Innovations for net-zero energy and materials systems

MARCH 2026

Innovation Brief Series

Carbon Capture and Utilisation

Enabling targeted carbon utilisation for high-value industrial application

Recycle and reuse carbon

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This innovation brief was created by Systemiq and the Energy Transitions Commission as part of the *Carbon in an electrified future* series. Each brief highlights a key technological innovation that can drive electrification, circularity, or carbon sourcing.

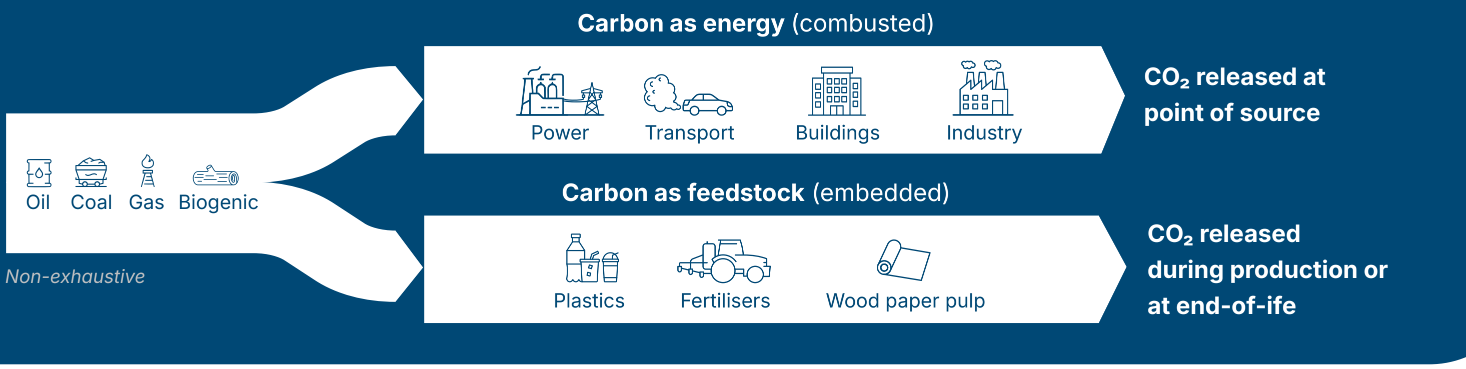
Learn more at www.energy-transitions.org/publications/carbon-in-an-electrified-future
www.systemiq.earth/resource-category/carbon-in-an-electrified-future

INNOVATIONS FOR NET-ZERO ENERGY AND MATERIALS SYSTEMS

Carbon Capture and Utilisation

Carbon sits at the centre of today's energy and materials systems

Carbon is the core component of the fossil fuels and material feedstocks that underpin today's energy and materials systems. When these carbon-based resources are combusted or transformed to produce energy, heat, mobility, and materials, they release carbon dioxide (CO_2). Achieving net zero requires both reducing the carbon entering the system and actively managing the residual carbon that remains.



Three steps towards net-zero energy and materials systems

1 Reduce carbon use

- **Increase supply of clean electricity**
- **Switch to electrification where possible**
- **Use clean hydrogen when not possible to electrify**

2 Recycle and reuse carbon

- **Increase durability and reuse of carbon products**
- **Scale recycling of carbon products**
- **Capture and reuse carbon emissions**

3 Source sustainably and manage end-of-life

- **Prioritise non-fossil carbon inputs and capture of unavoidable emissions**
- **Secure permanent storage for residual carbon**

Carbon Capture and Utilisation (CCU)

What is Carbon Capture and Utilisation?

Carbon capture and utilisation is the process of capturing CO_2 on the back of energy and industrial processes, and repurposing it into fuels, chemicals, or materials. CCU creates economic incentives for emissions reduction while supporting circular carbon cycles. CCU with fossil sources improves carbon efficiency but still adds fossil carbon to the atmosphere; biogenic CCU can be carbon-neutral with regrowth and full lifecycle accounting.

Key takeaways

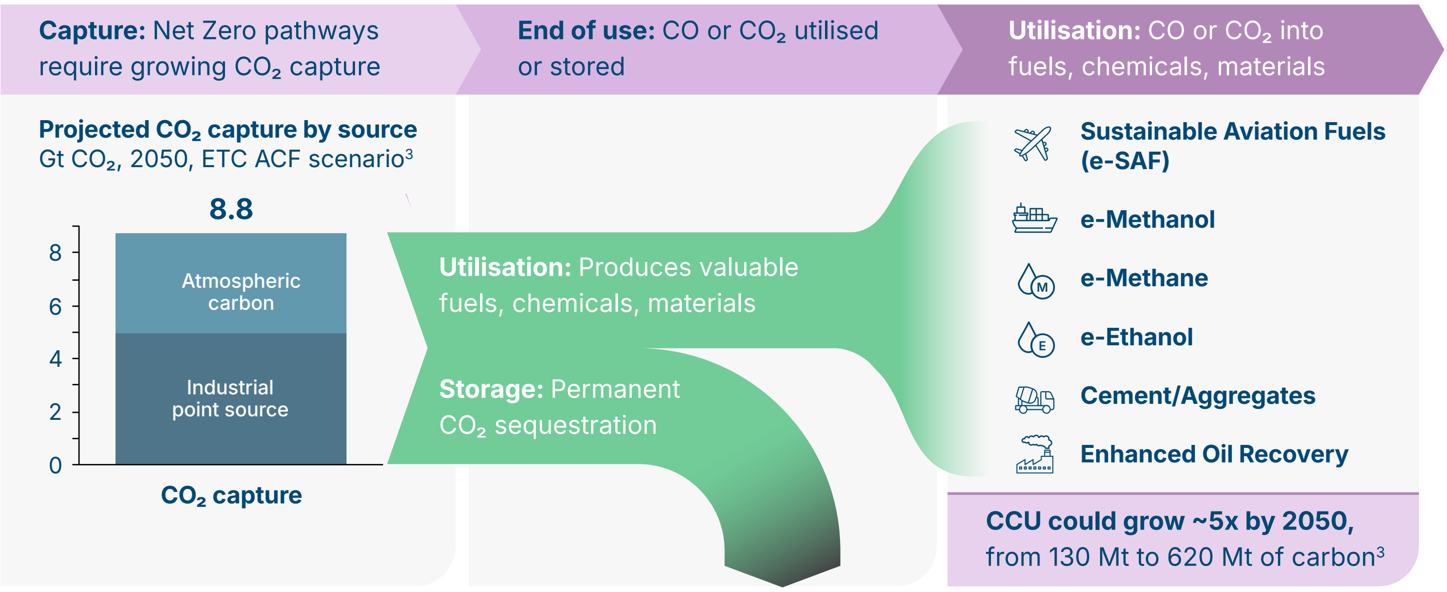
A **CCU offers a route to enable carbon reuse and produce low-carbon fuels and fuel precursors which is relevant in select use cases,** where there is a concentrated point source to abate, where this point source cannot be sequestered readily, and where carbon sourcing constraints exists.

B **CCU scale-up is constrained by economics.** Deployment of many CCU technologies depends on affordable green hydrogen, low-cost clean power, and CO and CO_2 supply. Carbon pricing or policy support will be needed to compete with fossil alternatives.

C **CCU deployment is early stage, with initial commercialisation underway,** led by hydrogenation (CO_2-to-methanol/methane) and biocatalysis (ethanol/e-SAF) with multiple facilities commissioned for operation by 2030.

A CCU enables carbon reuse, producing low-carbon fuels and fuel precursors

Captured CO_2 (from air or point sources) can be either stored or used[1,2]



Capture: Net Zero pathways require growing CO_2 capture

End of use: CO or CO_2 utilised or stored

Utilisation: CO or CO_2 into fuels, chemicals, materials

Projected CO_2 capture by source
Gt CO_2, 2050, ETC ACF scenario[3]

Utilisation: Produces valuable fuels, chemicals, materials

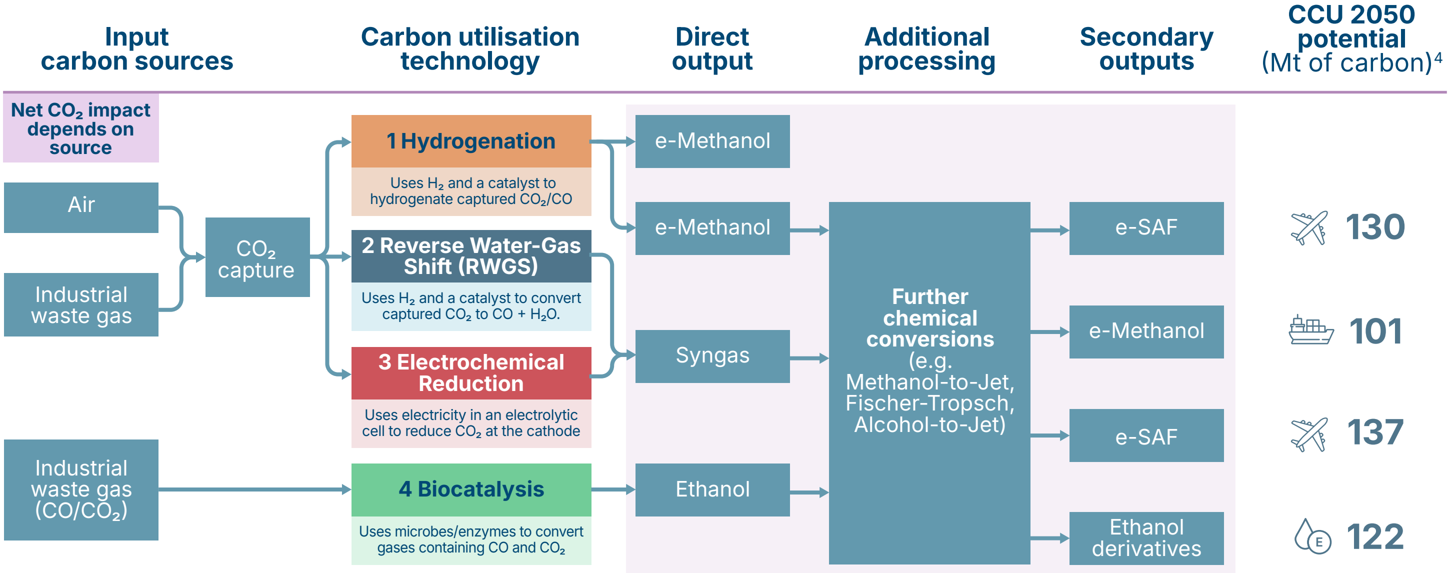
Storage: Permanent CO_2 sequestration

- **Sustainable Aviation Fuels (e-SAF)**
- **e-Methanol**
- **e-Methane**
- **e-Ethanol**
- **Cement/Aggregates**
- **Enhanced Oil Recovery**

CCU could grow ~5x by 2050, from 130 Mt to 620 Mt of carbon[3]

CCU is relevant for select use cases, where there is a concentrated point source to abate, where this point source cannot be sequestered readily, and where carbon sourcing constraints exists.

Key CCU technology routes yield different fuels and fuel precursors[4]



1 Hydrogenation
Uses H_2 and a catalyst to hydrogenate captured CO_2/CO

2 Reverse Water-Gas Shift (RWGS)
Uses H_2 and a catalyst to convert captured CO_2 to CO + H_2O.

3 Electrochemical Reduction
Uses electricity in an electrolytic cell to reduce CO_2 at the cathode

4 Biocatalysis
Uses microbes/enzymes to convert gases containing CO and CO_2

Performance of CCU technologies depends on input intensity and availability

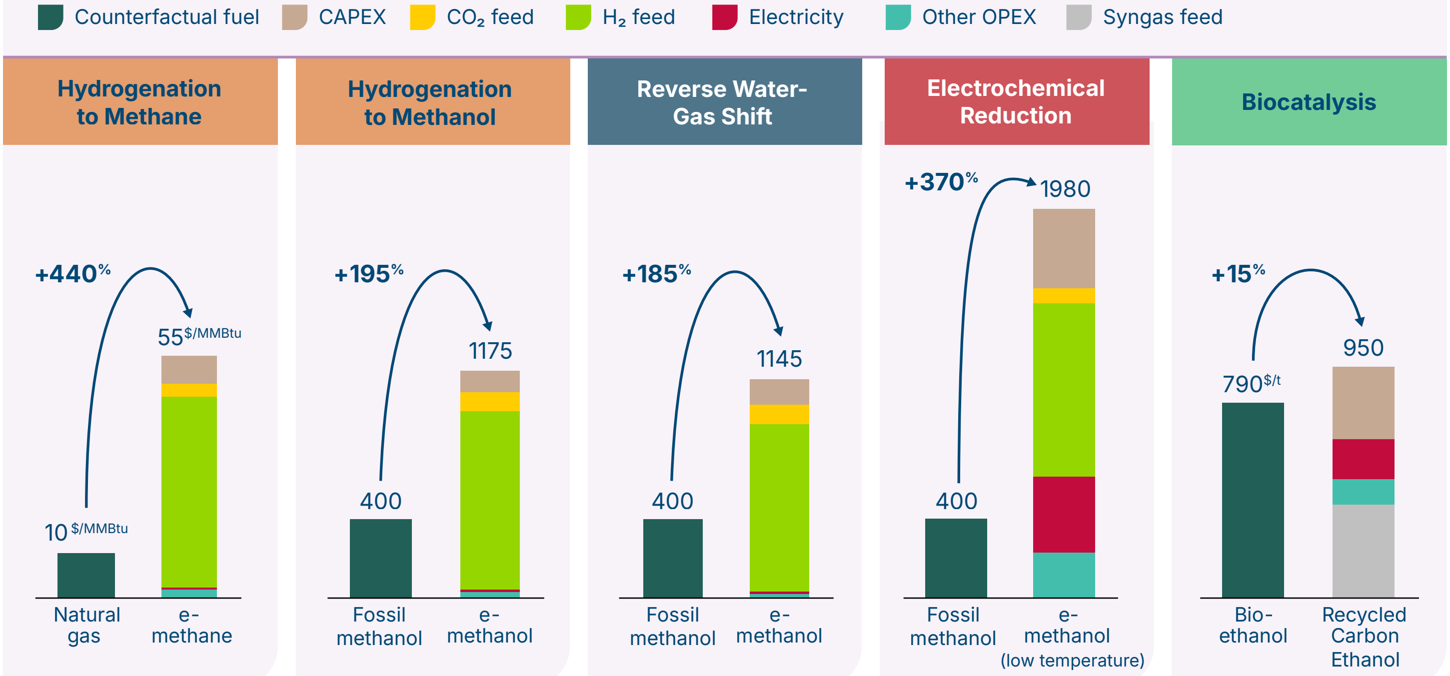
(e.g. low-cost clean electricity, hydrogen, feedstock)[5]

Hydrogenation (e-Methane / e-Methanol)	+ Most mature and scalable route, leveraging established reactor systems − Highly exposed to green H_2 prices
Reverse Water-Gas Shift (Syngas)	+ Syngas is versatile, with multiple fuel and chemical end uses − H_2 and heat-intensive, with additional conversion losses
Electrochemical Reduction (Syngas)	+ Primarily electricity-driven, reducing some reliance on H_2 supply − Power and CAPEX intensive, currently the costliest route
Biocatalysis (Ethanol)	+ Comparatively lower cost premiums − Constrained by feedstock availability and the need for tailored microbes

B CCU scale-up is constrained by economics

CCU costs remain significantly higher than fossil-based alternatives, in large part driven by green hydrogen costs

Levelised cost of production[6,7] $/t output, 2030

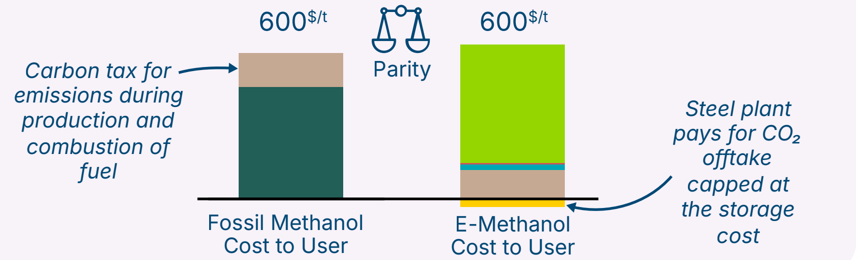


Hydrogenation and **RWGS** rely heavily on H_2, which makes up 70–85% of production costs

Electrochemical reduction is less H_2-dependent but remains the costliest due to high CAPEX and electricity demand

Biocatalysis has low H_2 exposure, scaling may be limited by bio feedstock availability

E-methanol example: ambitious carbon prices and favourable input costs needed for cost parity with fossil methanol by 2035[8]



Carbon tax for emissions during production and combustion of fuel

Steel plant pays for CO_2 offtake capped at the storage cost

What you need to believe for economic parity with fossil - illustrative assumptions[9,10]

H_2, \$/kg	2.3	Reduction from 4.5 \$/kg at today's levels
Carbon price, \$/t	100	
CO_2 storage, \$/t	20	

C CCU deployment is early stage, with initial commercialisation underway

Hydrogenation and Biocatalysis are the commercial front-runners with multiple announced and commissioned limited volume projects before 2030

Hydrogenation
(e-Methane / e-Methanol)

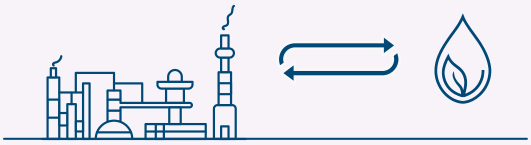
- **To methanol:** Carbon Recycling International commissioned the world's largest CO_2-to-methanol plant in China in 2022, producing 110 kt/y e-methanol.[11]
- **To methane:** MAN Energy Solutions and StormFisher announced a 200 MW Power-to-X project in 2025, targeting **~50 kt/y e-methane** in North America.[12]

Biocatalysis
(Ethanol)

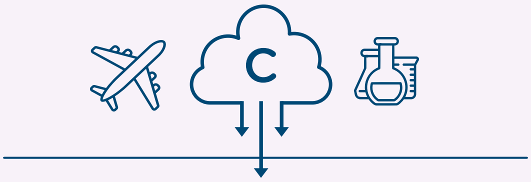
- **To ethanol and e-SAF:** Lanzatech has multiple projects and joint ventures including at Herøya Industrial Park targeting **24 kt/y e-ethanol** by 2029[13] and Dragon II with a planned production capacity of **80 kt/y SAF** by 2030[14].

CCU: Enabling targeted carbon utilisation for high-value industrial application

CCU can:



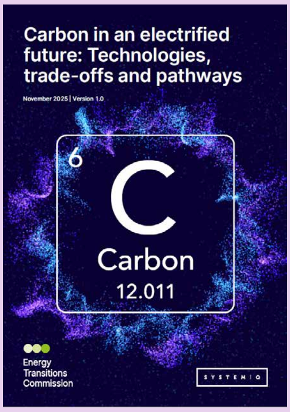
Enable carbon reuse and produce low-carbon fuels and fuel precursors which is relevant in select use cases, where there is a concentrated point source to abate, where this point source cannot be sequestered readily, and where carbon sourcing constraints exists.



Support decarbonisation of hard-to-abate sectors, particularly aviation and chemicals, where carbon-based molecules remain structurally required

Three priorities to scale CCU by 2030

Key priorities	Key players	Key actions
Robust carbon pricing & demand side market creation	Governments Regulators Producers	Robust carbon pricing (≥ \$100/tonne) and carbon border adjustment mechanisms; product standards or quotas, including blending mandates; public procurement mandates; financing mechanisms such as long-term offtakes, contracts for difference, and double-sided auctions for CCU-derived products to drive demand against fossil counterparts, especially in steel, cement, and chemicals.
Standardised monitoring, reporting and verification frameworks	Governments Regulators Certification bodies Producers	Credible certification is essential to unlock demand for CCU products. Standardised frameworks are needed for lifecycle assessment, carbon intensity thresholds, and time-bound accounting, particularly for e-SAF and e-methanol where blending mandates require verified claims.
Access to low-cost green H_2 and CO_2 supply and support industrial clusters	Renewable power developers Grid operators H_2 and CO_2 producers	Scale affordable green hydrogen to below \$2.5/kg and build out CO_2 and H_2 transport and storage networks to connect capture, conversion and end use. Support industrial cluster infrastructure.


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

November 2025 | Version 1.0

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Further reading: Also in this Innovation Brief Series

Electrification will drive the global transition to net zero, powering cleaner industries, homes and transport. But even in a world where electricity dominates, carbon molecules will play a remaining role in producing essential fuels and materials.

This innovation brief is part of the ***Carbon in an electrified future*** series. Each brief highlights a key technological innovation that can drive electrification, circularity, or sustainable carbon sourcing across three steps towards net-zero emissions energy and materials systems.

Explore more in the other briefings:

Reduce carbon use

Recycle and reuse carbon

Source sustainably and manage end-of-life


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Innovation Brief Series

Sodium-ion batteries

Diversifying beyond lithium-ion with a scalable alternative

Reduce the use of carbon

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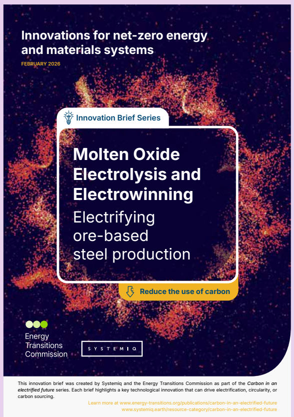
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Molten Oxide Electrolysis and Electrowinning

Electrifying ore-based steel production

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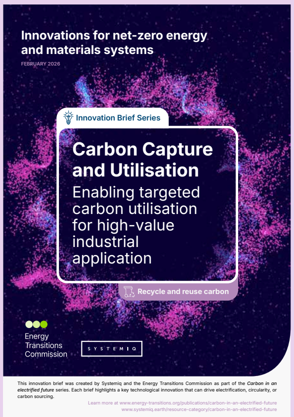
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Unlocking land for nature and biomass

Sources and notes

1. MPP (2024) EU PtX modelling
2. Systemiq (2022) Planet Positive Chemicals
3. Systemiq analysis based on MPP (2022) Making Net-Zero Aviation Possible, Systemiq (2022) Planet Positive Chemicals Report, ETC (2022) Carbon Capture, Utilisation & Storage in the Energy Transition: Vital but Limited, ETC (2023) Fossil Fuels in Transition
4. ETC and Systemiq (2025) Carbon in an electrified future: Technologies, trade-offs and pathways
5. ETC and Systemiq (2025) Carbon in an electrified future: Technologies, trade-offs and pathways
6. ETC and Systemiq (2025) Carbon in an electrified future: Technologies, trade-offs and pathways
7. Key cost inputs: CO2 $60/tCO2, Green H2 : ~3-5 $/kg, Electricity ~40-80 $/MWh. Chart assumes midpoint values.
8. Systemiq Analysis based on Systemiq (2022) Planet Positive Chemicals, Methanol Institute (2022) Carbon Footprint of Methanol
9. 2035 was chosen to reflect realistic mid-term assumptions (e.g., hydrogen and carbon prices) and avoid overly optimistic near-term economics
10. CO_2 feed comes from industrial waste gas streams, mainly from steel off-gas
11. Carbon Recycling International (2025) The Shunli CO_2-to-Methanol Production Plant
12. [MAN Energy Solutions (2025) MAN Energy Solutions and StormFisher Hydrogen partner on Power-to-X Methanation Reactor
13. LanzaTech (2024) LanzaTech and Eramet announce plans for first-of-a-kind integrated Carbon Capture, Utilization and Storage (CCUS) project in Norway
14. LanzaTech (2026) px Saltend Chemicals Park Named as Home to LanzaTech's Groundbreaking DRAGON II Sustainable Aviation Fuel Project, Set to Create SAF Jobs on the Humber
15. MPP (2021) Net Zero Steel Sector Transition Strategy

This document is supplementary to the full report- if reproducing or referencing the content, please use the following citation: "Energy Transitions Commission and Systemiq. (2026). Innovations for net-zero energy and materials systems | Carbon Capture and Utilisation - Enabling targeted carbon utilisation for high-value industrial application".