Whitepaper

FLEXIBLE, MODULAR CARBON CAPTURE GAS POWER PLANTS: THE FUTURE OF LOW-EMISSION ENERGY SUPPLY

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A Rolls-Royce solution

Flexible, modular carbon capture gas power plants, an economically attractive and technologically mature solution for reducing CO_2 emissions.

These power plants enable a low-emission energy supply and complement renewable energies and hydrogen technologies. Due to rising CO_2 prices and regulatory incentives, carbon capture is becoming a central component of the energy transition. Technologies such as **FLEXPOWER** PLUS® demonstrate that carbon capture can not only reduce emissions but also deliver economic benefits. Strategic investment, targeted funding and international cooperation are essential to unlock the full potential.

Executive Summary

This whitepaper presents flexible, modular carbon capture solutions as a strategic advancement for low-emission power generation, with a particular focus on decentralized gas engine plants. It outlines the technical maturity of amine scrubbing, the scalability of compact CCUS systems, and the growing demand for clean, dispatchable energy. Readers gain insight into how to structure viable CCUS business cases by leveraging policy incentives, cost benchmarks, and smart CO_2 utilization across fuels, chemicals, and building materials - unlocking secured revenue streams. The paper reviews global regulatory frameworks and funding mechanisms, including EU Innovation Fund support, U.S. 45Q tax credits, and emerging legislation in Germany, UK, Brazil, China, and other regions. It highlights major CO_2 storage initiatives and international cooperation on cross-border transport, emphasizing infrastructure readiness. Market forecasts indicate strong growth in engine-based CCUS capacity, reaching low gigawatt scale by 2030. Together, these insights position CCUS-enabled power generation as an important addition to the energy transition and a commercially attractive solution for future energy systems.

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ASCO All about CO_2

Historical overview of the development of carbon capture

The global energy transition is essential in the face of the climate crisis and rising temperatures. The continued emission of greenhouse gases from fossil fuels (-coal, oil and natural gas) – is driving global warming (Figure 1). This results in more frequent extreme weather events, including droughts, floods and heatwaves. which threatens millions of lives. These phenomena deepen social and economic inequalities, particularly in the regions least responsible for emissions.

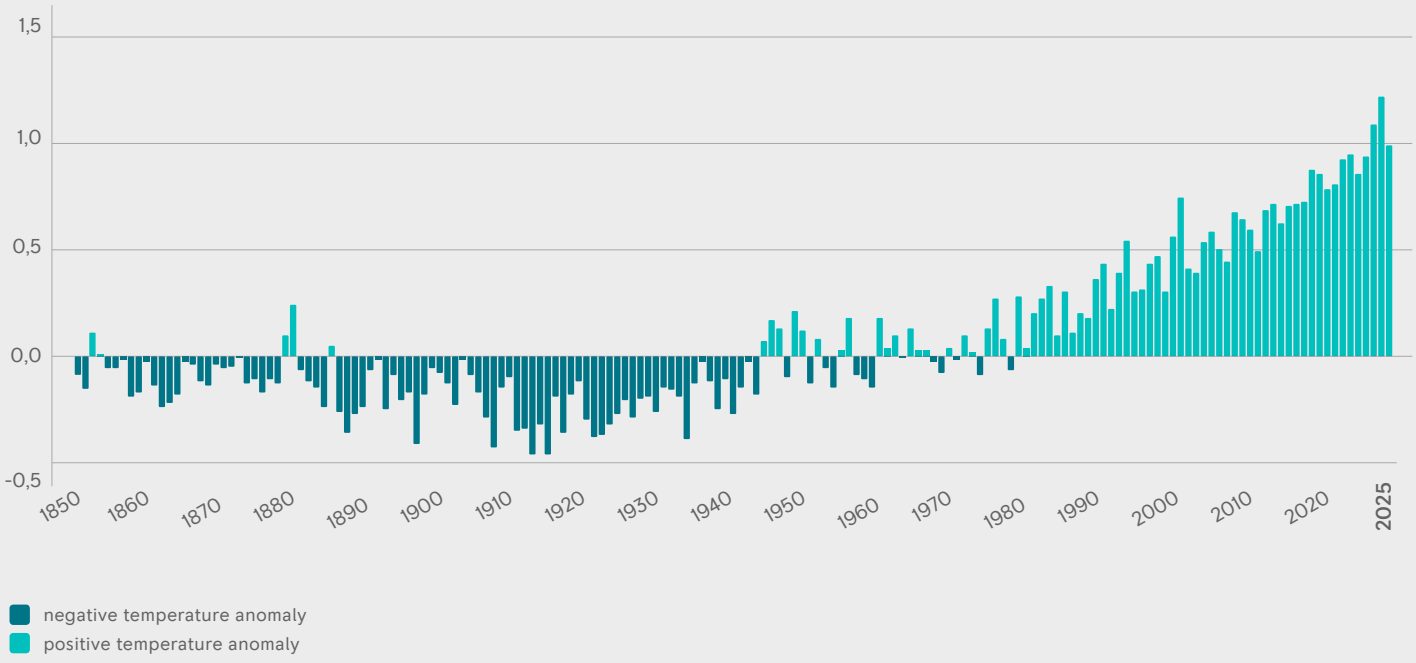
To address this and limit global warming, the United Nations (UN) convened in Paris on December 12, 2015 at the UN Climate Change Conference (COP21) and reached an agreement. **195 nations signed the Paris Agreement, committing to limit global warming to well below 2 °C and to pursue efforts to restrict it to 1.5 °C, with key emission reduction milestones set for 2030.**

195

NATIONS PLEDGED TO LIMIT GLOBAL WARMING

By 2050, global warming must be halted entirely – achieving 'net-zero' emissions Countries have submitted national action plans for climate protection, referred to as the „nationally determined contributions (NDCs)“,

Figure 1
Average temperature anomalies land and ocean. [4]



A comprehensive restructuring of the energy sector is needed.

The energy sector is a major contributor to global warming, emitting 16.3 Gt of CO_2 annually [1] To meet climate targets , the sector must undergo a comprehensive transformation. This includes expanding wind and solar energy, scaling hydrogen as an energy source, improving energy efficiency and building global partnerships to ensure access to low-emission energy. For emissions that cannot be avoided (hard to abate), Carbon Capture Utilisation and storage (CCUS) is the most viable solution.

A 45% reduction in global CO_2 emissions by 2030 is required to minimize global warming to 1.5 °C. [2]

45%
REDUCTION OF CO_2 IS REQUIRED

SINCE
2022
SEVEN LARGE PLANTS HAVE BEEN COMMISSIONED

The achievement of this goal can be effectively supported through the use of CCUS technologies. According to the International Energy Agency (IEA over 40 commercial carbon capture CO_2 recovery plants are currently operating worldwide, with combined annual capture capacity of exceeding 45 million tonnes.

Since January 2022, seven new large-scale capture plants have been commissioned including projects in the USA, Belgium and China.

More than 50 additional capture plants are expected to be operational by 2030. However, the current project pipeline represents only one-third of the capacity needed to meet 2030 net-zero targets. [3] This highlights that the energy transition is not only a technical challenge, but also a social and economic one that requires international cooperation and political commitment.

(CCUS) dates to the mid-20th century, when early studies explored methods for capturing CO_2 from fossil fuel combustion. However, it was not until the late 1970s and early 1980s that the first large-scale CCUS projects began to take shape.

One of the earliest commercial projects is the Sleipner field in Norway, commissioned in 1996 and is operated by Equinor. Each year approximately 1 million tonnes of CO_2 are injected into the Utsira formation in the North Sea. Around the same time, the Weyburn-Midale field in Canada, began using recovered CO_2 for enhanced oil recovery (EOR) - demonstration the potential for industrial utilisation.

These initial projects, although originally stemming from the oil production industry, laid the foundation for the global development and implementation of CCUS technologies. In the early 2000s, countries, including the USA, Canada and Australia, launched national CCUS programmes. The United States led with initiatives such as the “Clean Coal Power Initiative” and later the “FutureGen” project. However, the latter was discontinued due to high costs and technical challenges.

The development of CCUS in Europe began with the Sleipner project in Norway, in 1996 as the first commercial CO_2 storage project in the world, it expanded in the 2000s, when European countries, including the United Kingdom, the Netherlands and Germany, invested in research and pilot projects. **After a period of uncertainty and project cancellations in the 2010s, CCUS regained momentum thanks to renewed support from the European Union, which now considers CCUS as a key technology for 2050 climate neutrality.**

THE EU SEES CCUS AS KEY TO
2050
CLIMATE NEUTRALITY

The EU Innovation Fund and collaborative efforts among the countries bordering the North Sea are driving new CO_2 storage projects, particularly through cooperation between industry and governments. Active developments include Northern Lights in Norway, which facilitates cross boarder CO_2 transports and storage, alongside initiatives in the Netherlands, the UK and Denmark.

Policy drivers - incentives and regulation

Governments and industries are increasingly recognising the key role of CCUS technologies in achieving net-zero emissions targets. This shift is reflected in the growing political investment in research and development.

In Europe, the EU Innovation Fund supports low-carbon technologies and processes in energy-intensive industries. Alongside this, the EU Emissions Trading System (EU ETS) and national initiatives by the member states, are creating a more supportive political environment for CCUS. The EU ETS generates revenue for the Innovation Fund through an increase of 450 million allowances from 2020 to 2030, as well as unspent funds. Depending on the CO_2 price, the fund is expected to reach approximately €38 billion for the 2020 to 2030 period (based on €75/t CO_2). [5]

Several European countries launched new initiatives and expanded support for CCUS projects. The UK government has advanced its post-Brexit energy transition strategy, announcing the first CO_2 hubs and refined its business model for transportation and storage. Norway and the Netherlands have made firm political and regulatory commitments to promote CCS. Other EU member states are actively improving regulatory frameworks, removing barriers and providing political support.

In the United States, the Inflation Reduction Act's enhanced 45Q tax credits, offering up to $85 per tonne for industrial capture and storage, and $180 for direct air capture. These generous, bankable credits combined with the Department of Energy's funding for regional CO_2 hubs have triggered a wave of project announcements across multiple sectors. [6]

Canada has introduced a refundable CCUS Investment Tax Credit (covering up to 60% of eligible costs for DAC). This is paired with carbon price certainty via the Canada Growth Fund's contracts for difference. Provinces like Alberta also allocate storage rights and regulate sequestration hubs, giving developers a clear pathway from design to injection. [7]

China's support is driven by regulatory momentum. The national emissions trading system is expanding beyond the power sector to include heavy industry. Carbon pricing and the inclusion of CCUS in five-year plans are creating an incentive to invest in capture technology. [8]

In October 2024, Brazil enacted Federal Law 14,993/2024 ("Fuels of the Future"), its first legal framework for CCS. The law assigns oversight and licensing responsibilities to the Brazilian National Agency of Petroleum and Natural Gas (ANP) for capture, transport and geological storage (renewable 30-year permits). Policymakers are now developing funding mechanisms and Petrobras' 2025–29 plan allocates significant capital to CCS hubs. A regulated carbon market is also in development. [9]

Australia supports CCUS through its carbon crediting system. Projects can earn Australian Carbon Credit Units under a dedicated CCS methodology. The Safeguard Mechanism further creates demand for low-carbon compliance options. [10]

Across these regions a clear trend is emerging: the world's major economies are no longer debating **if** CCUS is necessary, but **how** fast they can scale it.

CCUS as a climate strategy

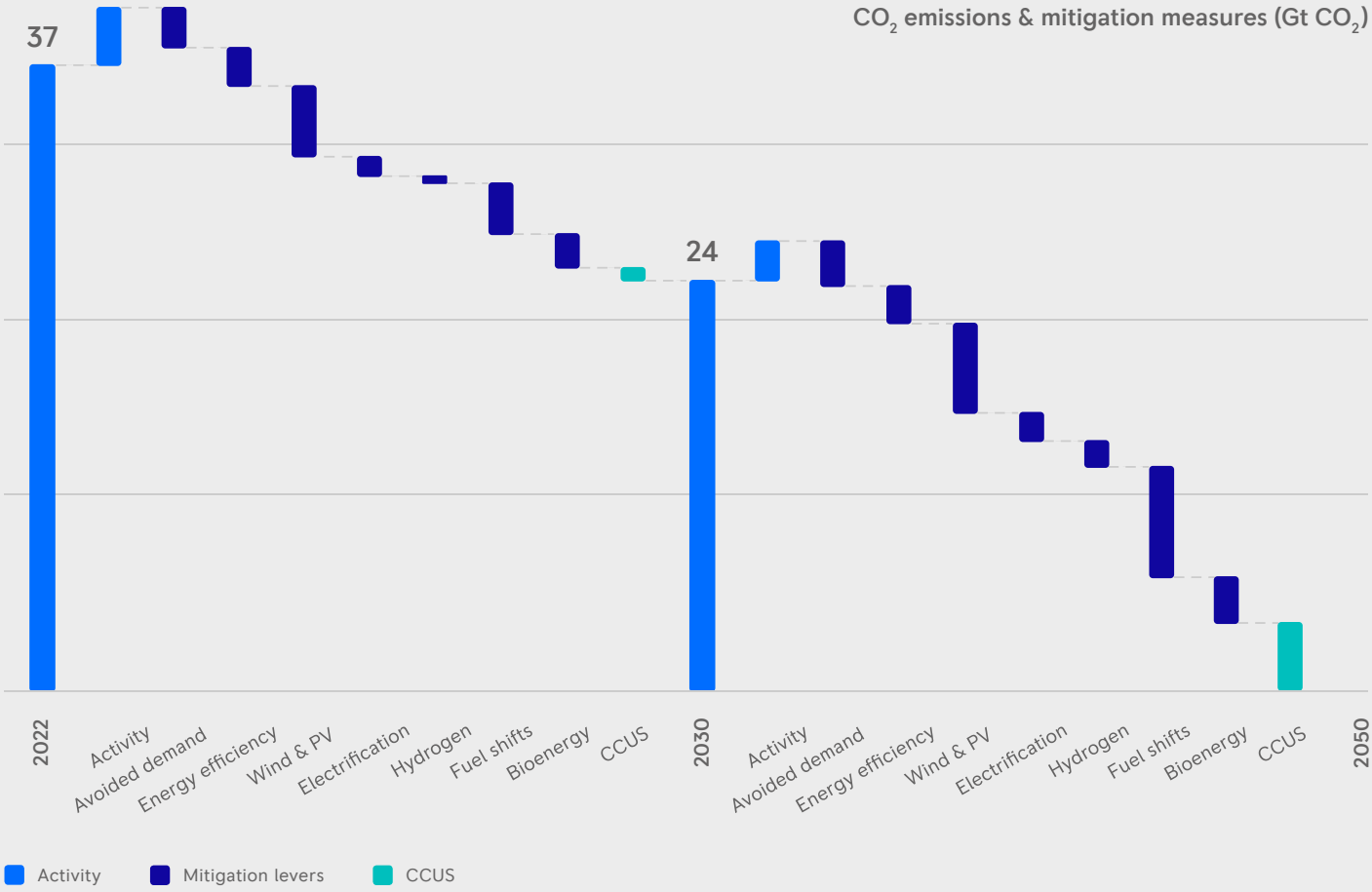
CCUS plays a crucial role in achieving net-zero emissions,especially given the current global energy demand. According to the IEA, CCUS could reduce global CO_2 emissions by almost 20% equivalent to around 37 Gt CO_2 per year by 2050 while also lowering the overall cost of climate protection by approximately 70%. [3]

However, CCUS is not a standalone solution. It must be integrated into a broader decarbonisation strategy. This strategy includes expanding renewable energy sources such as wind, solar and hydropower, improving energy efficiency in buildings, scaling hydrogen technologies, increasing the use of bioenergy and electrifying transport (Figure 2).

This holistic approach – often referred to as the decarbon-isation mix - is crucial to keeping the global temperature rise below the critical threshold of 1.5 °C and protecting our planet for future generations.

CCUS complements these efforts by addressing emissions from sectors where reductions are technically or economically challenging. It enables the continued operation of essential infrastructure while aligning with climate targets, making it a key enabler of a balanced and resilient energy transition.

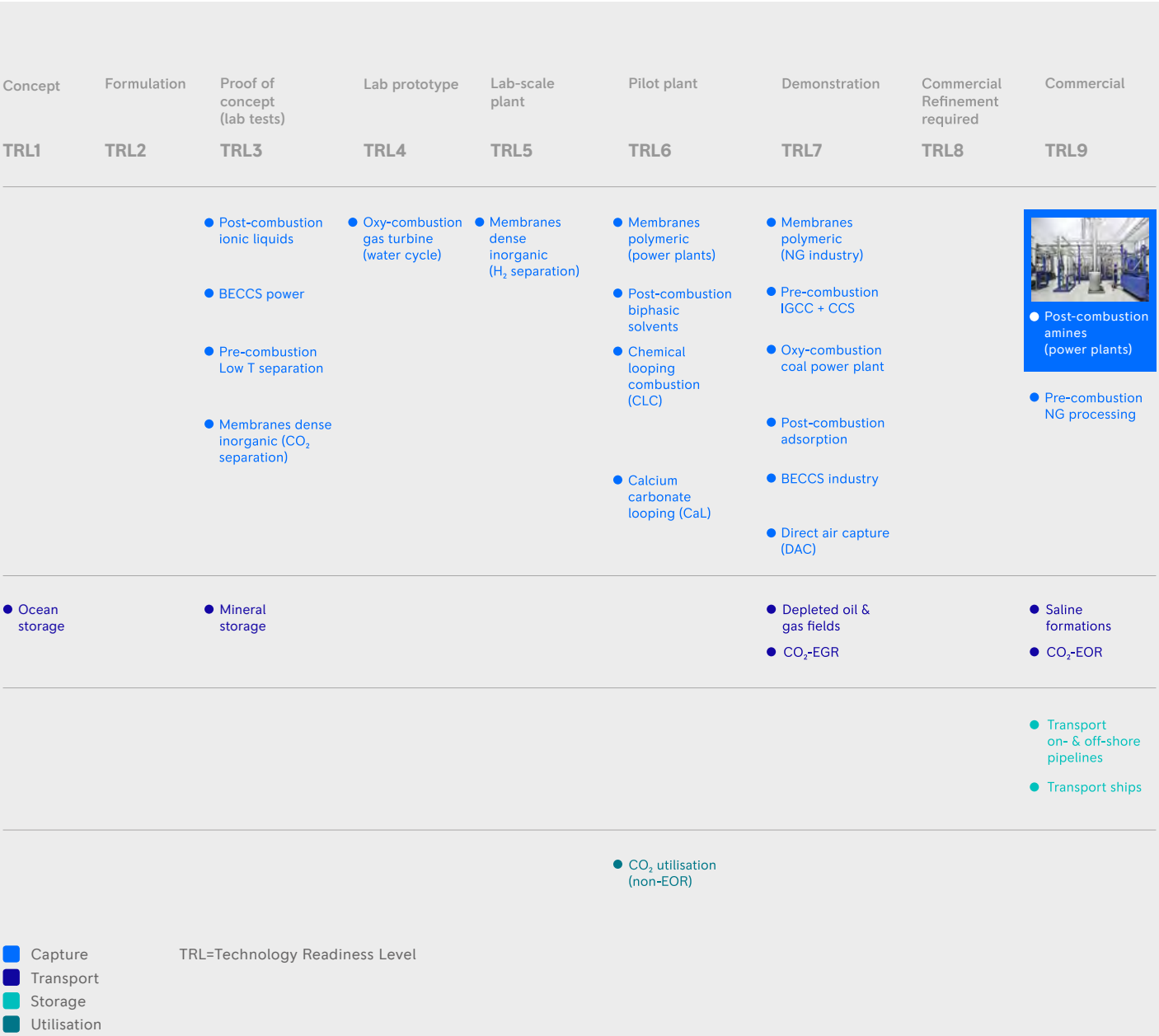
Figure 2
Emission reduction measures: As highlighted in green, CCUS plays a key role in lowering global CO_2 emissions. [11]



Efficient CO_2 recovery: amine scrubbing in industrial applications

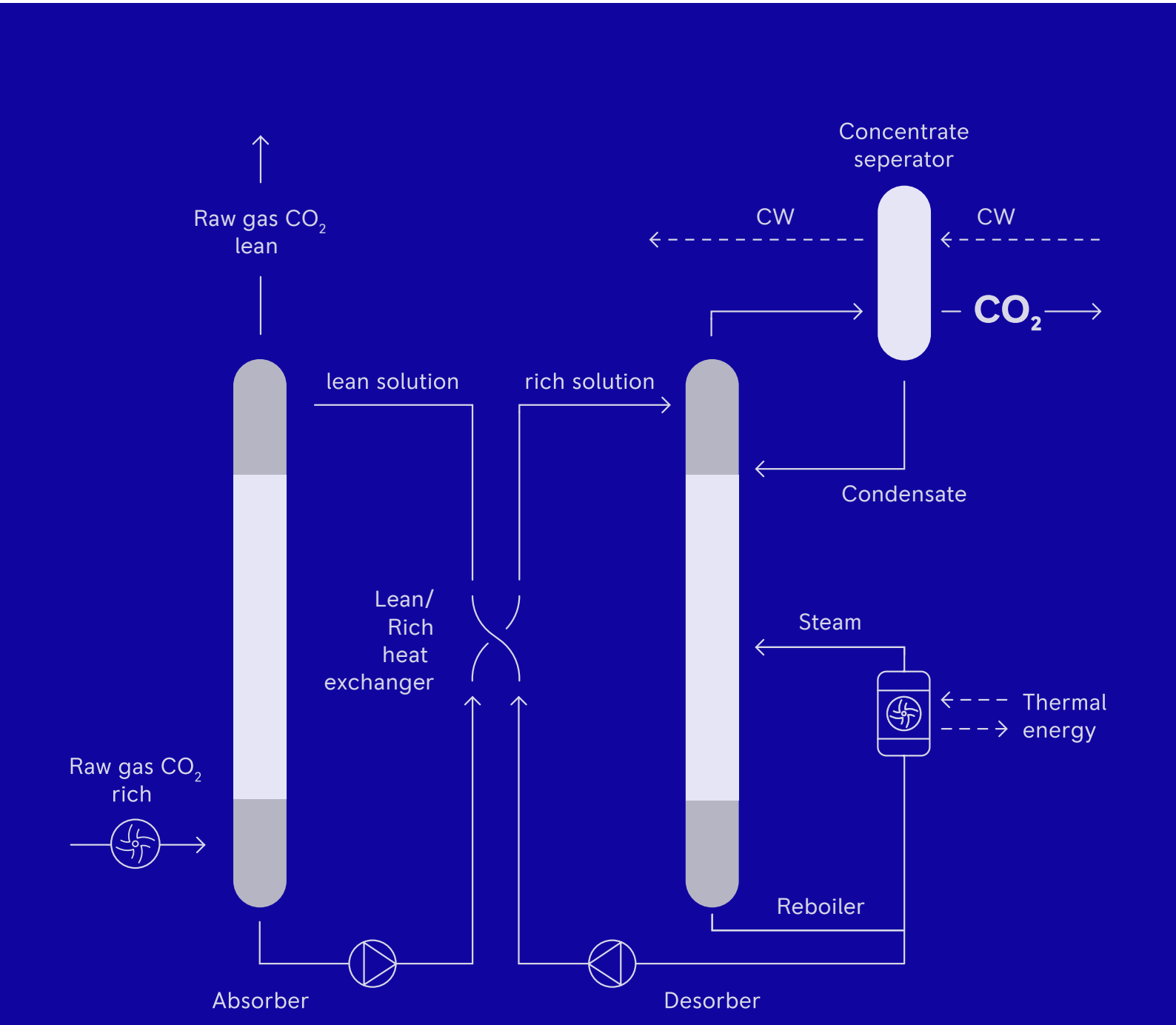
Carbon capture is the first step in the CCUS value chain. It is mainly used in „hard-to-abate“ industries, where CO2 emissions cannot be avoided. Several recovery technologies exist with different technology readiness Levels (TRL) (Figure 3)in a case study later in this whitepaper, the amine scrubbing method (post-combustion) is used, because it has, the highest TRL. This section focusses on that process.

Figure 3
Current technology readiness level (TRL) of CO_2 recovery processes



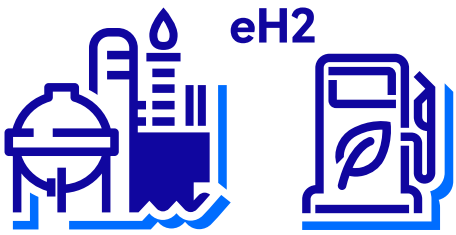
After pre-treatment of the flue gas, the carbon dioxide is extracted using amine scrubbing. Two columns are used in this process - a CO_2 absorber and a stripper - which are connected by a circulating chemical amine solution. The flue gas is fed into the absorber at the bottom, while the amine base is fed at the top, which enables counter current contact. During this interaction, the CO_2 reacts selectively with the amine and is bound in the flue gas. The amine enriched with CO_2 escapes at the bottom of the absorber and flows into the stripping column. Here, heat is added to the amine solution saturated with CO_2 via low-pressure steam, which releases the CO_2. The released CO_2 leaves the stripping tower and is compressed, dehydrated, purified and liquefied in subsequent processes for storage or transportation in tanks. (Figure 4)

Figure 4
ASCO process description of CO_2 recovery using amine scrubbing.



CO_2 utilization: industrial applications and innovations

The most common use of recovered CO_2 is in oil production, during EOR. It is injected into oil fields to optimise oil production. This does not cut emissions, as it leads to more fossil fuel production. **Beyond traditional applications of CO_2, such as in greenhouses or the beverage industry, ongoing research is advancing new methods that capture CO_2 or utilise it in closed cycles to reduce additional emissions.** The most important applications of CO_2 in the sense of the CCUS definition, i.e. to prevent additional emissions, are divided into three main categories:



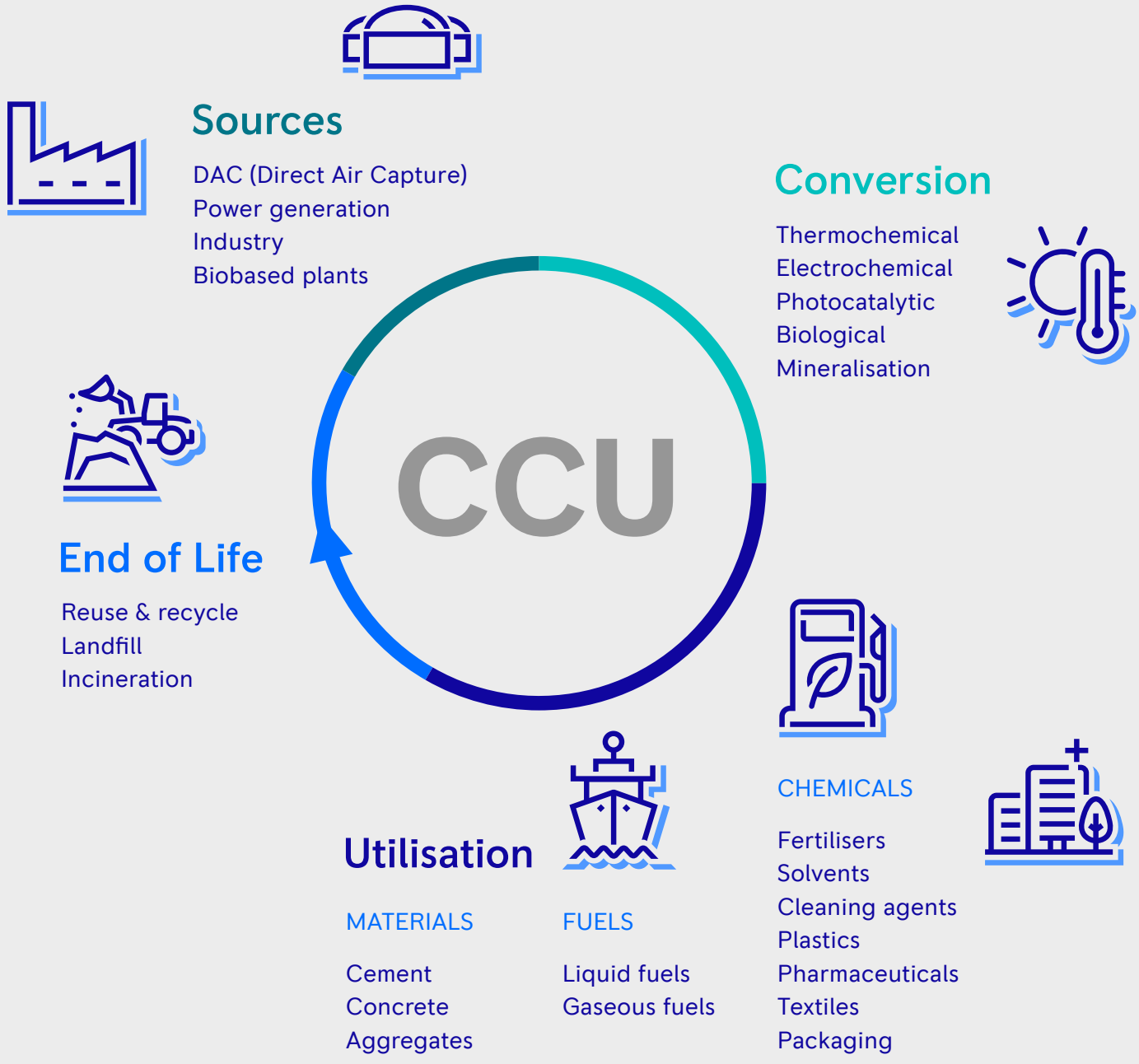
e-Fuels: In sectors such as aviation, shipping and heavy transport, where electrification is difficult to implement, synthetic fuels offers a climate-friendly alternative. They are produced by reacting CO_2 with hydrogen from renewable electrolysis and can be stored, transported and used in existing infrastructures. They also enable long-term energy storage, which makes renewable energy usable for hard-to-electrify sectors. The first flights with CCU kerosene already took place in 2021. Similarly, e-diesel can replace conventional diesel in trucks and stationary power generation applications, offering a drop-in solution that significantly reduces lifecycle CO_2 emissions while leveraging existing fuel distribution networks. Early pilot projects are already demonstrating its potential for heavy-duty transport.

Chemicals: Many everyday products such as plastics, packaging, textiles and pharmaceuticals are based on fossil carbon. CCU technologies enable the use of CO_2 as a raw material, making the chemical industry more sustainable. Products such as cleaning agents, polymers and insulating materials made from CO_2 are already commercially available. However, widespread use requires large amounts of renewable energy and the scaling up of existing technologies.

Building materials: The construction sector is responsible for 25% of global CO_2 emissions. CO_2 can be permanently bound in building materials through mineraliszation by reacting with calcium-containing materials and forming calcium carbonate. This reduces emissions and saves natural resources. Materials such as bricks, paving stones and cement are already produced using this method, which also recycles waste from the steel and construction industries.

These applications (Figure 5) reduce emissions and create economic opportunities by developing CO_2 -based industries. [12]

Figure 5
Overview of CO2 utilization options. [12]



CO_2 storage (CCS): key projects and developments

The amount of recovered CO_2 will rise sharply as capture projects expand. Over 90% will need to be stored in suitable rock formations to prevent the CO2 from being released into the atmosphere.

Europe is leading CCS development to meet its 2050 climate neutrality goal and reduce emissions by 55% by 2030 (vs. 1990). There are currently 191 large-scale CCS projects, with plans to store over 160 million tonnes of CO_2 by 2030, mainly in the North Sea. Important projects include

- The Dutch Porthos project reached its final investment decision (FID) in October 2023, construction began in early 2024, and the infrastructure is expected to be operational by 2026
- The Danish Greensand project, First CO2 March 2023
- The Ravenna hub off Italy, injecting 25,000 tonnes of CO_2 per year since September 2024. scaling to 4 million tonnes of CO_2 per year by 2030

Projects in Croatia, Bulgaria, France and Greece are also under development. At the same time, licensing for CO_2 storage areas is progressing. The UK has issued 21 licenses, Denmark three, while Norway opened two storage areas for applications in March 2024. [13]

To enable large-scale CCS implementation and ensure sufficient storage capacity, new political, legal and regulatory frameworks are being created. European governments and the EU are focusing on three main strategies:

- **Direct policy measures and financial incentives** such as tax benefits and Carbon Contracts for Difference (CCfD)
- **Support programmes** in the form of subsidies and strategic initiatives,
- **Comprehensive legal frameworks** for CO_2 transportation, storage and project approval.

Unlike in North America, where tax incentives dominate, Europe combines financial support with binding political requirements. Important regulatory progress was made in 2024. **The Net-Zero Industry Act (NZIA) sets an EU-wide target of 50 million tonnes of CO_2 storage capacity per year by 2030.** The revised directive contains new requirements for renewable and low-CO_2 hydrogen, particularly from CCS processes. In addition, the EU published its Industrial Carbon Management (ICM) strategy in February 2024 to accelerate the introduction of CCS technologies. **The planned Carbon Removal Certification Framework (CRCF) is intended to strengthen CCS measures in the future.**

A reassessment is also taking place at a national level: Germany is reforming its CO_2 storage law, while Austria considered lifting its ban on geological CO_2 storage in July 2024 to reduce emissions from hard-to-abate industries

Financial protection of CCS projects is also a key focus. More European countries are adopting CCfD to minimise financial risks and costs. A CCfD is a financial mechanism that guarantees a fixed carbon price to support low-carbon projects and reduce investment risk. Germany launched its first CCfD pilot programme in 2024, while France is preparing a similar initiative. The Netherlands continues to promote CCS through the SDE++ programme, which financially supports renewable energy and CO_2-reducing projects - including CCS - by bridging the cost-revenue gap; in the 2024 funding round, €11.5 billion was allocated, of which €1.039 billion supported 23 CCS/CCU projects.

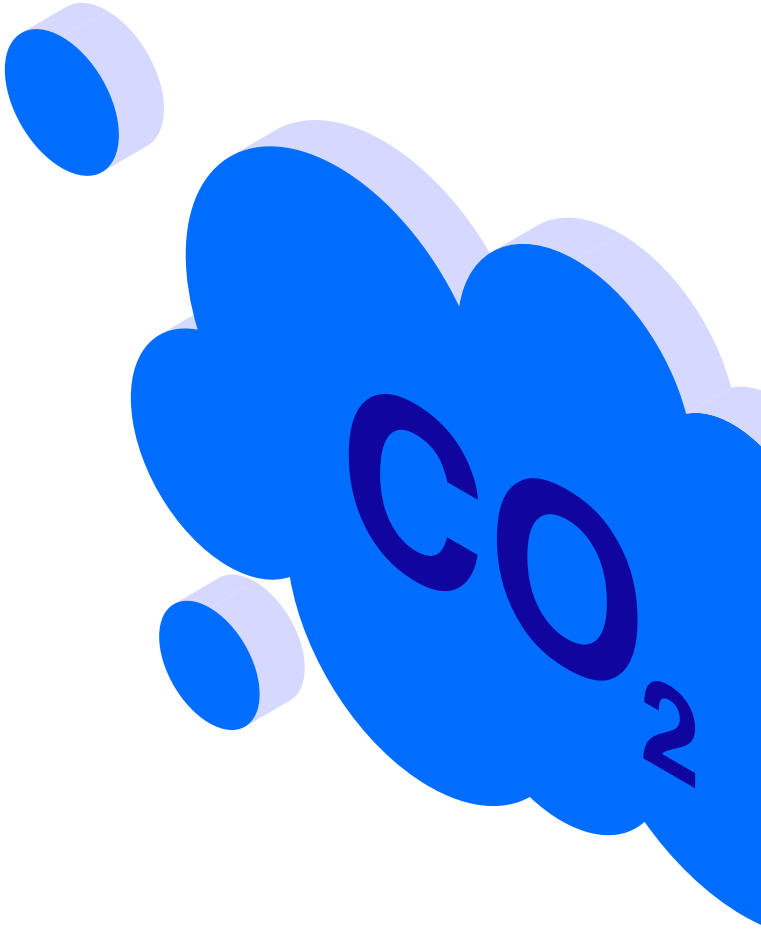
In parallel, more countries are developing their own industrial CCS strategies and roadmaps. The EU and six countries, Austria, Denmark, France, Norway, Switzerland as well as the UK, have already published national strategies, while Germany, Poland and Sweden are due to follow.

Direct financial support remains central to the European CCS expansion. The EU is providing significant funding through the Innovation Fund and the Connecting Europe Facility for Energy, while countries such as the UK further increased their CCS budgets in early 2024.

Interest in bioenergy with carbon capture and storage (BECCS) Is also growing. The UK updated its BECCS business model in 2023 to promote the use of this technology. In April 2024, Denmark awarded contracts to three companies for the storage of biogenic CO_2. The European Commission is actively supporting BECCS, for example by funding the Swedish bioenergy plant project in Värtan „BECCS Stockholm“ to the tune of almost SEK 20 trillion (~ €1.7 trillion).

Another key issue is international cooperation on cross-border CO_2 transport. In 2024, efforts to ratify the 2009 amendment to the London Protocol gained momentum to enable smooth CO_2 transportation and storage across borders. Switzerland ratified the amendment back in November 2023, while Germany and France are planning similar steps. The countries bordering the North Sea are particularly active, concluding bilateral agreements on cross-border CO_2 storage. Cooperation between Norway and countries such as Belgium, Denmark, the Netherlands and Sweden aim to facilitate cross-border transportation even before the final implementation of the protocol. [11]

With these developments, Europe is positioning itself as a leading region for CCS deployment (Figure 6). Clear political framework targeted financial incentives and growing international cooperation will further strengthen CCS as a key technology for the European climate strategy.



Global momentum: United States and beyond

While Europe is advancing through strong political frameworks and cross-border cooperation, momentum is equally visible across the Atlantic. The United States, though following a different policy and market-driven pathway, has emerged as one of the most dynamic regions for CCUS development, with projects advancing across power, industry and storage infrastructure.

In the power sector, Petra Nova in Texas remains the only operating coal-CCUS facility in the country. It restarted in 2023, signalling renewed international interest. If completed, Project Tundra in North Dakota could become the second commercial coal capture project, supported by up to $350 million U.S. from federal infrastructure funding.

Industrial projects are also moving quickly, often with lower costs and simpler transport solutions. Blue Flint Ethanol in North Dakota and Barnett Zero in Texas began operations in late 2023, while Wabash Valley Resources in Indiana received final federal well approvals for its gasification and fertiliser complex.

Pipeline and hub development is another bright spot. Summit Carbon Solutions won approval for the Iowa leg of its system linking 57 ethanol plants to storage in North Dakota, and Tallgrass is converting its 640-km Trailblazer pipeline for CO_2 transport, with injection permits already secured in Wyoming.

Storage capacity is expanding through acquisitions: ExxonMobil's purchase of Denbury added 2,000 km of CO_2 pipelines and 15 storage sites, while TotalEnergies' acquisition of Talos Low Carbon Solutions secured stakes in Gulf Coast storage projects.

More projects in the US are on its way:

- **California Resources Corporation** is developing its Carbon TerraVault hub
- **Louisiana** holds primacy for Class VI permits with dozens of applications pending
- **Wyoming** is advancing large hubs like Frontier's Sweetwater and Tallgrass's Eastern Wyoming projects [11]

Figure 6
Overview of global CO2 storage projects. [13]

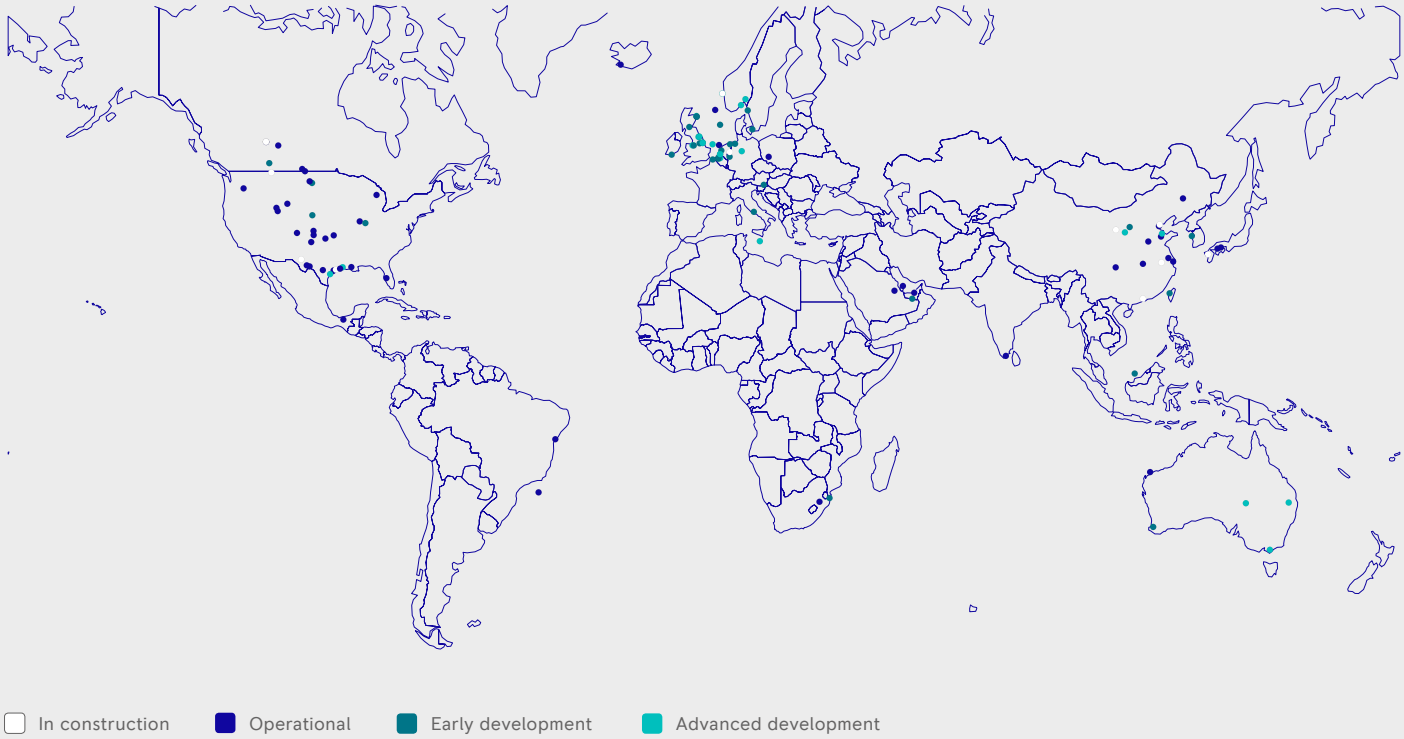


Table 1 highlights key carbon capture and storage hubs worldwide, showcasing their locations, storage capacities, and planned commercial operation dates (COD). Existing hubs like Quest in Alberta, Canada, and Gorgon in Western Australia have been operational since 2015 and 2019, respectively, with annual storage capacities of around 1 to 4 million tonnes of CO_2. Several large-scale projects are set to come online between 2024 and 2030, including Ravenna in Italy and Northern Lights off Norway's west coast, offering multi-million-ton storage capacities. Emerging hubs such as Kasawari in Malaysia and Project Greensand off Denmark's coast will expand CCS capacity further. Ambitious projects in the Middle East and Europe, like Jubail Industrial City in Saudi Arabia and the East Coast Cluster and HyNet in England, promise to store between 4.5 and 44 million tonnes of CO_2 annually, reflecting growing global efforts to scale CCS infrastructure as a critical component of climate mitigation.

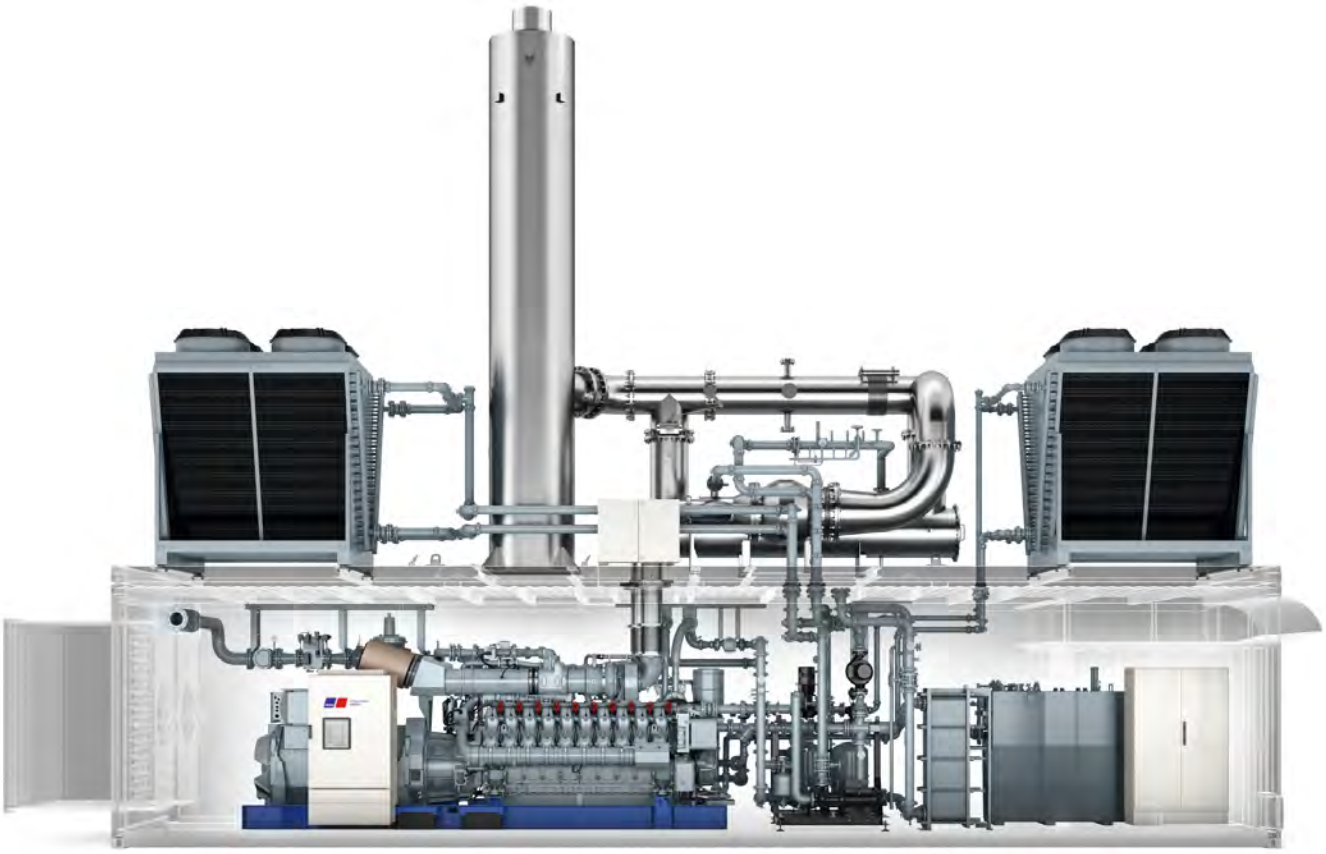


Table 1
Selected overview of CCS Hubs

Name of CCS Hub	Location	Storage Capacity	COD
Quest	Scotford, Alberta, Canada	**~1 Mt** CO_2 p.a.	2015
Gorgon	Barrow Island, Western Australia, Australia	**up to 4 Mt** CO_2 p.a.	2019
Alberta Carbon Trunk Line (ACTL)	Alberta, Canada	**up to 1.8 Mt** CO_2 p.a.	2020
Ravenna	Ravenna, Italy	**4–16 Mt** CO_2 p.a.	2024–2030
Northern Lights	West coast of Norway	**1.5–5 Mt** CO_2 p.a.	2024 *(Phase 1)*, 2028 *(Phase 2)*
Kasawari	Offshore Sarawak, Malaysia	**~3.3 Mt** CO_2 p.a.	2026
Project Greensand	Offshore west of Denmark	**0.4–8 Mt** CO_2 p.a.	2026 *(Phase 1)*, 2030+ *(Phase 2)*
Jubail Industrial City	Jubail, Saudi Arabia	**9–44 Mt** CO_2 p.a.	2027 *(Phase 1)*
Porthos	Port of Rotterdam, Netherlands	**2–5 Mt** CO_2 p.a.	2027
East Coast Cluster (Track 1)	NE England	**up to 27 Mt** CO_2 p.a.	2027
HyNet (Track 1)	NW England & North Wales	**4.5–10 Mt** CO_2 p.a.	2027

CCUS in the engine industry: growth forecasts and opportunities for power generation

CCUS is becoming increasingly important as a key technology for a low-emission energy future. While turbine solutions have dominated the CCUS power generation sector to date - especially for large-scale projects of 800 MW or more, promising opportunities are emerging in the engine power plant segment.

According to our forecasts, the annual installed capacity in this segment, which remains in the double-digit MW range in 2025, is expected to rise to several hundred MW per year by 2030.This could lead to an overall installed capacity in the low GW range.

Why engine-based solutions?

Engine solutions, especially high-speed variants, offer decisive advantages here. Standardised and compact CCUS products, such as those developed by suppliers like ASCO, enable faster operational readiness and are less complex than customised large-scale systems. In addition, synergies with on-road carbon capture systems allow these technologies to be adapted to smaller power generation systems. As industrialisation progresses, engine solutions are likely to become even more efficient, compact and user-friendly - a clear advantage for small to medium-sized plants that want to focus on CO_2 reduction in a flexible and cost-efficient manner. **A study by Independent Project Analysis (IPA) also estimates the costs of a typical CCUS project at around $500 million U.S. per 1 million tonnes of CO_2/year, which underlines the ecological challenges of large-scale CCUS solutions and puts additional emphasis on the economic efficiency of engine solutions. [14]**

The integration of CCUS in gas-fired power plants offers an effective way to significantly reduce CO_2 emissions while ensuring security of supply. Gas-fired power plants play a central role in the energy supply, as they are flexible and controllable, independent of geographical conditions, and can cope with fluctuations in the feed-in of renewable energies. **Gas-fired power plants come into play to ensure grid stability, especially during prolonged dark doldrums when wind and solar energy are not sufficiently available.** [15] In the current discussion about decarbonization, governments are focusing on green hydrogen; however, the widespread availability and affordability of green hydrogen is not yet feasible, which extends the timeline for a complete transition.

Biomethane is an already available but limited option, as the share in the overall gas grid is currently only in the low single digits for many countries. On top of that, there is not enough capacity to meet all gas-fired power plant demand. This is where CCUS comes into play. This technology makes it possible to separate CO_2 from the exhaust gases of gas-fired power plants and store it or use it for industrial applications. **Compared to other solutions, CCUS is already commercially available today and offers a direct option for CO_2 reduction.** In addition, CO_2 can be used as a commodity for industry, for beverage carbonation, the production of synthetic fuels or as a raw material in the chemical industry. Despite the initial investment costs, CCUS systems offer economic incentives, as they not only reduce emissions but also open up new sources of income.

CCUS and hydrogen: complementary technologies for reliable energy supply and industry

In the debate on decarbonising energy production, hydrogen is frequently portrayed as a competing technology to CCUS. A common concern is that a large-scale shift to hydrogen in the 2030s could undermine the business case for CCUS, potentially delaying investment and deployment. However, this view overlooks the distinct roles and complementary strengths of both technologies.

Hydrogen is increasingly recognised as a flexible solution for short-term demand spikes, particularly in so-called „peaker" power plants, which typically operate fewer than 2,000 hours per year and potentially even less in future energy systems.

While CCUS could theoretically be applied to peaker plants, the approach is still under development and not yet widely commercialised for such flexible use cases. **In contrast, CCUS is particularly well-suited for base load power plants, which operate more than 4,000 full-load hours per year and play a critical role in ensuring grid stability.** In these settings, CCUS significantly enhances both the climate performance and the economic viability of fossil-based generation by enabling low-carbon operations and aligning with emissions regulations and carbon pricing mechanisms. [16]

Rather than being competing solutions, hydrogen and CCUS address different needs within the energy and industrial sectors. Hydrogen is ideal for flexible power generation and certain industrial applications, while CCUS is essential for decarbonising high-load, continuous operations in both power generation and heavy industry. **They serve complementary roles and both are essential to achieve net-zero. [17]**

The economics of power generation with CCUS

Key Success Factors for Gas Engine Solutions with CCUS
Gas engine solutions combined with CCUS offer a pathway to low-carbon, dispatchable power. While deploying these systems presents unique considerations, each can be lever-aged as a success factor to unlock economic and operational viability:

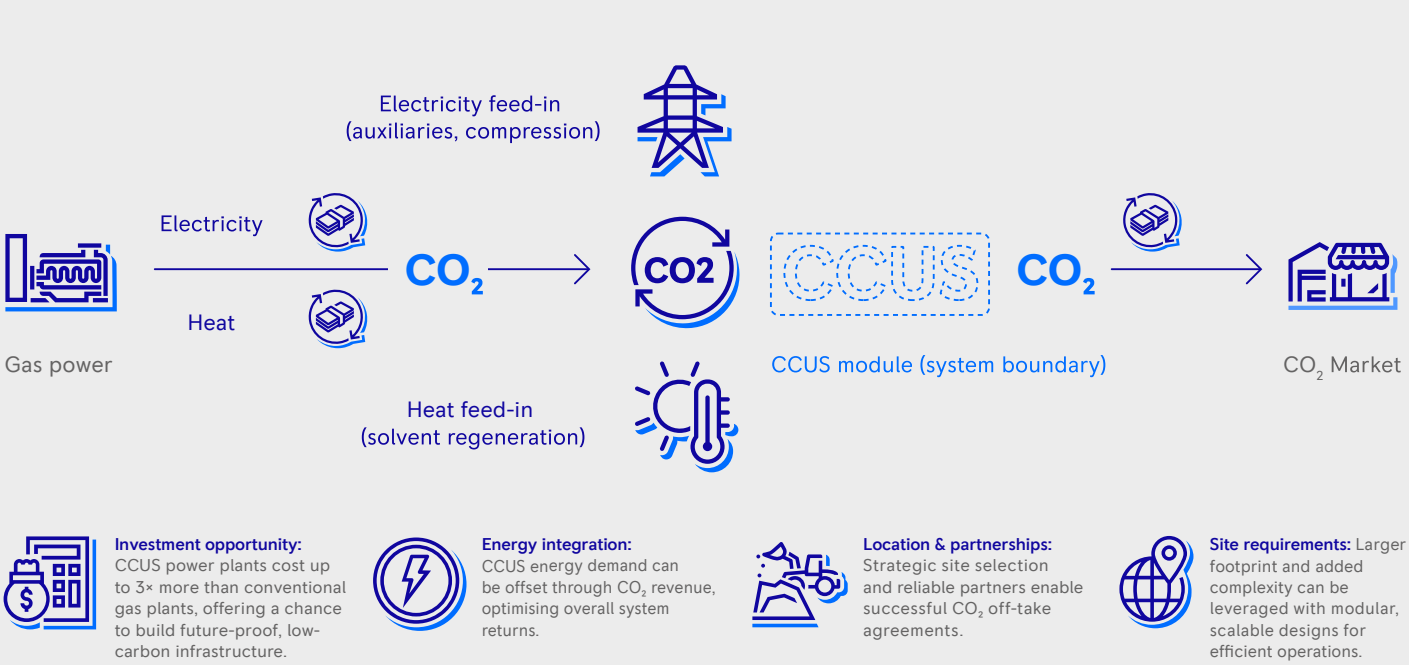
- **Capital Investment as a Growth Lever:** Small-scale carbon capture power plants require higher upfront investment—up to three times that of conventional gas engine systems (Figure 7). This investment builds state-of-the-art, future-proof infrastructure and positions companies as leaders in low-carbon energy.
- **Optimising Operating Costs through Revenue Mechanisms:** Higher energy consumption and additional maintenance needs can be offset by establishing stable, long-term CO_2 revenue streams. Mechanisms such as off-take agreements and participation in carbon credit markets help improve investment security and economic sustainability, even amid regulatory and technological uncertainties.
- **Strategic Space Management:** CCUS systems may require more physical space than conventional gas engines, but careful planning, modular design, and decentralised layouts allow efficient use of available areas, turning spatial requirements into a competitive advantage.

When these key success factors are achieved, gas engine solutions with CCUS create significant economic opportunities:

- **First-Mover Advantage:** Early adopters can secure market leadership and strengthen sustainability credentials.
- **Revenue Diversification:** Captured CO_2 opens new revenue streams and helps organisations prepare for tightening emissions regulations.
- **Regulatory Compliance**: CCUS enables companies to mitigate rising carbon costs under schemes such as the EU Emissions Trading System (EU ETS).
- **Strategic Partnerships:** Collaborating with experienced technology providers and industrial gas companies reduces risk and accelerates deployment.

By framing challenges as opportunities, gas engine solutions with CCUS emerge as scalable, economically viable, and future-proof pathways for low-carbon power generation, with strategic partnerships and modular, scalable designs key to reducing costs and ensuring long-term viability.

Figure 7
Key success factors for CCUS gas-fired power plants from the operator‘s perspective.



Customer perspective: economic drivers and market outlook

From the customer's perspective, the additional costs, particularly the increased energy demand, which reduces revenues from electricity and heat generation, must be offset by stable and predictable CO_2 revenues. Location-specific factors, such as the availability of existing infrastructure, play a decisive role, as transport and logistics costs significantly affect overall profitability.

Even after an investment decision, a key question remains: What happens to the captured CO_2?

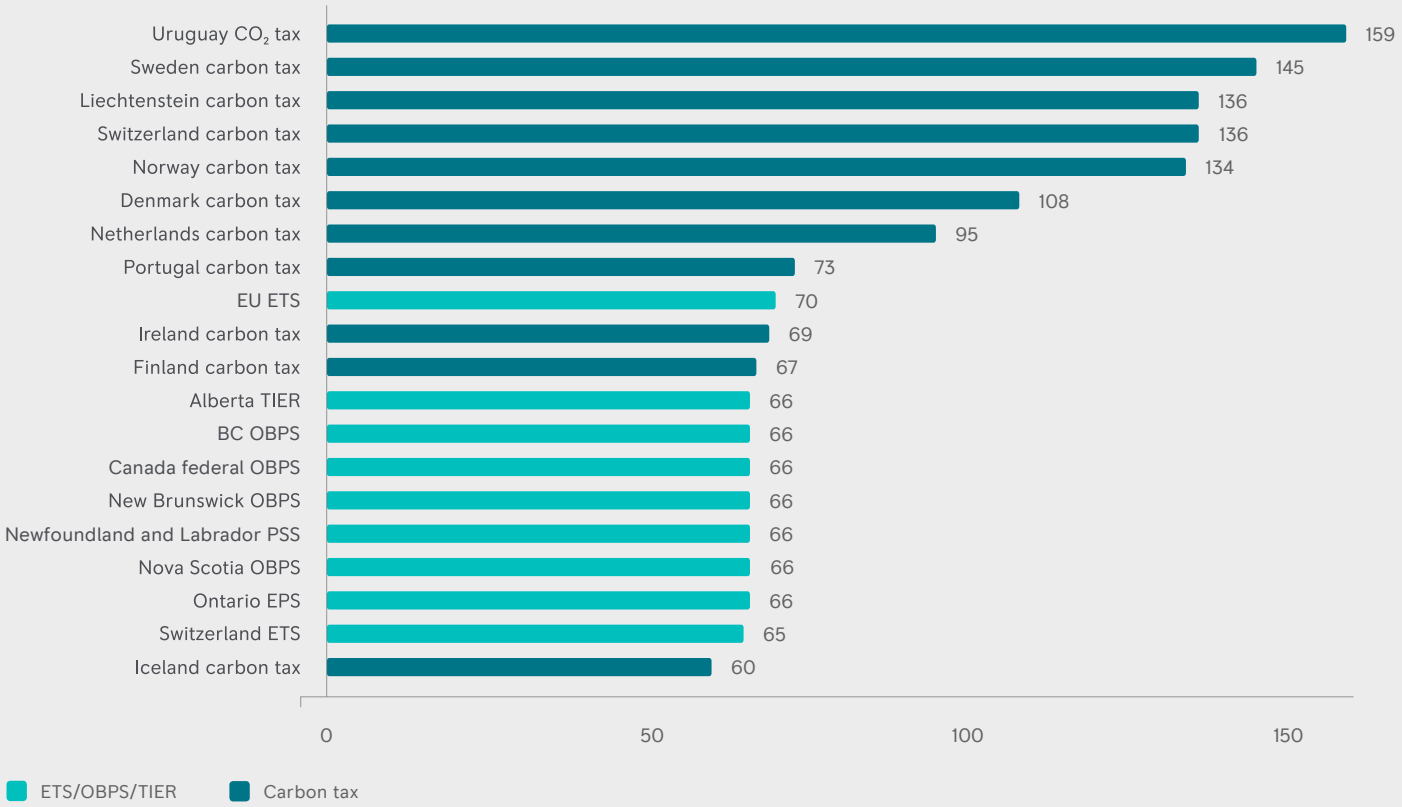
The economic viability of CCUS in gas engine systems depends on a well-balanced interplay between capital and operating costs, the regulatory and technological framework, and the ability to secure reliable long-term revenue streams.

A diversified approach underpins the most promising CCUS business models, as confirmed by current studies and market data. Major revenue streams include:

- **Sale of purified CO_2** to sectors with strong demand, such as the chemical, food, and beverage industries.
- **Avoidance of carbon costs,** including CO_2 taxes or the purchase of emissions certificates under schemes like the EU ETS.
- **Participation in carbon credit markets** to monetise emission reductions.

Figure 8 illustrates CO_2 prices across various markets. The continued rise in carbon prices, which are expected to persist, further reinforces the economic rationale for CCUS adoption. Operators that integrate CCUS into gas engine systems can not only reduce regulatory compliance costs but also benefit from direct savings, helping to offset the high initial investments and improve the long-term financial outlook. [18], [19]

Figure 8
Prices and coverage across ETSs and carbon taxes, as of April 1, 2025 [19]



In addition, the use of existing sequestration infrastructures offers an attractive business model. In regions such as the North Sea and parts of the Netherlands, there are geological storage facilities that have been successfully tested in current pilot projects (e.g., from the European CCS Demonstration Project Network). Long-term offtake agreements based on this infrastructure can ensure stable revenue streams and support the economic viability of CCUS plants in gas engine systems. [20]

Government subsidies and incentive systems are also of central importance. While countries such as Norway, USA, Canada, and Australia already have targeted funding programmes for CCUS, in Central Europe the funding landscape is more limited and less mature. Although European instruments such as the European Innovation Fund provide a basis, dedicated national programmes specifically addressing the challenges of CCUS in gas engine systems are still underdeveloped or lacking. **A targeted focus on pilot projects and demonstration projects could pave the way to scaling and underline technological maturity.** [20], [21]

Market-based mechanisms are also being discussed, such as capacity payments or subsidies for low-emission electricity from CCUS systems. In the UK, for example, the extent to which operators can receive higher remuneration for the use of CCUS in power plants is being examined, a concept that should also be considered in Central Europe.

Overall, the business model for CCUS in gas engine systems is based on several pillars:

- the sale of CO_2 as an industrial raw material
- ETS or carbon tax savings
- use of existing sequestration infrastructures
- targeted government subsidies and market-based incentives

A combination of these approaches, supported by current scientific data and pilot projects, forms the basis for viable business models that can contribute to the decarbonisation of energy generation in Central Europe in the mid- and long term.

Table 2 summarises once again all essential and potential business models for CCUS.

Table 2
Summary of potential business models for CCUS

Case	Market indication	CCUS business model	Requirements	Market example	Exemplary customer profile
1	High CO_2 trading prices, e.g. in the food and beverage industry	**Sale of liquid CO_2 in pure form as a commodity**	High CO_2 yield, purification and liquefaction necessary; proximity to the CO_2 customer important	UK, USA, Germany, Switzerland, Netherlands, Japan	Gas-fired power plant near Atlanta
2	High CO_2 taxes or high CO_2 ETS prices	**Avoid/reduce CO_2 tax or ETS**	ETS or CO_2 tax obligation; high CO_2 price; buyer for CO_2 or sequestration infrastructure available	EU, Switzerland	Cement factory in Germany
3	Remuneration mechanisms and infrastructure for CO_2 sequestration available	**Use of revenue from sequestration**	Infrastructure and supply chain required for CO_2 sequestration	USA [22], Nor- because [23]	Gas-fired power plant with access to carbon capture infrastructure in Illinois
4	Government funding available for **CCUS**	**Funding for CCUS installation thanks to state subsidies**	Government funding/ subsidies available; infrastructure required	Norway [23], Great Britain (planned) [24], Australia [25], Canada [26]	Cement factory in Canada
5	Financial incentives for energy generated using **CCUS** technology	**Higher energy revenues on the energy markets through CCUS use**	Government support mechanisms available; infrastructure required	Great Britain (planned) [24]	Gas-fired power plant in UK

From theory to practice: pioneering CO_2 capture with **FLEXPOWER** PLUS®

The long-term success of CCUS in gas engine systems depends on innovative business models and their practical implementation. The Worksop pilot project in the UK demonstrates that CO_2 capture is more than a theoretical concept (Figure 9).

Developed by Landmark Power Holdings (LMPH) in collaboration with Victory Hill, Rolls-Royce Power Systems with its brand mtu, and ASCO Carbon Dioxide, the plant is the first real-world application of the FLEXPOWER PLUS® **concept.** It combines modular power generation with integrated carbon capture, delivering 10 MW of clean, flexible dependable electricity and supporting the energy transition.

Figure 9
On the top: Worksop pilot plant (as of October 2025), representing the prototype **FLEXPOWER** PLUS® configuration.

On the bottom: Conceptual, further-developed **FLEXPOWER** PLUS® layout of a highly modular, flexible, and scalable 5 MW solution.

Key features of the Worksop plant:

- **efficient, flexible and dependable power generation** Modular design improves efficiency and grid priority. Proven technologies from Rolls-Royce (***mtu*** gas gensets), Turboden Mitsubishi (high-temperature ORC turbine) and Climeon (low-temperature ORC turbine ensure high overall electrical efficiency and grid stability.
- **Carbon Capture Utilisation (CCU):** ASCO's CCU modules capture CO_2 and convert it into food-grade quality, turning emissions into a revenue stream while reducing environmental impact.

One of the biggest challenges in CO_2 capture is cost. Worksop addresses this through a circular economy approach, selling captured CO_2 under a long-term offtake agreement with Buse Gase Ltd, guaranteeing stable income and demonstrating a scalable business model.

By integrating CCU with flexible power generation, the plant delivers low-carbon, adaptable electricity and supports grid stability, critical for managing intermittent renewables. Long-term purchase agreements for CO_2 and electricity further strengthen its economics. **The FLEXPOWER** PLUS® **solution is transferable to other regions and industries, offering a replicable and scalable model for decarbonising sectors that are hard to electrify.**

Looking ahead, Landmark Power Holdings, in collaboration with Rolls-Royce mtu and ASCO, is progressing a modular, containerised solution based on **FLEXPOWER** PLUS® technology. This next-generation system is conceived as a standardised, rapidly deployable plant that provides clean and cost-effective power generation. Its modular design facilitates swift market entry and adaptation to varied site conditions and production requirements.

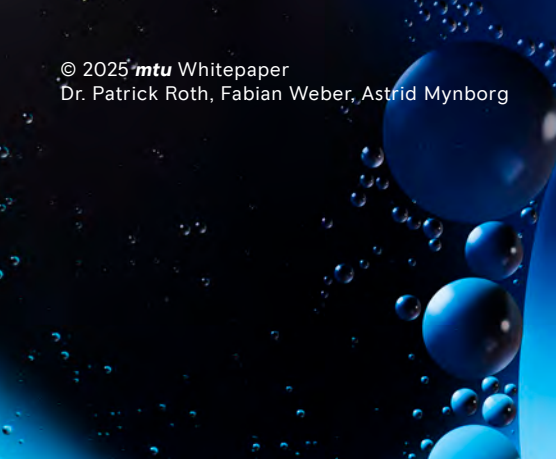
Furthermore, the containerised version presents potential as a "behind-the-meter" solution, enabling industries such as data centres, food and beverage manufacturers, and large-scale production facilities to generate low-carbon electricity on site. This reduces dependence on the national grid and lowers operational costs. This ongoing development aligns with the focus on scalable, flexible CO_2 capture solutions and underscores the vital role of CCU technologies in driving the energy transition.

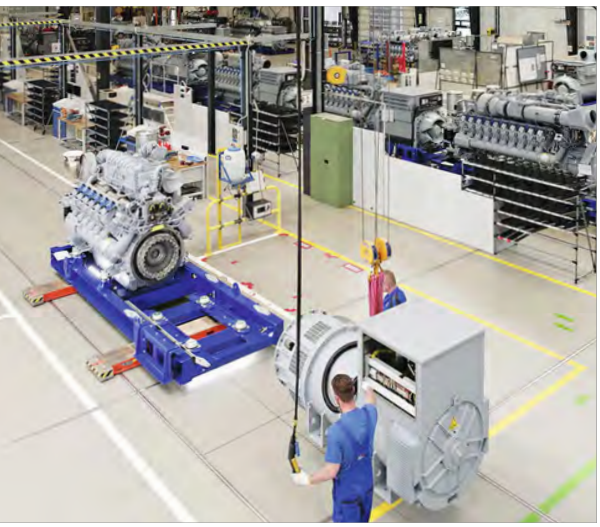
Setting the strategic course for CCUS

Establishing a strategic trajectory for CCUS is essential to build on existing momentum, particularly in the UK, where schemes like the Net Zero Innovation Portfolio and Cluster Sequencing Model have proven economic viability for CCUS projects, and recent government investments in clusters like HyNet and the East Coast cluster further confirm commitment. [27] However, this progress is only the beginning. **Continued advancement requires sustained policy support, technological innovation, and cooperation among industry, research institutions, and governmen**t.

Public awareness has surged across Europe, especially in Germany, with prominent advocates such as BDI, DGB, NABU, and WWF supporting CCUS as a critical climate solution. [17] This is reflected in Germany's May 2024 national CCUS strategy targeting unavoidable CO_2 emissions [28] and parliamentary discussions in September 2024 on amending the Carbon Dioxide Storage Act (KSpG) to enhance regulatory clarity [29], despite these advances, further action is needed to fully embed CCUS within national energy strategies.

At the EU level, mechanisms such as the Green Deal and Innovation Fund finance large-scale decarbonization projects [30], yet bespoke support for CCUS in gas engine systems is still missing. [31] Filling this gap will require dedicated grants, tax breaks, and infrastructure incentives. In the UK, funding is expanding: the Net Zero Innovation Portfolio was updated in April 2024 to support CO_2 transport and storage infrastructure [32], and the government plans four fully operational CCUS clusters by 2030, bolstered by recent spending review commitments. **[33] In the US, the Inflation Reduction Act (2022) revamped the 45Q tax credit to provide up to $85 per ton for permanently stored CO_2 [34], though its value is being debated in 2025 for adjustments amid inflation pressures.** [35] Additionally, the US Department of Energy's Title 17 Clean Energy Financing Program continues to offer loan guarantees for CCUS infrastructure under new interim funding rules established in 2023. [35] Ultimately, CCUS can meet global mitigation goals only if regulatory certainty, innovation, industrial participation, and social acceptance move forward together.





Closing statement: CCUS offers a great opportunity for gas-fired engine power plants

Carbon capture is a critical technology for industries seeking to reduce emissions while maintaining energy security. As renewable energy continues to grow, gas-powered solutions with integrated carbon capture offer a practical and low-emission bridge, particularly for operations that require stable and dispatchable power. With the emergence of modular and decentralised systems, carbon capture is now viable not only for large-scale utilities but also for industrial sites requiring localised, low-carbon power.

For companies facing rising carbon costs and tightening regulatory standards, carbon capture ensures long-term compliance and unlocks new economic opportunities. **Captured CO_2 can be monetised in various sectors such as food and beverage, chemicals, or construction materials, creating additional value beyond electricity or heat generation.** When paired with engine-based gas power generation applications, carbon capture enhances overall efficiency and makes business models more resilient. Rolls-Royce has already demonstrated this potential in practice.

The Worksop project, a 10 MW gas engine power plant with integrated carbon capture located in Nottinghamshire, UK, was developed in collaboration with ASCO CO_2 and Landmark Power Holdings. It delivers low-carbon, flexible power to the grid and stands as a replicable model for industries with high energy demands and decarbonisation goals. **For industrial companies requiring dependable, low-emission power with a clear path to regulatory and economic sustainability, carbon capture represents a scalable, future-proof solution.**

About our partners

About Landmark Power Holdings: LMPH, a developer of high efficiency decarbonized combined heat and power (CHP) projects, brings its patented **FLEXPOWER** PLUS® concept and will be leveraging both its technical expertise and patented technologies, showcased in its Worksop project in Nottinhamshire, UK.

Visit the website of Landmark Power to learn more about the **FLEXPOWER** PLUS® concept:

Solutions - Landmark Power Holdings

About ASCO Carbon Dioxide: ASCO has over 50 years of experience in developing and building carbon capture plants and will be providing valuable insights and solutions from the carbon capture industry. ASCO enhances scalability and efficiency through automation and modular designs.

Visit the website of ASCO to discover the carbon capture technology:

ASCO CO2 Stack Gas Recovery Plant (SGR)

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A Rolls-Royce solution

Get in touch with us to discover how our CCUS gas power plant solutions can benefit your business.

Carbon-Capture@ps.rolls-royce.com

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