Fossil Fuels in Transition:

Committing to the phase-down of all fossil fuels

Annex A

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Contents

1. Introduction

This technical annex is a supplement to the November 2023 ETC report *Fossil Fuels in Transition: Committing to the phase-down of all fossil fuels*. This document presents the modelling framework and methodology, key sources, underlying assumptions, and wider technical details relating to the demand pathways covered in the main document.

The main report presents two new ETC scenarios for future fossil fuel demand:

- 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.[1] If combined with significant carbon removals, this scenario would be compatible with limiting global warming below 2°C (to around 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 the rate of removals continues in the second half of the century.[2]

These two scenarios build on a combination of the Mission Possible Partnership's (MPP) work in hard-to-abate sectors,[3] Systemiq's *Planet Positive Chemicals* report for petrochemicals,[4] bottom-up regional power system studies from peers, and other sector-specific models developed by the ETC, notably for road transport and buildings. Exhibit A1.1 illustrates the main sources used for the modelling exercise for each sector.

Both the ACF and PBS are a balance of **descriptive** and **normative** scenarios.[5] In the short term, they are constrained by how quickly reductions can be achieved. But in the long term, when combined with credible assumptions around the scale-up of carbon removals, they would meet climate objectives. Most scenarios from the MPP that we have drawn upon in our modelling have a target to remain within a 1.5°C-compatible carbon budget.

1 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.

2 See Chapter 5 of the main report.

3 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), *Making net-zero concrete and cement possible.*

4 Systemiq (2022), *Planet Positive Chemicals.*

5 See Box B in the main report.

EXHIBIT A1.1

Sector		ACF	PBS
Transport	**Road** (LCV[1], MCV[2], 2-3 wheeler)	ETC road ACF model	ETC road PBS model
	Other transport[4]	Uses the same assumptions as ETC road trucking ACF model	Uses the same assumptions as ETC road trucking PBS model
	HCV[3]	ETC road trucking ACF model	ETC road trucking PBS model
	Aviation	MPP Prudent scenario	
	Shipping	MPP 1.5˚C scenario	
	Rail	ETC rail ACF model	ETC rail PBS model
Industry	**Steel**	MPP Technology Moratorium scenario	MPP Carbon Cost scenario
	Cement	MPP 1.5˚C scenario	
	Chemicals (excluding Ammonia)	Systemiq – Planet Positive Chemicals Low circularity most economic	Systemiq – Planet Positive Chemicals Low circularity no new fossil after 2030
	Ammonia	MPP Lowest cost scenario	MPP Fastest Abatement scenario
	Aluminium	MPP 1.5˚C scenario	MPP Fastest Abatement scenario
	Other industry	ETC other industry ACF model	ETC other industry PBS model
Buidlings	**Heating, Cooking, Other**	ETC building ACF model	ETC building PBS model
Power	**Power**	Collection of several country-based base-case policy aligned power models	Collection of several country-based ambitious power models
Other	**Energy transformation and non-energy uses**[5]	ETC ACF model, declining in line with overall demand by sector	ETC PBS model, declining in line with overall demand by sector

NOTE: [1] Light commercial vehicles; [2] Medium commercial vehicles; [3] Heavy commercial vehicles; [4] This is predominantly for heavy transport used in agriculture, mining and construction; [5] Non-energy uses of oil corresponds to oil being used as a feedstock to make a range of products which include bitumen, parrafin waxes and white spirit. These are coproducts of refining. RystadEnergy (2022), *Oil market transition report*.

2. Road Transport

Road transport accounts for 43% of oil, 1% of gas, and 0% of coal demand today.

2.1 Demand for road transport

A stock-flow model is used to construct pathways for the uptake of electric and zero-emissions vehicles across all modes of road transport. It includes passenger vehicles, two- and three-wheelers, buses, and commercial vehicles (light, medium, and heavy). Passenger vehicles are divided into two categories: private vehicles and shared vehicles (including robotaxis[6] and shared autonomous vehicles). It is broken down into three key stages:

1. **Demand and fleet size modelling:** This stage forecasts the growth in transport demand, encompassing vehicle kilometres travelled (vkm), and considers the impact of car sharing and robotaxis. It calculates total transport demand and fleet size, broken down by region.

2. **Fleet decomposition modelling:** Comprising two steps, this stage initially models the distribution between zero-emission and Internal Combustion Engine (ICE) vehicle sales using an S-curve approach.[7] The second step estimates the pace of ICE vehicle retirements, resulting in a predominantly zero-emission vehicle fleet in 2050. In the PBS scenario, retirements are forced such that there are no ICE vehicle left on the road in 2050.

3. **Consumption modelling:** This stage models energy consumption, encompassing oil, biofuels, hydrogen, and electricity. It factors in changing efficiency assumptions and consumption patterns over time, providing insights into the energy consumption of the road sector.

The demand and fleet size model starts with 2022 demand for vehicle kilometres per vehicle, by region.[8] We then assume different demand growth rates across regions and transport modes over time. On average, global passenger-vehicle-kilometre demand growth is around 2% per annum, leading to growth from approximately 18,000 billion kilometres travelled in 2022 to 30,000 billion kilometres travelled in 2050. Growth in passenger-vehicle-kilometres is taken from BNEF (2023), *Long-term electric vehicle outlook*, extrapolated to 2050, and used to calculate average growth rates by decade, by region and vehicle type. BNEF's modelling of passenger-vehicle-kilometres accounts for economic growth, population growth, demographic changes and urbanisation rates.[9]

The next step in our passenger vehicle outlook is to determine the use of shared mobility services (taxis, ride-hailing, and fleet-based car-sharing) to establish the split between private vehicles and shared mobility services. Our sharing model closely follows the approach used in BNEF (2023), *Long-Term Electric Vehicle Outlook* and assumes a growing proportion of kilometres travelled with shared vehicles instead of private vehicles [Exhibit A2.1].

Finally, the fleet size is calculated for each vehicle type by dividing the annual total kilometres travelled by the average annual distance covered by that vehicle type.[10] Exhibit A2.1 shows that the annual mileage of shared vehicles is expected to reach approximately 30% of the total in 2050 due to the adoption of high-usage autonomous vehicles and robotaxis. Without widespread adoption of shared mobility solutions to meet growing transportation demand, the global passenger fleet size would be approximately 600 million vehicles larger by 2050.

These assumptions are consistent across both scenarios. Once the fleet size is determined by transport mode and region, we proceed to model (i) EV adoption and (ii) retirements from 2023 to 2050.

6 Robotaxis are highly autonomous (Level-4) ride-hailing vehicles. There are 5 levels of automation, with level-5 being full automation.

7 S-curve methodology based on Rogers' innovation diffusion theory (1962). The points where the S-curve reaches 16% and 84% of sales respectively represent the maximum growth and inflection points. These points are defined as points on the curve in which the concavity changes.

8 BNEF (2023), *Long-Term Electric Vehicle Outlook.*

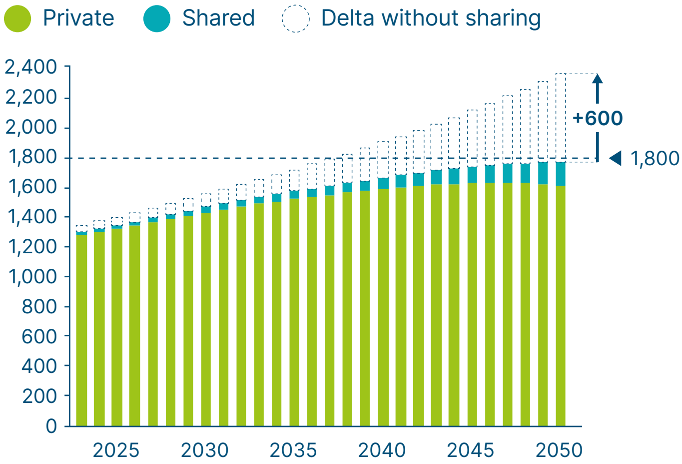
9 For example, higher rates of urbanisation are assumed to lead to reduced demand for cars. BNEF (2023), *Long-term electric vehicle outlook.*

10 Ibid.

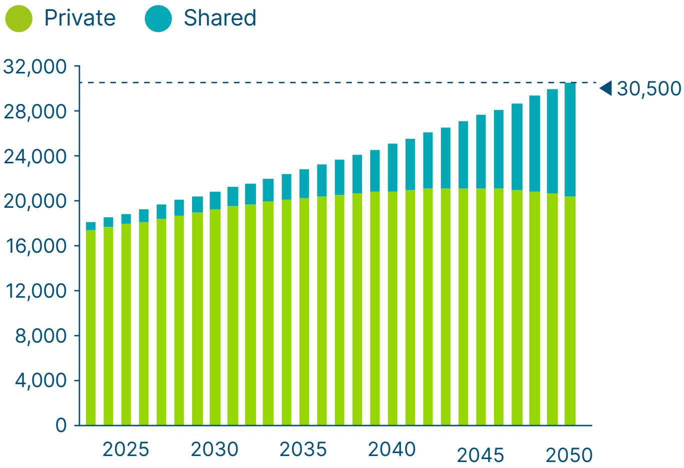
EXHIBIT A2.1

Passenger car fleet and vehicle kilometres travelled

Breakdown of passenger fleet between private and shared vehicles
million vehicles



Breakdown of passenger vehicles km travelled between private and shared vehicles
billion km



NOTE: Same fleet and vehicle km breakdown for both ACF and PBS scenarios.

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

2.2 Key assumptions in the ACF and PBS scenarios

Core assumptions	Subcategory	ACF	PBS	Source
Demand growth		Same assumptions across scenarios, specific to transport mode and region: • Passenger vehicles: 18,120 billion km in 2023, average CAGR of 1.9% p.a. • Light commercial vehicles: 2,280 billion km in 2023, average CAGR of 2.7% p.a. • Medium commercial vehicles: 840 billion km in 2023, average CAGR of 2.2% p.a. • Heavy commercial vehicles: 1,640 billion km in 2023, average CAGR of 2% p.a. • Buses: 260 billion km in 2023, average CAGR of 0.6% p.a. • Two/Three-Wheelers: 8,210 billion km in 2023, average CAGR of 1.6% p.a.		BNEF(2023), *Electric Vehicle Outlook.*
Efficiency improvements (2022–2050)	Internal combustion engines[1]	0.7% p.a.	1.6% p.a.	Multiple sources[3]
	Zero-emission vehicles[2]	1.6% p.a.		Systemiq analysis for the ETC.
Main decarbonisation technologies		• Battery electric vehicle (lithium-ion batteries, new battery technologies). • Fuel-cell electric vehicle. • Autonomous vehicles (robotaxis).		Systemiq analysis for the ETC.
Key uncertainties		• Zero-emission vehicle efficiency improvements could accelerate progress in the coming years. • S-curve take-off and rate of growth, especially for Heavy commercial vehicles (uptake could be slower). • Plug-in hybrid vehicles are not considered separately to fully electric vehicles (could underestimate the decline of fossil fuels). • Retirement rate and international trade of ICE vehicles at end of life could be slower (leading to greater residual fossil fuel demand through 2040s).		Systemiq analysis for the ETC.

NOTE: [1] For simplicity, plug-in hybrid vehicles are considered as ICE vehicles. 3.6% of ICE vehicle fuel demand currently comes from biofuels and 1% from natural gas. Both fuels are expected to play a decreasing role in the coming decades; [2] We assume that all zero-emission passenger cars, two- and three-wheelers, buses, and light commercial vehicles will be battery electric vehicles. For medium and heavy commercial vehicles, we expect fuel cell electric vehicles to play a role. [3] IEA (2021), *Global fuel economy initiative;* IEA (2023), *As their sales continue to rise, SUVs' global CO_2 emissions are nearing 1 billion tonnes*; US Department of Energy – Vehicles Technologies Office (2022), *Lightweight materials for cars and trucks.*

Zero-emission vehicles adoption methodology

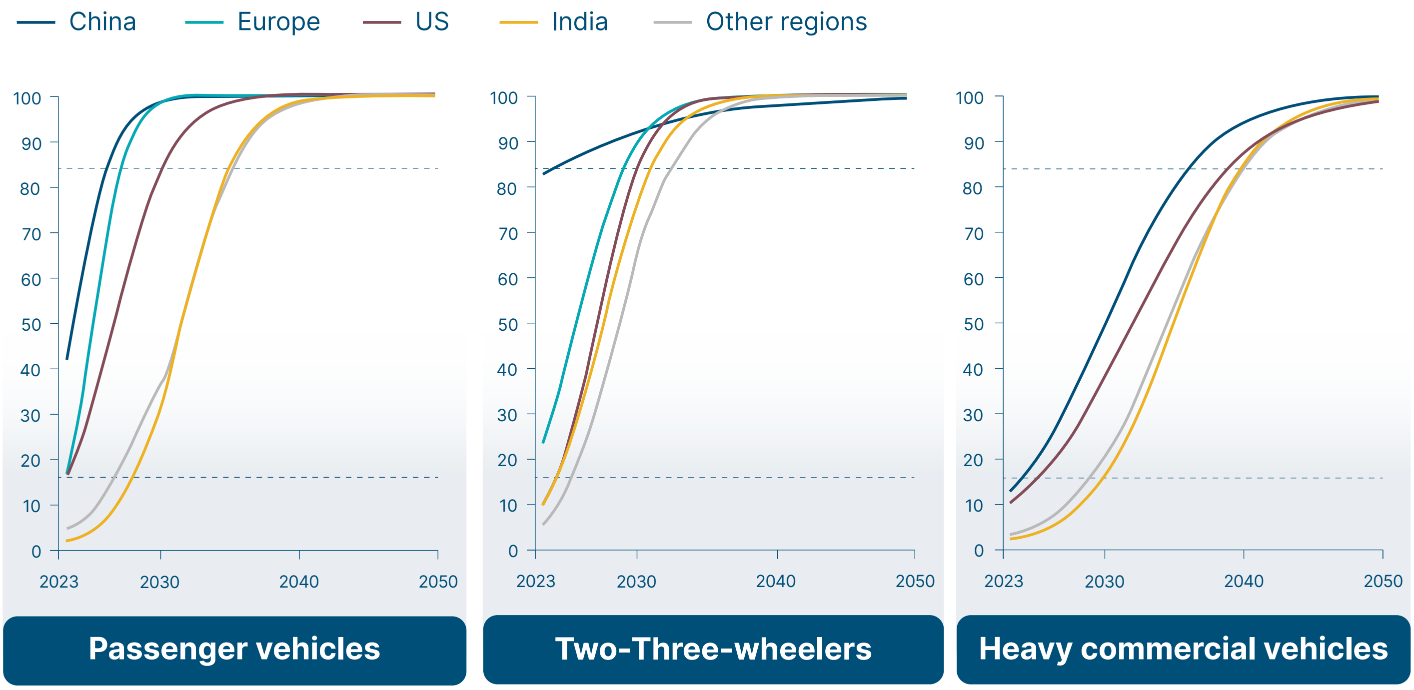
We model electric vehicle adoption that continues current trends by using S-curve exponential growth, based on Rogers (1962) *Innovation Diffusion Theory*.[11] The S-curves follow different trajectories in our PBS and ACF scenarios, with slower uptake in the ACF scenario [Exhibits A2.2 and A2.3]:

- Uptake in the PBS is designed to achieve near-zero oil consumption in the road transport sector by 2050, with more aggressive zero-emissions vehicle adoption, broadly aligned with both BNEF (2023), *Electric Vehicle Outlook* for most road transport segments, and MPP (2022) *Making Zero-Emissions Trucking Possible* for medium- and heavy-duty commercial vehicles.[12]
- Uptake in the ACF is assumed to be approximately three years slower than our PBS scenario.

EXHIBIT A2.2

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 points are calculated based on BNEF (2023), *Long-term 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), *Long-term electric vehicle outlook*; MPP (2022), *Making Zero-Emissions Trucking Possible*.

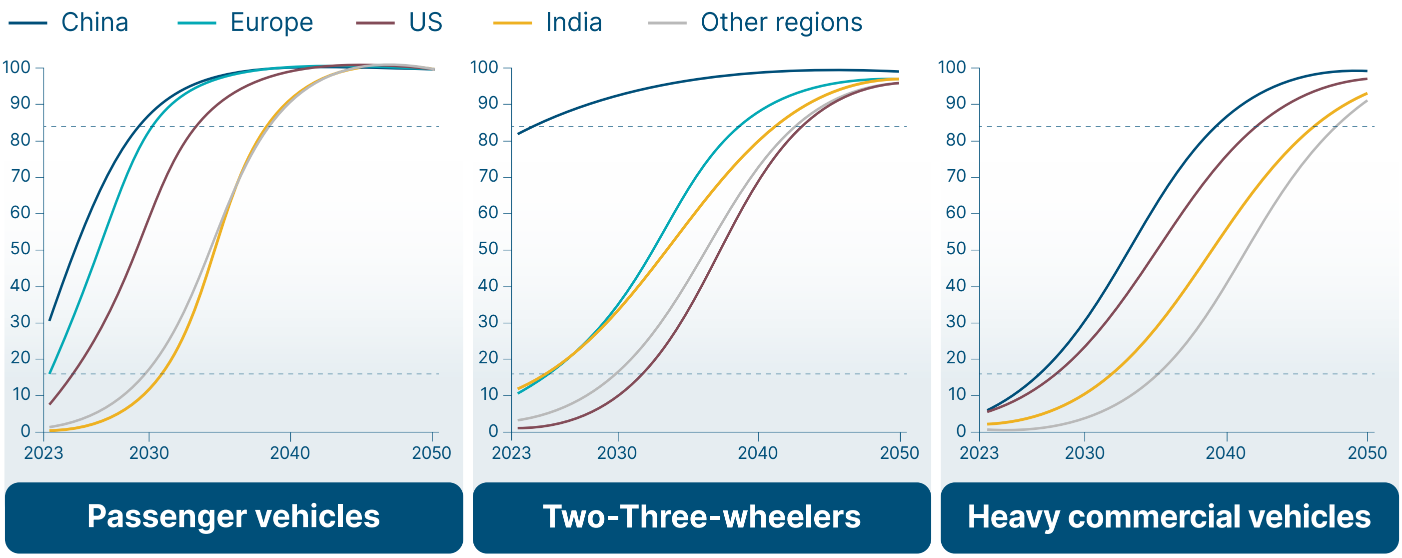
11 See also RMI (2022), *Harnessing the Power of S-Curves*.

12 S-curves for zero-emissions vehicle adoption for medium- and heavy-duty commercial vehicles follow those from MPP scenarios. These are modelled based on total cost of ownership decisions across ICE vehicles, which can be based on diesel or biodiesel, and zero-emissions vehicles, which can be battery-electric or based on hydrogen fuel cells. MPP (2022), *Making Zero-Emissions Trucking Possible*.

EXHIBIT A2.3

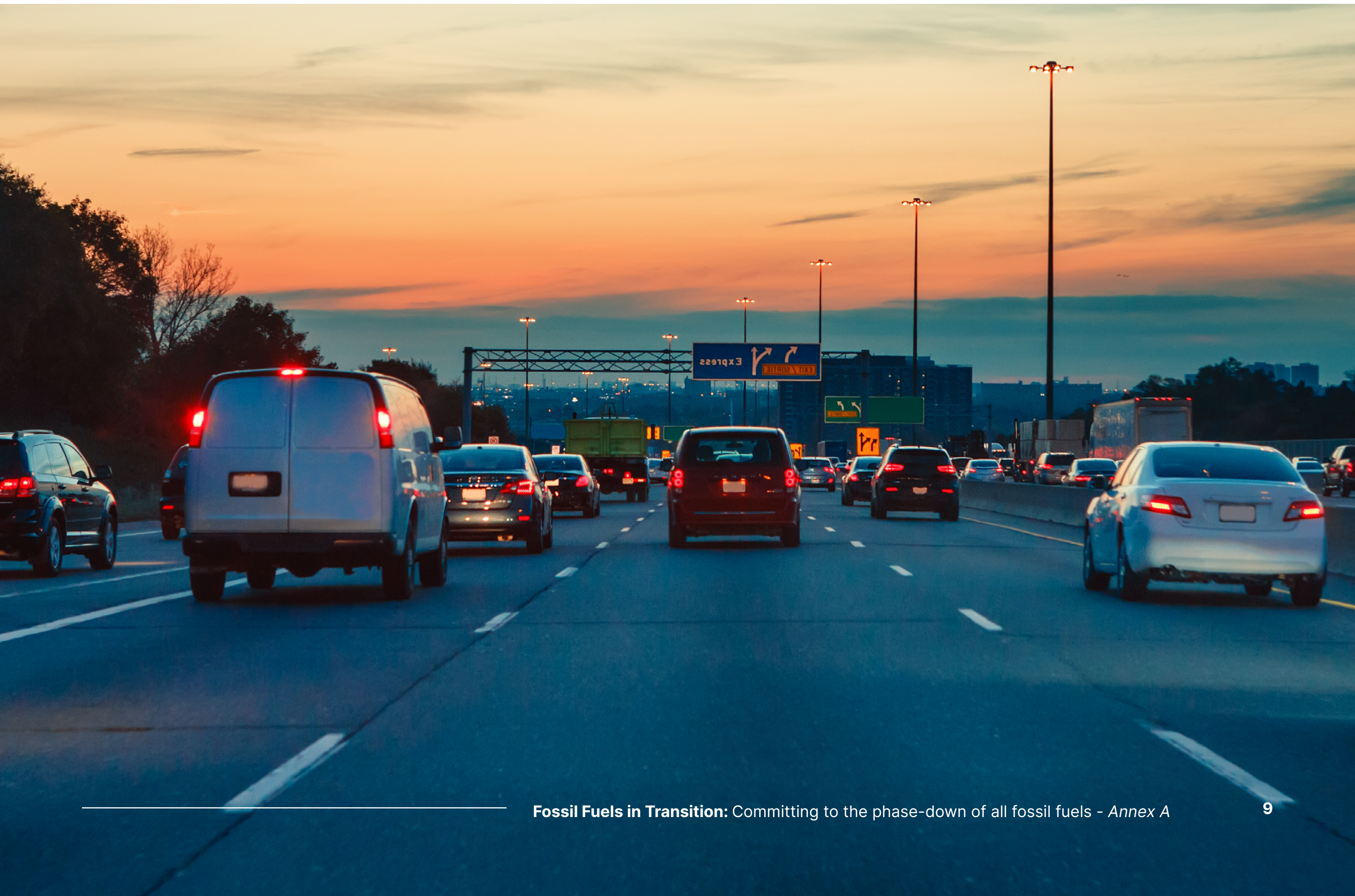
Share of electric vehicles as a function of total vehicle sales in the ACF scenario

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 point are calculated based on BNEF (2023), *Long-term 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), *Long-term electric vehicle outlook*; MPP (2022), *Making Zero-Emissions Trucking Possible.*



Retirements methodology

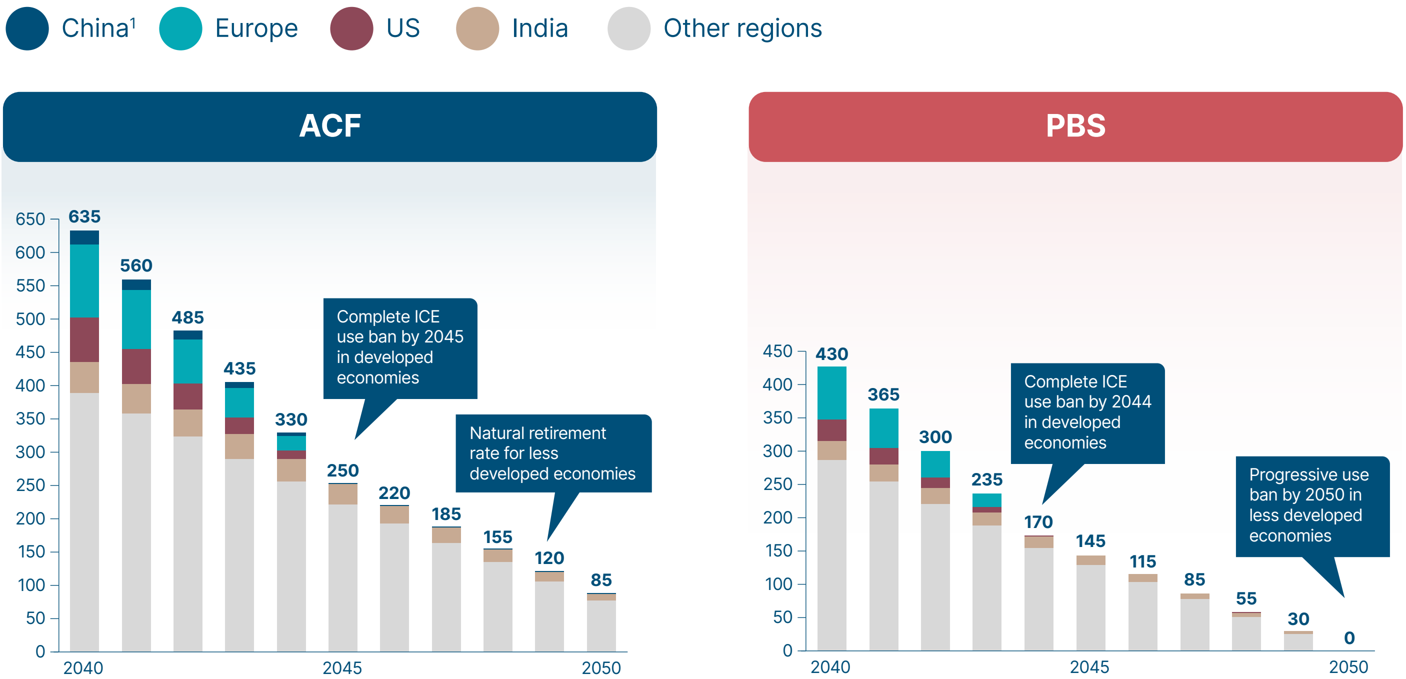
The pace at which existing ICE vehicles are retired from operation will vary significantly by country. It could be notably slow in some low-income countries where vehicle fleets often include a significant share of second-hand vehicles imported from developed economies.[13] However, retirement rates could also be accelerated through public policies, such as restrictions on the use of ICE vehicles in major cities, or incentives like subsidies for scrappage.[14]

In both the ACF and PBS scenarios, we assume typical vehicle lifespans of 15 years for passenger vehicles, 10 years for commercial vehicles, and 8 years for two- and three-wheelers.[15] Both scenarios also consider the possibility of public policies accelerating the retirement of ICE vehicles in the 2040s.[16] The PBS scenario pursues a more aggressive approach, paving the way for a fully zero emissions fleet by 2050 [Exhibit A2.4].

EXHIBIT A2.4

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.*

13 IEA (2023), *Global EV Outlook 2023.*

14 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.*

15 Systemiq analysis for the ETC; BNEF (2023), *Long-term electric vehicle outlook.*

16 A natural retirement rate was kept for heavy commercial vehicles in lower-income economies (i.e. India, Southeast Asia and Rest of World).

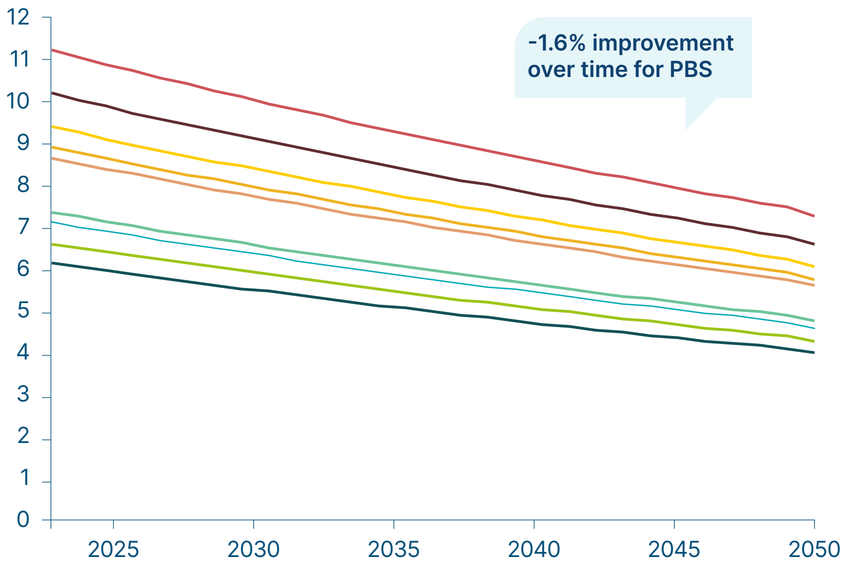
Fuel consumption model

The previous modelling stages provide a vehicle fleet for each transport mode and vehicle type (including battery electric vehicles and fuel-cell electric vehicles, and ICE vehicles), for each modelled region. The fleet size is combined with assumptions on fuel efficiency (also split by vehicle type and region), to calculate annual fuel consumption. Fuel efficiency is assumed to increase year-on-year at the rates shown in the Table in Section 2.2 [Exhibit A2.5].

EXHIBIT A2.5

Fuel economy improvements over time

Fuel economy of ICE fleet in the PBS scenario
LGE/100km



Weight increases are neutralising some of the benefits of more fuel efficient vehicles.

We therefore assume:

- **ACF:** -0.7% p.a. improvements over time
- **PBS:** -1.6% p.a. improvements over time if weight limit policies are implemented

NOTE: LGE = litres of gasoline equivalent.

SOURCE: Systemiq analysis for the ETC; BNEF (2023), *Long-term electric vehicle outlook*; IEA (2021), *Global Fuel Economy Initiative 2021.*

2.3 Final energy demand from 2022 to 2050

In the PBS scenario, oil consumption is projected to drop from 41 million barrels per day (mb/d) in 2022 to nearly 0 mb/d by 2050 [Exhibit A2.6], whereas in the ACF scenario residual oil demand in 2050 is around 6 mb/d. Concurrently, electricity and hydrogen consumption are anticipated to rise: by 2050, electricity consumption is projected to range between 8,000–12,000 terawatt-hours (TWh) annually. Consequently, this results in a reduction in final energy demand, as illustrated in Exhibit A2.6 below, declining from approximately 85–90 exajoules (EJ) in 2022 to below 40 EJ by 2050 due to the greater efficiency of electric vehicle motors, relative to combustion-based motors.

EXHIBIT A2.6

Road transport sector dashboard

NOTE: [1] Biofuels will grow until 2030 reflecting current fuel blending mandates in EU/US/Brazil. The EU for instance targets 3.5% advanced biofuel share in road transport by 2030. European Commission (2023).

SOURCE: Systemiq analysis for the ETC.

3. Other transport

Other transport includes rail, agriculture, construction, fishing, mining, and quarrying vehicles and accounts for 4% of oil, 0% of gas, and 0% of coal demand today. Given the large, highly energy-intensive nature of vehicles typically used in these industries, in both PBS and ACF scenarios we assume that oil demand from these sectors declines at the same rate as demand declines from heavy commercial vehicles, driven by the adoption of a mixture of battery- and fuel cell-electric vehicles, and hydrogen-derived synthetic fuels. Our PBS scenario is slightly more aggressive and ends with near-zero oil consumption in this category as well.

4. Aviation

Aviation accounts for 6% of oil, 0% of gas, and 0% of coal demand today.

4.1 Demand for aviation

Our trajectory for aviation is the same for both ACF and PBS scenarios and is taken from MPP (2022) *Making Net-Zero Aviation Possible*. All details are in the Technical Appendix of *Making Net-Zero Aviation Possible*. The aviation model is broken down in three stages:

1. **A demand model** forecasting future flight demand and energy required through 2050. Current flight movements and forecasts of Revenue Passenger Kilometres (RPKs) serve as inputs.[17] Data on aircraft fleet fuel consumption is used to project future energy demand in 2019-jet fuel equivalent (JFE).

2. **A fleet turnover model** in which aircrafts are retired when they reach a certain age.[18] New aircrafts enter the fleet to replace retired aircrafts and to meet any demand increase.

3. **A technology selection model** based on total costs of ownership for a range of technologies (HEFA,[19] Biofuels,[20] Hydrogen, Power-to-liquids[21]), subject to additional constraints and assumptions further described in the Technical Appendix of *Making Net-Zero Aviation Possible*. Within the model, technologies with varying green premiums are selected by lowest GHG abatement costs.

17 Revenue passenger kilometres represent the number of paying passengers carried on scheduled flights multiplied by the number of kilometres those seats were flown.

18 Aircraft retirement ages are assessed with a cumulative survival probability curve defined for each aircraft category as reported in Dray (2013), *An analysis of the impact of aircraft lifecycles on aviation emissions mitigation policies.*

19 HEFA means Hydroprocessed esters and fatty acids. HEFA are SAFs made from waste and residue fats, oils and greases that are produced through hydroprocessing of esters and fatty acids.

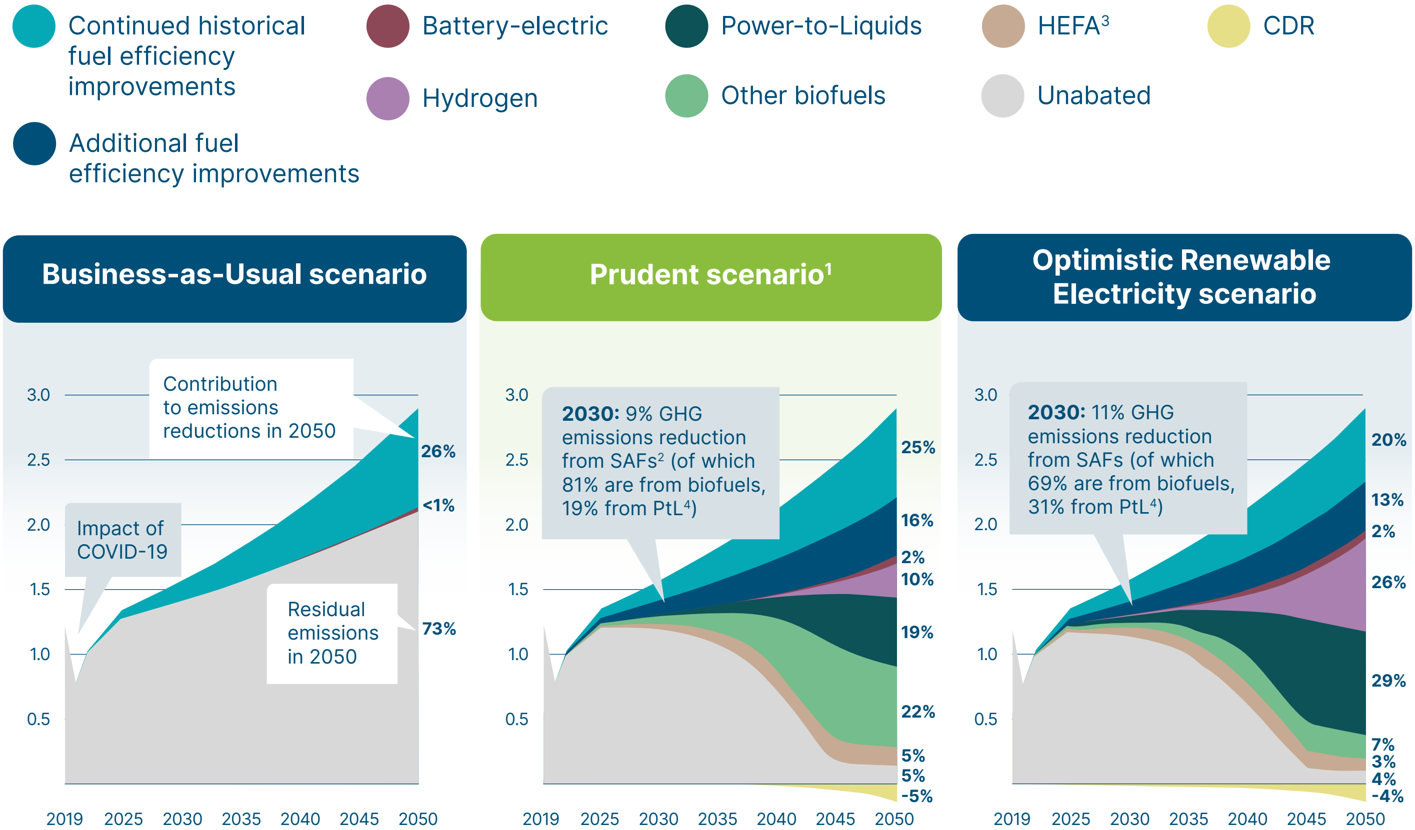
20 Biofuels are made from agricultural and forestry residues, municipal solid waste, as well as cellulosic energy crops via gasification and a subsequent Fischer-Tropsch synthesis.

21 Power-to-liquids refer to water and captured CO_2 converted into liquid fuels using renewable electricity, electrolysers, and a Fischer-Tropsch synthesis.

EXHIBIT A4.1

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 Acids; [4] Power-to-Liquids.

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

4.2 Key assumptions in the ACF and PBS scenarios

Both the PBS and ACF scenarios make use of the Prudent (PRU) scenario from MPP. The PRU scenario describes a trajectory to net-zero GHG emissions by 2050 that relies on technologies that either are already available or will enter the market over the coming decades, according to industry consensus.

Core assumptions	ACF	PBS	Source
Demand growth	• Aviation demand is assumed to grow strongly from 7,675 billion RPKs in 2022 to 19,220 billion RPK in 2050. • Impact of Covid-19 pandemic is modelled in line with IATA's assumption that global air travel will be back to 2019 levels by 2024, followed by growth of 3.0% p.a. between 2024 and 2050.		MPP (2022), *Making Net-Zero Aviation Possible*.
Efficiency improvements (2022–2050)	1.5% p.a. from 2019 to 2030, ramping up to 2% p.a. in 2030, then constant at 2% p.a. until 2050.		

Main decarbonisation technologies	• New aircrafts and airport infrastructure.
	• Renewable energy carriers:
	  • Production of HEFA, other biofuels, and PtL.
	  • CO_2 capture as feedstock for SAF production.
	  • Green hydrogen to power hydrogen aircraft and as feedstock for SAF production.
	  • Renewable electricity to power battery electric aircraft and SAF production.		

Key uncertainties	• Higher rebound post-Covid than expected in MPP scenario, leading to higher demand growth over short term. • Another optimal path might include continued use of conventional jet fuel, offset by DACCS,[1] leading to higher demand for oil through to 2050.		

[1] DACC(U/S) = Direct Air Carbon Capture (with Utilisation/Storage)

4.3 Final energy demand from 2022 to 2050

In both the PBS and the ACF scenarios, oil consumption is projected to drop from 5.9 mb/d today to 0 mb/d by 2050 [Exhibit A4.2]. Concurrently, electricity and hydrogen consumption are anticipated to rise significantly to around 5,400 TWh and 90 MtH_2, respectively, in 2050, alongside 9 EJ of bioenergy. This results in a rise in final energy demand growing from approximately 11 exajoules (EJ) in 2022 to around 18 EJ by 2050.

EXHIBIT A4.2

Aviation sector dashboard

NOTE: ACF and PBS are identical in our aviation model, carbon capture refers to direct air carbon capture and use (DACCU) for the production of sustainable aviation fuel (SAF).

SOURCE: MPP (2023), *Making net-zero aviation possible.*

5. Shipping

Shipping accounts for 5% of oil, 0% of gas, and 0% of coal demand today.

5.1 Demand for shipping

Our scenarios for the shipping sector build on the MPP's 2022 report *A Strategy for the Transition to Net Zero Emissions Shipping* and the 2021 report from the Maersk Mc-Kinney Moller Center for Zero Carbon Shipping *We Show the World it is Possible.* Three segments – bulk, tanker and container – account for around 90% of industry volume and 65% of emissions, making them the key focus areas for future emissions reduction pathways.

5.2 Key assumptions in the ACF and PBS scenarios

In our PBS scenario, 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 management of logistics and ship routing. Efficiency improvements are assumed to be slower in the ACF scenario, leading to longer-standing oil demand from shipping.

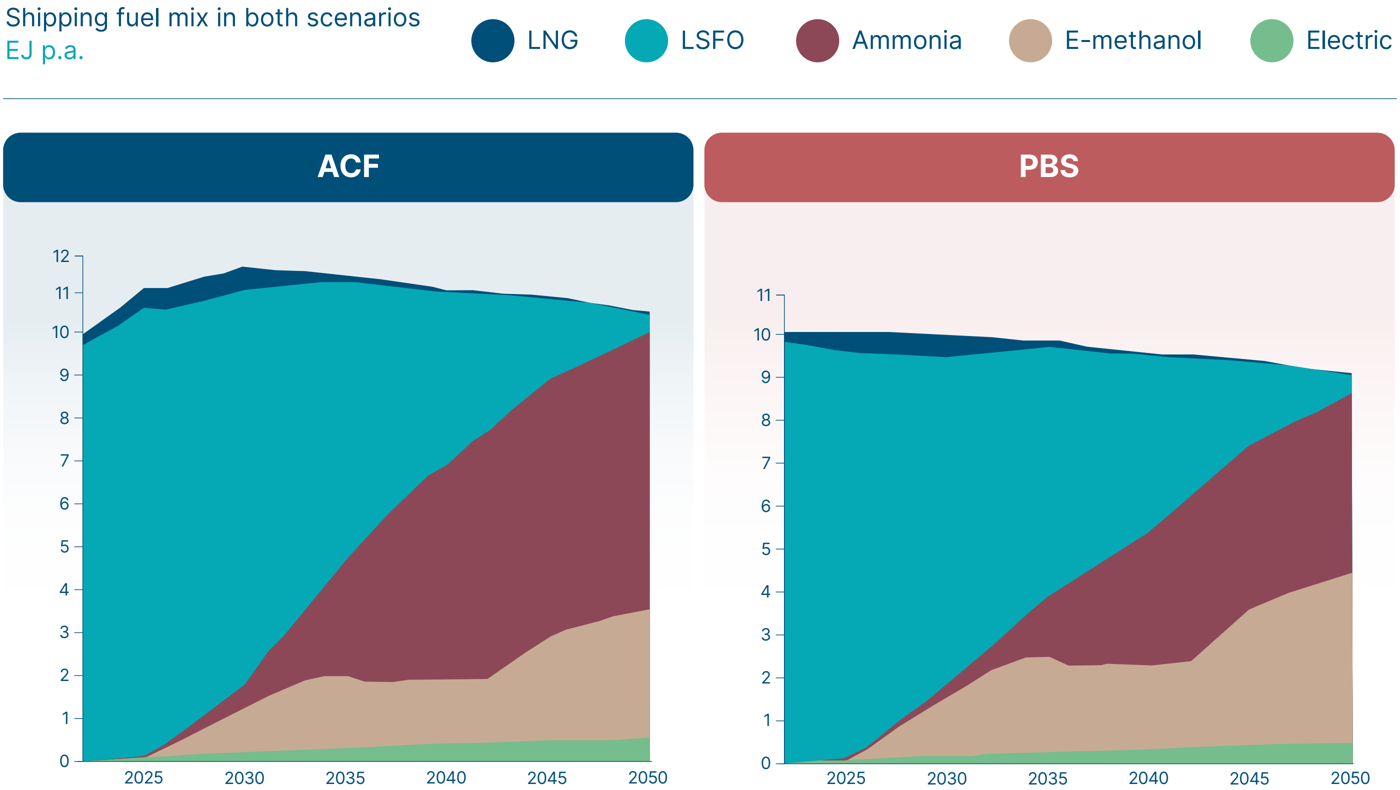
Core assumptions	ACF	PBS	Source
Demand growth	• Demand is 59,000 billion-tonnes miles in 2018, growing at 1% p.a. to 2050 for bulk carriers. • Demand is 14,000 billion-tonnes miles in 2018, growing at 0.1% p.a. to 2050 for tankers. • Demand is 13,000 billion-tonnes miles in 2018, growing at 2.4% p.a. to 2050 for containers.		Maersk Mc-Kinney Moller Center for Zero Carbon Shipping (2022), *We show the world it is possible.*
Efficiency improvements (2022–2050)	~1.2% p.a. CAGR of efficiency gains over the period (i.e. ~40% over the period).	~1.5% p.a. CAGR of efficiency gains over the period (i.e. >50% over the period). Thus demand growth is entirely offset by efficiency gains.	Systemiq analysis for the ETC.

Main decarbonisation technologies	• New ships and port infrastructures.
	• Renewable energy carriers:
	  • E-methanol, produced by using CO_2 captured from renewable sources (e.g.,bioenergy with carbon capture and storage (BECCS) and direct air carbon capture (DACC)) and green hydrogen.
	  • Ammonia produced with green hydrogen.
			MPP (2021), *A Strategy for the Transition to Zero-Emission Shipping.*

Key uncertainties	• Uncertainty over the pace of progress in 2023–30 for both fuel efficiency and uptake of zero emission fuels. • Nuclear power propulsion technologies are not considered due to current safety and public perception challenges, but could provide another significant decarbonisation option.		

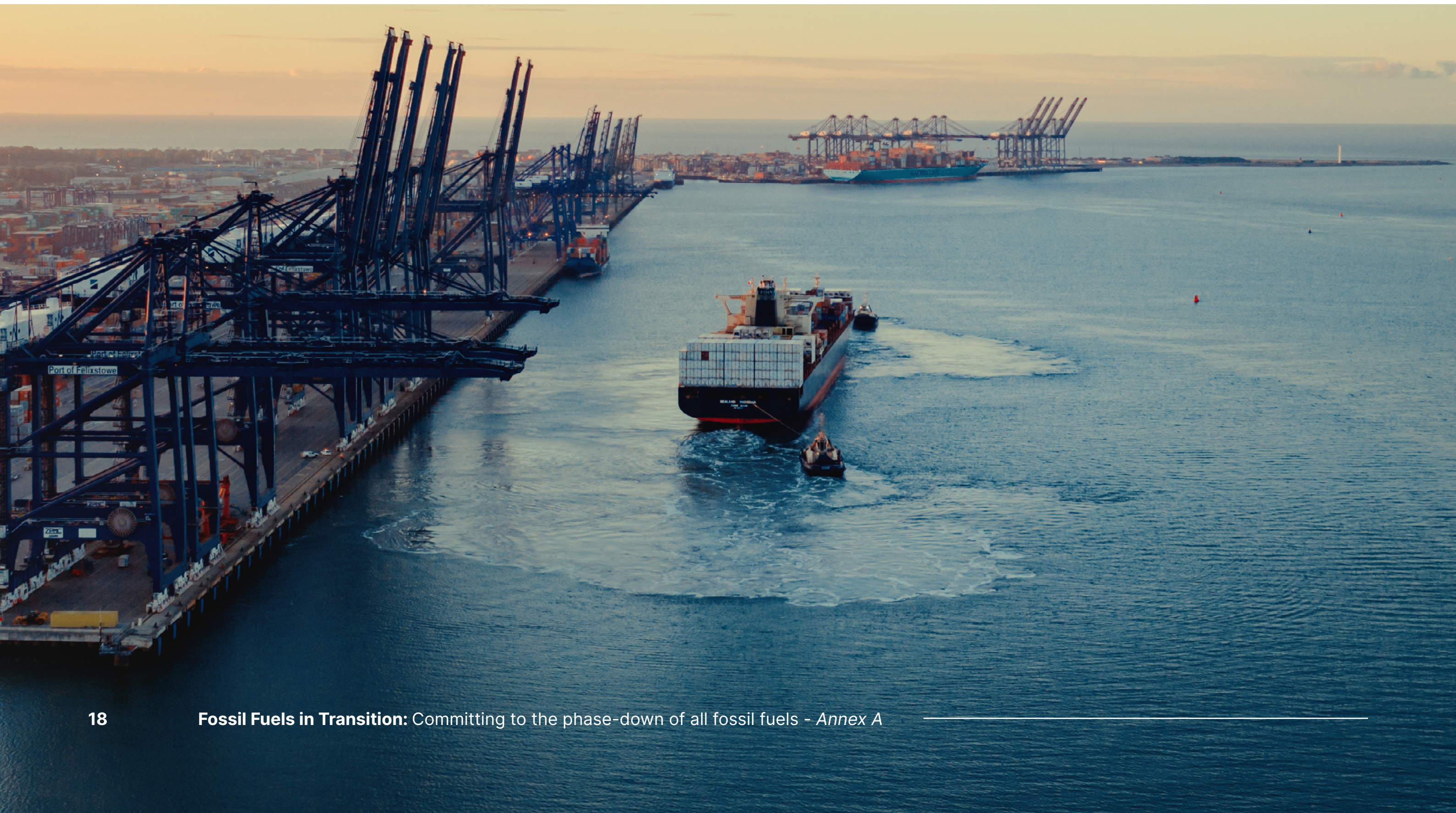
EXHIBIT A5.1

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 = Liquified Natural Gas

SOURCES: Systemiq analysis for the ETC; MPP (2021), *A Strategy for the Transition to Zero-Emission Shipping;* Mark Mc-Kinney Moller Center for Zero Carbon Shipping (2023), *We show the world it is possible.*



5.3 Final energy demand from 2022 to 2050

In both the PBS and the ACF scenarios, oil consumption is projected to drop from 5 mb/d to nearly 0 mb/d [Exhibit A5.2]. At the same time, electricity, gas and hydrogen consumption are anticipated to rise to around 800 TWh, 12.5 bcm and from 60–90 MtH_2 respectively, in 2050. Consequently, this results in a small reduction in final energy demand in the PBS scenario and a slight growth in final energy demand in the ACF scenario, from approximately 10 EJ in 2022 to around 11 EJ by 2050.

EXHIBIT A5.2

Shipping sector dashboard

NOTE: Carbon capture represents blue hydrogen for e-methanol production, no point-source CCS onboard ships is assumed.

SOURCE: 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.*

6. Industry

Industrial processes account for 20% of oil, 19% of gas, and 25% of coal demand today.

6.1 Steel

Steel accounts for 0% of oil, 1% of gas, and 15% of coal demand today.

6.1.1 Demand for steel

The steel scenario is taken from MPP (2022), *Making Net-Zero Steel Possible*. This model follows an asset-based, forward-looking modelling approach. The model calculates pathways for the turnover of the global steel production stock, establishing a set of techno-economic parameters that inform steel plant decision-making under various constraints in the Technology Moratorium scenario (used for the ACF scenario) or Carbon Cost scenario (used for the PBS scenario), optimising for total cost of ownership or abatement potential.

Twenty technology archetypes are considered in the model (including, for example, hydrogen based Direct Reduction of Iron (DRI) and continued use of coking coal with CCUS). Business cases for each of these archetypes consider feedstock, fuel, and energy consumption, associated emissions, and operating and capital expenditures from publicly available data sources. The model consists of four stages:

1. The model takes inputs that inform the economic parameters and emissions data for the 20 technology archetypes, regrouped across 5 main categories as per Exhibit A6.1.
2. Geospatial context parameters moderate the underlying costs of feedstock and other commodities, depending on whether a given plant is in a favourable location for that technology. This drives the plant economics (cost of steelmaking) and emissions profile that ultimately determine which technologies are more or less favourable.
3. At each investment decision point, the technology that has the lowest TCO is selected.
4. By aggregating all of these plant-level decisions, the model provides a detailed picture of the technologies, feedstock and energy inputs, emissions trajectories, and cost implications for the steel sector's transition.

Demand for steel is assumed to grow from ~1,950 Mt in 2020 to ~2,550 Mt by 2050 in both scenarios.

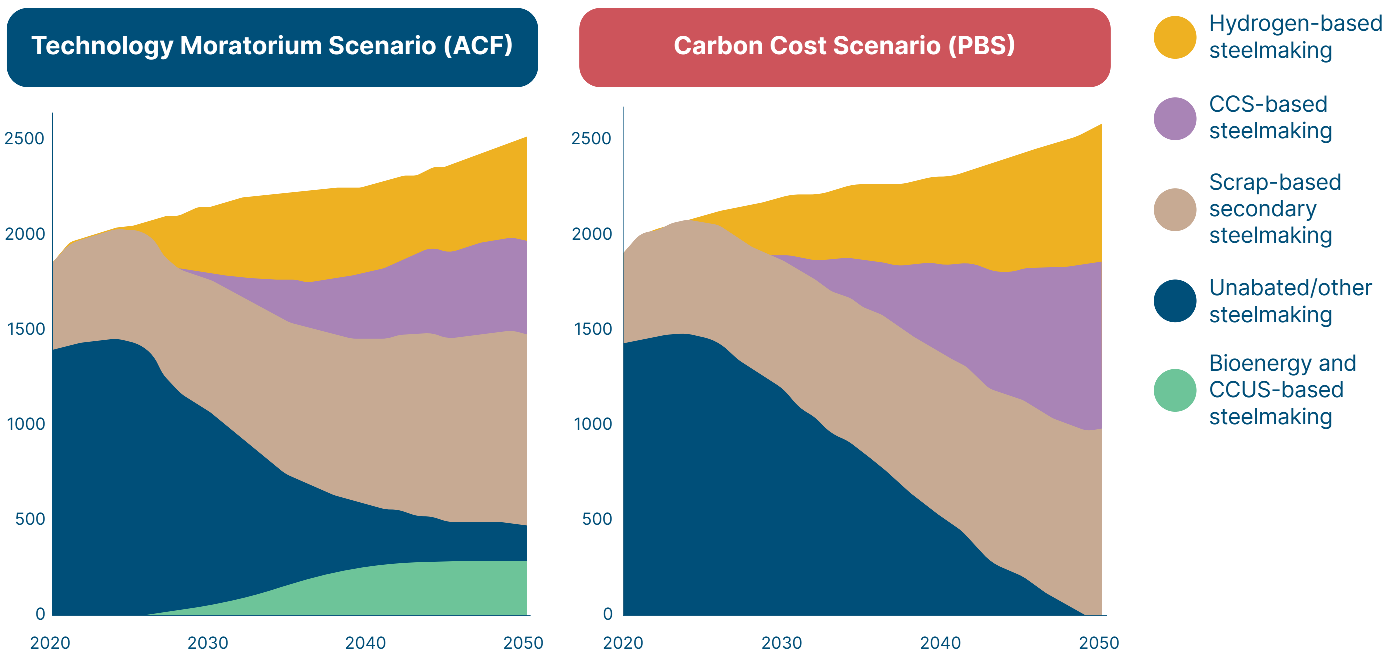
The **Technology Moratorium** scenario, used in our ACF scenario, takes an approach that confines investments to near-zero-emissions technologies from 2030 onwards to reach net-zero by 2050. As with the Carbon Cost scenario, the steel asset switches to whichever technology offers the lowest total cost of ownership (TCO) at each major investment decision. In the absence of measures to incentivise adoption in the 2020s, lower-emissions technologies are initially only built where they can compete on cost with the conventional steelmaking process.

The **Carbon Cost** scenario, used in our PBS scenario, illustrates how the steel sector might decarbonise if coordinated action to support low-CO_2 steelmaking takes hold this decade. The Carbon Cost scenario assumes that, at each major investment decision, the steel asset switches to whichever technology offers the lowest TCO. A carbon price is applied to each tonne of CO_2 emitted, increasing linearly from $0 in 2023 to $200 in 2050. The same price is applied to all Scope 1 and 2 emissions in all geographies. Both scenarios are shown in Exhibit A6.1, with the Carbon Cost scenario leading to faster decarbonisation.

EXHIBIT A6.1

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.*

6.1.2 Key assumptions in the ACF and PBS scenarios

Core assumptions	ACF	PBS	Source
Demand growth	Starting point in 2020: 1,950 Mt of steel per year, growing to 2,550 Mt in 2050.		MPP (2022), *Making Net-Zero Steel Possible*.
Efficiency improvements (2022–2050)	Scrap-based secondary steelmaking grows from around 500 Mt in 2020 to around 1,000 Mt by 2050 in both scenarios.		
Main decarbonisation technologies	• Increased scrap use. • Carbon Capture and Storage. • Green Hydrogen. • Iron reduction with green hydrogen.		
Key uncertainties	• Potential for circularity to reduce demand. • Impact of slowing Chinese economic growth and construction sector on demand trajectory in the near term. • Development of long-term demand off-take agreements to help low-carbon supply growth.		

6.1.3 Final energy demand from 2022 to 2050

Coal demand in the steel sector decreases from over 800 Mtce in 2022, down to around 150 Mtce in 2050 [Exhibit A6.2]. Demand for power grows over six-fold, from around 1,400 TWh in 2022 up to around 9,000 TWh in 2050, whilst demand for low-carbon hydrogen grows to 55–80 MtH_2 in 2050.

EXHIBIT A6.2

Steel sector dashboard

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

6.2 Cement

Cement accounts for 0% of oil, 1% of gas, and 4% of coal demand today.

6.2.1 Demand for cement

The cement scenario in our model corresponds to the net-zero scenario modelled in MPP (forthcoming), *Making Net-Zero Concrete and Cement Possible* [Exhibit A6.3]. Demand in this scenario is assumed to grow from ~4.2 Gt of cement in 2020 up to ~5.3 Gt of cement in 2050, together with a reduction in clinker-binder ratio from 0.63 currently, to 0.52 by 2050.

These assumptions are then coupled with bottom-up decision-making modelling for clinker production, aiming to minimise the total cost of ownership within a given set of constraints.

The cement decarbonisation model rests on two key principles:

1. The uptake of technologies that reduce emissions associated with clinker production is dictated by costs and technology availability (e.g., new heat sources such as electric kilns or green hydrogen, cryogenic capture, indirect calcination).
2. Location-based circumstances such as local energy prices and the availability of carbon storage sites (or utilisation opportunities) determine the optimal cost-effective technology choice.

The net-zero scenario is built from the 2050 roadmap developed by the Global Cement and Concrete Association, combined with analyses by MPP and others to determine the current and future supply of clinker.[22,23]

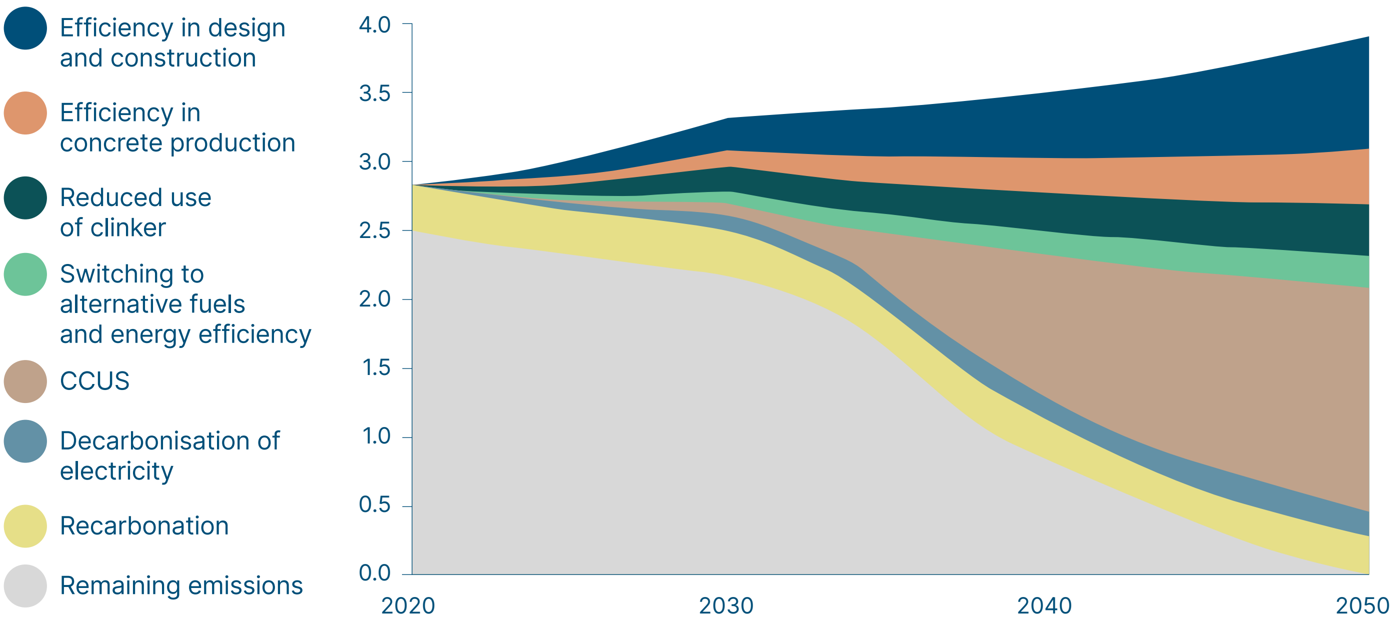
In the net-zero scenario, a carbon price is determined in such a way that it enables a 1.5°C emissions trajectory, with prices rising from $50 per ton of CO_2 up to $100 per ton of CO_2 by 2050. This set price acts as a proxy for the actions that are needed to close the competitiveness gap between conventional concrete and cement production processes, and those required to realise near-zero emissions. A variety of policy and value-chain levers can take the place of explicit carbon pricing: examples include the creation of differentiated markets for low-CO_2 concrete and cement, targeted capital or operational expenditure subsidies for the deployment of near-zero emissions technologies, and other regulatory measures that raise the cost of high-emissions technologies.

22 Global Cement and Concrete Association (2022), *The GGCA 2050 Cement and concrete Industry Roadmap for Net Zero Concrete.*
23 European Cement Research Academy (2022), *ECRA Technology Papers 2022.*

EXHIBIT A6.3

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*.

6.2.2 Key assumptions in the ACF and PBS scenarios

Core assumptions	ACF	PBS	Source
Demand growth	Demand for cement is projected to increase 49%, from 4.2 Gt in 2020 to 5.3 Gt in 2050.		MPP (Forthcoming), *Making Net-Zero Concrete and Cement Possible.*
Efficiency improvements (2022–2050)	The clinker-binder ratio falls from 0.63 in 2020 to 0.52 by 2050.[1]		
Main decarbonisation technologies	• CCS deployed from 2030 as the most significant mitigation option. • Green hydrogen deployed in limited amounts from 2030. • Alternative clinker chemistries deployed in limited amounts from 2030.		
Key uncertainties	• Potential for clinker-to-cement ratio to reduce demand further than assumed here. • Uptake of carbon pricing within the cement/concrete sector. • Development of CCUS projects could be slower than assumed. • Impact of slowing Chinese economic growth and construction sector on demand trajectory in near term. • Development of long-term demand off-take agreements to help low-carbon supply growth.		

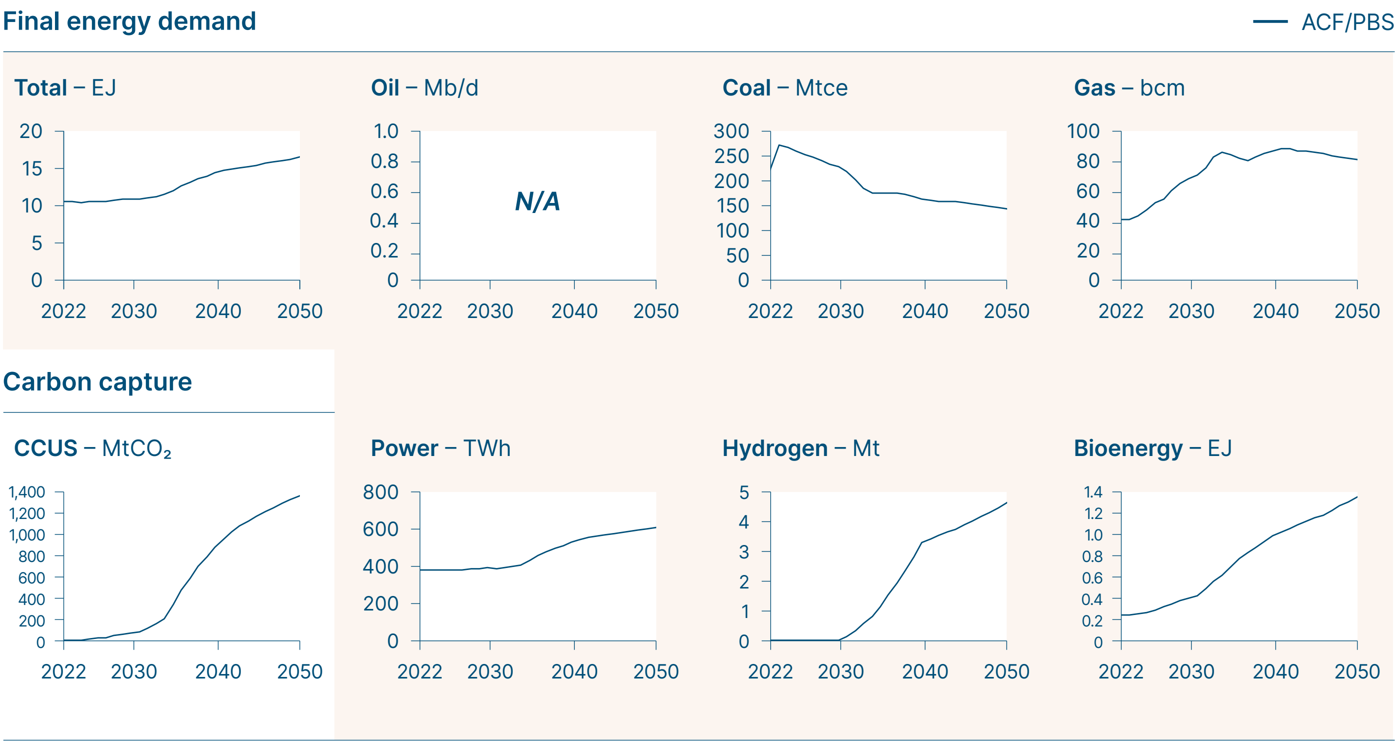
NOTE: [1] Cement clinker is a key intermediate product in cement production, and is a mixture of limestone and minerals. Clinker is then ground and mixed with a range of other materials to make cement. Binder is all material in concrete, such as cement, fly ash, limestone, with exact content varying by location, depending on local regulations.

6.2.3 Final energy demand from 2022 to 2050

Coal demand in the cement sector decreases from around 230 Mtce in 2022, down to around 150 Mtce in 2050, whereas gas demand roughly doubles from 40 bcm in 2022 to 80 bcm in 2050 [Exhibit A6.3]. Demand for power grows from around 380 TWh in 2022 up to around 600 TWh in 2050. Most mitigation in the cement sector is from the significant deployment of CCUS, rising to around 1.4 $GtCO_2$ in 2050, of which around 1.1 $GtCO_2$ is to abate process emissions from calcination.

EXHIBIT A6.3

Cement sector dashboard



NOTE: Our ACF and PBS scenarios are identical for cement.

SOURCE: MPP (forthcoming), *Making net-zero concrete and cement possible.*

6.3 Chemicals

Chemicals account for 16% of oil, 7% of gas, and 2% of coal demand today.

6.3.1 Demand for chemicals

Analysis of decarbonisation in the chemicals sector was carried out using two different models: for ammonia, scenarios are based on MPP (2022), *Making Net-Zero Ammonia Possible*, while for all the other chemicals, scenarios are based on Systemiq (2022), *Planet Positive Chemicals*.

Ammonia

The ETC's ACF scenario relies on MPP's Lowest-Cost (LC) scenario, while our PBS scenario is based on MPP's Fastest Abatement (FA) scenario, where technology changes prioritise the largest emissions reductions. A carbon price is applied in the LC Scenario to unlock a net-zero pathway that minimises total cost to the industry. This is set at 100 USD/tCO_2 from 2035 onwards, with a linear ramp-up starting in 2026 to ensure that initial technologies switch to net-zero compatible technologies.

The evolution of ammonia demand will be driven by a combination of three trends in the coming years: growing demand for food and goods (increasing use of ammonia-based fertiliser), expected uptake of ammonia as a zero-carbon fuel (e.g., in shipping), and the trend of fertiliser-use optimisation, where less fertiliser is applied to crops for the same yield.

- Demand for ammonia in existing applications[24] is assumed to grow at 1.1% per year.
- Shipping is expected to become the largest driver of low-carbon ammonia demand by 2050,[25] accounting for 295–670 MtNH_3 demand.
- Power generation is estimated to account for 35–105 MtNH_3 demand by 2050. Countries with severe constraints on land and/or renewable resources could rely on importing ammonia from low-cost production regions if the economics of importing hydrogen doesn't make sense. Countries like Japan or South Korea have for instance already planned to co-fire ammonia in coal power plants with potential expansion of ammonia usage to mixed combustion in CCGTs.
- There could also be some additional demand for ammonia as an energy carrier, up to 110 MtNH_3 in 2050.

The FA (PBS) scenario assumes demand growth ~0.5% per annum to 2050 for fertiliser, while the LC (ACF) scenario assumes a business-as-usual growth rate of ~0.9% per annum to 2050.

Other chemicals

Other chemicals include olefins, methanol, and aromatics. A detailed methodology of decarbonisation pathways in the Planet Positive Chemicals report can be found in the *Supporting Information for Planet-Compatible Pathways for Transitioning the Chemical Industry*.

The ACF scenario makes use of the Low Circularity Most Economic (LC-ME) scenario, while the PBS scenario draws on the Low Circularity No New Fossil After 2030 Scenario (LC-NFAX). In the LC-ME (ACF) scenario, demand for other chemicals is expected to reach around 680 Mt in 2050, whereas supply of these chemicals is expected to grow from 500 Mt in 2022, to reach 850 Mt in 2050.

Demand projections for other chemicals are based on the Reference Technology Scenario (RTS) from the IEA, but are then adapted to integrate the impact of key resource efficiency and circularity strategies, including direct elimination, reuse, and substitution, for demand in each of the key industries. Additional demand coming from adjacent sectors reaching net-zero is also considered (e.g., shipping fuel, wind power, and solar panel materials). Lastly, different steps in plastic waste management flows and end-of-life treatment options are included with recycling incentives and waste management costs.

The analysis in *Planet Positive Chemicals* also developed, in parallel, a supply model analysing how the demand for the eight primary chemicals can be met while reducing emissions from the production and feedstock lifecycle stages towards net-zero. The supply model thus chooses the best technology based on a set of parameters. Several external constraints are applied to enable the transition towards net-zero by 2050:

- Abated production technologies are preferred over non-abated technologies for new-build technologies.
- A fixed retrofit rate of 5% is applied.
- Non-abated production sites are decommissioned in the model starting from 2035.

6.3.2 Key assumptions in the ACF and PBS scenarios

Analysis of decarbonisation in the chemicals sector was carried out using two different models: for ammonia, scenarios are based on MPP (2022), *Making Net-Zero Ammonia Possible*, while for all the other chemicals, scenarios are based on Systemiq (2022), *Planet Positive Chemicals*.

24 Fertilisers and industrial applications such as explosives for mining and construction, plastics, cleaning products, and textiles.
25 Ammonia (NH_3) contains 82% nitrogen and 18% of hydrogen by mass.

Ammonia

The below table summarises key assumptions taken for ammonia.

<table>
<tr><th>Core assumptions</th><th>ACF</th><th>PBS</th><th>Source</th></tr>
<tr><td>Demand growth</td><td>Net-zero demand scenario with low demand for ammonia as an energy carrier, reaching around 560 Mt NH_3 by 2050.</td><td>Net-zero with medium demand for ammonia as an energy carrier, reaching around 830 Mt NH_3 by 2050.</td><td rowspan="3">MPP (2022), Making Net-Zero Ammonia Possible.</td></tr>
<tr><td>Efficiency improvements (2022–2050)</td><td colspan="2">Net-zero demand scenario includes 400 Mt of demand reduction by 2050 through circularity.</td></tr>
<tr><td>Main decarbonisation technologies</td><td colspan="2">• Green ammonia: electrolysis and ammonia synthesis powered by renewables.
• Blue ammonia: steam methane reformer, gas-heated reformer, autothermal reformer, all with CCUS.
• Biomass production through biomass digestion or gasification plus ammonia synthesis.
• Methane pyrolysis plus ammonia synthesis.</td></tr>
<tr><td>Key uncertainties</td><td colspan="2">• Uptake of CCUS for blue hydrogen could be slower than expected.
• Strength of offtake agreements for green hydrogen and green ammonia.
• Enabling transport and storage infrastructure for hydrogen and CO_2.
• Environmental concerns around role of ammonia in shipping could reduce demand.
• Development of ammonia demand in fertiliser due to dietary shifts (in either direction).</td><td></td></tr>
</table>

Other chemicals

The below table summarises key assumptions taken for other chemicals.

<table>
<tr><th>Core assumptions</th><th>ACF</th><th>PBS</th><th>Source</th></tr>
<tr><td>Demand growth</td><td colspan="2">From 500 Mt to 850 Mt supply of non-ammonia chemicals.</td><td rowspan="3">Systemiq (2022), Planet Positive Chemicals.</td></tr>
<tr><td>Efficiency improvements (2022–2050)</td><td colspan="2">Both scenarios assume a low circularity scenario.</td></tr>
<tr><td>Main decarbonisation technologies</td><td colspan="2">The 850 Mt of non-ammonia chemicals can be clustered into four key decarbonisation technologies:
1. CCUS is used to mitigate emissions from 43% of supply in 2050.
2. Use of low-carbon methanol to produce olefins & aromatics (MTX) mitigates emissions from 22% of supply in 2050.
3. Abated steam cracking mitigates emissions from 14% of supply in 2050.
4. Abated gas reforming mitigates emissions from 2% of supply in 2050.</td></tr>
<tr><td>Key uncertainties</td><td colspan="2">Potential to shift feedstocks to bio-based or recycled feedstocks is highly uncertain. If growth of alternative feedstocks is limited, the petrochemicals sector could continue to use 15-20 mb/d of oil for several decades in future.</td><td></td></tr>
</table>

6.3.3 Final energy demand from 2022 to 2050

Coal demand in the chemicals sector decreases from around 225 Mtce in 2022, down to 10–60 Mtce in 2050, whereas the gas demand pathway depends significantly on scenario, going from 450 bcm in 2022 to 120–600 bcm in 2050 [Exhibit A6.4]. Demand for power grows from around 400 TWh in 2022 up to around 2,700–10,500 TWh in 2050, predominantly for green hydrogen production.

EXHIBIT A6.4

Chemicals sector dashboard

NOTE: Chemicals include ammonia and petrochemicals.

SOURCE: Systemiq (2022), *Planet Positive Chemicals*, MPP (2022), *Making net-zero ammonia possible.*

6.4 Aluminium

Aluminium accounts for 0% of oil, 0% of gas, and 1% of coal demand today.

6.4.1 Demand for aluminium

The aluminium scenarios are taken from MPP (2021), *Making Net-Zero Aluminium Possible*. The models are based on a bottom-up, asset-by-asset approach that assesses the business case for switches to low-carbon technologies with the constraint of achieving net-zero by 2050–30 technology archetypes for refineries and 24 technology archetypes for smelters are considered in the model. Business cases for each of these archetypes consider feedstock, fuel, and energy consumption, associated emissions, and operating and capital expenditures from publicly available data sources.

The model assesses the technological, economic, and carbon emissions implications of 95 alumina refineries and 181 primary smelters in 11 regions transitioning to net-zero production, and assesses the appropriate decarbonisation technology. More details on the model can be found in the MPP (2023), *Aluminium Technical Appendix*.

6.4.2 Key assumptions in the ACF and PBS scenarios

The ACF scenario aligns with the MPP's 1.5°C aluminium scenario, while the PBS scenario corresponds to MPP's Fastest Abatement scenario. The main difference between these scenarios is that the 1.5°C-aligned scenario prioritises the lowest-cost technologies that meet the 1.5°C budget, whereas the Fastest Abatement scenario allows firms to choose only low-carbon options, but does not have a carbon budget constraint that imposes faster decarbonisation.

The Fastest Abatement scenario has a mechanism to switch to the lowest-emissions technology available in any given year, regardless of cost. This assumes that, starting from 2030, refineries and smelters make exclusively low-carbon decisions, transitioning to near-zero-carbon technologies by 2040. Various implementation methods, such as government-mandated environmental standards, conditional financing, or industry initiatives, can drive this transition.

The Fastest Abatement scenario accelerates the shift to lower-emission power sources, including replacing coal generation with gas generation, despite higher costs and marginal emissions savings. For smelters, the model requires two technological switches: transitioning from direct coal power to grid and captive gas before 2030, and then to captive gas with CCS by 2040. Other assumptions taken are summarised in the table below.

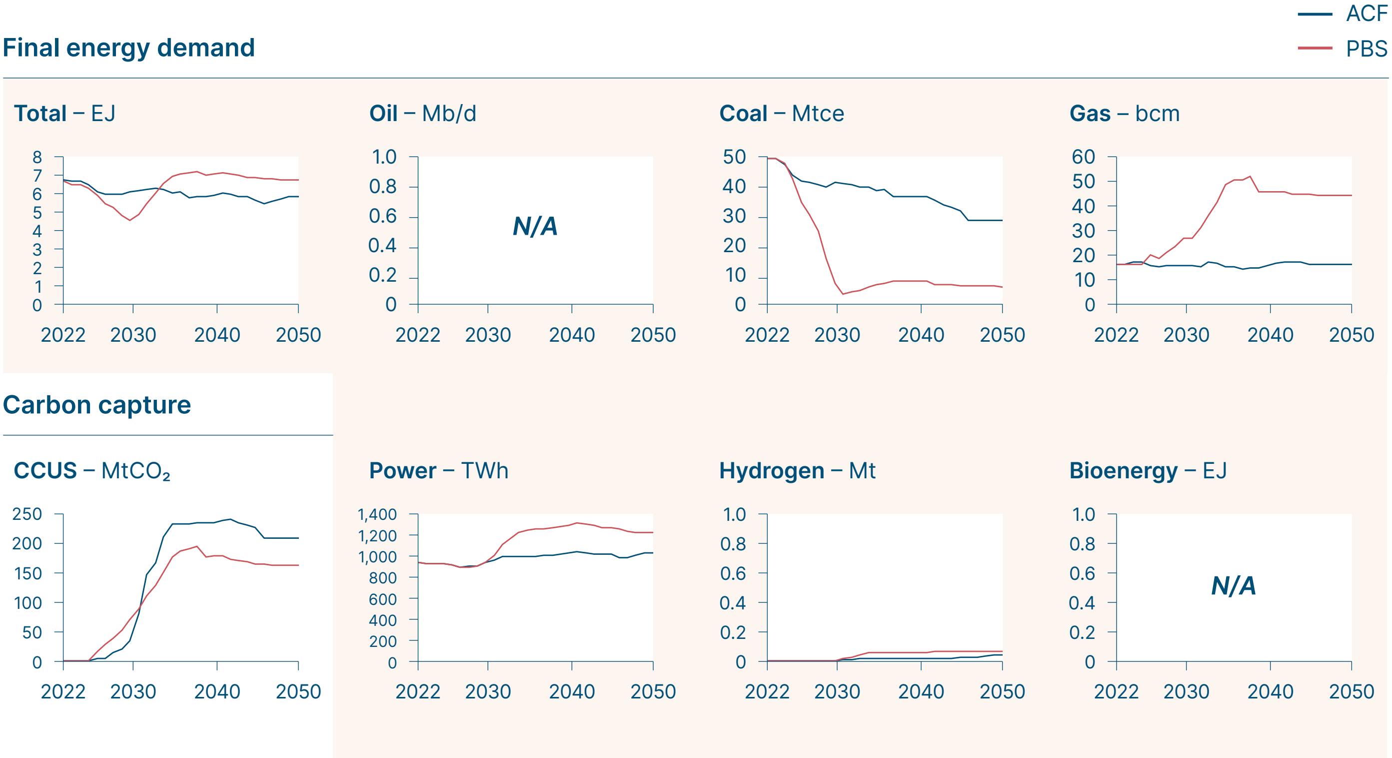
<table>
<tr><th>Core assumptions</th><th>ACF</th><th>PBS</th><th>Source</th></tr>
<tr><td>Demand growth</td><td colspan="2">Demand for aluminium grows from 100 Mt in 2020 up to 150 Mt in 2050.</td><td rowspan="3">MPP (2021), Making Net-Zero Aluminium Possible.</td></tr>
<tr><td>Efficiency improvements (2022–2050)</td><td colspan="2">Recycling: secondary supply of aluminium grows from 33% of total supply in 2020, up to 54% in 2050.
Resource and material efficiency helps limit total growth in total aluminium demand to 50% from 2020, roughly 17% lower than in a business-as-usual trajectory.</td></tr>
<tr><td>Main decarbonisation technologies</td><td colspan="2">Low-carbon electricity is the dominant mitigation strategy for aluminium production.
Heat recovery (mechanical vapour recompression), fuel switching (hydrogen & electrification) or concentrated solar thermal (CST) to produce alumina.
New technologies to capture carbon emissions.
Re-engineering anodes to make them inert.
Improved recycling technologies.</td></tr>
<tr><td>Key uncertainties</td><td colspan="2">Availability of low-carbon power in large quantities across key geographies.
Significant increase in secondary supply or scrap availability.
Ramp-up of carbon pricing in sector.</td><td></td></tr>
</table>

6.4.3 Final energy demand from 2022 to 2050

Coal demand in the aluminium sector decreases from around 50 Mtce in 2022, down to 5–30 Mtce in 2050, and gas demand goes from 15 bcm in 2022 to 15–45 bcm in 2050 [Exhibit A6.5]. Demand for power grows from around 930 TWh in 2022 up to around 1,030–1,230 TWh in 2050, and hydrogen use in the sector is minimal.

EXHIBIT A6.5

Aluminium sector dashboard



NOTE: CCUS is applied both to power generation for aluminium production, and directly on aluminium smelters.

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

6.5 Other/Light industry

The remaining other industries account for approximately one-third of all industrial energy consumption. These sectors consumed about 59 EJ of energy in 2020 (~65 EJ in 2022), with approximately 50% sourced directly from fossil fuels, around 15% from bioenergy, and over 30% from electricity [Exhibit A6.6]. This category accounts for 4% of oil, 9% gas and 4% of coal demand today.

Although this category covers a wide range of industrial sub-sectors, the key factor in fossil fuel demand across most of these sectors is the provision of low-to-medium temperature heat for industrial processes,[26] with the majority involving temperatures below 200°C [Exhibit A6.7].

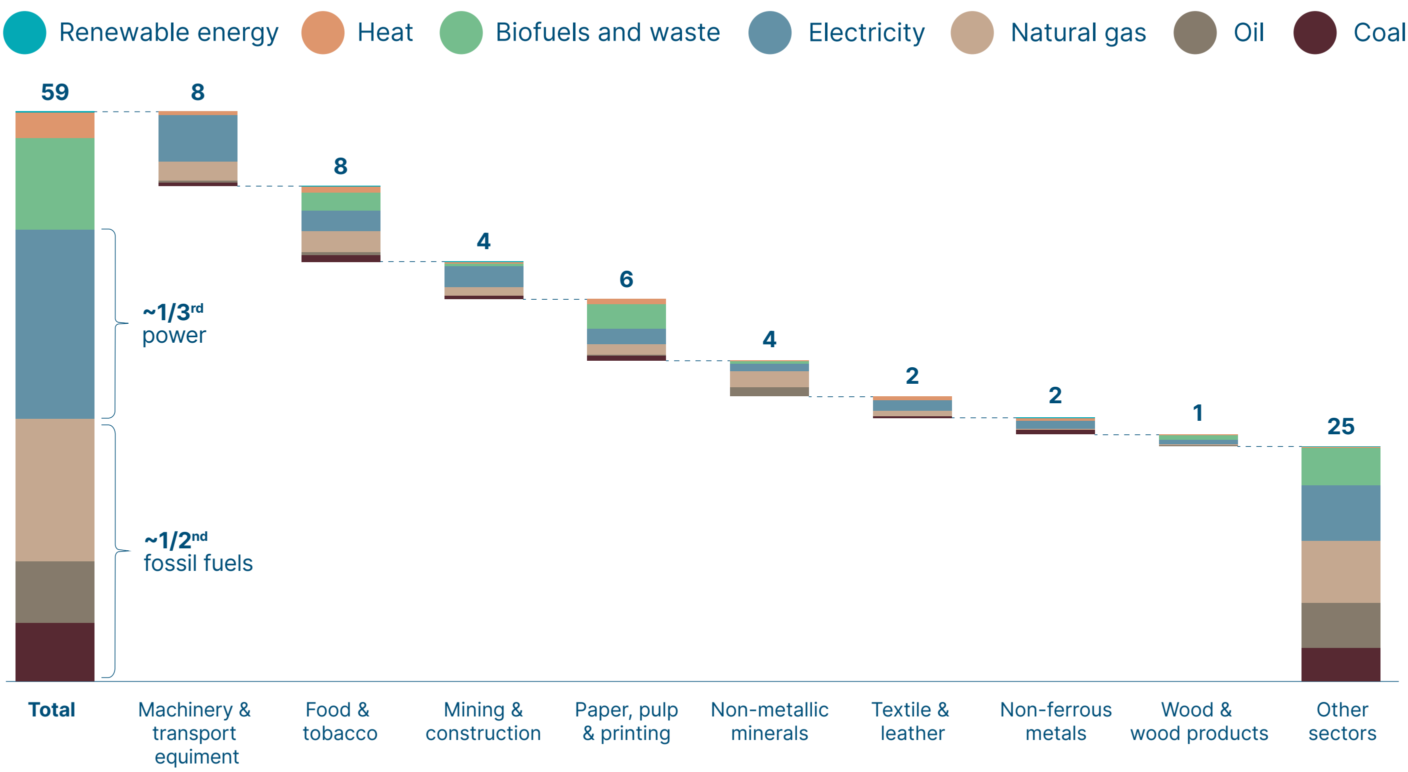
There are multiple technically-feasible routes to decarbonise this heat production, with electric heat pumps likely to be optimal in many applications below 200°C given higher efficiency than combustion-based processes.[27] The focus of our modelling for this sector, therefore, is the potential to replace heating technologies with low-carbon alternatives.

We begin with a total demand of 65 EJ in 2022 for these sectors and replace fossil fuels with alternative net-zero emissions solutions. This methodology follows a conventional S-curve deployment of clean energy technologies, with tipping points occurring between 2025 and 2040 depending on the region and scenario considered. Our PBS scenario accelerates deployment of low carbon technologies by 2–5 years ahead of our ACF scenario.

EXHIBIT A6.6

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 sub-sectors include but are not limited to pharmaceuticals, botanical products, furniture and any other subsectors not listed elsewhere.

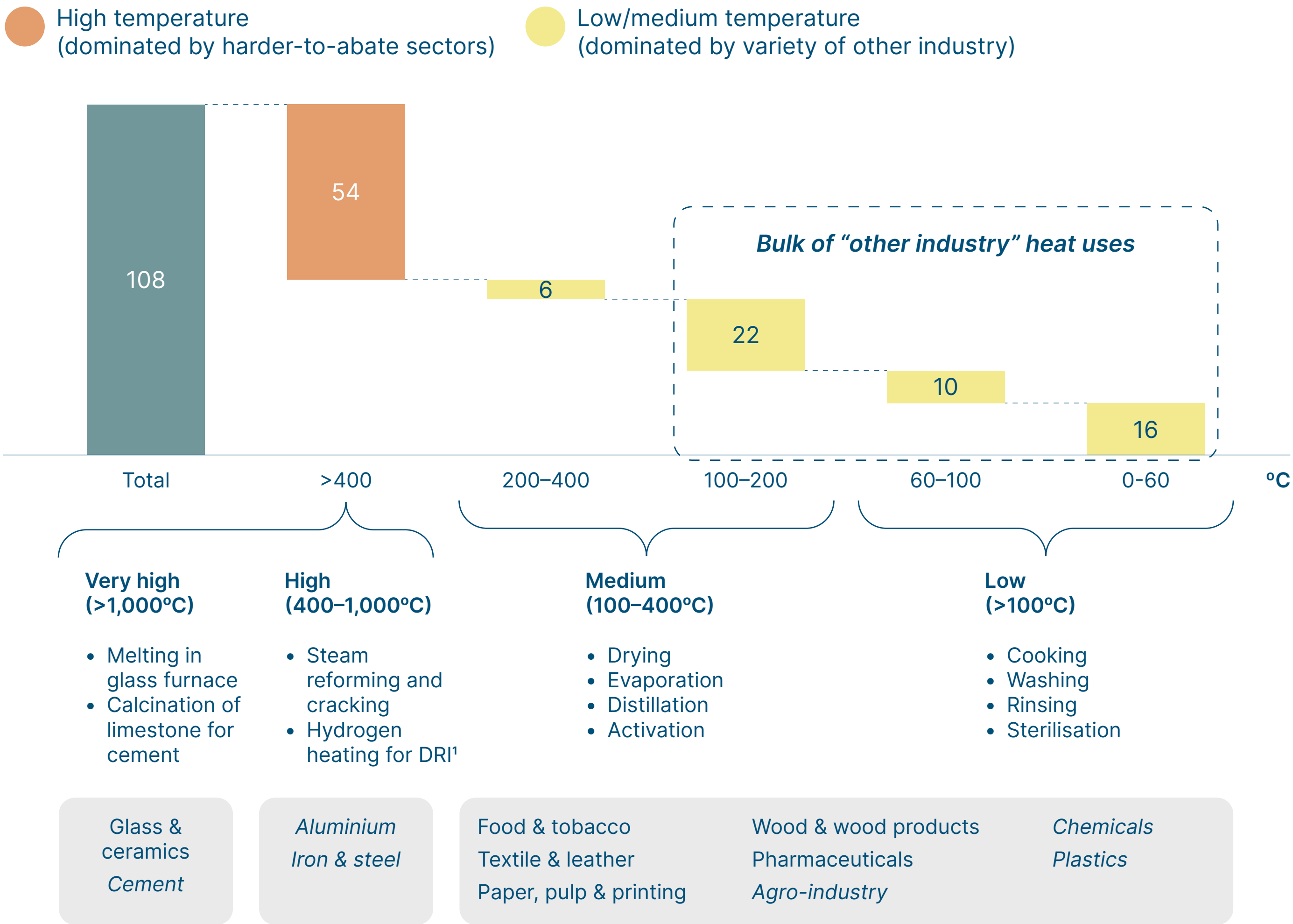
SOURCE: Systemiq analysis for the ETC; IEA (2022), *Energy Balance 2022*; IEA (2021), *Net Zero by 2050.*

26 Around 100–400°C.
27 MAN Energy Solutions (2022), *Industrial heat pumps white paper.*

EXHIBIT A6.7

Energy demand for process heat in industry by temperature range in 2018

Industrial heat demand by temperature range
EJ



NOTE: [1]Direct reduced iron; Listed heat uses and end-use sectors in grey boxes are non-exhaustive examples (sectors in italics are not included in "other industry").

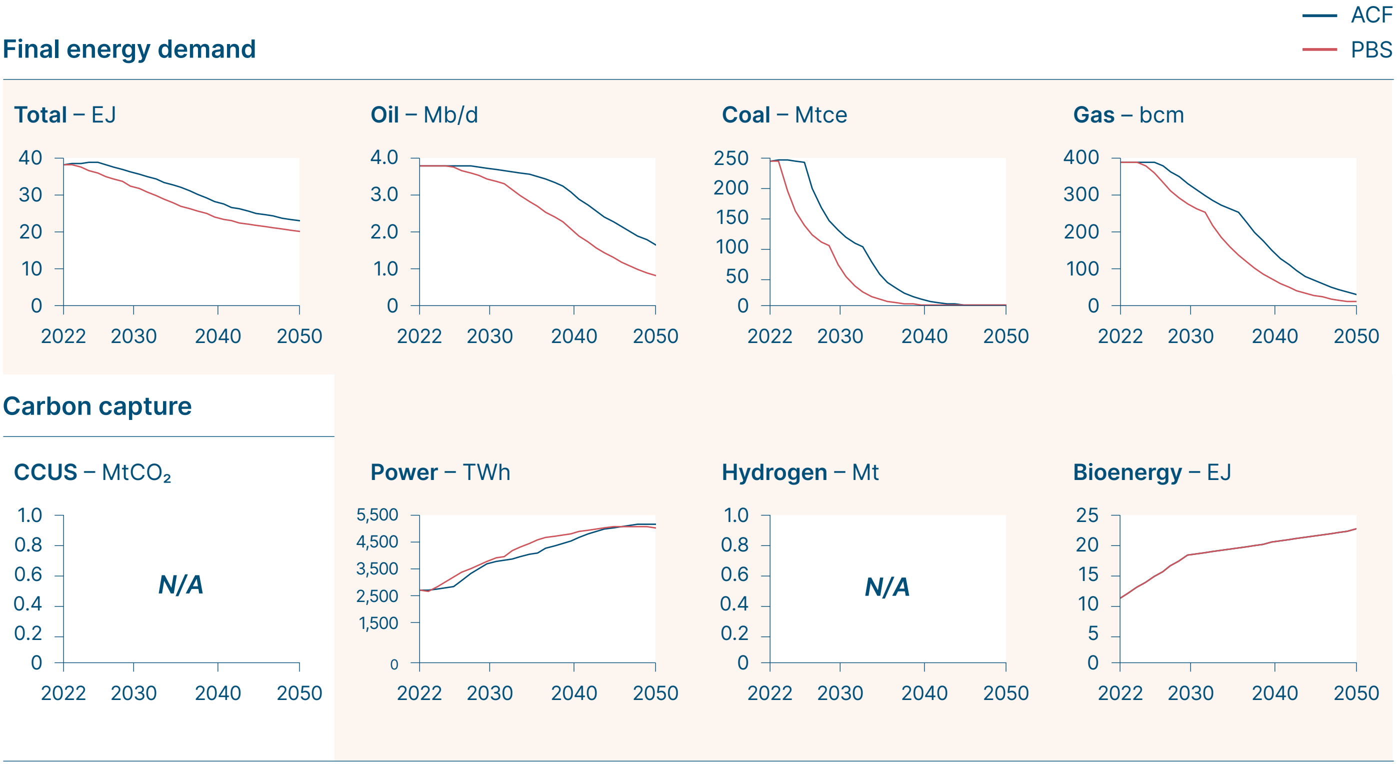
SOURCE: Systemiq analysis for the ETC; IEA (2022), *Industrial heat demand by temperature range.*

6.5.1 Final energy demand from 2022 to 2050

Coal demand in other industry falls sharply from around 250 Mtce in 2022, down to near zero in 2050, and gas demand falls from 390 bcm in 2022 to 10–30 bcm in 2050 [Exhibit A6.8]. Demand for power nearly doubles from around 2,700 TWh in 2022 up to over 5,100 TWh in 2050.

EXHIBIT A6.8

Other Industry sector dashboard



SOURCE: Systemiq analysis for the ETC.

7. Buildings

Buildings accounts for 8% of oil, 21% of gas, and 2% of coal demand today.

The ETC's model of decarbonisation in buildings incorporates three separate pieces of analysis on energy demand for heating, cooking and "other" (i.e. cooling, lighting and appliances – all of which are ~95% electrified currently). The model is split into four different regions: Europe (including the EU and the UK), North America (i.e. the US and Canada), China, and Rest of World (RoW).

Data on current fuel use in buildings by end-use and by region is fairly limited. The starting point for the model is a combination of estimates of global buildings' energy use by fuel for 2022 from IEA (2023) *World Energy Outlook* and estimates of global energy use by fuel and end-use in buildings for 2021 from IEA (2022) *World Energy Outlook*. We have then approximated these global totals to Europe, North America, China and RoW. Exhibit A7.1 breaks down energy used in buildings by end-use and energy source in 2022.

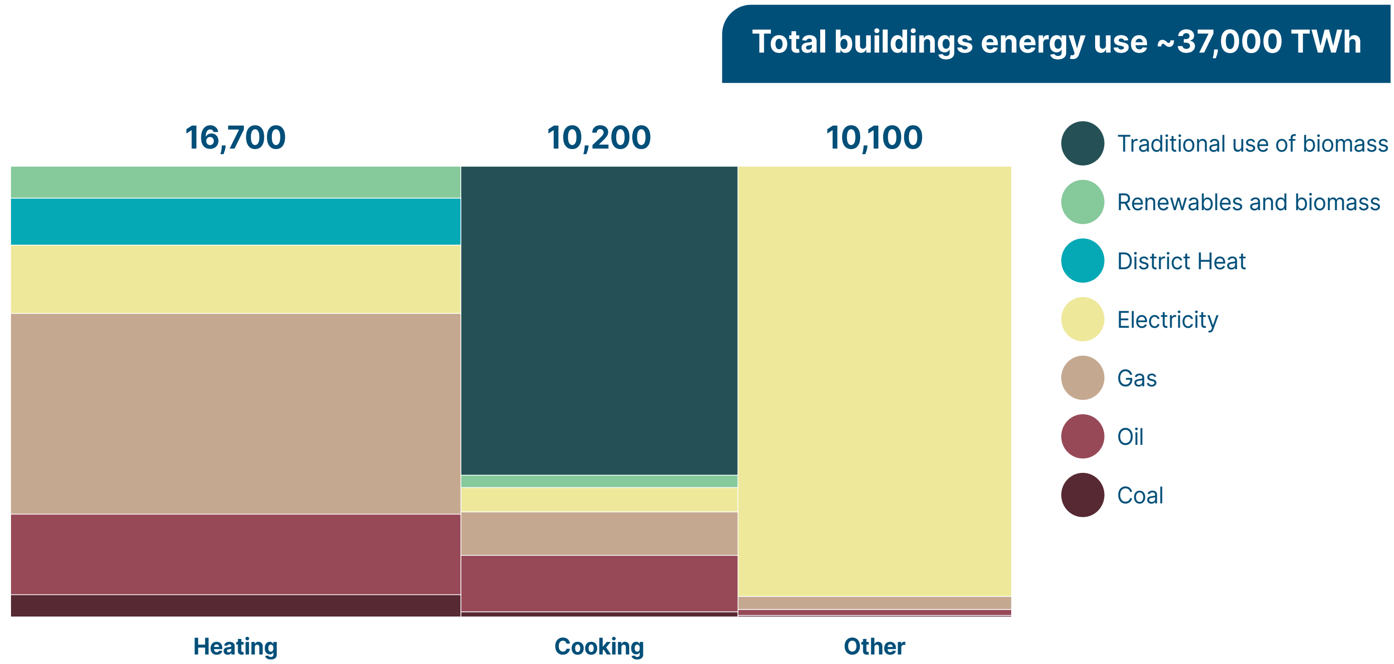
Our approach for modelling each region was as follows:

- **Europe and North America:** ETC analysis based on country-by-country fuel use in the IEA's Energy Balances dataset and fuel/end-use data in the IEA's Energy Efficiency dataset.
- **China:** ETC analysis of China's fuel use in the IEA's Energy Balances dataset, China's building energy split by end-use are from IEA (2017), *Energy Technology Perspectives,* and estimates of fuel used for heating are from Tsinghua Building Energy Research Center, *Annual Report of Building Energy in China*.
- **RoW:** Residual estimates from the IEA's global totals, after accounting for demand from Europe, North America and China.

EXHIBIT A7.1

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.*

Our modelling approach also differed according to building end-use:

- **Heating:** We developed a stock turnover model for Europe and North America to analyse the replacement of fossil fuel boilers with heat pumps (see Box 1). For China, we made assumptions about how fossil fuel use will decline each decade based on ETC research and engagement. For the RoW, we made high-level assumptions about how fossil fuel use will decline relative to our estimated Europe/North America pathways.
- **Cooking:** For Europe and North America, we made assumptions about how quickly fossil fuel use can be electrified. For China and the RoW, we made additional assumptions, based on IEA (2023), *A Vision for Clean Cooking*, about how a transition away from the traditional use of biomass might lead to a transitional increase in demand for oil for cooking this decade (i.e. LPG), before gradually electrifying to 2050.
- **Cooling, appliances and lighting ("other"):** Accounting for less than 5% of fossil fuel use, detailed modelling and analysis were not required; we made high-level assumptions about how rapidly 100% electrification can be achieved in each region. In addition, we used estimates from IEA (2022) *World Energy Outlook* of how final energy consumption will change over time, in response to baseline demand growth and efficiency improvements.

It should be noted that the ETC will be developing this buildings model much further throughout the ETC's upcoming workstream on energy productivity in 2024. Specifically, we will be broadening the focus of the model from the pace of fossil fuel decline to looking at the opportunities for energy, material and service efficiency and the implications for final energy consumption and electricity requirements.

BOX 1: THE ETC'S FOSSIL FUEL BOILER STOCK TURNOVER MODEL

The model begins with an estimate of the number of oil and gas boilers in Europe and North America, based on approximated oil and gas use for heating and average fuel consumption per boiler. Stock turnover is driven by two variables:

- Boiler replacement rate: every year, what percentage of oil/gas boilers get replaced (e.g., either as a result of reaching end-of-life or due to policy incentives)?
- Heat pump penetration rate: every year, what share of oil/gas boilers that are replaced, get replaced with a heat pump, as opposed to an equivalent fossil fuel boiler?

To estimate how these variables might change over time in Europe and North America, model assumptions were guided by three overarching policy assumptions:

- When will fossil fuel boilers be banned from new build homes?
- When will the sale of fossil fuel boilers be banned completely?
- When will running a fossil fuel boiler be banned? (i.e. when will gas distribution grids for buildings be stopped?)

The total number of heat pumps in the model is also driven by installations in new builds. We use estimates of the average number of new properties built in recent years and hold this constant over the time period. We assume that an increasing share of these new builds get built with a heat pump, determined by our assumptions for when policy will ban fossil fuel boilers being installed in new builds.

Exhibit A7.2 shows the building heating stock in Europe and North America in both scenarios over time.

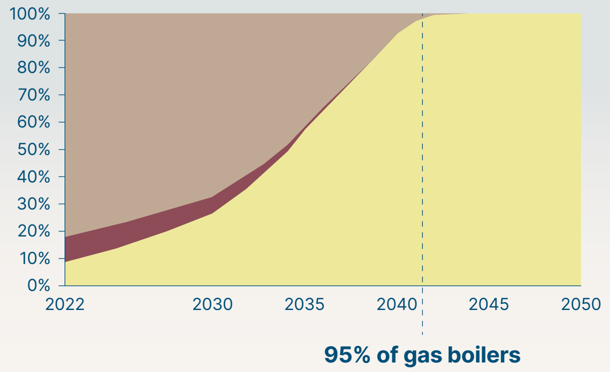
EXHIBIT A7.2

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

Building heating technology stock
% of stock

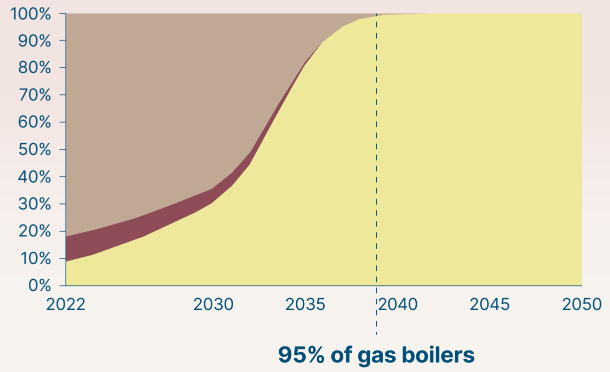
Gas Oil Heat pumps

ACF



95% of gas boilers phased out early 2040s

PBS



95% of gas boilers phased out by 2040

	ACF		PBS
No new gas boiler installations	2035 in Europe 2037 in US	**No new gas boiler installations**	2034 in Europe 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.*

7.1 Key assumptions in the ACF and PBS scenarios

Core assumptions	Subcategory	ACF	PBS	Source
Demand growth	Heating	Stock turnover of boilers in Europe occurs in line with indications of key policy changes (e.g., banning of new fossil fuel boilers expected ~2035 in Europe). US transition assumed to go slower than Europe's, reflecting weaker national ambition.	Accelerated heat pump uptake and increased the number of boiler replacements each year, reflecting stronger policy incentives and financial support.	Systemiq analysis for the ETC.
	Cooking	Transition of cooking with traditional use of biomass in Africa and rural Asia is more focused on LPG in the 2020s and 2030s, before gradually electrifying.	Cooking is dominated by fast electric uptake.	Systemiq analysis for the ETC; IEA (2023), *A Vision for Clean Cooking*
	Other	Rapid electrification this decade.	Even faster electrification this decade.	Systemiq analysis for ETC.
Efficiency improvements (2022–2050)	Heating	Heat pumps average efficiency assumed constant at 300% over time; while this is likely to increase over time due to advances in heat pump technology, holding it constant allows us to implicitly assume a role for resistive heating (which is at most 100% efficient). The main determinant of how efficiently a heat pump operates in a given building is the size of radiators and level of insulation, which prevents heat loss and enables better heat transfer to the room, therefore requiring less electric input to power the heat pump. For a heat pump to operate effectively and to reduce overall running costs, retrofitting is essential in many cases. This means that the impact of retrofitting on energy demand are encompassed within our heat pump efficiency assumptions; in other words, for a heat pump to operate at around 300% efficiency on average, we have assumed that in many cases retrofitting must have taken place. Indeed, in many cases it would be unlikely that retrofitting to a property may occur without the objective of fitting a heat pump. Gas/oil boiler efficiency assumed constant at 90% in Europe/North America over time. Efficiency gains can be expected in developing countries as they adopt more efficient assets; we have taken this into consideration in our high-level assumptions for RoW.		Systemiq analysis for the ETC.
Main decarbonisation technologies	Heating	Heat pumps will be the dominant solution to replace fossil fuel boilers, with a supporting role for resistive heating.		Systemiq analysis for ETC.
	Cooking	Electric cooking will dominate over the long-term, but there will be a transitional role for LPG and modern biofuels.		Systemiq analysis for ETC; IEA (2023), *A Vision for Clean Cooking.*
Key uncertainties	Heating	• Dominance of heat pumps vs resistive heating. • Pace and extent of building retrofits to complement the operational efficiency of heat pumps. • Ambition and global breadth of building codes and standards in new builds. • Baseline demand growth for heating. • Need for strong policies to support heat pumps, including subsidies or other mechanisms to reduce financial barriers to low-income households.		
	Cooking	Nature and pace of shift away from traditional use of biomass in cooking.		

7.2 Final energy demand from 2022 to 2050

Coal demand in buildings falls sharply from around 120 Mtce in 2022, down to near zero by 2040, gas demand falls from 870 bcm in 2022 to 5–10 bcm in 2050, and oil demand falls from around 8 Mb/d to near-zero by 2050 [Exhibit A6.6]. The electrification of heating leads to a near-doubling of demand for power, from around 13,000 TWh in 2022 up to 22–25,000 TWh in 2050. Demand for low-carbon hydrogen grows to around 20 Mt H_2 by 2050. Demand for biomass in buildings, predominantly traditional use of biomass for cooking, is assumed to decrease from 28 EJ in 2022 down to 3–4 EJ (of modern biomass) in 2050.

EXHIBIT A7.3

Buildings sector dashboard

NOTE: Our modelling for buildings focused on fossil fuel use in heating and cooking. Because other energy end-uses are already 95% electrified, we made high-level assumptions about how rapidly 100% electrification can be achieved in each region. In addition, we used estimates from IEA (2022) *World Economic Outlook 2022* of how final energy consumption will change over time, in response to baseline demand growth and efficiency improvements.

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

8. Power

Power accounts for 4% of oil, 39% of gas, and 65% of coal demand today.

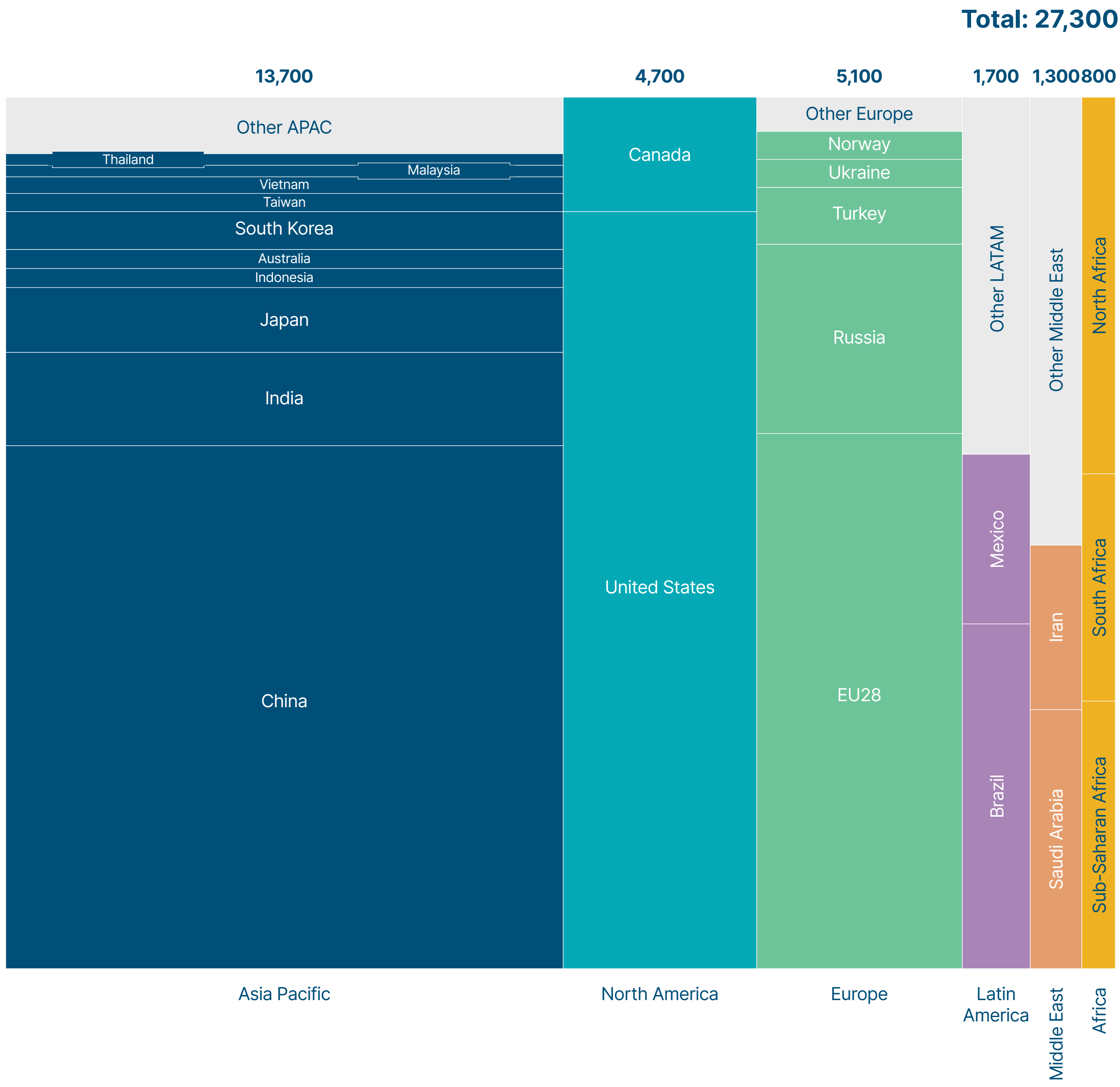
8.1 Power generation by region

To calculate global power generation, we used a bottom-up methodology that leverages work done for power systems on a country level, to better account for granular, region-specific assumptions around costs and power generation mixes. We started by looking at power generation data for 2022 and chose the top 22 power generating countries to model, ultimately covering >90% of total power generated [Exhibit A8.1]. In addition to total power generation, we collected data for generation mix by fuel/technology. Finally, countries were sorted into six different regions: Asia Pacific (APAC), North America (NAMR), Europe, Latin America, Middle East, and Africa.

EXHIBIT A8.1

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.*

For 15 of the 22 countries, we used work done by local experts, either our research partners or a respected organisation that also had an in-country presence. Power system models for the remaining 7 countries were then created using other countries as proxies [Exhibit A8.2].

EXHIBIT A8.2

Sources used for regional power modelling in our scenarios

Summary table on sources used for ETC's power model

Region	Source	ACF	PBS
South Africa	Meridian Economics (2020), *A vital ambition*	Base Case (stated policies)	Ambitious RE
Northern Africa	IRENA (2023), *Planning and Prospects for renewable power: North Africa*	Planned Scenario	Transition Scenario
SSA	WRI/ETC (2023), *A path across the Rift*	Scenario 2 (low electrification)	Scenario 1 (high electrification)
China	ICCSD (2023), *Towards carbon neutrality*	2°C Target-Oriented Scenario	1.5°C Target-Oriented Scenario
India	TERI (2023), *India 2050*	Unconstrained RE Scenario (URES)	No Fossil Scenario (NFS)
Japan	BNEF (2022), *New energy outlook*	ETS	NZS
South Korea	BNEF (2022), New energy outlook and Agora Energiewende (2021), *Climate neutrality roadmap for Korea*	BNEF - ETS	Agora Energiewende – K-map
Taiwan	South Korea as proxy[1]		
Indonesia	IEA (2022), *Energy Sector Roadmap to Net Zero Emissions Indonesia*	Announced Pledges (APS)	Net Zero (NZE)
Vietnam	Indonesia as proxy		
Malaysia	IRENA (2023) *Malaysia Energy Transition Outlook*	Transforming Energy Scenario (TES)	1.5C Scenario (1.5-S)
Thailand	Indonesia as proxy		
Australia	ETI (2023), *Pathways to industrial decarbonisation* and additional modelling by ETI for the ETC	Coordinated Action Scenario	Coordinated Action with additional demand from exports
EU27 + UK	Eurelectric (2023), *Decarbonization Speedways*	REPowerEU-inspired (REP)	Radical Action (RA)
Russia	IEA (2022), *World Energy Outlook*	STEPS	APS
Turkey	Poland as proxy		
Ukraine	EU as proxy		
Brazil	IEA (2022), *World Energy Outlook*	STEPS	APS
Mexico	BNEF (2022), *New energy outlook* and ETC modelling	BNEF - ETS	BNEF – ETS with ETC modelling[2]
Saudi Arabia	Australia proxy		
Iran	Saudi/Australia as proxy		
Canada	BNEF (2022), *New energy outlook* and ETC modelling	ETS	BNEF – ETS with ETC modelling[2]

ETC, Partner or Regional study	External agency study	Proxy

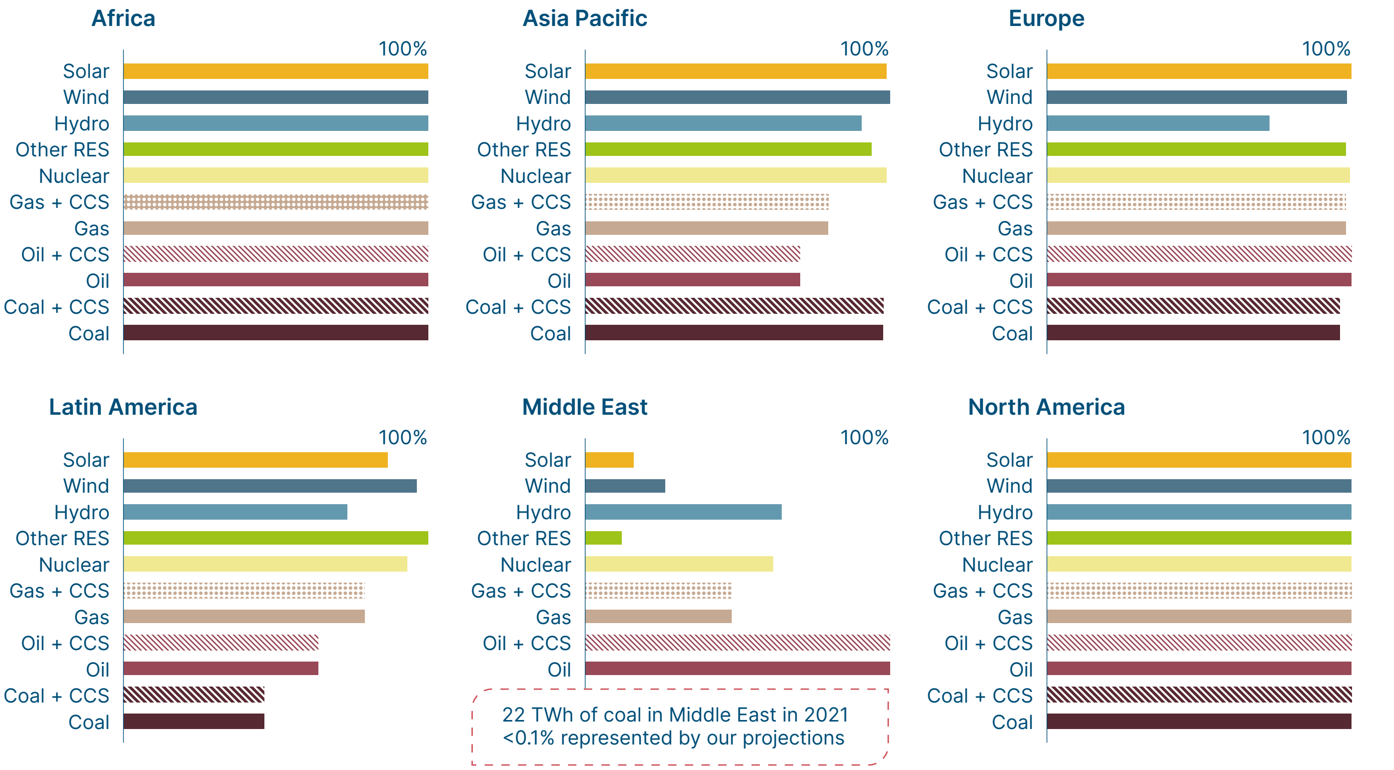
NOTE: [1] For proxies, power generation in 2022 is taken from BNEF (2022), New energy outlook as a starting point, and then total power demand and generation shares are modelled following the same path as proxy countries; [2] ETC modelling assumes 10% greater power demand by 2050, with an increased share of low-carbon power generation, especially for wind and solar.

We modelled the remaining "Rest of World" power generation by using the six different regions. We first used 2022 data to show what percentage of power generation by fuel/technology was covered by our country models [Exhibit A8.3]. While we had full coverage for North America and Africa, and near full coverage for Europe and Asia Pacific, we had the biggest gaps for Latin America and the Middle East due to the lack of available power system models for countries in these regions.

EXHIBIT A8.3

Share of power generation covered by regional power studies, by technology and region

Coverage by technology and region
%



NOTE: RES = Renewable Energy sources

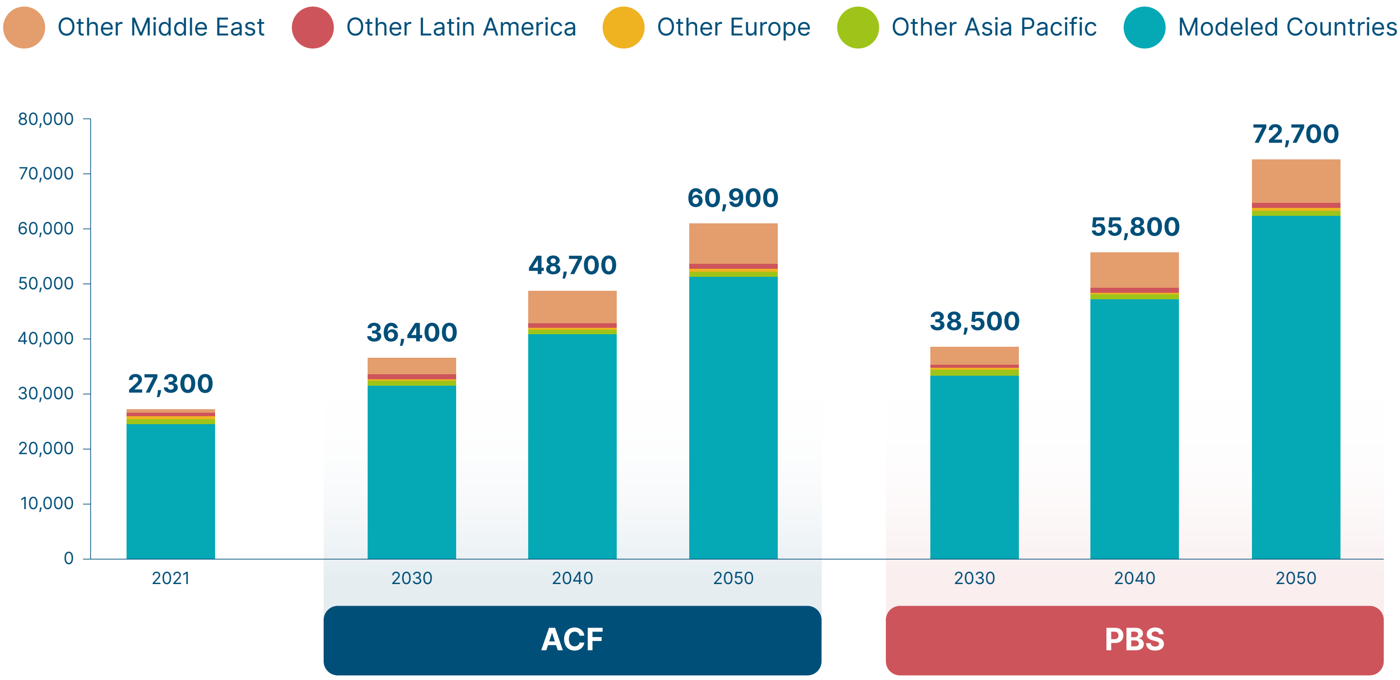
SOURCE: Systemiq analysis for the ETC.

We therefore had power generation models for 22 countries going from 2022 to 2050. For countries not included in our models, we assumed that the power generation mix was the same as for other countries in the same region (e.g., the coverage of power generation from solar in the Middle East remained constant across countries). We thus calculated total power generation for a region by calculating power generation from each fuel/technology across the region, and summing these together. Due to incomplete coverage by region, we ended up with 4 “other” calculations: Other APAC, Other Europe, Other Latin America, and Other Middle East [Exhibit A8.4]. We then summed all the regions to get a world total.

EXHIBIT A8.4

Total share of power generation covered by regional power system studies

Power generation
TWh



NOTE: All numbers are rounded.

SOURCE: Systemiq analysis for the ETC.

The national studies on which we have drawn suggest that by 2050, total global on grid power generation could lie in the range of 61–73,000 TWh. In addition, the use of captive renewables to produce green hydrogen could be significant – we estimate that providing up to 500 Mt of green hydrogen in 2050 could require 22,500 TWh of additional generation from wind and solar.[28] This therefore increases our range of 61–73,000 TWh range of direct electricity demand, up to a maximum possible range of 75–95,000 TWh [Exhibit A8.6]. The ETC will continue to assess future demand trajectories for power, as well as the potential for green hydrogen and the implications for wind and solar generation, in its upcoming work in 2024 and beyond.

28 Assuming an electrolyser efficiency of 45 kWh per kgH_2.

8.2 Key assumptions in the ACF and PBS scenarios

The table below summarises key assumptions by country in terms of overall power system growth to 2050, compound annual growth rate in wind and solar between 2023 and 2050, coal phase out date, and power generation (TWh) per capita in 2050.

EXHIBIT A8.5

Summary of studies and assumptions in ETC's power model

Region	System growth 2023–2050		Wind + Solar CAGR		Coal Phase Out Date		TWh per capita	
	ACF	PBS	ACF	PBS	ACF	PBS	ACF	PBS
EU27 + UK	2.2x	2.4x	7.4%	7.9%	By 2040		14.0	15.4
Russia	1.3x	1.2x	9.0%	9.6%	n/a		10.5	9.87
Turkey	1.8x	2.1x	8.8%	9.5%	By 2040		6.21	7.24
Ukraine	2.2x	2.4x	11%	12%	By 2040		10.2	11.2
Brazil	1.8x	2.1x	6.8%	7.6%	n/a	By 2040	5.08	5.59
Mexico	1.7x	1.9x	8.7%	9.2%	n/a		3.93	4.32
Saudi Arabia	2x	2.3x	23%	24%	No coal		16.2	17.9
Iran	2x	2.3x	23%	24%	By 2030		5.08	5.59
Canada	1.3x	1.5x	7.4%	8.1%	By 2030		18.5	20.3
United States	2.4x	4x	10.3%	12.4%	n/a	n/a	21.5	26.7
South Africa	1.8x	1.9x	10%	11%	n/a		5.14	5.33
Northern Africa	1.8x	3.5x	9.1%	16%	n/a		2.23	4.38
Sub-Saharan Africa	8x	16x	20%	22%	By 2030		1.02	2.07
China	1.6x	1.8x	7.4%	8.0%	n/a		10.14	11.45
India	3.5x	3.5x	13%	13%	n/a	By 2050	3.14	3.14
Japan	n/a	1.3x	6.5%	8.0%	n/a		9.80	13.0
South Korea	1.3x	2x	9.7%	13%	n/a	By 2040	16.8	28.9
Taiwan	1.3x	2x	11%	15%	n/a	By 2040	16.2	27.8
Indonesia	4x	6x	27%	29%	By 2050	By 2040	4.04	5.55
Vietnam	4x	6x	12%	14%	n/a		9.88	13.6
Malaysia	1.3x	1.9x	14%	15%	By 2050		5.78	8.80
Thailand	4x	6x	16%	17%	n/a		10.7	14.7
Australia	2x	5x	8.3%	11%	By 2040		18.51	45.72

SOURCE: Systemiq analysis for the ETC.

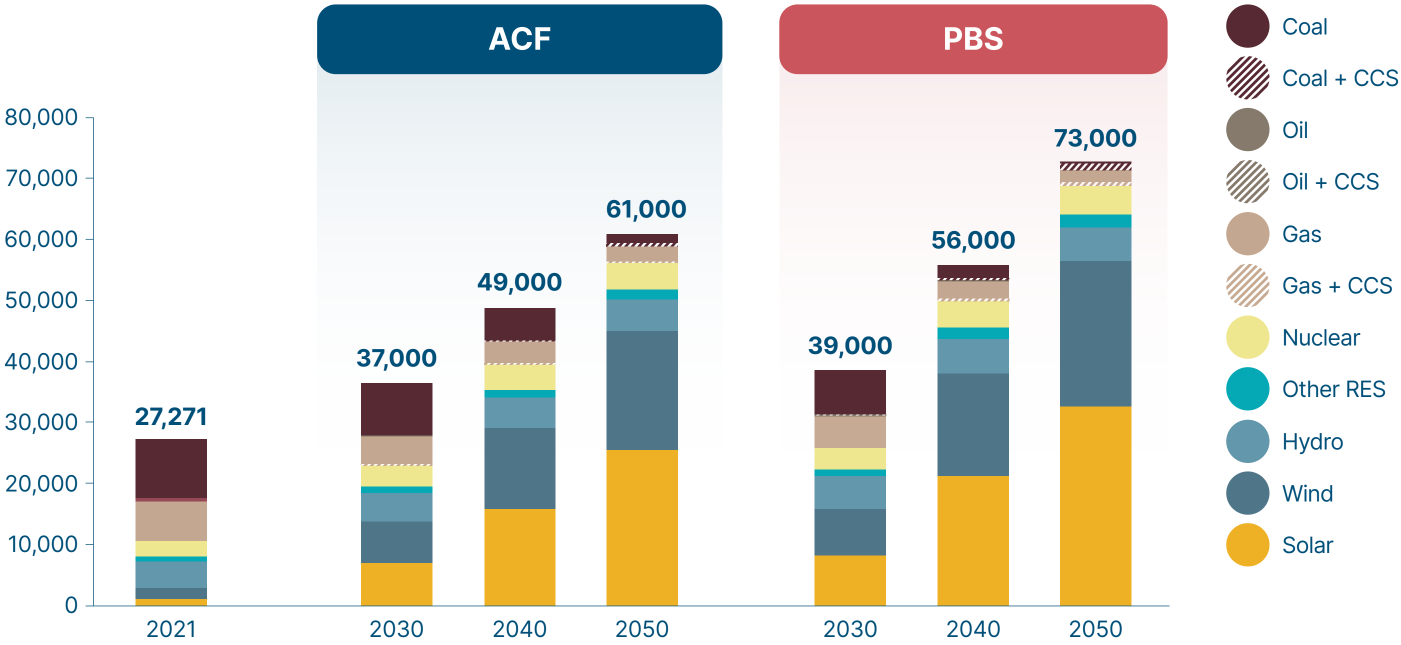
Our approach to understand power generation has uncertainties in both directions, particularly in developing economies:

- 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.
- However, technological development and cost reduction may also make existing thermal capacity uncompetitive faster than our scenarios assume, reducing the role for coal or gas, whether unabated or with CCUS.
    - In particular, faster cost reductions in solar PV and in batteries, combined with the massive scale 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 quality solar resources. Almost all past projections for the growth of solar PV have fallen far short of what actually occurred, and it is possible that the same will be true in the coming years.
- There is significant uncertainty for countries in the Middle East and Latin America, driven by a lack of detailed power system modelling for countries in these regions.

EXHIBIT A8.6

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.

9. Energy transformation

Energy transformation accounts for 6% of oil, 18% of gas, and 5% of coal demand today.

Energy transformation, sometimes referred to as “energy industry” or “energy industry own use”, pertains to all energy consumed to produce final energy carriers from primary energy carriers, including associated conversion losses. Crude oil refining, natural gas processing, coal-to-liquids or hydrogen production via coal gasification or steam methane reforming (SMR) are the largest sources of fossil fuel demand in energy transformation.

Fossil fuel use in energy transformation, including hydrogen demand in refining for fuel desulfurisation, is closely dependent on the supply needed to match the aggregate demand in any given year,[29] in particular for oil and natural gas, given almost all production is either refined (oil) or processed (natural gas).[30] Given this, oil and gas use in energy transformation follows the same decline as aggregate oil or gas demand for any given year in the ACF and PBS scenarios.

While coal use in energy processing mostly pertains to liquids production (e.g., diesel, gasoline, chemical feedstock, etc.) in China and South Africa,[31] coal demand in energy transformation follows the aggregate decline in coal demand across sectors rather than that of oil demand in these regions.

When not shown separately in the report, annual fossil fuel demand for energy transformation is allocated to end-use sectors based on each sectors’ share of specific fossil fuel demand in the given year.

29 Relationship would be linear if there were no efficiency improvements in the various conversion processes, which there historically have been.

30 Unrefined crude oil may be used directly in stationary power generation applications, in particular in the Middle East. RystadEnergy (2022), *Oil market transition report*.

31 Global Energy Monitor (2023), *Coal-to-Liquids*.

10. Final energy demand

Final energy demand includes all energy consumed by end users, including industry, households, transportation modes etc. and accounts for losses in energy transformation and in transmission and distribution of energy. This includes direct fossil fuel use, electricity and hydrogen consumption, as well as uses of bioenergy and heat. The sources for each element of final energy demand are listed in the table below.

Final Energy Demand	Source
Coal	ETC modelling of fossil fuel demand on a (sub-)sectoral basis, as described in Main Report and this Annex.
Oil	
Gas	
Electricity	ETC modelling of power demand on a (sub-)sectoral basis, as described in Main Report and this Annex.
Hydrogen and Derived Fuels	ETC modelling of hydrogen demand on a (sub-)sectoral basis, as described in Main Report and this Annex. Derived Fuels includes ammonia and sustainable aviation fuels, used in Shipping and Aviation.
Traditional Biomass	Assumed to phase down rapidly from current level of 24 EJ p.a., reduced by 50% by 2030, and falls to zero by 2050.
Modern Biomass	ETC modelling of bioenergy demand on a (sub-)sectoral basis, based on Mission Possible Partnership Sector Transition Strategies (for hard-to-abate sectors), and based on ETC (2021), *Bioresources within a Net-Zero Emissions Economy*; ETC (2022), *Mind the Gap*.
Heat	Assumed to ramp down from 15 EJ down to 6 EJ p.a., with heat from industry falling from 7-8 EJ in 2022 to near-zero in 2050, and heat from buildings remaining at 5-6 EJ in 2050.

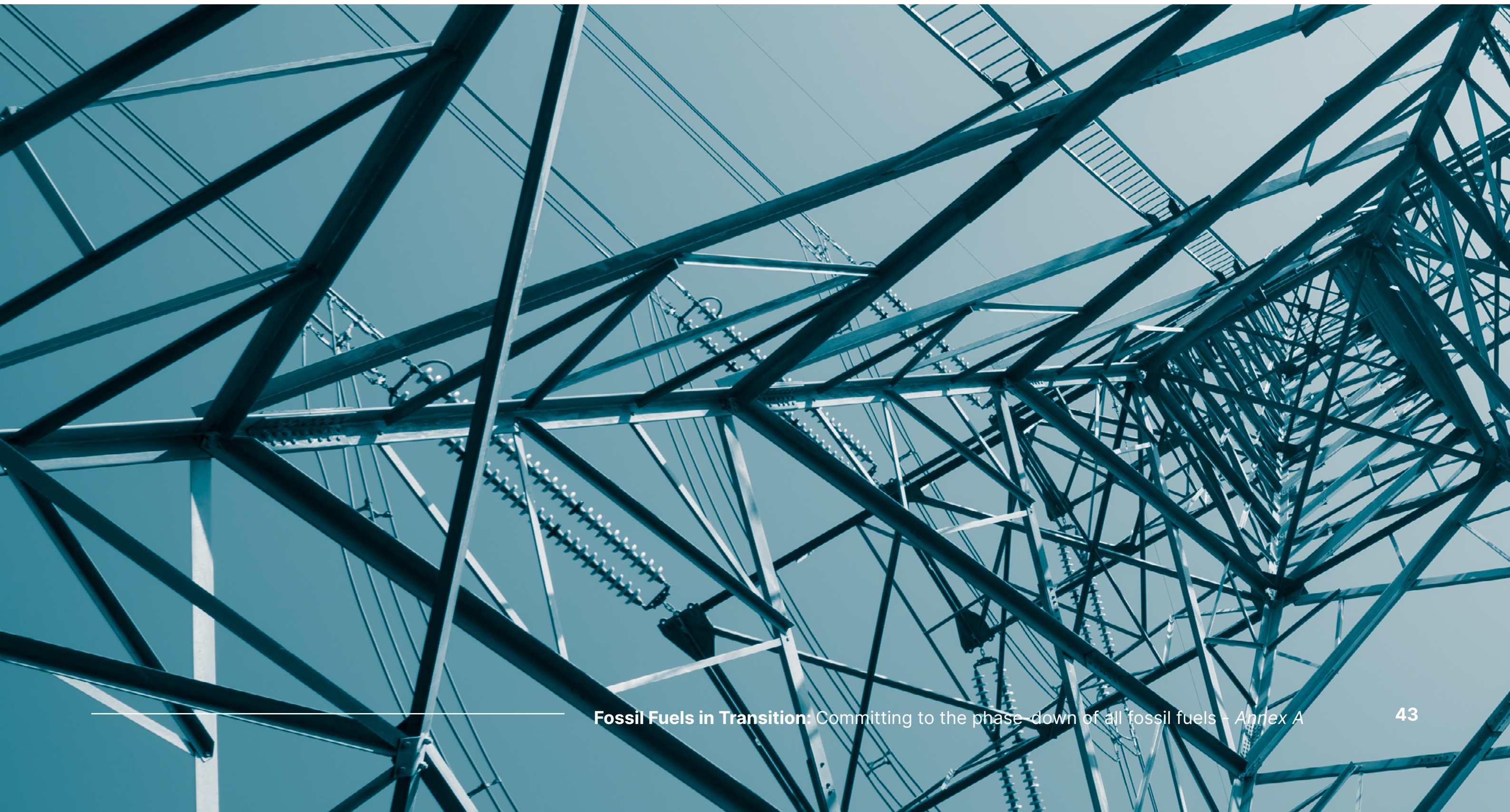
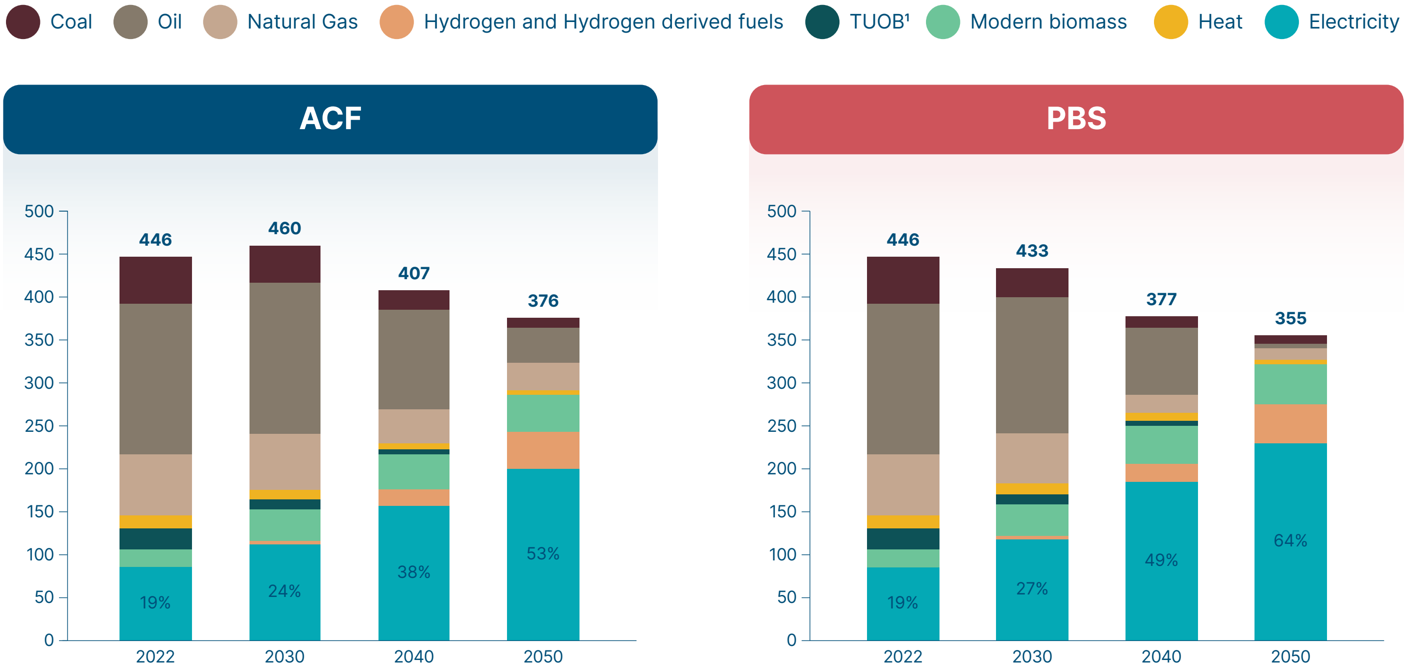


EXHIBIT A10.1

Final Energy Consumption in ACF and PBS to 2050

Final Energy Consumption
EJ



NOTE: [1] TUOB = Traditional Use Of Biomass.

SOURCE: Systemiq analysis for the ETC.

Oil[1,2]

Mb/d		2022	2030	2040	2050
ACF		**97**	**93**	**63**	**22**
Industry		**21**	**20**	**18**	**13**
	Aluminium	-	-	-	-
	Cement	-	-	-	-
	Chemicals	17	16	15	12
	Steel	-	-	-	-
	Other Industry	4	4	3	2
Transport		**55**	**57**	**34**	**6**
	Road Transport	44	45	30	6
	Aviation	6	7	3	0
	Shipping	5	5	2	0
Buildings		**8**	**7**	**2**	**0**
Power		**4**	**1**	**0**	**0**
Other		**9**	**8**	**6**	**2**
PBS		**97**	**84**	**42**	**4**
Industry		**21**	**20**	**13**	**3**
	Aluminium	0	0	0	0
	Cement	0	0	0	0
	Chemicals	17	16	11	2
	Steel	0	0	0	0
	Other Industry	4	4	2	1
Transport		**55**	**50**	**23**	**0**
	Road Transport	44	39	18	0
	Aviation	6	7	3	0
	Shipping	5	4	2	0
Buildings		**8**	**7**	**2**	**0**
Power		**4**	**1**	**1**	**0**
Other		**9**	**7**	**3**	**0**

NOTE: [1] All tables include energy transformation; [2] Subtotals may not sum to totals due to rounding.

Gas[1,2]

bcm		2022	2030	2040	2050
ACF		**4,170**	**3,560**	**2,400**	**1,900**
Industry		**1,140**	**1,250**	**1,020**	**1,110**
	Aluminium	20	20	20	20
	Cement	50	80	100	90
	Chemicals	520	630	530	700
	Steel	90	140	200	260
	Other Industry	450	380	170	40
Transport		**30**	**40**	**20**	**10**
	Road Transport	30	30	10	0
	Aviation	0	0	0	0
	Shipping	0	10	10	10
Buildings		**1,010**	**850**	**250**	**10**
Power		**1,900**	**1,380**	**1,100**	**770**
Other		**90**	**50**	**10**	**0**
PBS		**4,170**	**3,350**	**1,600**	**1,250**
Industry		**1,140**	**1,070**	**590**	**520**
	Aluminium	20	30	50	50
	Cement	50	80	100	90
	Chemicals	520	460	140	130
	Steel	90	180	210	230
	Other Industry	450	320	80	10
Transport		**30**	**40**	**20**	**10**
	Road Transport	30	30	10	0
	Aviation	0	0	0	0
	Shipping	0	10	10	10
Buildings		**1,010**	**770**	**120**	**0**
Power		**1,900**	**1,520**	**940**	**730**
Other		**90**	**50**	**10**	**0**

NOTE: [1] All tables include energy transformation; [2] Subtotals may not sum to totals due to rounding.

Coal[1,2]

Mtce		2022	2030	2040	2050
ACF		**5,780**	**4,800**	**2,820**	**1,180**
Industry		**1,650**	**1,440**	**760**	**410**
	Aluminium	50	40	40	30
	Cement	240	240	170	150
	Chemicals	230	270	70	60
	Steel	880	760	470	170
	Other Industry	250	130	10	0
Transport		**0**	**0**	**0**	**0**
	Road Transport	0	0	0	0
	Aviation	0	0	0	0
	Shipping	0	0	0	0
Buildings		**120**	**50**	**0**	**0**
Power		**3,880**	**3,230**	**2,050**	**770**
Other		**130**	**80**	**10**	**0**
PBS		**5,780**	**3,970**	**1,440**	**820**
Industry		**1,650**	**1,090**	**450**	**330**
	Aluminium	50	10	10	10
	Cement	240	240	170	150
	Chemicals	230	200	20	10
	Steel	880	570	260	160
	Other Industry	250	70	0	0
Transport		**0**	**0**	**0**	**0**
	Road Transport	0	0	0	0
	Aviation	0	0	0	0
	Shipping	0	0	0	0
Buildings		**120**	**40**	**0**	**0**
Power		**3,880**	**2,760**	**970**	**500**
Other		**130**	**80**	**10**	**0**

NOTE: [1] All tables include energy transformation; [2] Subtotals may not sum to totals due to rounding.

Carbon Capture[1]

$MtCO_2$		2022	2030	2040	2050
ACF		**45**	**785**	**4,190**	**8,490**
Of which point source for fossil fuel use		**45**	**545**	**3,030**	**4,840**
Industry		**5**	**250**	**1,870**	**2,870**
	Aluminium	0	35	235	210
	Cement	1	70	885	1,370
	Chemicals	3	110	315	505
	Steel		30	440	790
Transport		**0**	**30**	**250**	**690**
	Aviation (DACCU)	0	25	160	490
	Shipping (Blue H_2)	0	5	90	110
Fossil Fuel Processing		**40**	**180**	**250**	**120**
Power		**1**	**120**	**820**	**1,745**
BECC		**0**	**170**	**630**	**870**
DACC		**0**	**50**	**370**	**2,295**
PBS		**45**	**985**	**3,900**	**7,700**
Of which point source for fossil fuel use		**45**	**740**	**2,735**	**4,050**
Industry		**5**	**340**	**1,650**	**2,240**
	Aluminium	0	70	180	160
	Cement	1	70	885	1,370
	Chemicals	3	70	70	70
	Steel	0	140	520	640
Transport		**0**	**30**	**250**	**600**
	Aviation (DACCU)	0	25	160	490
	Shipping (Blue H_2)	0	5	90	110
Fossil Fuel Processing		**40**	**220**	**195**	**50**
Power		**1**	**170**	**800**	**1,655**
BECC		**0**	**170**	**630**	**870**
DACC		**0**	**50**	**370**	**2,295**

NOTE: [1] Subtotals may not sum to totals due to rounding.

Hydrogen[1]

MtH_2		2022	2030	2040	2050
ACF		**95**	**105**	**210**	**360**
Industry		**55**	**50**	**80**	**120**
	Aluminium	0	0	0	0
	Cement	0	0	5	5
	Chemicals	50	40	50	60
	Steel	5	10	25	55
Transport		**0**	**20**	**90**	**205**
	Road Transport	0	0	10	20
	Aviation	0	5	30	90
	Shipping	0	15	60	85
Energy Transforamtion / Fossil Fuel Processing		**40**	**35**	**25**	**20**
Buildings		**0**	**0**	**10**	**20**
Power		**0**	**0**	**0**	**0**
PBS		**95**	**120**	**335**	**590**
Industry		**55**	**70**	**210**	**310**
	Aluminium	0	0	0	0
	Cement	0	0	5	5
	Chemicals	50	50	150	225
	Steel	5	20	60	80
Transport		**0**	**20**	**85**	**190**
	Road Transport	0	0	10	20
	Aviation	0	5	30	90
	Shipping	0	15	45	75
Energy Transforamtion / Fossil Fuel Processing		**40**	**30**	**15**	**10**
Buildings		**0**	**0**	**10**	**20**
Power		**0**	**0**	**10**	**60**

NOTE: [1] Subtotals may not sum to totals due to rounding.

Final Energy Demand – By Fuel

EJ		2022	2030	2040	2050
ACF		**446**	**460**	**407**	**375**
Electricity		**85**	**112**	**156**	**200**
Coal		**54**	**45**	**22**	**12**
Oil		**175**	**174**	**117**	**41**
Gas		**70**	**65**	**35**	**30**
Hydrogen and derived fuels		**1**	**4**	**21**	**44**
Biomass		**46**	**48**	**46**	**43**
	Traditional	24	12	6	0
	Modern	22	36	40	43
Heat		**15**	**12**	**9**	**6**
PBS		**446**	**433**	**377**	**355**
Electricity		**85**	**118**	**185**	**229**
Coal		**54**	**34**	**13**	**9**
Oil		**175**	**158**	**79**	**7**
Gas		**70**	**56**	**17**	**11**
Hydrogen and derived fuels		**1**	**5**	**24**	**46**
Biomass		**46**	**49**	**50**	**48**
	Traditional	24	12	6	0
	Modern	22	37	44	48
Heat		**15**	**12**	**9**	**6**

Fossil Fuels in Transition:
Committing to the phase-down of all fossil fuels

Annex A

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Energy
Transitions
Commission

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