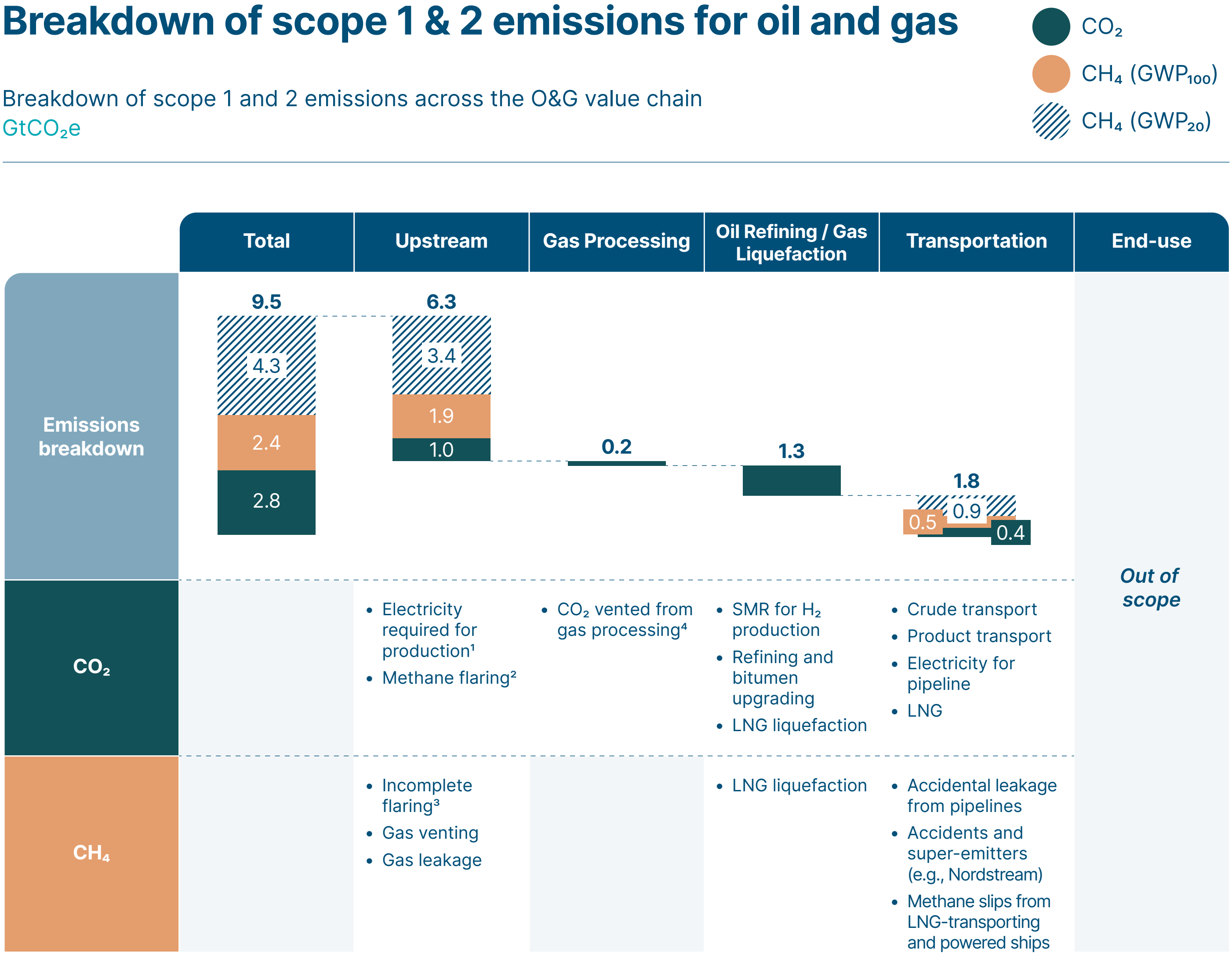
## 8.2 Emissions from oil and gas production

Exhibit 8.4 illustrates the nature of scope 1 and 2 emissions from oil and gas, which arise during upstream production, natural gas processing and liquefaction, oil refining and transport of both fuels.[304]

**EXHIBIT 8.4**

# Breakdown of scope 1 & 2 emissions for oil and gas

Breakdown of scope 1 and 2 emissions across the O&G value chain
$GtCO_2e$




**NOTE:** All numbers are rounded; GWP = Global Warming Potential, using a $GWP_{20}$ for methane of 82.5; using a methane $GWP_{100}$ for methane of 30; Hydrogen production units create a relatively pure stream of $CO_2$ that is often vented: this accounts for 60% of the total $CO_2$ emitted by a steam methane reformer (SMR) and it is straightforward to capture it; LNG liquefaction requires cooling it to -162 °C, which is an energy intensive process that is usually powered by consuming a portion of the gas flowing to the (often remote) facility.
[1] 700 $MtCO_2$ from onsite power generation to power rig operations, [2] 260 $MtCO_2$ from complete methane flaring, [3] 8 Mt of methane emissions / 240 $MtCO_2eq$, [4] 25 $MtCO_2$ is already captured today and mostly used for enhanced oil recovery, a smaller fraction is directly stored in depleted fields.

**SOURCE:** Systemiq analysis based for the ETC; IEA (2023), *Emissions from Oil and Gas Operations in Net Zero Transitions.*

The intensity of these emissions (i.e. emissions per barrel of oil or per cubic metre of gas) varies greatly between different production sites [Exhibits 8.5 and 8.6]. Most of this variation comes from upstream emissions, with the emissions intensity of oil varying 50 times from lowest to highest emitting fields, and 33 times for natural gas.[305]

One way to reduce scope 1 and 2 emissions might therefore be to focus on oil and gas production from those types of fields which have low emissions intensity, but there are limits to the effectiveness of such an approach.

304 IEA (2023), *Global methane tracker 2023.*
305 Systemiq analysis for the ETC; OCI (2023), *Oil and gas emissions dataset.*

**Oil:** the variation in total emissions is partly explained by the carbon content of the different oil products and the higher energy consumed for their extraction and conversion.[306] For instance, lifecycle emissions of heavy and extra-heavy oil and oil sands are systematically higher per barrel produced compared to other oil resources (e.g., light or medium oil) [Exhibit 8.7].[307] And although technically feasible, reducing these emissions is costly and will only bring emissions broadly in line with the average intensity of other oil resources.[308,309] There are thus strong arguments to prioritise the phase-out of such oil resources and for financial institutions to refuse to finance or insure them.

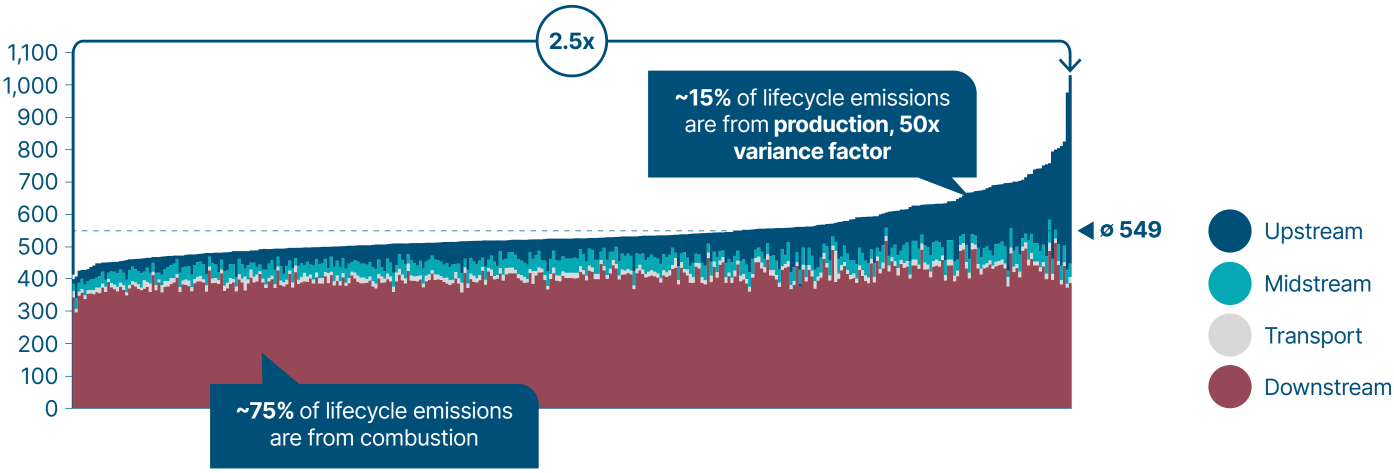
However, most of the variation in lifecycle emissions reflects differences in technical efficiency in production, processing, transport and refining, with no clear correlation between type of oil and emissions intensity.[310]

**Natural gas:** compared to oil, there is far less variation in the nature of end-products, and no specific type of source which results in inherently higher emissions intensity. Differences in the technical efficiency of operations are the dominant cause of variation in lifecycle emissions, with significant differences across regions and countries that reflect various degree of stringency and enforcement of best practices and penalties. Unlike oil, the method of gas transport has a material impact on emissions, with LNG – around 10% of global gas supply, and growing - increasing emissions from transport by around 60% compared to pipelines.[311]

**EXHIBIT 8.5**

## Lifecycle emissions intensity of oil production

Lifecycle (scope 1–3) emissions intensity for oil
$kgCO_2e/boe$




**NOTE:** Emissions intensity shown above is for lifecycle emissions of 70% of the oil and gas wells currently in operation. A $GWP_{100}$ of 30 for methane and 273 for nitrous oxide is used.

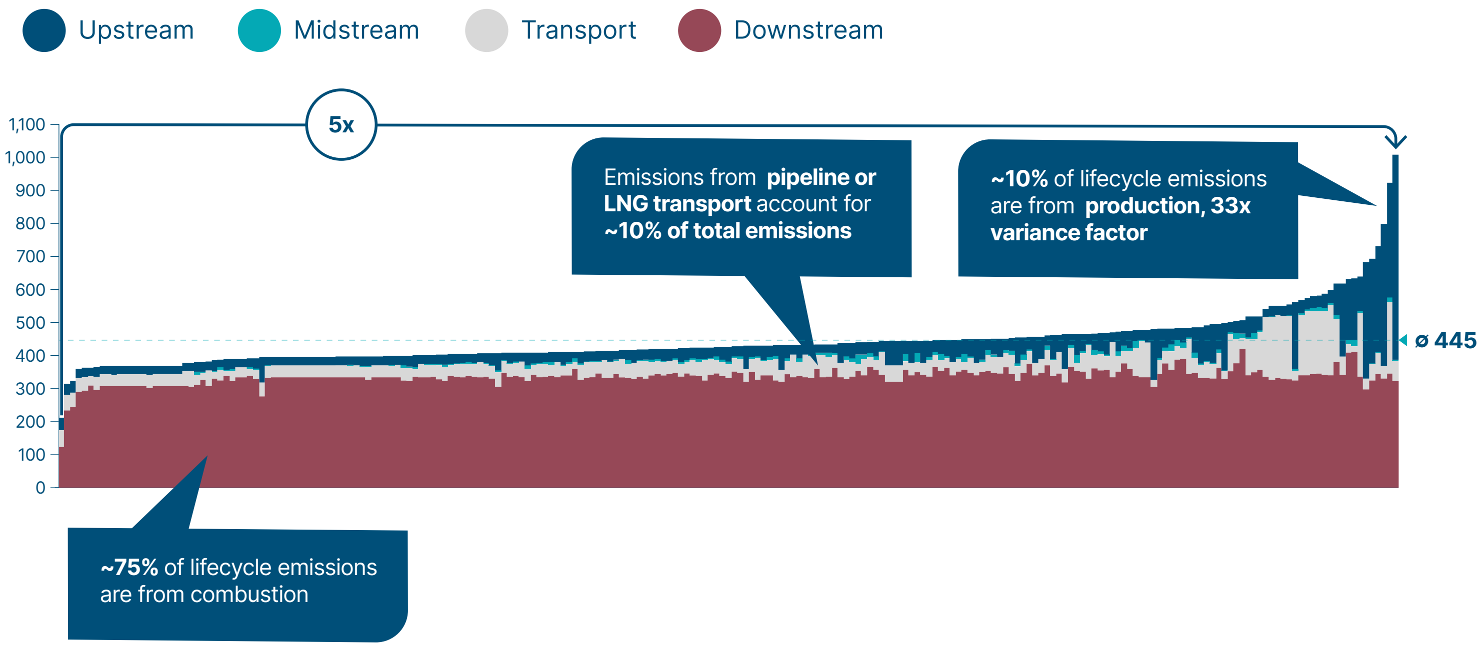
**SOURCE:** Systemiq analysis for the ETC; OCI+ (2023), *Oil and gas production emissions database*; RMI (2022), *Know your oil and gas.*

306 RMI (2022), *Know your oil and gas.*
307 Ibid.
308 Mitigation levers include CCUS, solar steam for enhanced oil recovery, green hydrogen for desulphurisation or catalyst use in refining. Source: Ibid.
309 Systemiq analysis for the ETC; OCI (2023), *Oil and gas emissions dataset.*
310 Only extra-heavy oil, heavy oil and acid natural gas have comparably higher average upstream emissions intensity compared to other resource types. Source: Systemiq analysis for the ETC; OCI (2023), *Oil and gas emissions dataset.*
311 Systemiq analysis for the ETC; OCI (2023), *Oil and gas emissions dataset.*

EXHIBIT 8.6

## Lifecycle emissions intensity of gas production

Lifecycle (scope 1–3) emissions intensity for natural gas
$kgCO_2e/boe$



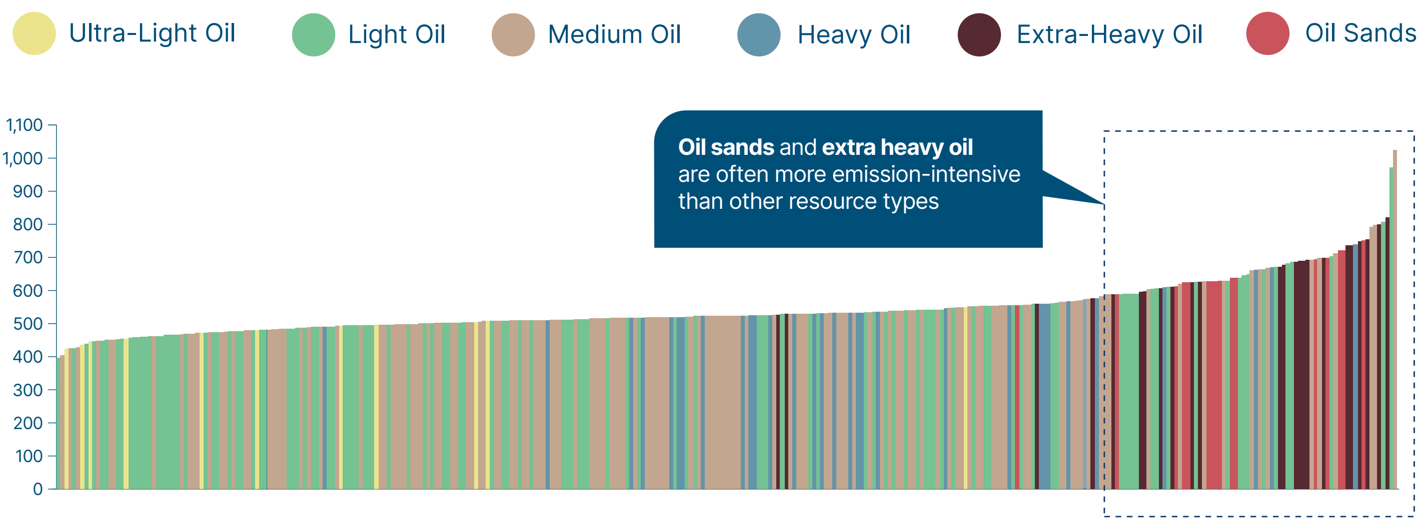

**NOTE:** Emissions intensity shown above is for lifecycle emissions of 70% of the oil and gas wells currently in operation. A $GWP_{100}$ of 30 for methane and 273 for nitrous oxide is used.

**SOURCE:** Systemiq analysis for the ETC; OCI+ (2023), *Oil and gas production emissions database*, RMI (2022), *Know your oil and gas*.

EXHIBIT 8.7

## Lifecycle emissions intensity by oil resource type

Lifecycle emissions intensity per oil type
$kgCO_2e/boe$




**NOTE:** Emissions intensity shown above is for lifecycle emissions of 70% of the oil and gas wells currently in operation. A $GWP_{100}$ of 30 for methane and 273 for nitrous oxide is used.

**SOURCE:** Systemiq analysis for the ETC; OCI+ (2023), *Oil and gas production emissions database*, RMI (2022), *Know your oil and gas*.

The main priority is therefore to drive down scope 1 and 2 emissions intensity across all fields, bringing these emissions to best-in-class levels and eliminating them where feasible.

### 8.2.1 Levers to abate scope 1 and 2 emissions from oil and gas

Exhibit 8.8 illustrates where methane emissions from oil and gas production arise. Eliminating non-emergency (or routine) methane flaring, addressing fugitive emissions (leaks) and avoiding venting by upgrading existing equipment (e.g., pumps) and infrastructure are "no-regret" strategies for the oil and gas industry. In particular:

Methane that is currently flared can serve many purposes, including being used in EOR, for onsite power generation with CCS, or being brought to market via pipelines, as compressed natural gas, or as LNG if associated conditioning and transport infrastructure is available. Reducing methane emissions from flaring can also be achieved by deploying flares with high combustion efficiencies (striving for at least 98%), and continually monitoring the efficiency of flares.

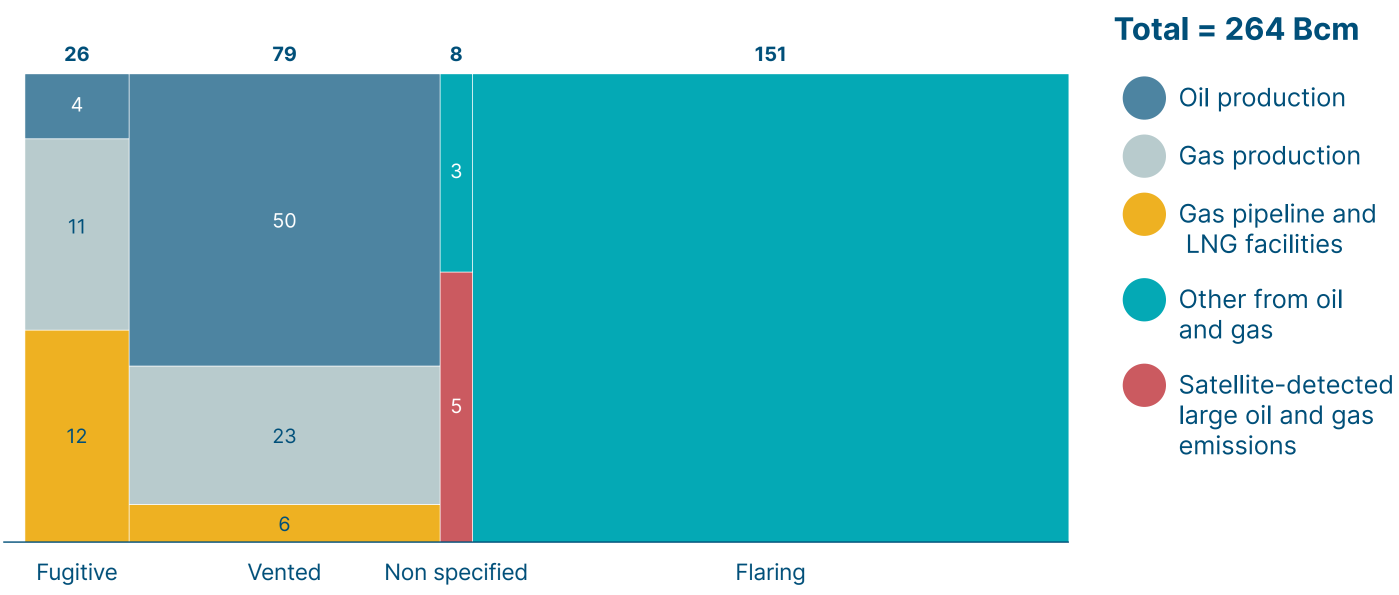
Fugitive methane leaks can be addressed through more frequent leak detection and repair (LDAR) campaigns, and the replacement of existing equipment [Exhibit 8.9]. LDAR is today labour-intensive and thus costly, but significant progress in satellite and drone technologies is expected to cut costs and enable more systematic monitoring of methane leaks.

Implementing these strategies could have resulted in an additional 264 Bcm of natural gas being marketed in 2022, equivalent to the European Union's annual imports from Russia before the invasion of Ukraine, and in turn reducing emissions equivalent to 2.6 $GtCO_2e$.[312,313]

**EXHIBIT 8.8**

## Sources of methane emissions for oil and gas production in 2022

Methane emissions sources
Bcm




**NOTE:** Fugitive methane emissions occur from leakages that are not intended, for example because of a faulty seal or leaking valve. Vented methane emissions are the result of intentional releases, often for safety reasons, due to the design of the facility or equipment (e.g., pneumatic controllers) or operational requirements (e.g., venting a pipeline for inspection and maintenance). Flaring occurs when oil field operators opt to burn the "associated" gas that accompanies oil production rather than using or marketing it. Flaring also includes methane emissions from incomplete combustion of associated gas. Non-specified emissions are significant sources of emissions detected externally (mostly via satellite technology) and cannot be clearly attributed to either leaks, venting or flaring.

**SOURCE:** Systemiq analysis for ETC; IEA (2023), *Methane tracker.*

312 IEA (2023), *Global methane tracker 2023.*
313 More than half of flaring for instance occurs within 20km of existing gas pipelines. Capterio (2020), *We must minimize flaring gas near existing pipelines.*

While 75% of current methane emissions from oil and gas production, processing and transport could be reduced with existing and proven technologies, much of which at low or no cost, current targets like the Global Methane Pledge only aim for a 30% reduction by 2030, and major emitters like Russia, Iran, Turkmenistan, and China have not committed.

Beyond methane, oil and gas companies can further reduce scope 1 and 2 emissions by improving operational efficiencies and electrifying upstream and refining operations with clean electricity, in particular to power drilling rigs, pumps, compressors, and other equipment. Such measures could halve upstream $CO_2$ emissions but in most cases incur additional capital spending for operators.

In refining, analysis suggests that operational improvements, enabled by digital technologies, can reduce emissions by ~30% at no or negative cost.[314] Other abatement measures include the deployment of CCUS for natural gas processing, captive grey hydrogen production in refining and bitumen upgrading, and in LNG liquefaction. These would incur additional capital investments and running costs to producers but could shave off another 160 $MtCO_2$ of emissions.[315]

Overall, recent analysis from the IEA suggests that:

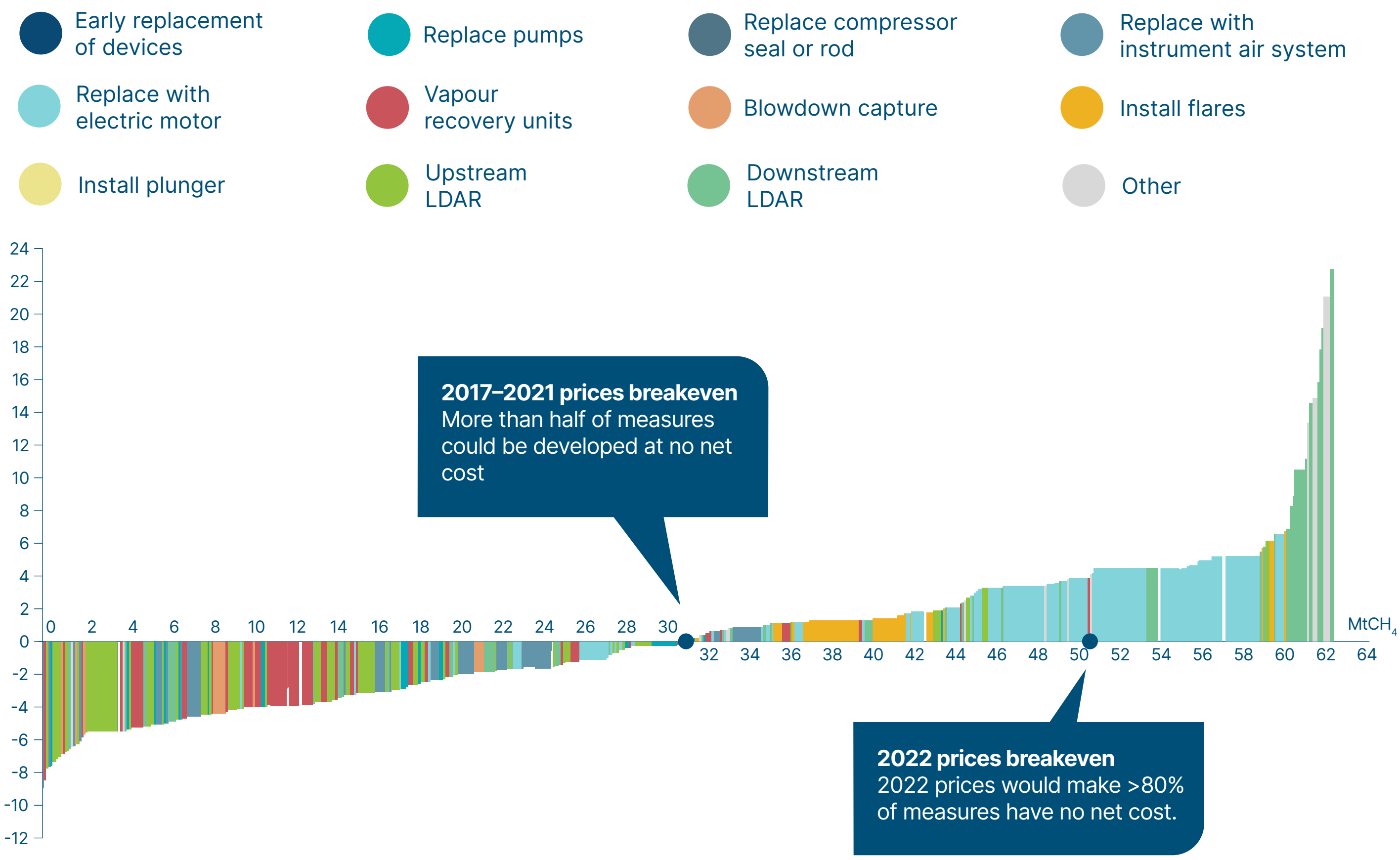
- 60% (equivalent to 3.1 $GtCO_2e$) of scope 1 and 2 emissions from oil and gas production could be reduced by 2030 at a net cumulative cost of $345 billion, about 8% of annual profits from the industry in 2022 (or 20% of average annual profits between 2000–2021).[316,317]
- 30 $MtCH_4$ from oil and gas production could be eliminated at zero or negative costs, and 60 $MtCH_4$ (equivalent to 48% of methane emissions from fossil fuels) can be eliminated for less than $20/$tCO_2e$ [Exhibit 6.8].[318]

314 Concawe (2019), *CO2 reduction technologies: Opportunities within the EU refining system (2030/2050)*.
315 IEA (2023), *Emissions from oil and gas operations in net-zero transitions.*
316 Estimates of the cost of emissions reduction is highly sensitive to the assumed price of natural gas.
317 IEA (2023), *Emissions from oil and gas operations in net-zero transitions.*
318 Ibid.

EXHIBIT 8.9

# Marginal abatement cost curve of scope 1 & 2 methane emissions from oil and gas

Methane abatement cost curve for oil and gas production
$/MMBtu




**NOTE:** LDAR = Leak Detection and Repair.

**SOURCE:** IEA (2023), *Global Methane Tracker 2023.*

## 8.2.2 Implications for commitments and policy on oil and gas scope 1 and 2

It is therefore vital that countries and fossil fuel companies commit to significant and rapid reductions in scope 1 and 2 emissions. These should include specific targets for methane, which is the most effective lever to reduce short-term temperature increases, as explained in Box I, and should also include targets to eliminate routine gas flaring, currently responsible for around 95% of all flared gas today.[319] These should be backed by taxes and/or penalties on $CO_2$ and methane emissions resulting from oil and gas production, such as the Methane Emissions Charge in the US, which taxes methane emissions at $900–1,500 per tonne.[320]

Several oil and gas companies, in particular IOCs, have already made commitments to reduce emissions from production, transport and processing, and in some cases with specific targets for methane reductions [Exhibit 8.10].[321] And the COP28 Presidency will seek to achieve industry-wide agreement to scope 1 and 2 emissions reduction for oil and gas.

319 Ibid.
320 EPA (2023), *Methane Emissions Reduction Programme.* Equivalent to $30-50/t$CO_2$.
321 Systemiq analysis of sustainability reports from selected publicly listed companies.

EXHIBIT 8.10

# Scope 1 & 2 targets and progress from international and national oil companies

| | | $CO_2$ | | | | | Methane ($CH_4$) intensity | | | | | | Gold Standard | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Company Type** | **Company** | **Intensity vs. Absolute** | **Target** | **Target date** | **Baseline** | **Normalized target to 2030** | **Intensity vs. Absolute** | **Value in 2022 (% or $ktCH_4$)** | **Target** | **Target date** | **Baseline** | **Normalised target to 2030** | **Operational vs. equity** | **Divestments included** |
| | *ETC Aligned* | *Intensity* | *-50%* | *2030* | *2022* | *-50%* | *Intensity* | | *-75%* | *2030* | *2022* | *-75%* | *Equity* | *No* |
| **IOCs** | BP | *Absolute* | *-50%* | *2030* | *2019* | *-15%* | *Intensity* | *0.05%* | *-50%* | *2030* | *n.a.* | *n.a.* | Operational | Yes |
| | Total Energies | *Absolute* | *-40%* | *2030* | *2015* | *-29%* | *Absolute* | *42kt* | *-80%* | *2030* | *2020* | *-69%* | Operational | Yes |
| | Shell | *Absolute* | *-50%* | *2030* | *2016* | *-30%* | *Intensity* | *0.05%* | *Near-zero by 2030* | | | | Operational | Yes |
| | Eni | *Absolute* | *-35%* | *2030* | *2018* | *-29%* | *Intensity* | *0.08%* | *Near-zero by 2030* | | | | Operational | Yes |
| | Exxon | *Absolute* | *-100%* | *2050* | *2016* | *n.a.* | *Intensity* | *n.a.* | *-60/70% in flaring* | *2030* | *2016* | *n.a.* | Operational | Yes |
| | Conoco Philips | *Intensity* | *-50-60%* | *2030* | *2016* | *-20%* | *Intensity* | *n.a.* | *-50/60%* | *2030* | *2016* | *n.a.* | Equity | *n.a.* |
| | Chevron | *Absolute* | *-100%* | *2050* | *2018* | *n.a.* | *Intensity* | *n.a.* | *n.a.* | *n.a.* | *n.a.* | *n.a.* | Operational | *n.a.* |
| **NOCs** | Saudi Aramco | *Intensity* | *-15%* | *2035* | *2018* | *n.a.* | *Intensity* | *0.05%* | *Near-zero by 2030* | | | | Operational | *n.a.* |
| | Equinor | *Absolute* | *-50%* | *2030* | *2015* | *-28%* | *Intensity* | *0.02%* | *Near-zero by 2030* | | | | Operational | *Yes* |
| | Petro China | *n.a.* | *n.a.* | *2024* | *n.a.* | *n.a.* | *Intensity* | *0.4%* | *-50%* | *2025* | *2019* | *n.a.* | Operational | *Yes* |
| | Petrobras | *Absolute* | *-30%* | *2030* | *2015* | *n.a.* | *Intensity* | *n.a.* | *-55%* | *2025* | *2015* | *n.a.* | *Operational* | *Yes* |
| | Petronas | *In process of setting targets and accounting for their $CO_2$ and methane emissions* | | | | | | | | | | | | |
| | Sinopec | | | | | | | | | | | | | |
| | CNOOC | | | | | | | | | | | | | |
| | Gazprom | | | | | | | | | | | | | |

**NOTE:** Non-exhaustive list. IOC=International Oil Company; NOC=National Oil Company.

**SOURCE:** Systemiq analysis for the ETC; 2022 annual reports from selected O&G companies.

However, commitments from the industry still fall short of what is technically feasible and should be achieved to limit global temperature increases to 1.5°C. And while commitments have been made to reduce flaring or methane emissions, in line with industry-standard initiatives such as the World Bank's *Zero Routine Flaring by 2030* or OGCI's *Aiming for Zero Methane Emissions* initiative, actual progress in reducing emissions has stagnated over the last few years [Exhibit 8.11].

At the global level, the oil and gas industry must:

- Commit to reduce scope 1 and 2 $CO_2$ emissions intensity of production by at least 50% by 2030 versus 2022, reaching net-zero by 2050.[322]
- Commit to reduce methane emissions by 75% by 2030,[323] ultimately reaching near-zero emissions by 2050, to be on a 1.5°C trajectory.

Given the discrepancy between bottom-up and top-down estimates for methane emissions,[324] achieving this target requires the implementation of more comprehensive, reliable and transparent measurement and accounting methods for oil and gas companies.

322 In line with IEA Net-Zero. IEA (2023), *Emissions from oil and gas operations in net-zero transitions.*
323 Relative to 2022 baseline, in line with the IEA Net-Zero scenario. IEA (2023), *Emissions from oil and gas operations in net-zero transitions.*
324 IEF Methane Initiative (2021), *Methane mitigation in the energy sector.*

As Exhibit 8.10 shows, most IOCs already meet guidelines established by the OGCI and MiQ,[325] but most NOCs do not report their emissions; and the overall methane intensity of oil and gas production, which is still far from what is required on a 1.5°C trajectory [Exhibit 8.11]. This in part reflects the fact that OGCI and MiQ targets only include methane emissions from operated assets and fail to account for emissions from non-operated joint ventures (NOJV) with NOCs.[326] Including emissions from NOJV would force IOCs to extend best operational practices and collaborate with NOCs to reduce their much greater methane emissions.

Given these facts, standard setters (such as OGCI and MiQ) should:

- Commit to establish an industry-wide accounting framework to improve the transparency, tracking and monitoring of methane emissions.
- Set targets and guidelines to include methane emissions from NOJV on an equity basis, targeting reductions in $CO_2$ and methane emissions intensity at least in line with those required in the IEA Net-Zero scenario.[327]

At the company level, all oil and gas company targets should include:

- Commitments to reduce scope 1 and 2 $CO_2$ emissions intensity of production of operated assets by at least 50% by 2030,[328] and reach net-zero by 2050 at the latest.
- Commitments to limit methane emissions intensity of operated assets to at least 0.2%[329], and ideally 0.05%[330] by 2030, reaching near-zero as soon as possible and by 2050 at the latest.
- Commitments to adopt best-in-class industry standards for emissions accounting and reporting, including third-party monitoring and verification.

Gold standard commitments should:

- Count $CO_2$ and methane emissions from NOJVs on an equity basis to extend best operational practices from IOCs to assets operated by NOCs, crucial to deliver required emissions reductions.
- Not count asset sell-off and divestments towards meeting set targets unless buyer has also set gold standard commitments.[331,332]

325 MiQ is an independent non-profit established by RMI and Systemiq to facilitate a rapid reduction in methane emissions from the oil and gas sector. They have developed the MiQ standard to certify upstream natural gas production. Their standard is based on company practices, monitoring technology deployment and methane intensity. A-grade corresponds to a methane intensity <0.05%, B-grade <0.10%, C-grade <0.20% and D-level <0.50%. Note that methane emissions intensity targets from OGCI and MiQ are expressed on a percentage $m^3$ of methane emitted by $m^3$ of marketed natural gas, for operated assets only.

326 MiQ (2023), *MiQ Standard – Onshore Production*; OGCI (2023), *2023 OGCI Progress Report*.

327 When accounting for emissions from NOJVs, this would imply reaching methane emissions intensities of 0.8% by 2030. Systemiq analysis for the ETC; IEA (2023), *Emissions from oil and gas operations in net-zero transitions*.

328 Relative to 2022 baseline, in line with the IEA Net-Zero scenario. IEA (2023), *Emissions from oil and gas operations in net-zero transitions*.

329 Measured as % $m^3$ of methane emitted per $m^3$ of marketed gas, in line with MiQ C-level certification. MiQ (2023), *MiQ Standard – Onshore Production*.

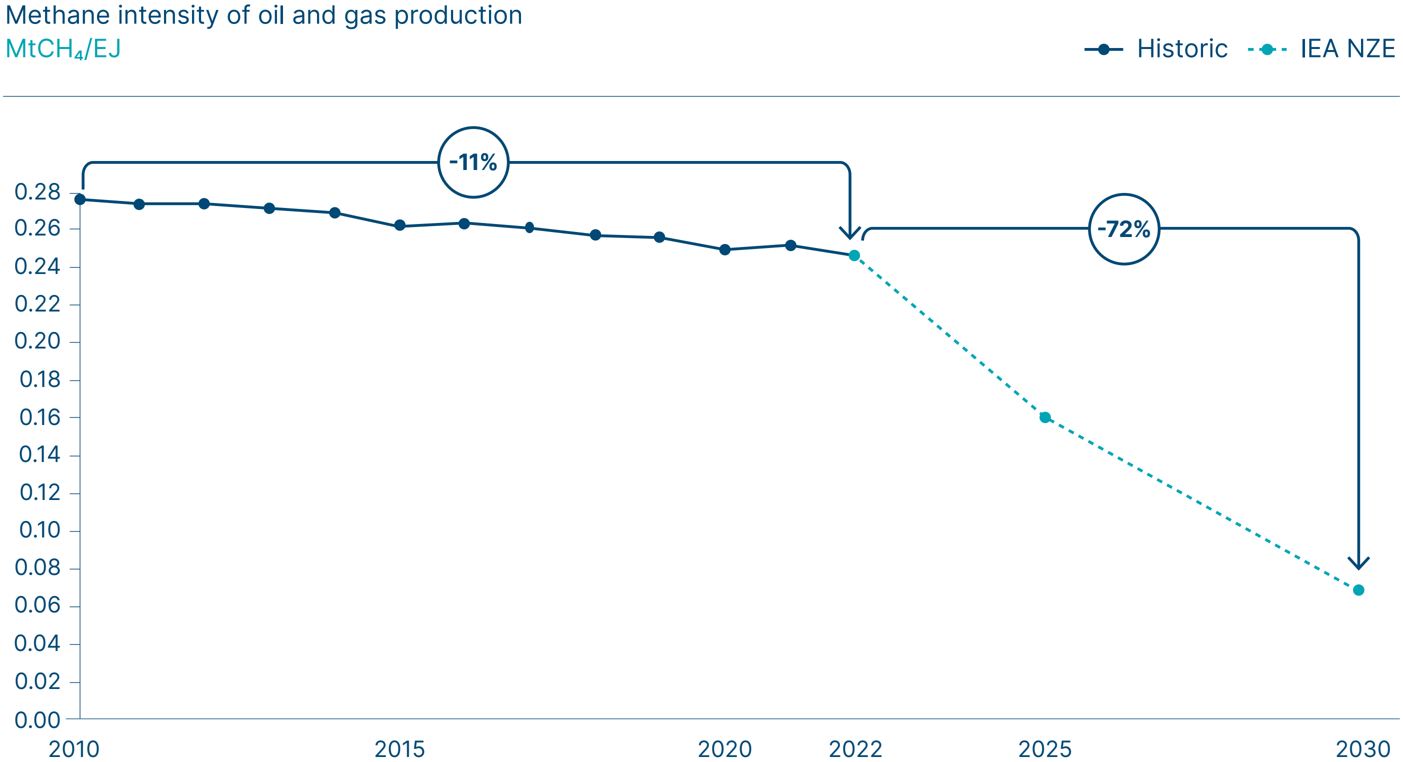
330 In line with MiQ A-level (best in class) certification. MiQ (2023), *MiQ Standard – Onshore Production*.

331 Analysis suggests that emissions from flaring have increased significantly as stake in Umuechem oil field was sold from a consortium of IOCs (Shell, TotalEnergies and Eni) to an NOC (Trans-Niger Oil and Gas). Environmental Defense Fund (2023), *How risks in O&G M&A could hamper the energy transition*.

332 Analysis suggests that most progress from IOCs to reduce scope 1 and 2 emissions from oil and gas production has been achieved by selling off most polluting sites. Arnold et al. (2023), *Transferred emissions are still emissions: Why fossil fuel asset sales need enhanced transparency and carbon accounting*; BloombergNEF (2023), *Divesting fossil fuels is driving big oil's emissions cuts*.

EXHIBIT 8.11

## Evolution of methane emissions intensity of oil and gas production in the IEA Net Zero Scenario




**NOTE:** Methane intensity of oil and gas production in the IEA NZS for 2025 and 2030 is computed by dividing projected methane emissions with reported oil and natural gas supply.

**SOURCE:** Systemiq analysis for the ETC; IEA (2023), *Emissions from oil and gas operations in net zero transitions*; Energy Institute (2023), *Statistical review of world energy*.

Gaining such commitments from as wide a range of IOCs and NOCs as possible should be a priority objective at COP28. And company commitments should be reinforced by government-enforced monitoring and reporting rules, and by regulations which require specific reductions by specific dates, with penalties for failure which create strong financial incentives to drive rapid action.

But achieving the feasible reductions across all countries will be challenging given the many countries and companies involved in fossil fuel supply and the significant discrepancy in production efficiency standards currently in place, reflected by the methane intensity of production across countries in Exhibit 8.12.[333]

Technical assistance programs should therefore be used to help lower- and middle-income countries achieve necessary reductions, and importing countries should be willing to place restrictions or taxes on oil or gas imports from countries with emissions-intensive production. This would be in line with the principle of the Carbon Border Adjustment Mechanisms (CBAM) being introduced by the EU to incentivise the decarbonisation of heavy industry in other countries. Certification mechanisms to guarantee that the oil and gas produced meets a certain emissions threshold could be valuable tools and send strong signals to markets.

However, it is likely that such measures will only have a partial effect on emissions in a world where crude oil, oil products and natural gas (such as LNG) are traded in fungible and sometimes opaque markets. In addition, major differences in the effectiveness with which targets and regulations are monitored and enforced will likely remain.[334]

Moreover, even if scope 1 and 2 emissions-intensity is significantly reduced, much larger scope 3 emissions will remain as long as fossil fuel is used in any application where fuels are combusted and CCS is not applied.

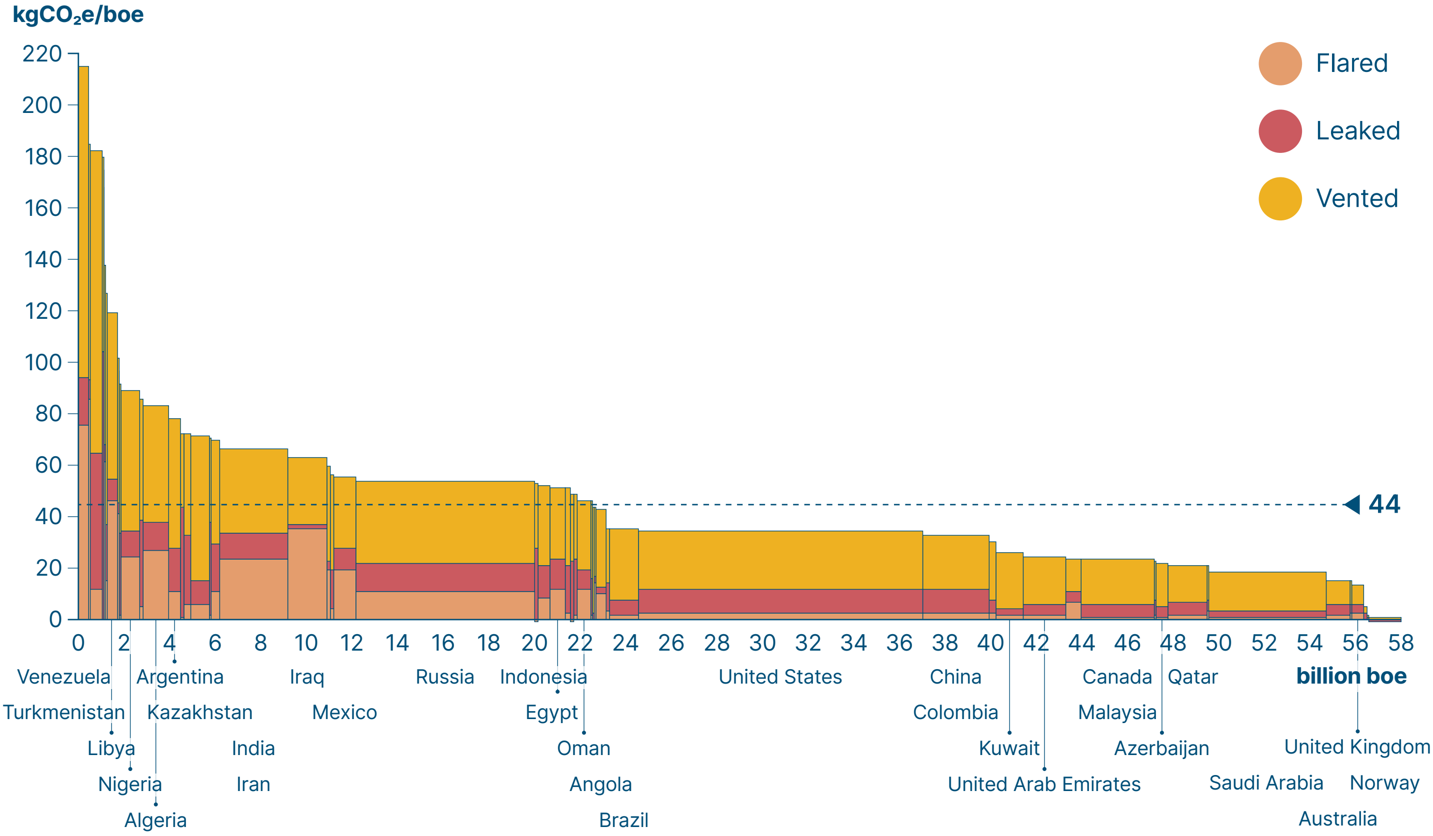
Commitments to reduce scope 1 and 2 fossil emissions from coal, oil and gas must therefore be additional to, and not instead of, commitments to reduce scope 3 emissions to net-zero by 2050.

333 Capterio (2023), *Gas flaring shows modest improvement – but not in the countries that matter most.*
334 Financial Times (2023), *EU urged to crack down on imports of Indian fuels made with Russian oil.*

EXHIBIT 8.12

# Methane emissions intensity of oil and gas production by country in 2022

Relative carbon intensity of production




**NOTE:** GMP = Global Methane Pledge. In this analysis, we use a 100-year Global Warming Potential of 30 to calculate the $CO_2$-equivalent of methane.

**SOURCE:** Capterio (2023), *Why COP28 is right to prioritize global methane and flaring reduction;* IEA (2023), *Global methane tracker 2023;* World Bank (2022), *Global gas flaring data;* Energy Institute (2023), *Statistical review of world energy 2023.*

# Chapter 9

# Actions to deliver required emissions reduction

This report has set out how significant fossil fuel demand reductions of 12–21% by 2030, 44–64% by 2040 and 73–85% by 2050 are possible under accelerated and stretching, but feasible, policies in our ACF and PBS scenario.

Assessment of the implied GHG emissions and the ambitious but necessary deployment of point-source CCS and removals, both nature-based and engineered, shows that reductions in fossil fuel consumption any less than those implied by the ACF and PBS would not be compatible with meeting climate objectives.

Delivering such reductions in fossil fuel demand will require strong and ambitious policies enforced globally and across sectors, as detailed in Chapter 5.3. These policies should reinforce and accelerate the decline in fossil demand already taking place through policies around the world, such as long-term contracts for renewables, electric vehicles uptake, and carbon pricing. Action must also extend to areas where stronger policy is required to go further, such as incentivising a switch to clean heating and cooking, or stronger support for early-stage projects in the heavy transportation and industrial sectors, alongside the development of associated infrastructure.

In addition to reducing demand for fossil fuels, policies that restrict the supply of fossil fuels are also likely to be required, as set out in Chapter 7.

Matching reductions in fossil fuel demand with reductions in supply is essential to manage the transition to net-zero emissions by mid-century. New and increased commitments from fossil fuel companies, financial institutions, policymakers and the COP process will be required to drive this transition.

This chapter summarises the actions argued for in this report, by stakeholder.

### Oil and gas companies[335]

- Commit to no new exploration to discover new oil and gas basins/fields.
- Commit to net-zero scope 1, 2 and 3 emissions by mid-century, including:
  - Set absolute reduction targets in the production, transportation of oil, oil products and natural gas, accompanied by specific pathways for the decline in fossil fuel production over time, with transparent justification for any significant divergence from the reduction range indicated by our ACF and PBS scenarios.
  - Undertake credible assessments of the maximum role which CCS, DACCS, and NBS removals can play in meeting stated targets, and ensuring any use of point-source CCS is monitored to ensure high capture rates of carbon (i.e. in excess of 90%).
  - Commitments to reduce scope 1 and 2 $CO_2$ emissions intensity from operated assets by at least 50% by 2030 versus 2022, reaching net-zero by 2050 at the latest.
  - Commitments to limit methane emissions intensity of operated assets to at least 0.2%[336], and ideally 0.05%[337] by 2030, reaching near-zero as soon as possible and by 2050 at the latest.
  - Commitments to adopt best-in-class industry standards for emissions accounting and reporting, including third-party monitoring and verification.
  - The purchase and retirement of high-quality carbon removal credits equal to any residual GHG emissions after CCS on the pathway to net-zero.

**Gold standards commitments** for climate credible-pathways should include:

- Targets for the absolute reduction in production of oil, oil products and natural gas, with 2050 end points and interim targets for 2030 and 2040 at least in line with those implied in the ACF, and ideally in line with the PBS.
- Accounting for $CO_2$ and methane emissions from non-operated joint ventures (NOJVs) on an equity basis.
- Making clear that divestments and asset sell-offs will not be used to meet stated emissions reduction objectives unless the offtakers have also committed to gold standards.

335 Stated commitments are particularly applicable to integrated oil companies. Standard-setters should seek to develop activity-based guidelines, given the fragmentation and wide range of company types involved in the oil and gas sector.
336 Measured as % $m^3$ of methane emitted per $m^3$ of marketed gas, in line with MiQ C-level certification. MiQ (2023), *MiQ Standard – Onshore Production.*
337 In line with MiQ A-level (best in class) certification. MiQ (2023), *MiQ Standard – Onshore Production.*

### Coal companies

- Commit to no development of new mining capacity, either through new projects or extension of existing projects.
- Commit to net-zero scope 1, 2 and 3 emissions by mid-century, including:
    - Absolute reduction targets in the production of coal, accompanied by specific pathways for the decline in fossil fuel production over time, with transparent justification for any significant divergence from the reduction range indicated by our ACF and PBS scenarios.
    - Targets to reduce scope 1 & 2 methane intensity from operating coal mines by 30% by 2030, and by at least 50% by 2040, reaching near-zero by 2050.
    - Systematic flooding of abandoned mines where possible.
    - Targets to reach zero methane venting from abandoned coal mines, while reaching minimum flaring efficiency threshold of 98%.

### Governments

- Commit to enforce policies to reduce fossil fuel consumption as stated in Chapter 5.3.
- Commit to no further issuance of new exploration licenses to discover oil or gas nor approve the opening or extension of new coal mining capacity.
- Explicitly reject the idea that all national fossil fuel reserves must be exploited.
- Remove any subsidies or tax breaks that incentivise the production of fossil fuels.
- Introduce targets and penalties to incentivise reduction of scope 1 and 2 emissions from oil, gas and coal production which falls within their jurisdiction, and consider extending this to imported fossil fuels (e.g., via Carbon Border Adjustment Mechanisms).
- Commit to increase mobilisation of investment in clean energy supply in developing economies, including via multilateral development banks.
- Develop clear and globally consistent requirements for climate reporting (e.g., scope 1, 2 and 3 emissions) and transition planning, and set out a clear timeline for the enforcement of such disclosure.

### COP28

- Reiterate the COP26 commitment to phase down the use of coal, and gain commitments from all countries and governments to phase down the use and production of oil and gas.
- Seek commitments from all fossil fuel-producing companies to reach net-zero scope 1, 2, and 3 emissions by around mid-century.
- Call for future COPs to aim to gain commitments which narrow the range of uncertainty about how fast fossil fuel use can and must decline.

### Financial institutions

- Stop all financing to new oil and gas exploration.
- Stop all financial flows to any new coal mine development, or for capacity expansion of existing mines.
- Restrict financing of infrastructure and assets which are likely to lock-in use for multiple decades (as described in Chapter 5.3).
- Commit to only financing fossil fuel companies with credible strategies to reach net-zero scope 1, 2, and 3 emissions by mid-century, as stated in this Chapter.
- Set portfolio-level financed emissions targets (including scope 3 emissions from fossil fuel clients) that decline in line with at least – but ideally exceeding – the level of ambition stated in the ACF.
- Commit to a steadily increasing ratio of investments in new clean energy supply and technologies, in line with estimates stated in Chapter 7.3.
- Restrict financing of fossil fuel developments with significantly higher scope 1 and scope 2 emissions than other sources.

## Standard setters

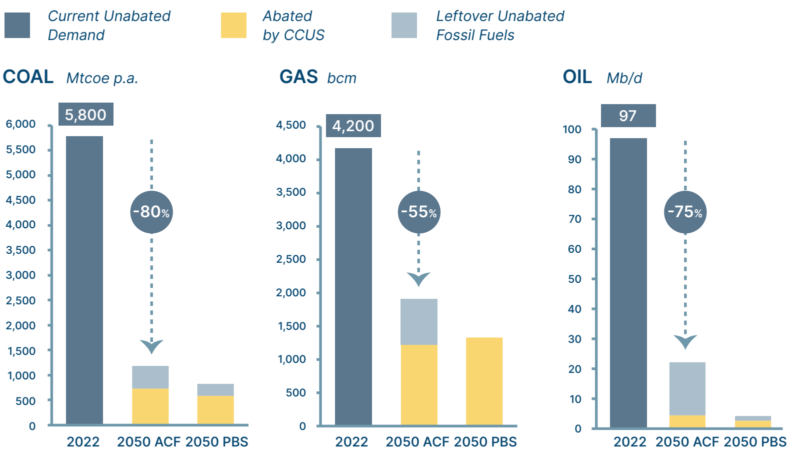
- Develop a practical standard and methodology for assessing the commitments for oil and gas companies, building on the recommendations outlined in this report.
- Commit to only endorsing fossil fuel company targets which include commitments to significantly reduce oil and gas supply in 2050 (ideally via absolute production reduction targets by 2050), as well as to achieve net-zero scope 1, 2 and 3 emissions by that date.
- Commit to establish an industry-wide scope 1 & 2 emissions accounting framework to improve the transparency, tracking and monitoring of methane emissions.
- Set targets and guidelines to include methane emissions from NOJV on an equity basis, targeting reductions in $CO_2$ and methane emissions intensity at least in line with those required in the IEA Net Zero scenario.

Energy Transitions Commission

# FOSSIL FUELS IN TRANSITION

## It is not prudent to rely on significantly higher use of carbon capture or removals – the priority must be to bring down fossil fuel demand

### CARBON CAPTURE IS OFTEN IMPRACTICAL OR MORE EXPENSIVE




For most coal applications, CCUS would be more expensive than an alternative.

For most gas use, carbon capture would either be impractical or uneconomic.

For most uses of oil today, using CCUS would be completely impractical.

## Carbon Capture and Storage (CCS/U) is vital, but limited to three contexts:

**INDUSTRIAL PROCESSES**

- Where industrial processes cannot be decarbonised by other options (e.g. cement)

**CARBON DIOXIDE REMOVAL**

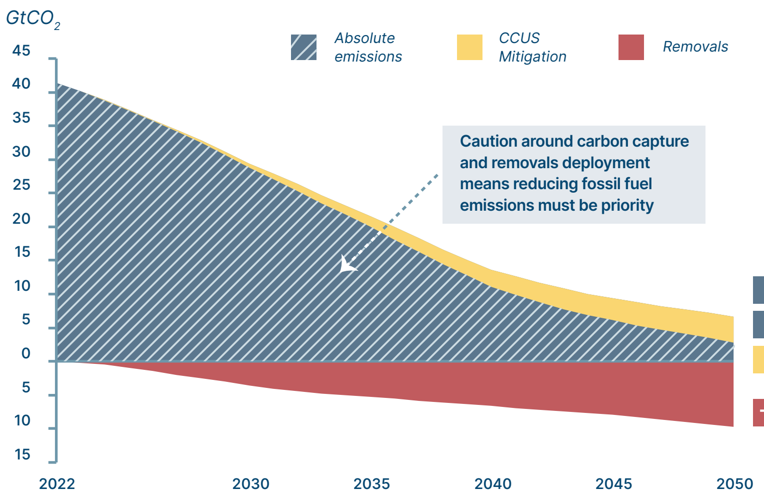
- Where it can be used to provide engineered removals (e.g., Bioenergy with Carbon Capture and Direct Air Capture)

**ECONOMIC ROLE**

- Where it is the cheapest way to abate emissions

Although the **CCUS** pipeline is growing, it is far **off track what is needed for a 1.5°C** pathway

### REACHING NET-ZERO EMISSIONS BY MID-CENTURY IS POSSIBLE, WITH A LIMITED ROLE FOR CARBON CAPTURE AND REMOVALS




7 $GtCO_2$ of absolute emissions...

3 $GtCO_2$ of emissions after applying

4 $GtCO_2$ of CCUS...

-10 $GtCO_2$ of carbon removals

## Carbon Dioxide Removals (CDR) need to scale: it is crucial to reduce carbon budget overshoot and get back to 1.5°C:

- Nature-based (e.g., planting trees) and hybrid (e.g., biochar) solutions can scale quickly in the short term, together with...
- A range of hybrid and engineered, durable solutions in the mid-to-long term (e.g., Direct Air Capture)

Recent developments suggest a **faster scale-up** in removals than shown here is **very unlikely**

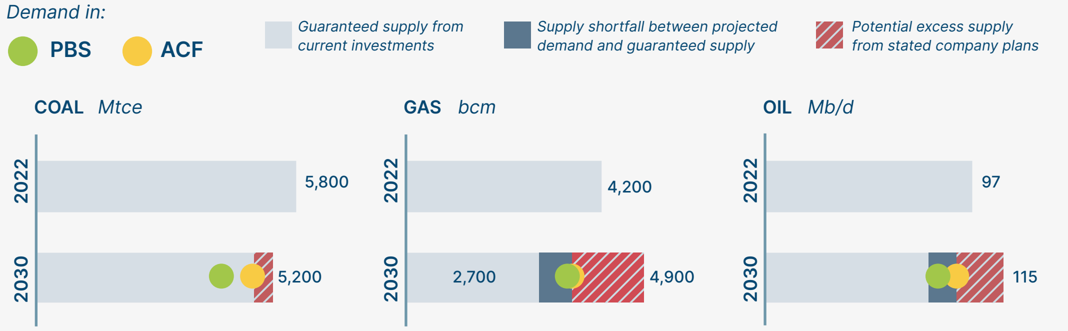
## Any new supply must be consistent with climate targets and falling demand

### JUST 8-10% OF CURRENTLY KNOWN FOSSIL FUEL RESOURCES CAN BE BURNED TO STAY WELL BELOW 2°C

**6,000 $GtCO_2$**
Carbon embodied in all known fossil fuel resources

**505-630 $GtCO_2$** fossil fuels emissions in ETC scenarios

### COMPANY PLANS FOR SUPPLY IN 2030 MIGHT BE TOO HIGH, LEAVING A RISK OF STRANDED ASSETS




**No new supply needed;** stated company plans could lead to overcapacity.

At most **600-700** bcm of new supply needed in 2030. Stated government plans could lead to overcapacity.

At most **5-13** Mb/d new supply needed in 2030. Stated government plans could lead to overcapacity.

Energy Transitions Commission

# FOSSIL FUELS IN TRANSITION

## What new fossil fuel production might be needed, at most?

**PBS** *scenario* — If the world really gets on track for 1.5°C, then pretty much none.

**ACF** *scenario* — A slower decline in fossil fuel demand might mean some small need for new production.

**Either way the majority of fossil reserves and resources will need to be kept in the ground.**

## Key actions to get on track for net-zero by mid-century:

### GOVERNMENTS

- Put in place policies to scale clean energy technologies and rapidly phase down fossil fuel use.
- Reject the idea that all national fossil fuel reserves need to be exploited.
- No new issuance of exploration licenses to discover oil or gas nor approve the opening or extension of new coal mining capacity.
- Clear targets and penalties to incentivise reduction of fossil fuels (internal combustion engine restrictions and bans, carbon pricing, etc.).

### OIL AND GAS COMPANIES

- Commit to no new exploration for new oil and gas fields or basins.
- **Commit to reaching net-zero scope 1, 2 and 3 emissions by mid-century:**
  - Commit to achieving a large part of these emissions reductions via phase-down of production of oil and gas.
  - Provide credible assessments of maximum role for CCS and CDR to meet company emissions reductions.
  - Commit to reduce scope 1&2 $CO_2$ emissions by >50% by 2030, reaching near-zero by 2050.
  - Commit to reduce methane emissions by 75% by 2030, reaching near-zero by 2050.

### COAL COMPANIES

- Commit to no development of new mining capacity, including extending existing projects.
- **Commit to reaching net-zero scope 1, 2 and 3 emissions by mid-century:**
  - Commit to achieving a large part of these emissions reductions via phase-down of production of coal.
  - Commit to absolute reduction targets of scope 1 & 2 $CO_2$ emissions by 30% by 2030, >50% by 2040, reaching near-zero by 2050.
  - Commit to targets of zero methane venting from abandoned coal mines, while reaching minimum flaring efficiency of 98%.

**Gold standards for climate-credible pathways for fossil fuel companies should include:**

- 2030 and 2040 interim targets for absolute reduction in production of oil and natural gas.
- Divestments and asset sell-offs cannot count towards stated emissions reduction objectives.
- Account for emissions and production from non-operated joint ventures (NOJV) on an equity-basis.

### FINANCIAL INSTITUTIONS

- **Restrict financing of key fossil demand and supply projects that lock in use for multiple decades:**
  - Stop financing any coal developments or expansions.
  - Very tightly restrict financing of short-term oil and gas development.
  - Stop financing long-term fossil fuel demand infrastructure, e.g., coal blast furnaces.
- Commit to only financing fossil fuel companies with credible strategies to reach net-zero scope 1, 2 and 3 emissions by 2050.
- Commit to steadily increasing ratio of investments in new clean energy supply and technologies.
- Restrict financing fossil fuel developments with significantly higher scope 1 & 2 production emissions than other sources.

### STANDARD SETTERS

- Commit to only endorsing fossil fuel company targets which include commitments to significantly reduce oil, gas and coal supply in 2050, as well as achieving net-zero scope 1, 2 and 3 emissions by mid-century.

# Acknowledgements

**The team that developed this report comprised:**

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# Fossil Fuels in Transition:

## Committing to the phase-down of all fossil fuels

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Energy
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