# Carbon in an electrified future: Technologies, trade-offs and pathways

Executive Summary | November 2025 | Version 1.0

Energy
Transitions
Commission

SYSTEMIQ

**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.**

**This report was developed by ETC and Systemiq. Systemiq is a system-change B-Corp certified company founded in 2016 to transform markets and business models in five key systems: nature and food, materials and circularity, energy, urban areas, and sustainable finance. Systemiq combines strategic advisory with high-impact, on-the-ground work, and partners with business, finance, policymakers and civil society to deliver system change.**

The ETC Commissioners come from a range of organisations – energy producers, energy-intensive industries, technology providers, finance players and environmental NGOs – that operate across developed and developing countries and play different roles in the energy transition. This diversity of viewpoints informs this 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.

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.

The ETC's and Systemiq's *Carbon in an Electrified Future: Technologies, Trade-offs and Pathways* executive summary analyses how carbon can be reduced, used, sourced and disposed of at end-of-life in a net-zero global economy. It focuses on the role of electrification, hydrogen, circularity, carbon sourcing and management technologies, including the key system trade-offs and scenarios illustrating their impact. This executive summary will be followed by main report, chapter summaries and supplementary innovation briefs.

This report was developed in consultation with ETC Members, but it should not be taken as members agreeing with every finding or recommendation. The ETC team would like to thank the ETC members, member experts and the ETC's broader network of external contributors for their active participation in developing this work, and Systemiq for its analytical and coordination support. This work has been made possible through the generous support of the Quadrature Climate Foundation.

This report should be cited as: ETC and Systemiq (2025), *Carbon in an electrified future: Technologies, trade-offs and pathways*.

Energy
Transitions
Commission

SYSTEMIQ

**Learn more at:**

**www.energy-transitions.org**
**www.linkedin.com/company/energy-transitions-commission**
**www.twitter.com/ETC_energy**
**www.youtube.com/@ETC_energy**
**www.systemiq.earth**

Front cover and Report design: Burnthebook.


Carbon Recycling International
AGA

# ETC Commissioners

**Mr. Bradley Andrews,**
Chief Executive Officer – SLR Consulting

**Mr. Benoit Bazin,**
Chairman and Chief Executive Officer – Saint Gobain

**Ms. Sonia Brown,**
Group Head of Strategy, Innovation, and Market Analytics – National Grid

**Mr. Harry Boyd-Carpenter**
Managing Director, Sustainable Infrastructure Group – EBRD

**Mr. Ahmad Butt,**
Executive Chairman – Deep Science Ventures

**Dr. Zhao Changwen,**
Chair Professor of Lingnan College, and Head of National Academy of Development, Sun Yat-sen University – Center for International Knowledge on Development (CIKD)

**Mr. John Creyts,**
Chief Executive Officer – Rocky Mountain Institute

**Mr. Spencer Dale,**
Chief Economist – bp

**Mr. Bradley Davey,**
Executive Vice-President, Head of Corporate Business Optimization – ArcelorMittal

**Ms. Faustine Delasalle,**
Chief Executive Officer – MPP

**Mr. Agustin Delgado,**
Chief Innovation and Sustainability Officer – Iberdrola

**Dr. Vibha Dhawan,**
Director General – The Energy & Resources Institute

**Dr. Julio Friedman,**
Chief Scientist – Carbon Direct

**Mr. Matthew Gorman,**
Director of Carbon Strategy and Sustainability – Heathrow Airport

**Mr. Craig Hanson,**
Managing Director and Executive Vice President for Programs – World Resources Institute

**Mr. Seb Henbest,**
Group Head of Climate Transition – HSBC

**Dr. Thomas Hohne-Sparborth,**
Head of Sustainability Research (at Lombard Odier Investment Managers) – Lombard Odier

**Dr. Jennifer Holmgren,**
Chief Executive Officer – LanzaTech

**Ms. Naoko Ishii,**
Director, Center for Global Commons and Professor, Institute for Future Initiatives – Center for Global Commons

**Dr. Mallika Ishwaran,**
Chief Economist – Shell plc

**Mr. Greg Jackson,**
Founder and Chief Executive Officer – Octopus Energy

**Mr. Timothy Jarratt,**
Group Executive, Market Development and Strategy – Ausgrid

**Mr. Zou Ji,**
Chief Executive Officer and President of Energy Foundation China – EF China

**Mr. Lars Johansson,**
COO – Volvo

**Mr. Shaun Kingsbury,**
Chief Investment Officer – Just Climate

**Mr. Zheng Li,**
Executive Vice President – Institute of Climate Change and Sustainable Development, Tsinghua University

**Mr. Bruce Lourie,**
President of the Ivey Foundation – The Transition Accelerator

**Mr. Johan Lundén,**
Senior Vice President, Project and Product Strategy Office – Volvo

**Mr. Rajiv Mangal,**
Vice President Safety, Health & Sustainability – Tata Steel

**Ms. Laura Mason,**
Chief Executive Officer – L&G

**Mr. Carl Moxley,**
Group Climate Director – L&G

**Mr. Nicholas Mazzei,**
Vice President Sustainability - Europe – DP World

**Ms. Maria Mendiluce,**
Chief Executive Officer – We Mean Business Coalition

**Mr. Jon Moore,**
Chief Executive Officer – BloombergNEF

**Mr. Simon Morrish,**
Founder and Chief Executive Officer – X-links

**Mr. Fabricio Sousa**
Global President, Worley Consulting & Technology Solutions

**Mrs. Damilola Ogunbiyi,**
Chief Executive Officer – SEforAll

**Mr. Martin Pei,**
Executive Vice-President and Chief Technology Officer – SSAB

**Mr. Alistair Phillips-Davies,**
Chief Executive Officer – SSE

**Mr. Andreas Regnell,**
Senior Vice President, Head of Strategic Development – Vattenfall

**Mr. Ian Simm,**
Founder and Chief Executive Officer – Impax Asset Management

**Mr. Sumant Sinha,**
Chairman, Founder and Chief Executive Officer – ReNew

**Ms. Anna Skarbek,**
Director, Climate Works Australia – Climate Works Centre

**Ms. Marijn Steegstra,**
Head of Client Coverage NL & Energy Transition, Europe and Africa – Rabobank

**Lord Nicholas Stern,**
IG Patel Professor of Economics and Government – Grantham Institute – LSE

**Ms. Marina Taib,**
Senior Vice President, Corporate Strategy – Petronas

**Mr. Greg De Temmerman,**
Deputy CEO and Chief Science Officer – Quadrature Climate Foundation

**Mr. Chacko Thomas,**
Group Chief Sustainability Officer – Tata Sons (Sustainability Group)

**Mr. Simon Thompson,**
Senior Advisor, Rothschild & Co – Rothschild

**Mr. Alan Thomson,**
Global Energy Director – Arup

**Mr. Nigel Topping,**
Former UN Climate Change High-Level Champion – UK Climate Change Committee

**Dr. Robert Trezona,**
Founding Partner – Kiko Ventures

**Mr. Jean-Pascal Tricoire,**
Chairman – Schneider Electric

**Ms. Laurence Tubiana,**
Chief Executive Officer – European Climate Foundation

**Mr. Fabby Tumiwa,**
Executive Director – IESR

**Mr. Adair Turner,**
Chair – Energy Transitions Commission

**Senator Timothy E. Wirth,**
Vice Chair – United Nations Foundation

**Mr. Haimeng Zhang,**
Vice President – LONGi

**Mr. Lei Zhang,**
Chief Executive Officer – Envision Group

# Contents

Introduction 6

1 & 2. The role of electrification and hydrogen 9

3. Circularity levers that reuse and recycle carbon 11

4. Sustainable sources of primary carbon 13

5. Managing carbon at end-of-life 15

6. Technology trade-offs 16

7. Technology scenarios by mid-century 18

Key conclusions and recommendations 20

# Introduction

**Carbon is one of the most common elements on the planet, a crucial building block of nature and a foundation of human biology, technology and economic activity.** Over millions of years, carbon-based molecules derived from plant and animal life were transformed through heat and pressure into fossil fuels. These fuels enabled the Industrial Revolution and have powered dramatic increases in human living standards over the past 200 years. However, the impact of this carbon use upon the climate has not yet been sufficiently accounted for in the design of the global economy.

**It is essential that carbon is sourced, utilised and managed at end-of-life in a way that results in net-zero emissions in a sustainable global economy.** This can be achieved if unnecessary carbon is eliminated via electrification, recycled or reused, sourced renewably (e.g., from sustainable bioresources), or sourced from fossil but with emissions neutralised. This report analyses recent technological developments that could either further reduce the need for carbon molecules or enable their sustainable sourcing, use and disposal. It describes different scenarios paving the way to a net-zero global carbon system by 2050, with an evaluation of their technological, economic, energy efficiency and environmental tradeoffs. It aims to inform system decision-makers of the implications of these differing approaches to the role of carbon in the energy and materials transition. In doing so, it aims to help chart the most pragmatic, de-risked and ambitious pathway to net zero, as well as incept new, or steer existing, multi-stakeholder system initiatives able to overcome key system gaps blocking the transition.

**Human use of carbon-based molecules today in the energy and materials sectors amounts to around 11.5 Gt carbon per year.** The vast majority, 9.8 Gt (85%), comes from fossil sources including coal, oil and gas. These are primarily used as fuels for electricity generation, transportation and heating, and as feedstocks for the production of chemicals and materials such as fertilisers and plastics. This generates around 37.1 Gt of $CO_2$ emissions each year. An additional 1.5 Gt of carbon (13%) is sourced from bioresources, while 0.2 Gt (<2%) is provided by recycled or reused carbon[1] [Exhibit 1].

**Electrification and power sector decarbonisation will be the primary levers to reduce demand for carbon**, and all major net-zero scenarios project a dramatic increase in electrification's role in the final energy mix. However, even in a highly electrified economy, carbon will still need to play a role in the energy and materials systems. Exhibit 2 shows the carbon demand implied in the Energy Transition Commission's (ETC) mid-century Accelerated but Clearly Feasible (ACF) scenario, projecting that the direct use of electricity could grow from 19% of global energy demand in 2022 to 62% in 2050.

Residual demand for carbon in 2050 derives from two main groups: firstly, from sectors where electrification or the use of hydrogen and non-carbon hydrogen-derivatives (e.g., green ammonia) are technically or economically infeasible. For example, long-distance aviation faces battery energy density constraints that preclude direct electrification and low hydrogen volumetric energy density is likely to similarly limit hydrogen-powered flight.

---

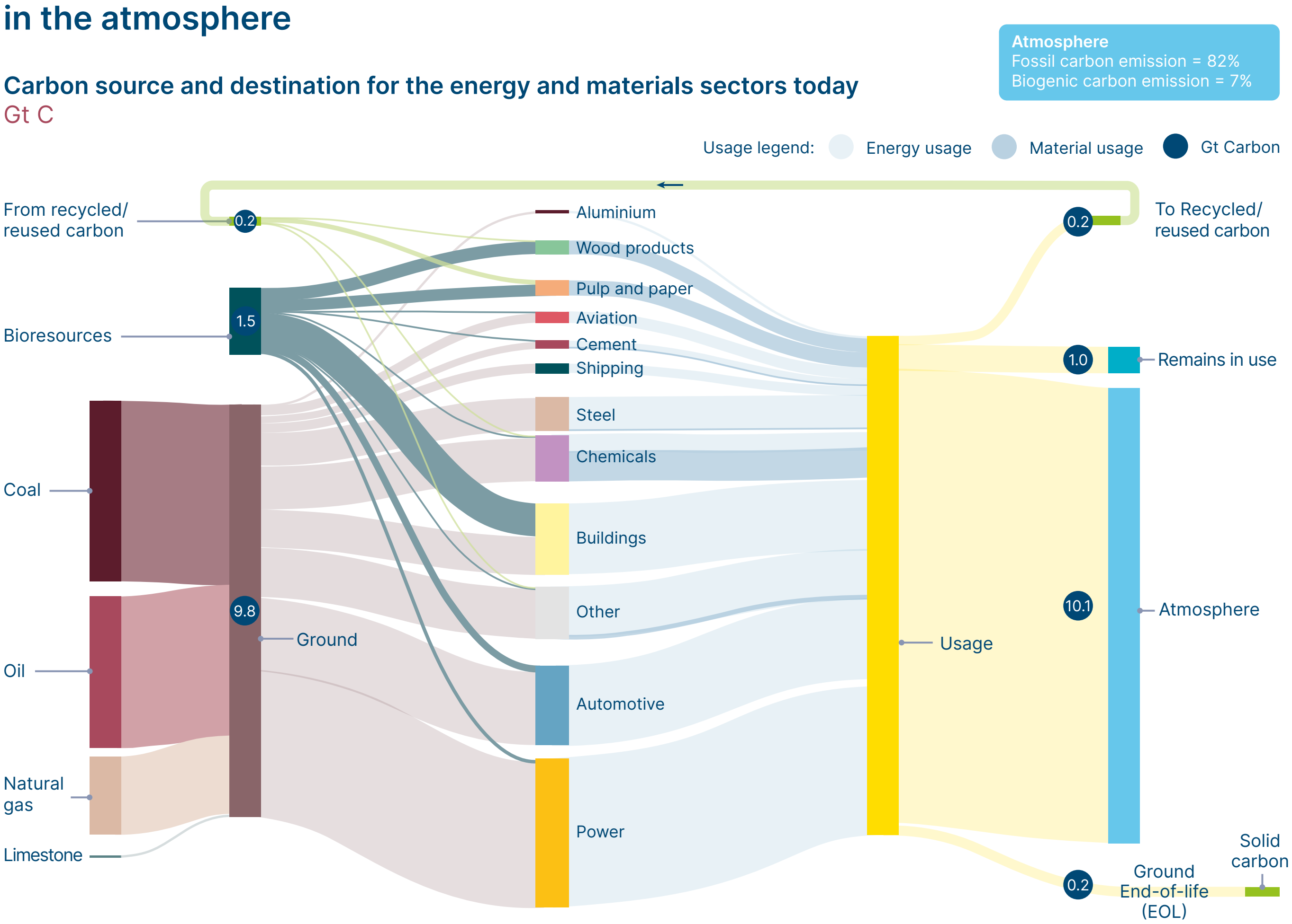
[1] Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition*.

**Exhibit 1**

## The majority of carbon today comes from fossil sources and ends up in the atmosphere

### Carbon source and destination for the energy and materials sectors today

Gt C



**SOURCE:** Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition*.

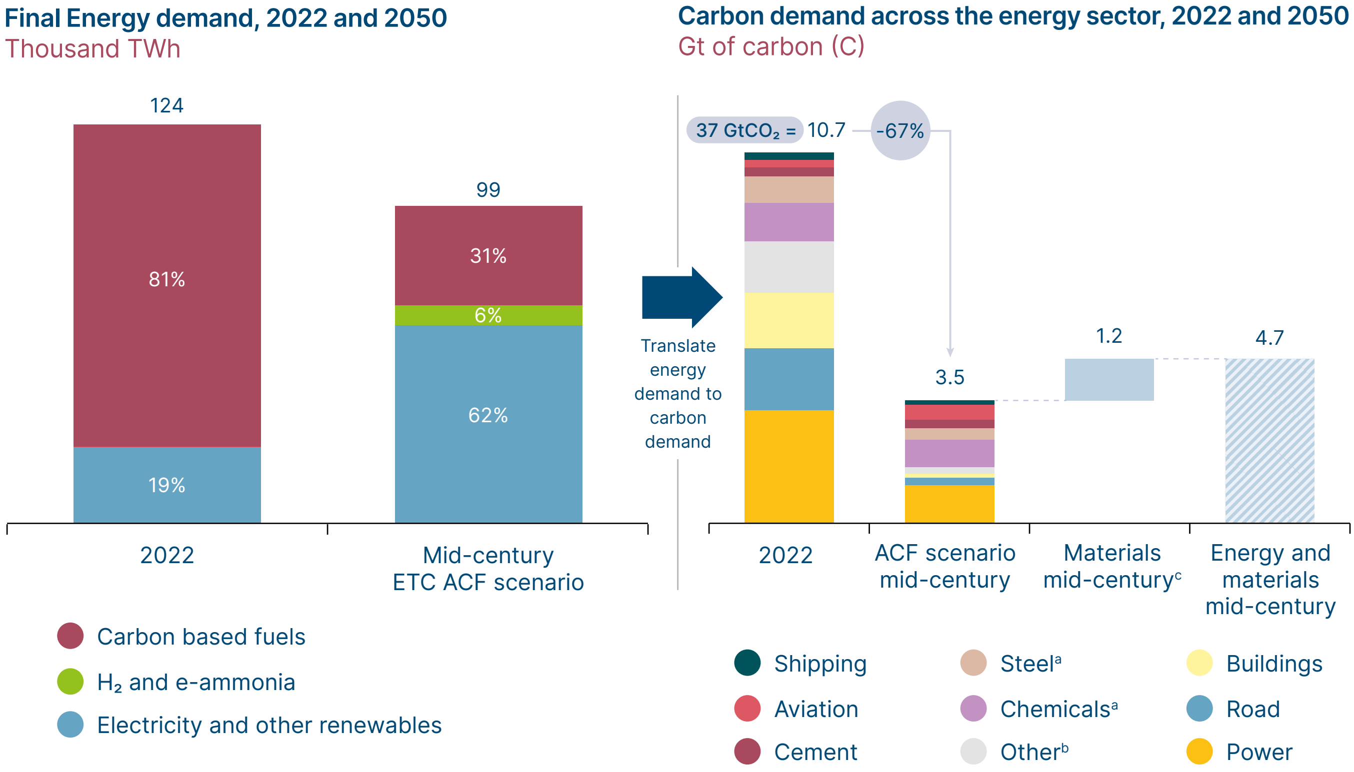
Secondly, demand will continue from sectors where carbon is an essential feedstock, notably in the production of materials such as chemicals, plastics, pulp, paper and timber. Carbon demand from energy inputs reduces down to 3.5 Gt of carbon, rising to 4.7 Gt inclusive of materials, more than halving the demand for carbon overall by 2050.

**To achieve a net-zero emissions economy will therefore require not only electrification and the use of hydrogen, but also a system that ensures carbon is sourced, used and disposed of in a responsible fashion.** This report focuses on the role that new technology developments could play in either further reducing the need for carbon input, or in enabling its sustainable sourcing, use and disposal, via the following analysis:

1. The maximum potential role of direct electrification.
2. The contribution of hydrogen and non-carbon hydrogen derivatives.
3. The potential to recycle and reuse carbon molecules, whether via plastic recycling, carbon capture and utilisation or other means.
4. The potential to scale sustainable sources of primary carbon, including sustainable bioresource supply, direct carbon capture from the atmosphere and point source carbon capture to enable abated fossil use.
5. Options for managing carbon at end-of-life by storing it in gaseous or solid form.
6. Trade-offs between alternative approaches in terms of technology, cost, energy efficiency and impact on nature.
7. Scenarios illustrating different approaches to reduction, sourcing, utilisation and disposal in a net-zero global economy.

**Exhibit 2**

## The need for carbon molecules in the global energy and materials sectors will decline by mid-century, but up to 4.7 Gt will still be required



**Final Energy demand, 2022 and 2050**
Thousand TWh

**Carbon demand across the energy sector, 2022 and 2050**
Gt of carbon (C)

**NOTE:** Carbon-based fuels include those fuels that also require carbon sources, e.g. e-methanol and synthetic aviation fuels; ACF = Accelerated but Clearly Feasible scenario, based on ETC (2023), *Fossil Fuels in Transition* with minor updates; [a]Includes energy-based carbon feedstocks (e,g, oil, gas), a proportion of which end in the final products (e.g. chemicals for plastics and steel), and others end in process emissions; [b]Includes remaining sectors, primarily other industry and other transport; [c]A majority made up of wood products for timer and pulp and paper.

**SOURCE:** Chemicals: Systemiq (2022), *Planet Positive Chemicals* (BAU Net-Zero scenario); Biomass: ETC (2021), *Bioresources within a Net-Zero Emissions Economy*; Steel: MPP (2022), *Making net-zero steel possible*; MPP (2022), *Making net-zero aviation possible*; Cement: MPP (2023), *Making net-zero concrete and cement possible*. Cotton, Bitumen and Soda Ash: Systemiq analysis (2025).

# 1 & 2. The role of electrification and hydrogen

Electrification and hydrogen are treated together in this section because they represent the two primary vectors for delivering clean energy in a net-zero system. They both substitute fossil fuels across end uses and together determine how much residual demand remains for carbon molecules.

**Scaling up direct electrification and clean hydrogen can meet up to 83% of total final energy demand and thus reduces the role of carbon molecules down to as little as 17% by 2050.** Direct electrification offers a cost-effective and scalable pathway to decarbonisation, and there is strong evidence for a greater role for electrification beyond those sectors already electrifying, such as electric vehicles and building heating. Exhibit 3 compares an "Unconstrained" scenario with maximum electrification and hydrogen against the two scenarios which the ETC published in its *Fossil Fuels in Transition* report (2023).[2] As shown, direct electrification could eventually account for 77% of final energy demand up from 71% in the previously most ambitious "Possible But Stretching" (PBS) scenario. Technology breakthroughs can increasingly be applied to processes requiring high-temperature industrial heat, such as electrowinning or molten oxide electrolysis to steel-making and the electrification of heat input to cement kilns, to unlock a higher share of electrification in final energy demand. Similarly, advanced battery chemistries may play a greater role in short-haul shipping and regional aviation.

**In contrast to electrification, hydrogen will play an important, but marginally smaller than anticipated role.** Hydrogen will continue to be essential in fertiliser production as a feedstock for ammonia, in maritime fuels as a building block for fuel molecules such as e-methanol and ammonia, and in steel as a process reagent for direct reduction. However, as electrification technologies advance, hydrogen is being displaced from other applications, particularly those where it would otherwise serve mainly as a heat source, such as iron ore reduction, heat generation for cement production and for road transport. The direct use of hydrogen could account for 6% of final energy demand versus 8% in ETC's PBS scenario [Exhibit 3]. Coupled with the increased role of electrification, demand from carbon molecules almost halves in the final energy mix vs. the ACF base case. However, this scenario assumes an unconstrained supply of zero-carbon electricity, but still leaves a need for 1.6 Gt of carbon demand for energy inputs.

**Notably, two developments could still expand the role of hydrogen:** firstly, if costs fall sharply e.g., via the emergence of naturally occurring "geological hydrogen", which could be competitive if recoverable at scale.[3] Secondly, hydrogen's role could still expand if electrolyser costs continue to reduce, particularly through scale-up and next-generation designs such as high-efficiency solid oxide systems. However, both of these technology pathways remain uncertain, with geological hydrogen still in early stages of development and access to abundant, low-cost renewables also playing a key role in the competitiveness of electrolysis-based hydrogen.

---

[2] ETC (2023), *Fossil Fuels in transition.*

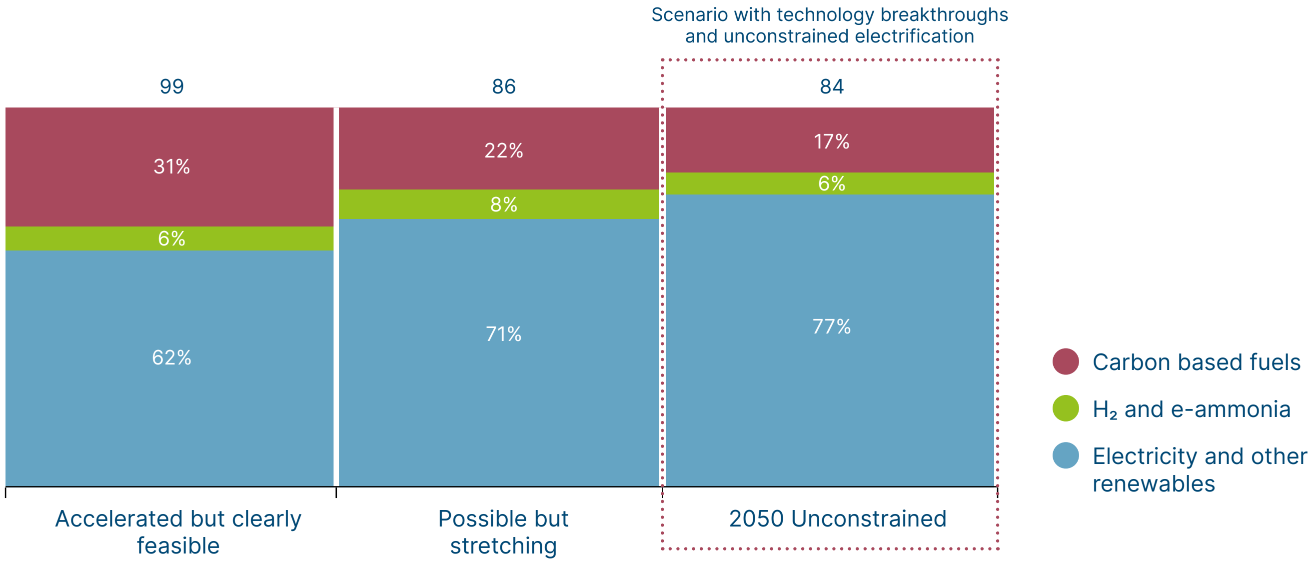
[3] Hydrogen Science Coalition (2024), *Everything you need to know about natural or geologic hydrogen.*

Exhibit 3

## An unconstrained electrification scenario with technology disruptions can reduce the share of carbon molecules to ~17% of final energy demand

### Global final energy demand by energy source and scenario

Thousand TWh (%), 2050



**SOURCE:** ACF scenario and PBS scenario based on ETC (2023), *Fossil Fuels in Transition.*

# 3. Circularity levers that reuse and recycle carbon

**Following the elimination of carbon demand from electrification and hydrogen scale up, the remaining supply of carbon can be met from either primary or secondary sources.** Primary sources of carbon include fossil, biogenic or atmospheric/ocean capture (discussed in Chapter 4 of main report). Secondary sources can be met by circulating carbon that is already in the system, such as recycled materials or industrial process emissions captured and reused.

**Global carbon use today is overwhelmingly derived from primary sources** (98%), most of which is from coal, oil and gas.[4] This carbon is predominantly used once and emitted to the atmosphere today, with recycling and secondary sourcing of carbon limited to less than 2% of global carbon system demand. This is particularly true in the two critical materials sectors; while pulp and paper achieve recycling rates of around 50%, plastics, the main output from the chemicals sector, are recycled at just 8–9%[5] of total production today.

**Circularity technologies** aim to reduce primary demand by meeting as much as possible with secondary carbon technologies. This can be achieved, particularly in plastics, by reusing products (reuse), materials (recycling through mechanical or chemical processes) or carbon molecules (Carbon Capture and Utilisation, CCU). Unlocking plastics circularity at scale will require a portfolio of complementary technologies to be applied.

- **Reuse** models for materials extend the lifespan of material products without changing their composition, for example replacing single use items like plastic cups with more durable products, or deposit-return schemes. These models would offer significant emissions reduction potential, but would require large-scale behaviour change from consumers, brands and retailers, accompanied by well-designed policy that disincentivises single use.

---

[4] Systemiq analysis for the ETC; ETC (2023), *Fossil Fuels in Transition*.

[5] Systemiq (2024), *Plastic Treaty Futures*; Systemiq analysis for the ETC; Systemiq (2022), *ReShaping Plastics*; Systemiq (2020), *Breaking the Plastic Wave*, and Systemiq, (2022), *Plastic IQ*; Geyer R et al. (2017), *Production, use, and fate of all plastics ever made*. Sci Adv. 2017 Jul 19;3(7).

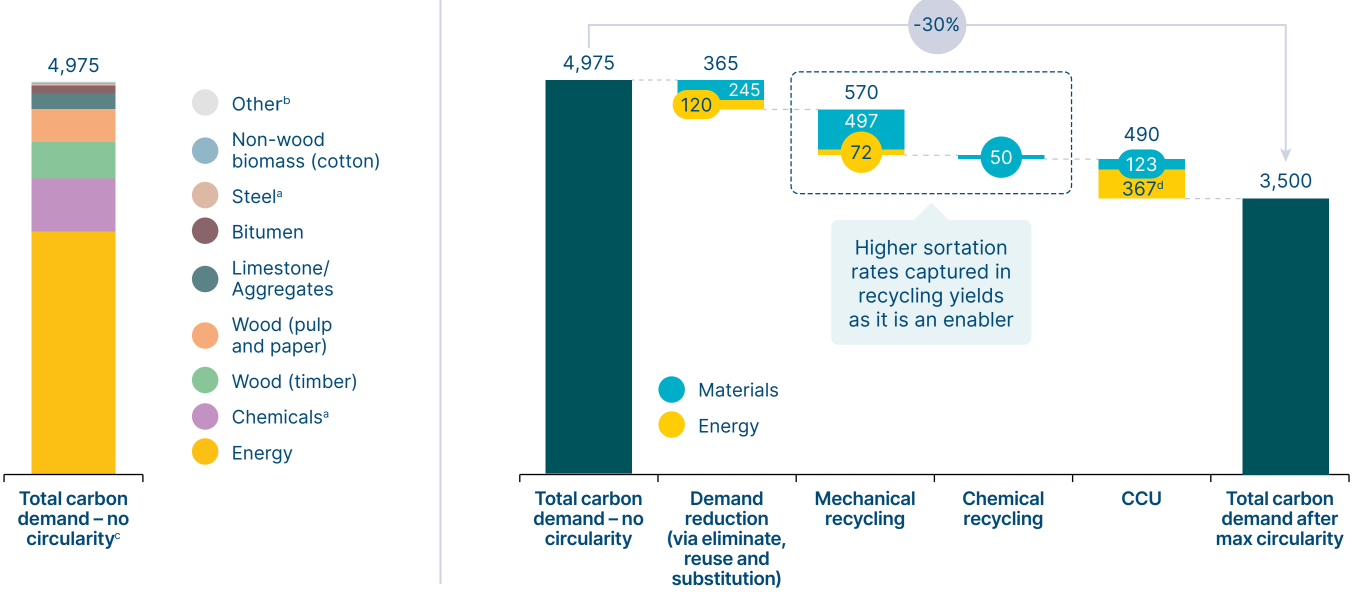
- **Mechanical recycling** is the most resource efficient option, not requiring any change to the chemical composition of plastics, delivering major emissions savings compared with virgin fossil production.[6] Scaling depends on cleaner input streams and supportive policies, such as design-for-recycling, recycled-content mandates, Extended Producer Responsibility (EPR) schemes and carbon pricing. Constraints remain around feedstock quality and competition with low-cost virgin polymers, where advanced sortation may play a significant system-enabling role.
- **Chemical recycling and thermo-conversion** should complement mechanical routes by targeting waste streams that cannot be mechanically processed. Depolymerisation, pyrolysis and gasification all deliver $CO_2$ savings, but remain costly and feedstock-sensitive. Their viability depends on strong policy levers; landfill restrictions, mass-balance certification and carbon pricing.
- **CCU** technologies could eventually close another carbon loop by converting captured $CO_2$ into fuels, chemicals and materials. Final emissions from these technologies depend on the $CO_2$ source that is recycled (i.e. whether it originates from biogenic, atmospheric or fossil-based processes), and the end use of the resulting product. While promising, most CCU pathways remain twice as expensive as fossil-based equivalents and require strong policy incentives, low-cost green hydrogen and access to concentrated $CO_2$ sources. This matters because these dependencies mean CCU is not likely to scale on market forces alone.

**In an ambitious "Stretch" scenario for circularity, 30% of total residual carbon demand in the system in 2050 could be met from recycled or reused carbon, reducing primary demand from 5 to 3.5 Gt** [Exhibit 4]**.** This includes recycling, reuse, substitution (to lower carbon intensive materials), eliminating unnecessary materials and reducing carbon-based energy use. Mechanical recycling and CCU are the largest circularity levers, meeting 70% of reused carbon demand, followed by demand reduction via elimination, reuse and substitution. Chemical recycling plays a critical but niche role in managing hard-to-recycle plastics and complex waste streams.

**Exhibit 4**

## Circularity levers could reduce 30% primary carbon demand by mid-century

**Carbon demand across the energy and materials sectors by mid-century**
Million tonnes of carbon (C)



**NOTE:** [a]Chemicals and steel include the feedstock from the energy system that has remained in material, i.e. plastic, in order to show the circularity levers. [b]Other includes carbon ash, biochar, carbon fibre, charcoal. [c]Total carbon demand is shown without applying the circularity levers included in ACF. Enhance Oil Recovery (EOR) does not reduce the carbon demand.

**SOURCE:** Energy: Systemiq analysis for the ETC; ETC (2023), based on *Fossil Fuels in Transition*; Chemicals: Systemiq (2022), *Planet Positive Chemicals* (BAU Net-Zero scenario); Biomass: ETC (2021), *Bioresources within a Net-Zero Emissions Economy*; Steel: MPP (2022), Making net-zero steel possible.; MPP (2022), Making net-zero aviation possible; Cement: MPP (2023), Making net-zero concrete and cement possible. Cotton, Bitumen and Soda Ash: Systemiq analysis (2025).

---

[6] Fossil emissions for PET plastic is based on Eco-profiles produced for Plastic Europe; Life Cycle Assessment for Cradle-to-Gate (Raw Materials/Energy, Precursos production, Polymer production). Plastics Europe (2022), *Eco-profiles*.

# 4. Sustainable sources of primary carbon

**Residual carbon demand after scaling electrification, hydrogen, reuse and recycling must be met by sustainable primary sources that operate within ecological limits. However, constraints on primary supply vary considerably by source.** Atmospheric and ocean-based capture directly reduce greenhouse gas concentrations, but currently remain constrained by cost. Fossil carbon, by contrast, is only compatible with a net-zero economy if all associated emissions are captured at point source and stored, or offset through high-quality permanent removals elsewhere in the economy. Biomass can be a source of sustainable carbon, but only if managed responsibly to avoid land-use change, food competition, biodiversity loss and carbon stock depletion. Meeting the residual demand will depend on scaling a portfolio of key technologies for primary carbon sourcing, each offering distinct opportunities and limitations:

- **Direct air capture (DAC)** offers theoretically limitless carbon sourced directly from the atmosphere. Current systems rely on solid sorbents and liquid solvents, while emerging electrochemical approaches could reduce energy intensity if proven at scale. Early expectations of rapid cost declines have proved overly optimistic, with projections revised upward (to \$235 per $tCO_2$ for 2050),[7] though innovation and scale could still bring costs down over time. DAC's core strengths are its modularity, geographic flexibility and ability to deliver high-integrity removals, but near-term adoption remains limited by high costs, large energy requirements and slow scaling.
- **Ocean-based carbon dioxide removal (o-CDR)** has potentially more favourable techno-economics and could play a major role, with processes such as seawater electrolysis locking $CO_2$ into stable carbonates, while generating hydrogen as a by-product. However, these technologies remain at an early stage and ecological trade-offs are still being validated, requiring careful governance before large-scale adoption.
- **Point-source capture reduces emissions from large industrial facilities by targeting concentrated $CO_2$ streams and is a major lever to abate fossil carbon** if continued to be used as a carbon source. Scale up of point-source capture has been slower than anticipated due to retrofitting challenges, site-specific complexities and impurities such as particulates and sulphur oxides.[8] Current liquid absorption and solid adsorption technologies are proven but energy-intensive and sensitive to impurities. Next-generation point source capture options such as Calcium Looping for cement and the Allam-Fetvedt Cycle for power could enhance feasibility, though both require substantial investment and are best suited to specific contexts such as cement kilns or gas turbines. Even with high capture rates, up to 25% of lifecycle emissions may persist from upstream methane and $CO_2$, highlighting the importance of complementary measures including methane abatement, electrification and low-emission hydrogen for upstream activities.[9]

---

[7] Systemiq analysis for the ETC (2025); Climeworks (2021), *Climeworks opens the world's largest carbon-capture facility in Iceland;* Ozkan (2024), *Atmospheric alchemy: The energy and cost dynamics of direct air carbon capture.*

[8] Neerup et al. (2023), *Solvent degradation and emissions from a $CO_2$ capture pilot at a waste-to-energy plant.*

[9] IEA (2023), *Emissions from Oil and Gas Operations in Net-Zero Transitions: A World Energy Outlook Special Report on the Oil and Gas Industry and COP28.*

- **Biomass remains the most immediately available and usable sustainable source of carbon, with a prudent estimate of sustainable supply of between 40–60 EJ (1–1.6 Gt of carbon).** However, with effective governance of land use, food systems and ecosystem protection, an upper bound of supply could increase beyond ETC's previous upper bound estimates of 120 EJ, or 68% of carbon demand in 2050.[10] This would only occur in a holistic system change scenario, that would depend on agricultural productivity improvements, dietary shifts, alternative proteins and new feedstocks. In practice, sustainable supply is constrained by competing land needs for food, feed, timber and nature restoration. Opportunities include repurposing degraded land where food crops can no longer be grown, deploying high-yield crops and harnessing aquatic sources such as macro- and microalgae, but these options would need to carefully consider trade-offs with food security and ecosystem restoration. Efficiency gains in conversion processes could also reduce feedstock requirements, particularly in sectors like aviation. Scaling the sourcing of sustainable biomass will require robust governance to prevent food displacement, biodiversity loss and land degradation, ensuring biomass becomes a cornerstone of the 2050 carbon mix without breaching ecological limits.

An optimal carbon supply mix will depend on relative costs, technological progress and public acceptability. However, the overarching principle must be clear that all sources of carbon must be subject to strict sustainability, permanence and governance criteria.

---

[10] Based on previous estimates from ETC (2021), *Bioresources within a Net-Zero Emissions Economy*.

# 5. Managing carbon at end-of-life

**Sourcing carbon sustainably is only part of the challenge of establishing a sustainable global carbon system; end-of-life carbon management must guarantee permanence and prevent re-emission.** Large-scale storage of $CO_2$ will be indispensable for achieving net-zero. ETC analysis indicates that by 2050, 8.8 Gt of $CO_2$ must be captured each year, with around 6.8 Gt requiring permanent storage and the remaining 1.8 Gt of $CO_2$ directed to utilisation pathways.[11] Current deployment, at just 0.05 Gt per year, highlights the magnitude of the challenge – a more than 100-fold scale-up is needed to bridge the gap. Two main options for carbon storage exist:

**Geological storage** in sedimentary reservoirs and aquifers is the most mature option, with vast global capacity (~50,000 Gt of $CO_2$) and relatively low costs. However, it faces practical constraints including injection limits, site variability, leakage risks and uneven regional distribution.[12] In-situ mineralisation, which reacts $CO_2$ with basaltic or ultramafic rock to form stable carbonates, offers even greater permanence and theoretical capacity, but remains at an earlier stage of development.

**Solid carbon storage**, particularly for plastics, can also provide permanent solutions when managed through engineered landfills or storage systems. Incineration with Carbon Capture and Storage (CCS) is effective but costly, while advanced landfill technologies combined with methane capture and monitoring can deliver similar abatement at significantly lower cost and technical complexity, if implemented rigorously.

For $CO_2$ storage, onshore geological storage typically offers the lowest costs at about $5–55 per tonne. Offshore storage can be comparable when connected by pipeline, but costs often exceed $55 per tonne when $CO_2$ must be liquefied and shipped. On average, in-situ mineralisation remains 50% more expensive than onshore geological storage but could improve with scale. For solid carbon, incineration with CCS costs $260–310 per tonne of waste, while advanced landfill and biological treatment with methane capture can achieve similar abatement for around $30 per tonne. However, these costs must be considered alongside the availability of each option. Not all regions have access to suitable geological formations for $CO_2$ storage, land availability may constrain landfill deployment in urban areas and incineration may be more viable where revenue from energy recovery is possible. The choice of end-of-life carbon management solution must therefore balance cost, permanence and local feasibility.

Gaseous and solid storage are both technically viable, but require rigorous regulation and monitoring to guarantee permanence. Over-reliance on storage risks locking in fossil extraction and delaying systemic change. Therefore, the strategic priority remains clear: minimise the need for storage by reducing primary carbon use, scaling recycling and maximising circularity, while deploying safe storage only for the unavoidable remaining carbon.

[11] ETC (2022), *Carbon capture, utilisation and storage in the energy transition.*

[12] Peter Kelemen et al. (2019), *An Overview of the Status and Challenges of $CO_2$ Storage in Minerals and Geological Formations*;Bo Wei et al. (2023) *$CO_2$ storage in depleted oil and gas reservoirs: A review*; Nader Mosavata et al. (2024), *Brucite: Revolutionizing $CO_2$ Mineralization for Sustainable and Permanent Carbon Sequestration.*

# 6. Technology trade-offs

**The transition to net-zero must go beyond emissions abatement, requiring a new, systemic approach to managing the carbon molecules embedded in fuels, products and infrastructure.** Feedstock and energy constraints mean that sustainable carbon must be treated not as an abundant, disposable input but as a precious, finite resource to be used wisely, reused as far as possible and managed carefully at end-of-life. A wide range of technologies can enable a low-emissions carbon economy, from mature options like mechanical recycling, to emerging solutions like ocean carbon removal and in-situ $CO_2$ mineralisation.

**Choosing the right technology mix means navigating trade-offs in technology readiness, cost, energy intensity and environmental impact.** Technology pathways to net-zero should factor in multiple dimensions to assess which solutions are most viable, scalable and sustainable, and at which point in the coming decades. These include:

- **Technology readiness**: how scalable and close to deployment a solution is. For example, while many solutions across categories are at TRL 6–9, meaning they are already demonstrated at pilot or approaching commercial scale, several gaps exist where technology choices are still only at TRL 4-5 (i.e. being validated in a lab or pilot environment). Options such as electrowinning, metal oxide electrolysis (MOE), geological hydrogen extraction, in-situ mineralisation and cultured meat could enable a better, more efficient system but require further technology acceleration before commercial deployment is viable.
- **Energy input costs**: **how energy-intensive the process is and how future energy prices might affect competitiveness.** For example, DAC and CCU technologies  are currently among the more expensive abatement technologies due to high energy demands, but could become more competitive if renewable electricity becomes cheaper, especially in regions with abundant solar or wind resources.
- **Natural resource and environmental impacts**: **what impact does a solution have on land, water and biodiversity.** For example, bioenergy can demand significant land use and offer low natural resource efficiency, while circular approaches like material reuse and recycling offer far higher resource efficiency and reduced biodiversity risks.

**Cost of abatement across technologies varies significantly**, as shown in Exhibit 5. Mature circular solutions such as mechanical recycling and plastic reuse reduce carbon emissions while delivering cost savings to the system by displacing virgin production and end-of-life disposal costs. However, early-stage CCU options like hydrogenation to e-methanol remain prohibitively expensive at over $1,000 per $tCO_2e$. Mid-range cost technologies such as point-source CCS and industrial electrification could become competitive as carbon pricing strengthens, with the EU ETS projected to reach $150 per $tCO_2$ by 2030.[13]

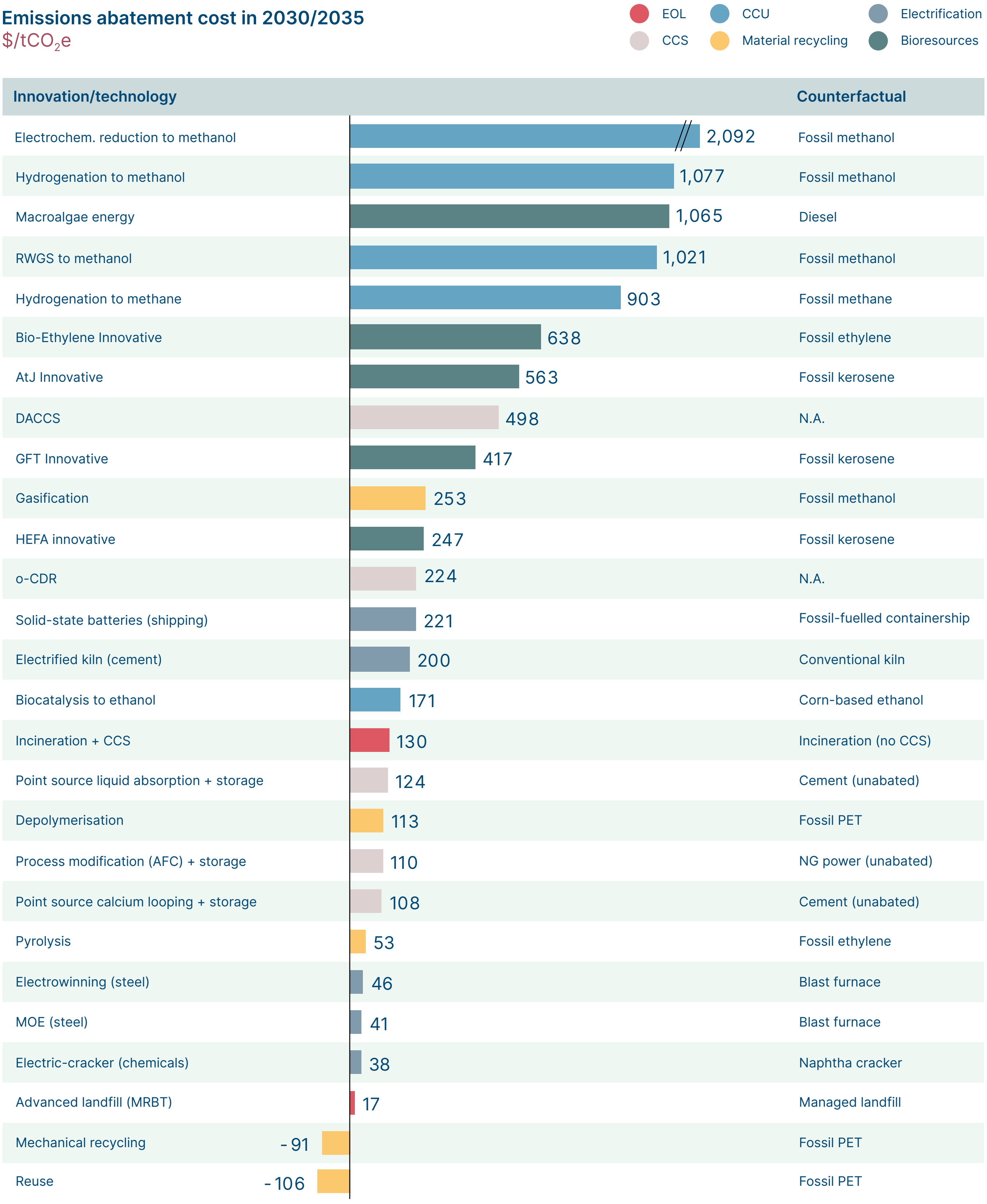
**Irrespective of which pathway to net-zero is taken, a consistent set of barriers constrain progress.** Infrastructure bottlenecks, high capital and operating costs, heavy dependence on low-cost clean energy and feedstock availability limit competitiveness with at-scale fossil incumbents. At the same time, regulatory uncertainty, fragmented standards and weak demand signals delay investment and scale-up. Overcoming these systemic barriers will require coordinated policy, robust carbon pricing, clear certification frameworks and accelerated build-out of enabling infrastructure. Without these enabling factors, even the most promising technologies may struggle to deliver their potential at pace and scale.

---

[13] Homaio (2024), *What are the EUA price forecasts for 2030?*

**Exhibit 5**

## Cost of emissions abatement in 2030/2035 vs their counterfactual product, fuel or system



**Emissions abatement cost in 2030/2035**
$\$/tCO_2e$

**NOTE:** 2030/2035 timeline used due to lower TRL technologies (4-5) unlikely t be commercially ready in 2030. Analysis assumes $50/MWh electricity price. “Material Recycling” technologies include an avoided waste incineration emissions credit; DACCS = Direct Air Carbon Capture and Storage; GFT = Gasification-Fischer-Tropsch; HEFA = Hydroprocessed Esters and Fatty Acids; AtJ = Alcohol-to-Jet; o-CDR = Ocean-based Carbon Dioxide Removal; CCUS = Carbon Capture and Storage; AFC = Allam-Fetvedt Cycle; MOW = Molten Oxide Electrolysis; MRBT = Material Recovery and Biological Treatment; PET; Polyethylene terephthalate; N.A. = Not applicable. Innovative HEFA, AtJ and Bio-ethylene refer to those fuels being produce with advanced and innovative catalysts.

**SOURCE:** Systemiq analysis for the ETC (2025).

# 7. Technology scenarios by mid-century

It is difficult to predict the combination of technologies that will emerge over time as relative costs and market environments evolve. However, this report presents four scenarios developed to illustrate the spectrum of possible pathways, their technology interdependences and the subsequent impact on key system indicators, in order to understand trade-offs at a system level.

Each scenario is compatible with achieving net-zero emissions and each results in a very significant reduction in the demand for carbon, with total carbon inputs falling from 11.5 Gt today to between 3.3 and 4.8 Gt in all scenarios by mid-century. However, there are significant differences in the balance between recycling/reuse, sustainable carbon sources (biogenic, ocean or atmosphere) and the use of fossil fuels offset by carbon capture and storage coupled with permanent carbon removals.

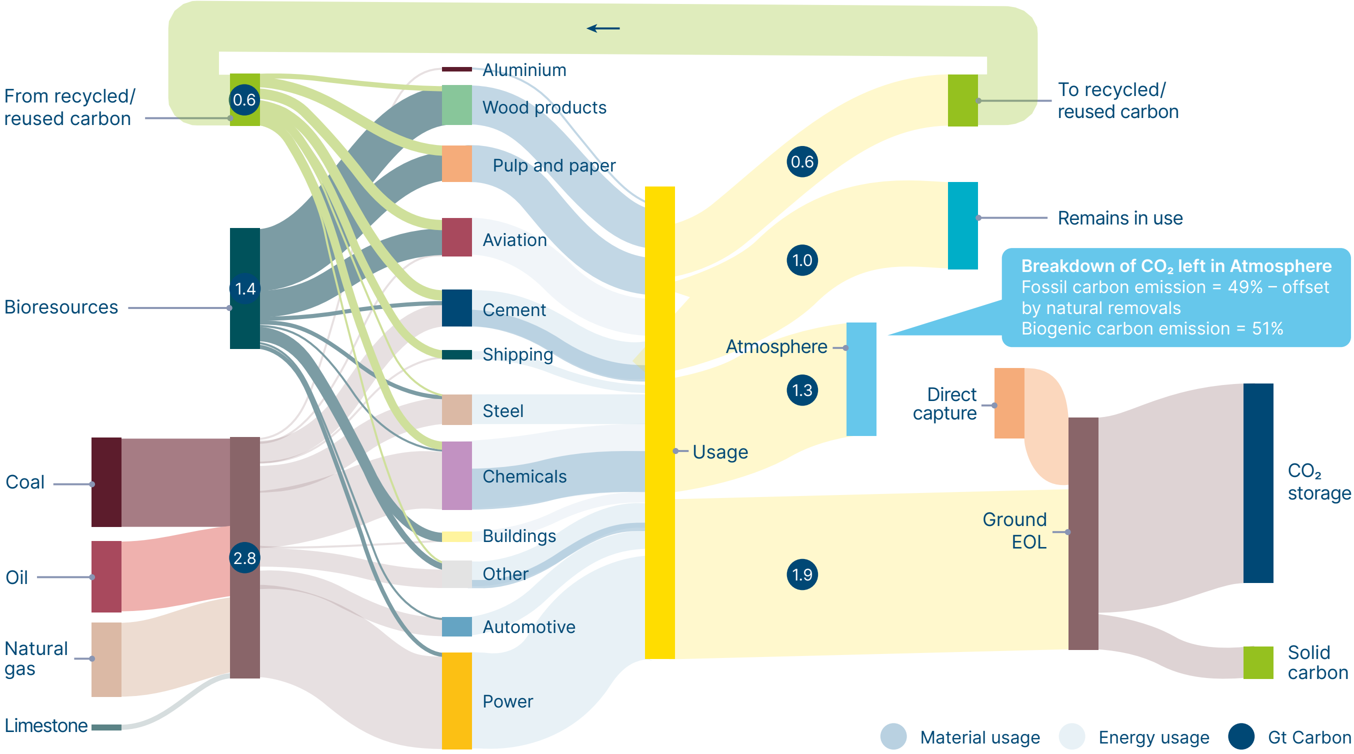
**The "Baseline" scenario**, presented in Exhibit 6, broadly reflects the ETC's ACF pathway. Recycled/reused carbon grows from 0.2 Gt today to 0.6 Gt by 2050, but this still leaves a primary carbon demand of 4.2 Gt which is met by 1.4 Gt of sustainable bioresources and 2.8 Gt of continued fossil fuel use. At end-of-life, over half of system carbon (2.7 Gt) must be stored in either gaseous or solid form, while 1.3 Gt is emitted to the atmosphere, offset by 0.8 Gt

**Exhibit 6**

## In a baseline decarbonisation scenario, 57% of carbon supply still derives from fossil fuels extracted from the ground

### ACF, carbon source and destination for the energy and materials sectors by mid-century

Gt C



**Breakdown of $CO_2$ left in Atmosphere**
Fossil carbon emission = 49% – offset by natural removals
Biogenic carbon emission = 51%

**SOURCE:** Systemiq analysis for the ETC (2025).

of DACCS  and 0.5 Gt of natural offsets. This scenario makes conservative assumptions about the progress of both direct electrification and recycling technologies, but as a result places dependence on extensive carbon storage scale up, with gaseous $CO_2$ storage reaching 8.8 Gt of $CO_2$ by 2050.

**The "Minimum Primary Carbon"** scenario, presented in Exhibit 7, combines ambitious electrification with strong growth in reuse and recycling. Carbon demand falls to only 3.3 Gt, less than a third of today's level, of which nearly 30% is provided by reuse and recycling, leaving only 2.4 Gt of required primary carbon supply. Fossil supply declines to just 1.1 Gt (a 90% reduction from today's level), with bioresources remaining broadly stable. Achieving this requires abundant low-cost green power and large-scale recycling systems. This pathway sharply reduces dependence on removals, with storage needs less than half those in the Baseline scenario (~3.2 Gt vs 8.8 Gt $CO_2$).

The **"Minimum Fossil Carbon"** scenario shows the scale of sustainable bioresource supply needed if large-scale carbon storage were infeasible or too costly, and fossil use had to fall far below the Baseline. Total carbon demand remains low at around 3.6 Gt, supported by ambitious electrification. Recycled and reused carbon rises to 0.6 Gt (16%), with primary carbon of 3.0 Gt met almost entirely by bioresources (2.4 Gt) and minimal fossil input (0.6 Gt). End-of-life carbon management dependence is dramatically reduced, with only 1.8 Gt $CO_2$ requiring storage, as bioenergy can achieve near carbon-neutrality without CCS. This scenario depends on major bioresource expansion and careful land-use management.

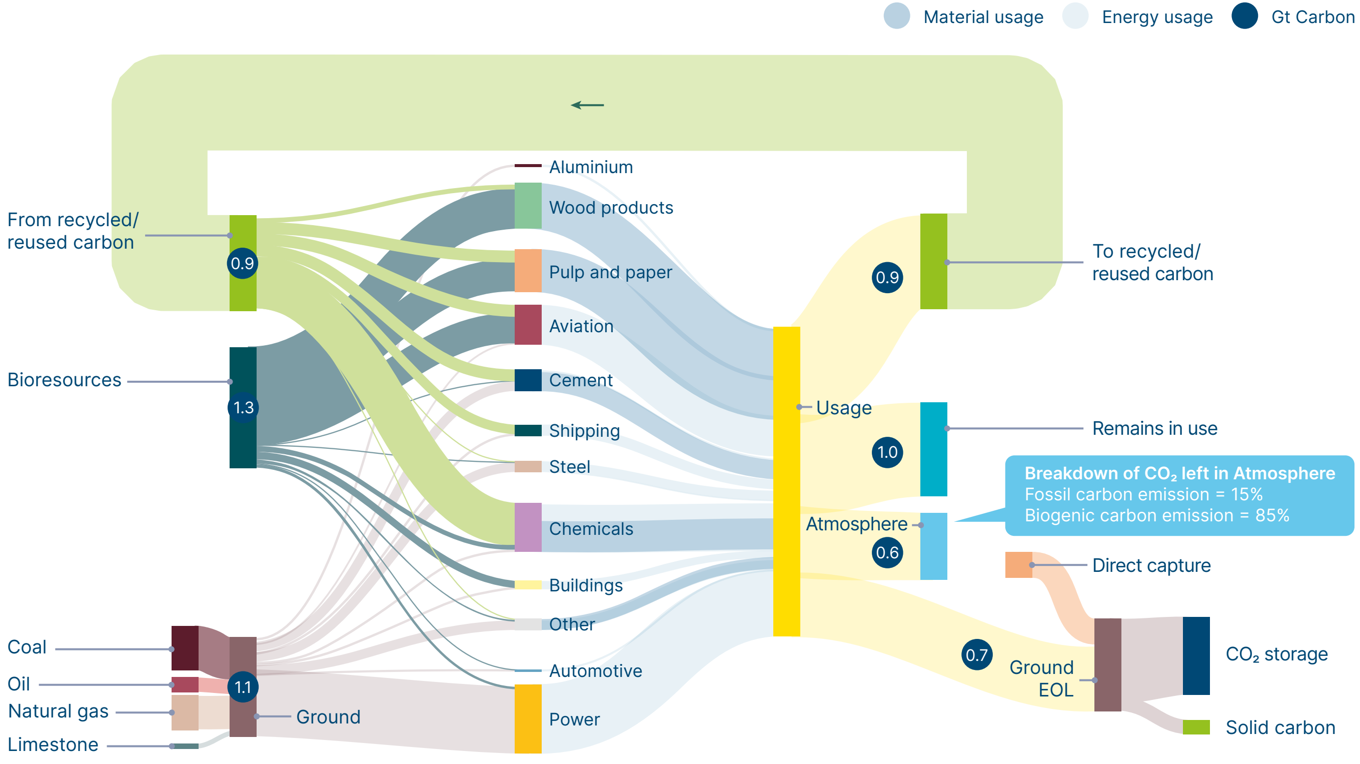
The **"Fossil Fuel in Perpetuity"** scenario illustrates that should fossil fuel use remain much higher than in the Baseline, greater dependence is placed upon scaling up end-of-life storage. Total fossil supply remains around 3.2 Gt of carbon, about one-third of today's level, while recycling rises only modestly to 0.4 Gt. Primary carbon of 4.2 Gt is mainly fossil-based, with limited bioresource input (1.0 Gt). At end-of-life, around 2.7 Gt of carbon (~10 Gt $CO_2$) must be stored, exceeding both IEA and ETC net-zero scenarios.

Given the significant variance between these illustrative scenarios, (particularly in the concentration of dependence upon particular technology groups), decision-makers should carefully evaluate the trajectory upon which they are placing the system to avoid a disorderly transition in the event of failing to scale a single key technology.

**Exhibit 7**

## In the Minimum Primary Carbon scenario, only 33% of the carbon supply is derived from fossil fuels

**Minimum primary carbon, carbon source and destination for the energy and materials sectors by mid-century**
Gt C



**SOURCE:** Systemiq analysis for the ETC (2025).

# Key conclusions and recommendations

A net-zero global economy will remain dependent upon the use of carbon, even after decarbonisation. The challenge in transitioning to a sustainable global carbon economy is not just about reducing carbon use, but about managing the carbon that remains —where it comes from, how it circulates through the economy, and what happens to it at end-of-life.

**1. Carbon demand will persist even in a highly electrified world, so it must be actively planned for and managed.**

Between 3-5 Gt of carbon will still be needed across energy and materials sectors by mid-century, down from 11.5 Gt today. The transition to net-zero is not a journey to zero carbon use, but to zero carbon emissions. In sectors like aviation, steel and chemicals, i.e. those using carbon for feedstock or industrial processes, carbon is difficult to substitute due to fundamental constraints like energy density and process chemistry. Planning must therefore focus not only on reducing emissions, but also on building a sustainable system to source, use and dispose of carbon in perpetuity.

**2. Electrification and re-use are the most efficient tools for reducing carbon usage in the energy and materials sectors.**

Direct electrification powered by clean electricity is the most efficient decarbonisation route in many sectors, and can offer low abatement costs relative to scaling many sourcing and circularity technologies. Technologies such as high-temperature electric heating, molten oxide electrolysis and advanced battery chemistries could displace fossil carbon if scaled. Unlocking the full potential of electrification depends on rapid deployment of renewable generation, investment in grids and storage and policies that accelerate clean power buildout.[14] Similarly, reuse also offers a relatively mature and cost-effective upstream measure to reduce carbon molecule demand in the materials sectors.

**3. Circularity can play a significant role in reducing primary carbon demand, but requires substantial policy interventions to achieve scale.**

A maximum of a third of carbon used in 2050 could be from circular sources. However, circular technologies currently do not offer discrete drop in solutions and require a more holistic and integrated systems approach to scale. Upstream interventions for the materials sector, elimination, reuse and substitution, can significantly reduce total system carbon demand in tandem with cost savings. But reuse for example, would require major behaviour change along the value chain. Mechanical recycling of pulp, paper and plastics is already proven and scalable, but for recycling plastic, scale-up would depend on sufficient quality feedstocks and competition against low-cost virgin fossil production. Other circular technologies further downstream like CCU and chemical recycling face significant business case challenges. Irrespective of potential or constraints, scaling each circularity technology will require a coordinated operational

---

[14] A large evidence base on these requirements has been developed in other ETC reports including ETC (2023), *Financing the Transition: How to Make the Money Flow for a Net-Zero Economy*; ETC (2025), *Power Systems Transformation: Delivering Competitive, Resilient Electricity in High-Renewable Systems*.

transformation of the value chain, as well as supportive policy interventions. Operational transformation requirements include changes to product design and manufacture, value chain digitisation, brand and retailer operations, consumer behaviour and waste system operations. These changes must be underpinned by robust regulation e.g., carbon accounting and mass balance methodologies, effective carbon pricing to unlock recycling business cases and public support to incentivise first movers. Without this, even the best technologies risk falling short of their potential.

**4. Linear end-of-life solutions are being advanced and will play a role in a pragmatic and timely transition, especially where circularity solutions are challenged, but should be carefully scaled to avoid giving license to inefficient sourcing and use of carbon.**

Not all carbon can be reused or recycled. While every effort should be made to use carbon efficiently first, responsible disposal at end-of-life will be required in 2050. In these cases, linear solutions like geological storage and advanced landfilling provide necessary backstops. New technology advancements such as in-situ $CO_2$ mineralisation offer high permanence with fewer leakage risks, while methane-stabilising landfill systems can reduce emissions from residual waste. Given the challenges in scaling key end-of-life carbon management technologies in recent decades, a pragmatic, scientific approach should be taken to applying mature, cost-effective and environmentally effective technologies available today. However, these must be scaled with robust governance to ensure storage permanence, avoid negative environmental externalities and avoid incentivising the inefficient use of carbon.

**5. Sustainable primary biogenic carbon supply is constrained and direct sourcing technology (DAC, o-CDR) is still emerging, while fossil is abundant. Although there is significant potential to scale sustainable sources of primary carbon, strategic usage of abated fossil and carbon removals will be necessary to deliver a timely transition.**

Biomass, DAC and o-CDR represent the most viable sources of sustainable primary carbon, but each comes with trade-offs and thus the available supply of sustainable carbon is constrained. There is a potential upside to biomass sourcing through alternative biotech and utilising degraded land, but sustainable biomass is otherwise largely land-constrained and must be carefully governed to avoid food security and biodiversity risks. DAC is scalable but energy intensive and expensive today, while o-CDR offers promise at lower cost but is in an early-stage of technology maturity. Fossil carbon is abundant and affordable, but incompatible with long-term climate goals unless paired with durable removals. Therefore, technologies for abating fossil will be a pragmatic component of the transitioning system. However, their deployment must balance scaling up of end-of-life carbon management with scale up of sustainable carbon sourcing to avoid overdependence on a single technology group.

**6. While areas of the carbon system have commercially viable abatement solutions, several key gaps still exist in the carbon technology landscape. Further strengthening of the technology acceleration ecosystem is needed where promising technologies are still immature.**

Many of the most promising technologies such as high-temperature industrial heat, alternative proteins and o-CDR, are still at low TRLs (4-5) or costly to deploy. However, accelerated commercialisation is critical, even from a low base, given their higher potential to address the hardest parts of the system transition compared to existing solutions. Their success will depend on factors such as access to a robust innovation ecosystem within a mature industrial value chain, abundant clean energy and a willingness to invest in long-term system value over short-term returns. In some select areas, such as chemical recycling, where current business cases are challenging and Greenhouse Gas (GHG) performance is critical, further breakthrough innovation may still be required to achieve significant technology scale up.

**7. Flexibility in the solution mix is essential, given the trade-offs across the different technologies, meaning the “optimal” mix will vary significantly by geography, sector and time horizon.**

The variance between potential net-zero system-level scenario technology mixes in 2050 is considerable. Reconciling different market characteristics, such as energy availability or industrial structure, with different technology constraints, such as energy intensity or operational complexity, will lead the optimal technology mix to vary significantly by region. For example, biomass-focused strategies can help reduce $CO_2$ storage needs, but land availability and sustainability constraints can drive up costs. Electrification and circularity focused technology mixes tend to reduce both fossil demand and overall system costs, although only if supported by rapid buildout of clean power and enabling infrastructure. Fossil-focused technology mixes lean more strongly on removals technologies such as DAC, which is energy intensive, expensive and requires storage.

At this stage in the transition, system decision-makers are empowered to embark on very different technology pathways to reach a net-zero world. The resulting concentration of technology dependence, and thus technology transition risk, is significantly higher in some technology mixes than others. Moreover, they result in very different final net-zero system operating models in 2050. Therefore, consideration must be given not just to reach net-zero, but also to avoiding the creation of new long-term sustainability challenges similar to those faced today, following net-zero in 2050. While market forces will help determine which technologies scale, this will be guided by robust regulatory, standardisation and certification frameworks to protect natural and social capital, as well as deliver economic growth. System decision-makers should aim to build diverse, adaptive portfolios that balance cost, technical readiness and resource efficiency, while staying responsive to evolving constraints and opportunities.

**8. For a majority of carbon technologies, policy interventions will determine what scales first and how fast; carbon pricing is a critical lever but should be part of a broader policy architecture.**

Some key technologies have breakthrough potential and viable business models independent of policy, where industry will likely move first. Others do not, and for these, a pragmatic approach must be taken, using policy to unlock lower-performing but technologically mature solutions now to achieve sufficient scale-up by 2050. Carbon pricing is a critical technology-neutral lever in scaling these key low-emissions technologies. Findings suggest that prices of up to \$200 per $tCO_2$ may be required to bring many essential emerging technologies to cost parity. Projections for the EU ETS point toward steadily rising prices, and the introduction of the European Carbon Border Adjustment Mechanism (CBAM) shows how policy is beginning to expand carbon costs globally.

However, carbon pricing alone is unlikely to be sufficient and must be part of a broader policy architecture focused on the highest impact technologies with the greatest propensity to scale. Policy makers must also identify leading technologies with direct and cross-sectoral abatement potential and with the greatest likelihood of cost reduction to parity e.g., low energy intensity technologies. Equally, policy makers must also identify those technologies facing systemic inertia that require early incentives to catalyse their transition. These objectives can be achieved via instruments such as mandates, EPR schemes, design standards and public procurement. System-level infrastructure investment, tax incentives and certification systems will also be essential to support emerging technologies and safeguard environmental integrity.

## Looking forward

**This report aims to have several functions in enabling the carbon transition.** It seeks to provide a holistic view of the carbon system at a global level, coupled with use as a more granular reference document for side-by-side comparison of the best available technologies to transition the system. It aims to provide a common foundation of techno-economics for system decision makers across all systems change levers to chart the most ambitious, feasible and de-risked pathway to a thriving, long-term sustainable global carbon economy by 2050—one in which overall carbon demand is reduced by more than 70% compared to today. Moreover, in this critical decade, it is hoped that this common foundation of insight can be used to incept new, or steer existing, multi-stakeholder system initiatives able to directly address key system gaps in carbon efficiencies, sustainable sourcing, technology innovation and end-of-life management. Translating these insights into national, local, policy and corporate contexts will be the next essential step to ensure that the finite economic and natural capital available to deliver the energy transition is deployed to greatest effect in the coming years.

# Acknowledgements

**The team that developed this report comprised:**

Lord Adair Turner (ETC Chair), Eveline Speelman (Systemiq Partner), Faustine Delasalle (ETC Vice-Chair), Ita Kettleborough (ETC Director), Mike Hemsley (ETC Deputy Director), Peter Goult (Systemiq Senior Director), Andrea Bath and Ioannis Tyraskis (Lead authors) and Jason Martins and Gustavo Raschke Rameh (Supporting lead authors) with guidance from Mathias Becker, Ben Dixon, Rupert Simons, Sophie Herrman, Laetitia de Villepin, Elena Pravettoni and input from Emilie Wesseling, Marlene Kick, Dan Ellis, Hugo Stevens, Phoebe O'Hara, Max Steveton, Mike Webster, Trishla Shah, Rafal Malinowski, Alasdair Graham and support from John Allen, Shane O'Connor, Manuela Di Biase, Apoorva Hasija, Elizabeth Lam, Lina Morales, Viktoriia Petriv, Caroline Randle(SYSTEMIQ) and Jorge Coelho de Jesus.

**The team would also like to thank the ETC members and experts for their active participation:**

Nicola Davidson (ArcelorMittal); Kellie Charlesworth, Charlotte Higgins and Sally Prickett (Arup); James Butler and Timothy Jarratt (Ausgrid); Albert Cheung (BloombergNEF); Gareth Ramsay (bp); Sanna O'Connor-Morberg, Meera Atreya and Nikki Stuckert (Carbon Direct); Justin Bin LYU and Yi Zhou (CIKD); Adam Tomassi-Russell and Katherine Collett (Deep Science Ventures); Thomas Coulter and Annick Verschraeven (DP World); Adil Hanif and Dimitri Koufos (EBRD); Fu Sha (EF China); Cedar Zhai and George Wang (Envision); Keith Allott, Rebecca Collyer and Dan Hamza-Goodacre (European Climate Foundation); Eleonore Soubeyran (Grantham Institute, London School of Economics); Matt Prescott (Heathrow Airport); Randolph Brazier, Kash Burchett and Sophie Lu (HSBC); Francisco Laveron and Rodolfo Martinez Campillo (Iberdrola); Yanan Fu (ICCSD); Chris Dodwell (Impax Asset Management); Andy Wiley (Just Climate); Ben Murphy (Kiko Ventures); Freya Burton and Michael Koepke (LanzaTech); John Bromley and Nick Stansbury (L&G); Maria Von Prittwitz and Kyllian Pather (Lombard Odier); Vincenzo Cao (LONGi); Abbie Badcock-Broe, Gerard Kelly, Simon Orr (National Grid); Arthur Downing, Rachel Fletcher, Max Forshaw (Octopus Energy); Rahim Mahmood and Amir Hon (PETRONAS); Leonardo Buizza and Madeleine Luck (Quadrature Climate Foundation); Susan Hansen (Rabobank); Udit Mathur (ReNew); Greg Hopkins and Brian Payer (RMI); Emmet Walsh (Rothschild); Emmanuel Normant (Saint Gobain); Vincent Petit (Schneider Electric); Brian Dean (SEforAll); Charlotte Brookes and Halla Al-Naijar (Shell plc); Jonny Clark (SLR Consulting); Martin Pei and Jesper Kansbod (SSAB); Alistair McGirr and Ryan McKay (SSE); Abhishek Goyal (Tata Sons); Saurabh Kundu (Tata Steel); A K Saxena (TERI); Reid Detchon (United Nations Foundation); Mikael Nordlander (Vattenfall); Niklas Gustafsson (Volvo); Molly Walton (We Mean Business Coalition); Karl Hausker, Jennifer Layke, Zachary Byrum and Richard Waite (World Resources Institute); Paul Ebert and Kirk Neubauer (Worley); Richard Hardy (X-Links).

**The team would also like to thank the ETC's and Systemiq's broader network of experts for their input:**

Ville Väliaho and Lauri Peltola (Coolbrook); Edward Sanders and Guarav Sant (Equatic); Daniel Goodwin and Paul Reginato (Homeworld Collective); Andrew Symes (OXCCU); Andreas Wagner and Alexandre Kremer (Radical Dot); Pedro Vidinha (USP); Gonçalo Pereira (UNICAMP); Mike Muskett (Tranby Technology); Henrik Wareborn; Prachi Jangid and Nathan Curry (The Transition Accelerator).

Energy
Transitions
Commission

SYSTEMIQ

Download the
digital report