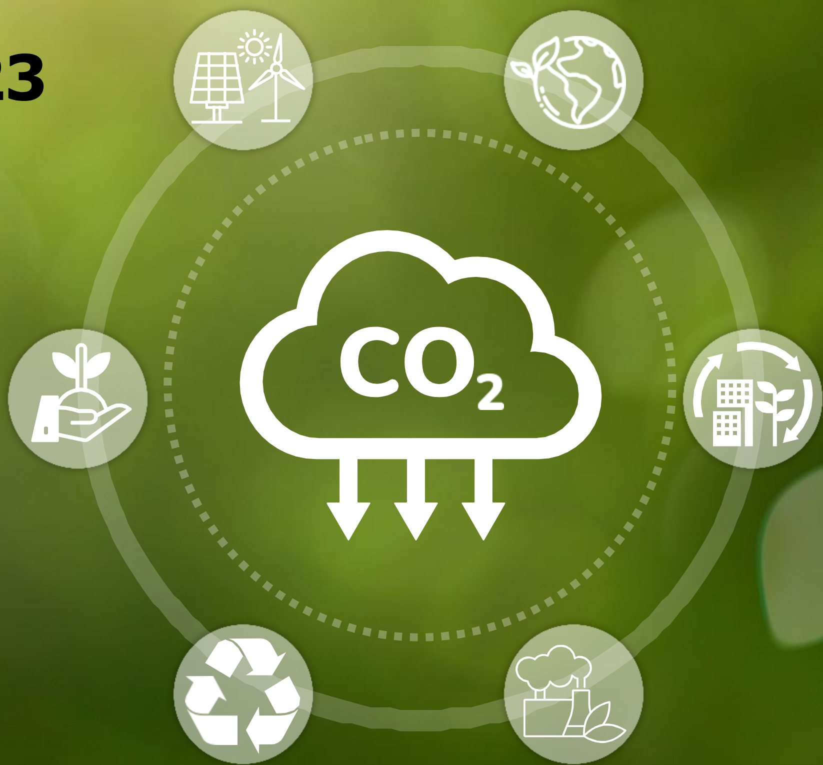
GAS FOR CLIMATE
A path to 2050

Guidehouse

Best practices of CCUS infrastructure in Europe

September 2023



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Glossary

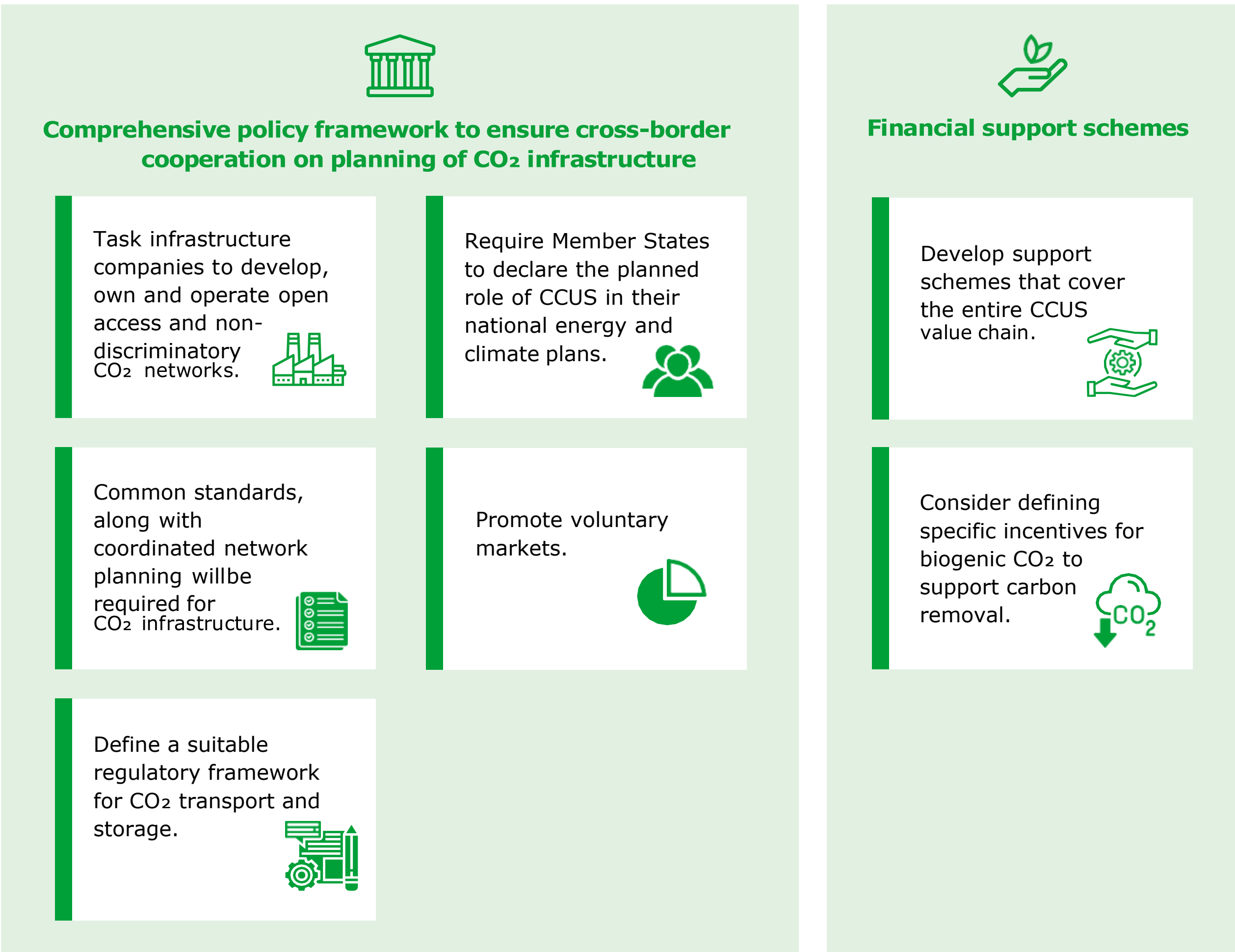
BECCS	Bioenergy with Carbon Capture and Storage
CCfD	Carbon Contracts for Difference
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization, and Storage
CEF-E	Connecting Europe Facility - Energy
DACCS	Direct Air Carbon Capture and Storage
EC	European Commission
EU ETS	European Union Emissions Trading System
GHG	Greenhouse Gases
IPCEI	Important Projects of Common European Interest
NZIA	Net-Zero Industry Act
PCI	Projects of Common Interest
TPA	Third-Party Access
TSO	Transmission System Operator

Executive Summary

The globally agreed target of limiting the average temperature rise below 1.5°C set out in the Paris Agreement requires swift and bold action, using all available options. Among the identified options, Carbon Capture, Utilization, and Storage (CCUS) technologies are experiencing a new political momentum and are an indispensable tool (and in some cases the only tool, specifically in hard-to-abate sectors) in reaching the EU goal of climate neutrality by 2050. CCUS will play a pivotal role in achieving net-zero emissions by 2050 as highlighted in reports from the IPCC, the IEA, and the European Commission. Moreover, the EU has clearly outlined paths to climate neutrality which include large-scale industrial CCUS, thereby underlining the importance of facilitating a rapid and efficient scale-up of the CCUS value chain.

Currently, however, there are several policy gaps inhibiting CCUS deployment including legislative uncertainty and missing funding options across the CCUS value chain. To mitigate these uncertainties, the European Commission should urgently propose

Figure 1. CCUS policy recommendations (Source: Guidehouse)



a regulatory framework for CCUS that reflects its increased importance. Flexibility in this regulatory framework will be needed to accommodate Member State (MS) particularities on CCUS development, while key regulatory principles for a mature CO2 market should be defined upfront to create certainty for investors and prevent expensive ex-post regulatory interventions. Further, available sources of funding currently cover only a small portion of project types or value chain components, and these are typically very early stage or pilot projects. A wider range of funding instruments available to a broader group of projects would significantly de-risk project development across the value chain. Successful deployment of large-scale CCUS projects will necessitate a proper risk and liability allocation between the different market players in the value chain and more guidance is required from the EU and Member States to define this. With regards to CO2 transport, gas infrastructure companies can play an important role, as they are best placed to develop open access and non-discriminatory transport infrastructure. Their existing capabilities and experience to build and operate natural gas infrastructure can be leveraged to develop CO2 infrastructure, which is also associated with natural monopoly characteristics. A CO2 transport network owned and operated by Transmission System Operators (TSOs) prevents inefficiencies with a holistic view of the overall CCUS market, avoiding lock-ins due to decision-making based on individual business interests.

This paper assesses best practices associated with CCUS deployment while providing a holistic overview of the current policy and regulatory landscape related to CCUS across Europe. As a result of this analysis recommendations are derived to support CCUS deployment to meet short- and long-term climate targets (see Figure 1).

1. The need for CCUS

Carbon capture, utilization, and storage (CCUS) technologies are increasingly coming to the mainstream of climate mitigation solutions. CCUS will be one of the principal pillars to achieving significant emission reductions by 2030. Along with renewables and reductions in energy intensity, CCUS will play a pivotal role in achieving net-zero emissions by 2050, as highlighted in reports from the IPCC, the IEA, and the European Commission. For some sectors, CCUS represents oneof the main available tools to support the decarbonisation of industry in the short-term, as current installations are connected to highly integrated industrial complexes that may have economic lifetimes exceeding 50 years. The most recent IPCC report[1] indicates that CCUS will be required before 2030 to meet the Paris climate goals in 2050 and is one of the few mature technologies to reduce CO_2 emissions on an industrial scale. In addition, the models used by the IPCC outline that CCUS will not only be a short-term solution and will need to remain to be deployed well beyond 2050. The IPCC's 1.5°C scenarios estimate that an average of 15 Gt of CO2 per year needs to be captured and stored by 2050, while the IEA's 'Net zero by 2050' scenario includes 7.1 Gt of CO2 stored yearly by 2050. The European Commission's 1.5°C scenarios indicate that between 280 and 600 million tonnes (Mt) of annual CO2 capture will be required withinthe EU by 2050.[2] Nonetheless, currently global rates of CCUS deployment are far below those in modelled pathways limiting global warming to 1.5°C to 2°C.

Enabling conditions such as policy instruments, greater public support and technological innovation are needed. **Some sectors with hard-to-abate emissions will not achieve net-zero emissions without CCUS**. Certain industries, e.g., cement, lime, steel, or glass production, emit CO_2 not related to the combustion of fossil energy. CCUS is the key solution to mitigate process related emission from these industries allowing them to continue operating in the EU. Deploying CCUS also provides the added benefit of enabling the scale-up of adjacent technologies. This includes the ramp-up of the hydrogen economy by contributing towards the production of sizeable volumes of blue hydrogen and enabling the circular economy of carbon through recycling of industrial process and biogenic CO_2 into carbon neutral materials or the production of synthetic fuels (e.g., sustainable aviation fuels).

Reducing emissions is likely not enough to achieve net-zero. The deployment of carbon dioxide removal (CDR) technologies is therefore urgently needed to meet long-term climate targets. The IPCC and IEA foresee a high probability of needing negative emissions in the long-term. Achieving and sustaining net negative emissions post-2050 can reduce the net effect of historic emissions and a potential global temperature overshoot compared to agreed climate goals. The need for negative emissions highlights, on the one hand, the need for additional deployment of CDR solutions (e.g., bioenergy capture

1 IPPC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. [Link]

2 CCUS Forum (2022). A Vision for Carbon Capture, Utilization and Storage in the EU. [Link]

and storage (BECCS), direct air capture and storage (DACCS), biochar[3], mineralisation[4], and enhanced weathering[5]), compared to pathways without overshoot. The principle of recycling carbon highlights the benefits of emissions captured and/or used from biomass-based processes. Emissions from biogas or biomethane combustion are those that have been compensated for upstream through the photosynthesis process and therefore, theydo not increase the overall amount of CO_2 but rather circulate it in short carbon cycles.

CCUS is part of the EU policy pipeline in 2023. CCUS plays a key role in the next phaseof the Green Deal implementation. The Fit for 55 package impact assessment highlights the need to test and deploy CCUS this decade, while the recently published Net Zero Industry Act proposal stresses the demand for additional CO_2 storage sites. In terms of support for CCUS, the European Commission opened a call for CCUS under the EU Innovation Fund, an expansion of the eligibility for Projects of Common Interest (PCI) applications to receive Connecting Europe Facility – Energy (CEF-E) support, and the creation of a CCUS forum. However, there is a need for coordinated action across the continent to fill existing regulatory and funding gaps that hinder the development of transport and storage infrastructure for CCUS.

3 Biochar is a carbon-rich solid product produced from the pyrolysis of biomass residues that permanently binds carbon, thereby creating negative emissions [Link]

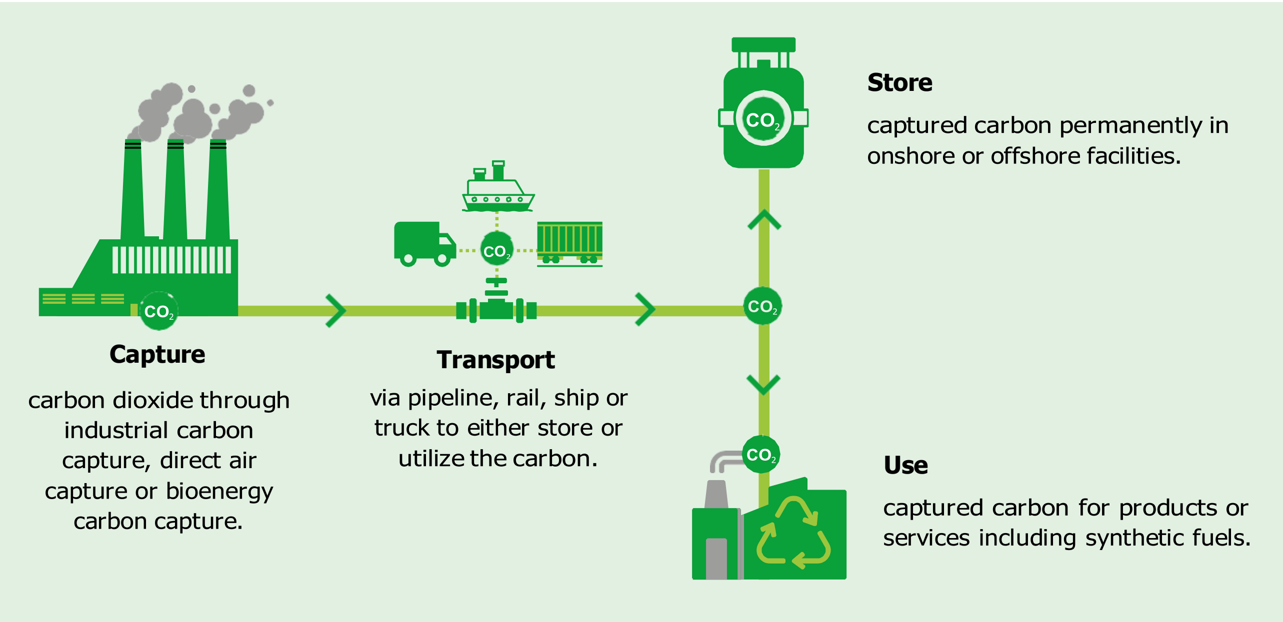
4 Carbon mineralisation is the process by which carbon dioxide becomes a solid mineral [Link]

5 Enhanced weather involves storing carbon in the ocean through a chemical reaction that remove CO_2 from the atmosphere [Link]

2. CO_2 infrastructure as an enabler of CCUS

CCUS is a collection of technologies that facilitate the capture of CO_2 emissions from industrial or power generation sources, or the removal of CO_2 directly from the atmosphere. Once the CO_2 has been captured it is often compressed into a dense state to take up less volume and subsequently transported (e.g., via rail, ship, pipeline, and/or trucks). It then can be stored underground in deep geological formations, or it can be used as a feedstock in commercial products and processes (see Figure 2).

Figure 2. CCUS supply chain roadmap (Source: Guidehouse)



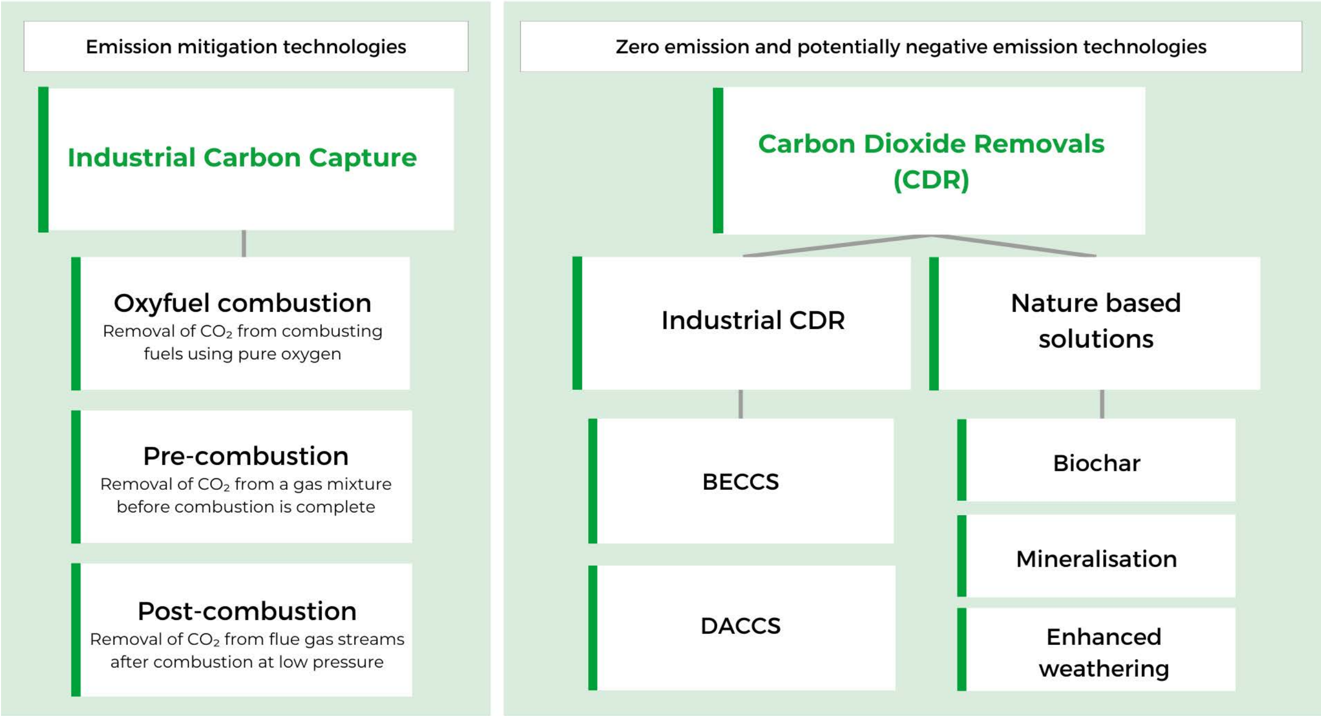
2.1. Carbon capture, storage, use, and removal options

Carbon capture applications can be grouped into emission mitigation and zero or negative emission technologies. Emission mitigation technologies can reduce, but not fully avoid, emissions from industrial processes or power generation. The main methods by which CO_2 is captured are post-combustion, pre-combustion, and oxyfuel combustion.[6] Each of these methods either use chemical absorption or physical separation to capture CO_2 with the most appropriate capture method being dependent on the use case. Zero or negative emission technologies such as BECCS and DACCS do not add CO_2 to the atmosphere while the latter even remove it.

The main carbon capture and carbon removal technologies are displayed in Figure 3 below.

6 London School of Economics and Political Science: Grantham Research Institute on Climate Change and the Environment. March 2023. "What is carbon capture, usage and storage (CCUS) and what role can it play in tackling climate change?" [Link]

Figure 3. Industrial Carbon Capture and CDR technologies (Source: Guidehouse)



CO_2 storage facilities are an essential component of CCUS infrastructure, and it is estimated that there is nearly 500 Gt of theoretical capacity for CO_2 storage in Europe.[7] There is approximately 116 Gt of onshore storage capacity and the offshore storage capacity is approximately 244 Gt.[8] However, the current availability of storage sites is very limited and varies widely across Europe. Storage capacity is concentrated in certain countries while others have relatively limited onshore and/or offshore potential.

Utilizing the carbon that is captured not only reduces overall emissions, but it also presents a significant opportunity for recycling CO_2. There are several use cases that are dependent upon increasingly large volumes of CO_2 being available as a feedstock. The projected demand from use cases in sectors such as food & beverages, greenhouses, chemicals, and fuels is expected to increase in the coming years. The chemicals and fuels sectors are forecasted to have especially large demand for CO_2 with increasing production of synthetic fuels. Table 1 below projects the upper limit of future CO_2 demand in Europe across the chemical and fuel sectors.

If the captured CO_2 is of biogenic origin, the CO_2 has been compensated for upstream through the photosynthesis process and therefore does not increase the overall amount of CO_2 when utilized. An exemplary use case is biomethanation. This is the process of upgrading biogas to obtain biomethane which is of a standard that can be injected into the natural gas network. Additional biogenic CO_2

7 ENTEC (2023). EU regulation for the development of the market for CO_2 transport and storage. [Link]

8 Clean Air Task Force (2021). EU Geological CO_2 storage summary. [Link]

captured from the biomethanation process can further serve as a feedstock to also produce synthetic methane to meet future natural gas demand by recycling CO_2 through the short carbon cycle.

Table 1. Forecasted demand of CO_2 as a feedstock for chemicals and fuels in Europe (Source: DECHEMA and CEFIC)[9]

Product	2025	2030	2035	2040	2045	2050
Methanol	190.1	33.5	43.3	52.0	59.1	70.1
Urea	0.2	0.7	2.0	3.9	5.9	8.0
Ethylene / Propylene	3.9	12.3	25.3	53.6	91.4	131.1
Benzene, Toluene, Xylene	3.4	11.2	23.5	45.6	87.6	149.7
Synthetic diesel	47.1	79.4	102.9	136.9	181.1	219.5
Synthetic kerosene	14.3	24.9	31.8	44.7	66.9	94.4

2.2. Options to transport CO_2

Safely and reliably transporting CO_2 is imperative in the deployment of CCUS. Options to transport CO_2 include pipeline, rail, shipping and by truck. The viability of each option is dependent on several factors including, the volume of CO_2 to be transported, cost, and distance. Table 2 presents a high-level assessment of CO_2 transport options.

Table 2. CO_2 transport options (Source: Guidehouse)

Transport Option	Benefits	Drawbacks	Use cases
Pipelines	• Since CO_2 can be transported in various phases, it can result in lower conditioning costs, less strict composition conditions and less energy required. • The safest option for transport.	• Requires the development of a regulatory framework and/or support schemes to allow sizing the pipeline infrastructure to future CO_2 injection demand.	• Cost-effective option for large volumes that are going to be transported and stored (on- and offshore storage). • Potential for pipelines to act as a viable carrier for onshore and offshore storage depending on the volumes and distance. • Potentially a viable option to use onshore and offshore storage for industrial clusters due to economies of scale.

9 DECHEMA and CEFIC (2017). Low carbon energy and feedstock for the European chemical industry. [Link]

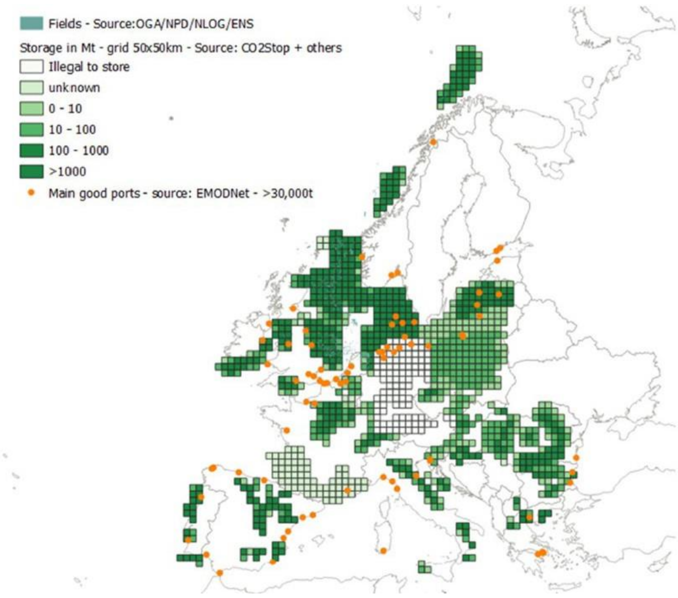
Transport Option	Benefits	Drawbacks	Use cases
Ships	• Can be more suitable for seasonal and remotely placed emitters and simply increase capacity by using them more frequently, or building more ships in a gradual way.	• Requires necessary port infrastructure. • Continuity risk due to dependency on weather conditions.	• Shipping can be used with multiple offshore storage sites or for industries that are not part of a cluster and are located next to a source of water. • Import and export terminals will also be needed to connect ships to emitters and storage systems. • Terminals will also be the destination of onshore collecting logistics, which can also be in various forms depending on the volumes, distance, etc.
Rail	• Can be a cost-effective option for transporting small and medium quantities of CO_2 across medium to long distances.	• Likely that trucks or pipelines will be needed for CO_2 to be carried to the rail options. • Current rail infrastructure is already at maximum capacity in many regions, limiting rail as a viable option.	• A logistic solution to connect small or remote emitters to a main infrastructure (e.g., pipelines, terminals) or as a kick off solution.
Trucks	• Can be a viable option in a project/ramp-up phase.	• Can be a costly and relatively inefficient option especially in highly congested areas. • Overall emissions reduction is compromised if fossil transport fuels are used in the trucks.	• Transporting CO_2 by truck is a viable option for small quantities. • A logistic solution to connect small or remote emitters to a main infrastructure (e.g., pipelines, terminals) or as a kick-off solution.

2.3. Expected CO_2 infrastructure development and the envisioned role for TSOs

There is an expanding gap between the growing need for and the availability of CO_2 infrastructure due to the slow pace at which projects are being developed. CO_2 storage projects typically entail a long development cycle as a result of large lead times to permit and develop sites, assessment of detailed geological data, and high upfront investments.

However, timely and coordinated action between the private sector and governments can accelerate the deployment of these projects towards reaching the proposed target of 50 Mt of annual CO_2 storage capacity by 2030. Europe has significant potential to store CO_2 as shown in Figure 4 below.

Figure 4. Potential CO_2 storage locations across Europe (Source: Carbon Limits)[10]



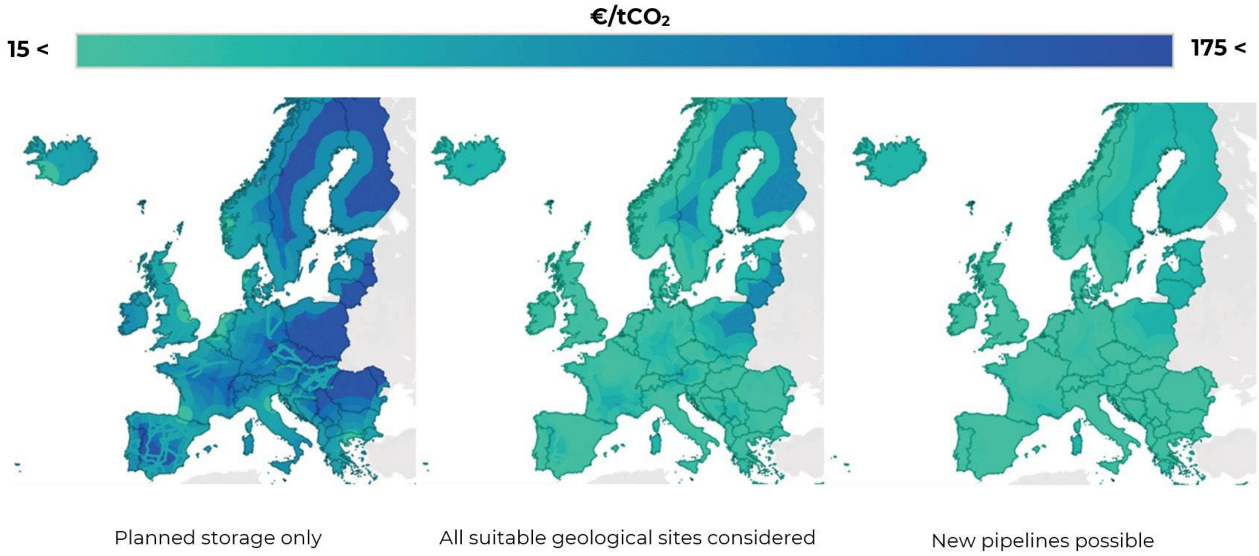
Across Europe, many of the highest carbon-emitting industries are in what is referred to as ‘industrial hubs’. These hubs present a unique opportunity to capture CO_2 from multiple emitters and use shared infrastructure for transport and storage. CCUS development around industrial hubs utilises economies of scale and by allocating capital costs between multiple users, allows smaller facilities to connect to infrastructure that would otherwise be impractical or too costly to do alone. As such, it can help with the energy transition by creating new job opportunities, reducing economic barriers, and catalysing new investment, specifically in energy-intensive industries.

However, geography plays a key role in determining costs for transport and storage and future transport and storage infrastructure buildout needs to be considered holistically. The heatmaps below highlight the variation in CO_2 transport costs across Europe by assessing the proximity of storage sites and the mode of transportation from emitters. As can be seen from the image, some regions in Central and Eastern Europe have little access to CO_2 storage posing a challenge in bridging capture and transport volumes to accessible CO_2 storage options. That said, based on the heatmap there are several regions that are geologically viable alternatives for both storage and pipelines. Solutions to this include building new coordinated CO_2 pipelines across Europe to reduce transport costs. By developing underutilized regions (the dark blue areas in the map) across Central and Eastern Europe, there is an opportunity to create low- cost access to storage at a maximum cost of €60/t CO_2 across most regions in Europe.[11] A siloed and restricted buildout of storage capacity solely within planned sites is likely to result in costs exceeding €175/t CO_2.

10 Carbon Limits (2021). Study on the reuse of oil and gas infrastructure for hydrogen and CCS in Europe. [Link]

11 Clean Air Task Force (2023). Mapping the cost of carbon capture and storage in Europe. [Link]

Figure 5. Variation in transport and storage costs in Europe across different scenarios (Source: CATF)[12]



Effective transportation of CO_2 through pipelines has significant cost reduction benefits for the CCS value chain and is a key component to enable rapid growth of the sector. There is an opportunity for TSOs to play an important role here, as they are best placed to develop open access and non-discriminatory pipeline infrastructure. Their existing capabilities to build and operate natural gas pipelines can be leveraged to develop CO_2 infrastructure, which is also associated with natural monopoly characteristics. A CO_2 transport network owned and operated by TSOs prevents inefficiencies with a holistic view of the overall CCUS market, avoiding lock-ins due to decision-making based on individual business interests.

As a result of this broader view, a level playing field is created between different industrial clusters. The transport infrastructure can then be built and dimensioned in such a way that non-discriminatory access can be granted to all parties with a carbon capture intention. However, the speed of deployment and viability of TSOs to develop the infrastructure will depend on the policy framework. In addition, the geographical spread of storage potential across Europe necessitates TSO collaboration and best practices will need to be leveraged to develop cross-border infrastructure.

12 Clean Air Task Force (2023). Mapping the cost of carbon capture and storage in Europe. [Link]

3. Analysis of CCUS projects and policies in the EU

3.1 Analysis of selected CCUS projects

With more than 480 CCUS projects identified globally, assessing what makes some projects successful and the potential challenges faced by others is key to accelerating CCUS deployment across Europe.[13] This section aims to provide an overview of some existing CCUS projects and policies, while highlighting potential success factors and challenges that are faced in the deployment of CCUS more broadly.

Figure 6. Overview of selected TSO-driven CCUS projects across the EU (Source: Guidehouse)

The selected projects above as well as the extended list in the Annex highlight the fact that there is significant momentum and advancement on CCUS projects. Private parties (e.g., CCS technology providers, large emitters of CO_2, and storage developers) and gas infrastructure companies are leading the way with advancements on transport and storage projects that bring together key components of the value chain. The developments in CCUS are not confined to a certain country or region, but rather are developing across the EU with a key element of many projects being cross- border transport. This necessitates strong collaboration between public and private entities across borders, which is a necessary

13 Guidehouse (2023). Analyst Insight: Megatrends Impacting Carbon Capture 1Q23. [Link]

component to facilitate the buildout of large-scale, capital-intensive infrastructure with natural monopoly characteristics, as is the case for CO_2 infrastructure. In certain projects, there is also a diversity of transportation options being considered as unique geographical characteristics allow for a combination of pipelines and ships to be deployed for least-cost transport. Most importantly, the projects above have also emphasized deep engagement with local institutions and communities to ensure support from key stakeholders.

3.2 Overview of CCUS policies and regulations in the EU

This section presents an overview of the current policy and regulatory landscape for CCUS in the EU, including an analysis of gaps that hold back the development of CCUS. Figure 7 shows existing and proposed strategies, policies & regulations, and support schemes mapped along the CCUS value chain.

The EU has already taken several steps to support the development of CCUS. The initial impetus came from the 2009 CO2 Storage Directive (CCS Directive), which introduced an initial regulatory framework for the sector focusing primarily on storage, establishing rules for the selection, operation, and closure of CO2 storage sites. It also mandates Member States to develop measures to ensure that third parties have access to CO2 transport networks and storage sites in a transparent and non-discriminatory way. While the CCS Directive supported the development of certain projects, there was no wide-scale boost to the sector. This was due to a confluence of reasons including low EU ETS prices which were insufficient to incentivise CCUS.

Meanwhile, there have been further developments in the EU. The proposed Net-Zero Industry Act (NZIA)14 is a key piece of legislation that provides some initial elements of harmonisation and de-risking in relation to to the CCUS value chain, recognising its contribution to Europe's climate neutrality target. In particular, the NZIA outlines a clear objective for CO2 storage of at least 50 Mt of annual injection capacity by 2030 and the obligation for Member States to publish potential CO2 storage areas. These objectives could change as certain components of the proposed legislation are still undergoing stakeholder consultation. It is worth noting that while the NZIA is a good step towards ensuring more certainty for emitters, it is crucial that the CO2 storage capacity have access conditions which are non-discriminatory, transparent, and open, otherwise there may be a risk that companies who are both emitters and storers will foreclose the market, restricting emitters without their own storage access.

To reflect the increasing importance of CCUS, the European Commission is preparing an Industrial Carbon Management Strategy due to be released in the fourth quarter of 2023. The strategy is expected to provide guidance and clarity on the future role of CCUS in the EU. To substantiate the strategy and facilitate the deployment of CCUS, the CCUS Forum was established in 2022 bringing together representatives of EU institutions, third countries, NGOs, business leaders and acade-

14 The Net Zero Industry Act is a proposal for a regulation establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem. [Link]

mia. Recently, the CCUS Forum published two issue papers as input for the strategy.[15]

Under the updated **Renewable Energy Directive** (RED III), **ReFuelEU Aviation** and the **FuelEU Maritime** regulations, CO_2 utilisation is incentivised through sector-specific synthetic fuels targets. However, not all CO_2 sources are permissible indefinitely. While biogenic and atmospheric CO_2 do not have a fixed time horizon, carbon from industrial processes can only be used until 2041, carbon from power plants until 2036. The ReFuelEU Aviation regulation stipulates that, from 2025, all flights departing from an EU airport will be obliged to uplift a minimum share of sustainable aviation fuels (SAF), starting at 2% in 2025. In 2030, the percentage will rise to 6%, and gradually to 70% by 2050. These targets will include requirements for synthetic fuels (e-kerosene) of 1.2% for 2030 and 2% for 2035. The FuelEU Maritime regulation requires vessels above 5,000 tonnes calling at EU ports to reduce the annual average carbon intensity by 2% in 2025 to 80% in 2050, compared to the average in 2020, also incentivising a switch to synthetic fuels.

The **Trans-European Networks for Energy (TEN-E)** regulation allows for CO_2 projects to receive PCI status which speeds up permitting and environmental assessments. Such projects can engage with a single authority for permitting and also have lower administrative costs for environmental permits due to a more streamlined review process. Regarding transport, the focus is primarily on pipelines with references to other types of transport, but they lie outside the scope of the regulation (e.g., shipping). PCI projects can furthermore apply for **Connecting Europe Facility (CEF-E)** funding.

Next to CEF-E, additional support schemes along the CCUS value chain in the EU include mechanisms such as the **Innovation Fund** and the **Recovery and Resilience Facility**. In particular the Innovation Fund has supported approximately 20 CCUS projects since 2021 (with new projects continually being granted funding) and covered parts of the value chain and modalities that have not been covered under other schemes (such as shipping).

The inclusion of CO_2 storage (and, under the proposed revision, certain forms of CO_2 utilisation) in the **EU Emissions Trading Scheme (ETS)** allows emitters participating in the ETS to reduce their compliance costs by capturing and permanently storing CO_2 or if the CO_2 is permanently chemically bound in a product, providing a push for CCUS.

Based on the existing and proposed CCUS policies and regulations, we identified two major gaps: 1) lack of harmonised legislative framework supporting CCUS markets at scale and 2) funding gap along the CCUS value chain.

Gap 1: Lack of harmonised legislative framework supporting CCUS markets at scale. As seen in Figure 7, there is currently no dedicated and comprehensive policy and regulatory framework in the EU that addresses all aspects of the CCUS value chain. This gap poses challenges for market players including CO_2 emitters, users, and infrastructure developers in determining long-

15 The CCUS Forum issued papers for the Communication on a CCUS strategy include: "A vision for Carbon Capture, Utilization and Storage in the EU" [Link] and "Towards an European Cross-Border CO_2 Transport and Storage Infrastructure" [Link]

term investment needs because of uncertainty in the future outlook.

Regarding storage, Member States have considerable flexibility in how they choose to implement the CCS Directive. Germany has effectively limited CO_2 injection to pilot projects, although new developments such as an upcoming national Carbon Management Strategy indicate a change in direction. Countries like Austria, Latvia, Lithuania, Slovenia, and Finland have virtually prohibited CO_2 storage. In addition, while most Member States have transposed the CCS Directive, they are yet to develop a regulatory framework to govern the permitting process for CO_2 storage. This poses a barrier to CO_2 storage deployment, as regulators, administrations, operators, and the public do not have a clear set of rules and standards to follow. This lack of regulation is specifically an issue for onshore sites which are typically surrounded by residential areas, industries, etc. that require the compliance of regulations to assure safe and controlled exploration and operation processes. As a result, there is a potential 50% shortfall in developed storage capacity projected by 2030 given announced project timelines[16], even though there is an estimated 500 Gt of theoretical capacity for CO_2 storage in Europe[17]. The proposed NZIA could increase certainty on the role of storage by, among others, requiring Member States to publish "areas where CO_2 storage sites can be permitted on their territory". However, the NZIA is not yet adopted and certain objectives may change.

CO_2 transport is not sufficiently addressed in existing policies. Developing CO_2 transport infrastructure such as pipelines and import/export terminals is a highly capital-intensive process that needs clear regulations addressing permitting, efficient ownership structures, and network access rules to de-risk project development. While some elements of the CCS Directive cover CO_2 transport and the TEN-E regulation focuses on CO_2 infrastructure via the development of PCI, the development of an overarching regulatory framework for CO_2 transport is still missing.[18]

It is also important to note that biogenic CO_2 is a topic that has not been given the requisite coverage over its role in emissions avoidance as well as in defining rules governing its treatment in emissions monitoring and accounting regimes. Biogenic CO_2 can be utilized as a carbon-neutral feedstock in other sectors (see Table 1) or permanently stored to deliver negative emissions. However, the current regulatory framework does not incentivise the storage of biogenic CO_2 (e.g., from biogas upgrading or the use of bioenergy in industry) despite its environmental benefits.

Gap 2: Funding gap along the CCUS value chain. At this current stage of project development across the CCUS landscape, there continue to be funding gaps along the value chain. Developers face significant upfront cost and risk to build out transportation and storage infrastructure in advance due to uncertainty regarding future CO_2 supply and demand volumes. They face the question of whether their large upfront CAPEX can be recovered

16 CCUS Forum (2022). A Vision for Carbon Capture, Utilization and Storage in the EU. [Link]

17 ENTEC (2023). EU regulation for the development of the market for CO_2 transport and storage. [Link]

18 CCUS Forum (2022). A Vision for Carbon Capture, Utilization and Storage in the EU. [Link]

across long time horizons, especially if low volumes persist for a period prior to eventual scale up.

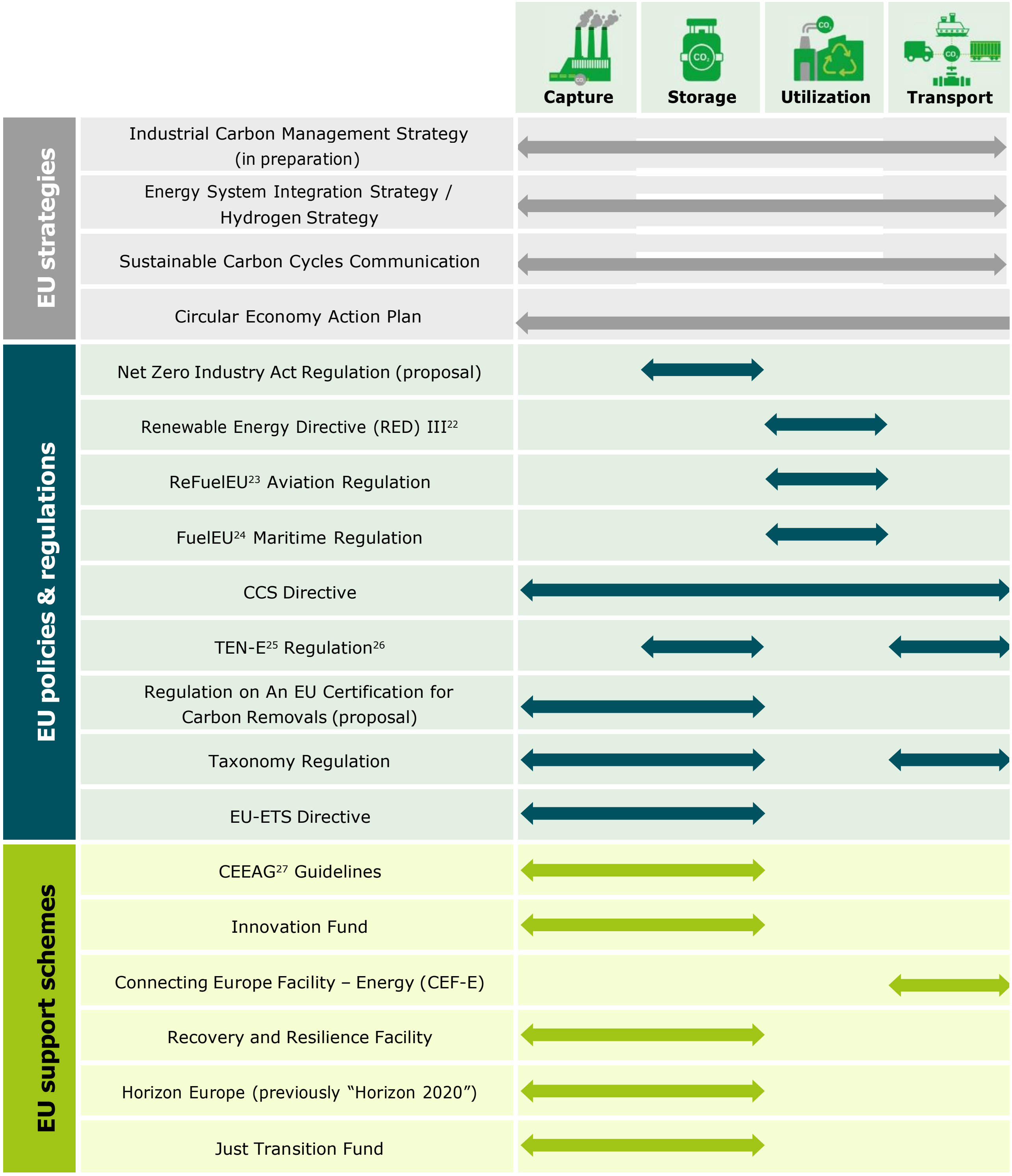
Additionally, CCUS imposes a cost on emitting industries, which will slow implementation at the scale needed unless that cost can be recouped through additional revenue or internalised via regulation. In the EU, the carbon price under the EU ETS is currently the main driver for decarbonising the power and industry sectors. While the carbon price is expected to increase over time (in line with the EU's climate goals), in the near term it remains too low and unpredictable for driving investment in technologies like CCUS, which requires supporting infrastructure.[19]

Closing the funding gap through a combination of EU and Member States' support schemes will be necessary to make initial CCUS investments bankable. Available sources of funding currently cover only a small portion of project types or value chain components, and these are typically very early stage or pilot projects. A wider range of funding instruments available to a broader group of projects would significantly de-risk project development across the value chain. For example, the EU Innovation Fund has provided support to 11 projects to date (and most recently another 11 new projects were announced in the third call for proposals[20]) but the demand for funding far exceeds availability. The focus is still to develop demonstration-scale projects rather than provide financing towards larger-scale development, which could bring in further investment from the private sector. Another example is CEF-E which thus far has only supported CO_2 pipelines and associated equipment and only recently included injection facilities.

19 Clean Air Task Force (2022). A European Strategy for Carbon Capture and Storage. [Link]

20 European Commission (2023). Innovation Fund: Projects Selected for Grant Preparation. [Link]

Figure 7. Overview of the CCUS policy landscape in the EU (Source: Guidehouse based on ERCST)[21]



21 European Roundtable on Climate Change and Sustainable Transition (ERCST), 2023, EU CCUS policy: Net-Zero Industry Act & upcoming Commission's Communication. [Link]

22 RED III refers to the revision of the Renewable Energy Directive II.

23 REFuelEU is the EU regulation specifically aimed at the aviation sector.

24 FuelEU is the EU regulation specifically aimed at the maritime sector.

25 TEN-E refers to the 2022 revision of the trans-European energy (TEN-E) infrastructure regulation.

26 Shipping is not in scope of the TEN-E regulation.

27 CEEAG refers to the 2022 guidelines on State aid for climate, environmental protection and energy.

4. Policy recommendations

The previous chapters have shown the need to overhaul the current EU policy and regulatory framework for CCUS, while also providing financial support for the entire CCUS value chain. Future policy and regulatory measures need to be developed with a view across the entire value chain, including EU-level quantifiable and verifiable milestones for CCUS toward 2050 (with 2030-2040 intermediate goals). They should also address key aspects of CO_2 transport and storage infrastructure such as TPA, quality standards, and standardised guidelines for infrastructure planning. Considering the early stage of the CCUS infrastructure landscape, long-time horizons for development, and the yet-to-be-formulated policy and regulatory frameworks, support schemes that bridge financing gaps and de-risk projects will be crucial in maintaining momentum towards reaching the EU target of reducing emissions by 55% by 2030, compared to 1990 levels. While there is a lot to do in this regard, multiple support schemes already exist at a Member State level, and some could benefit from further revisions to ensure maximum value is provided to the market players.

4.1. Comprehensive policy framework to ensure coordinated planning of CO_2 infrastructure

→ **Task infrastructure companies to develop, own and operate open access and non-discriminatory CO_2 networks.** Given their long-standing experience in developing an operating energy infrastructure, TSOs, in collaboration with relevant (public) companies and entities, should be relied upon for the task of ensuring future CO_2 networks are open access and non-discriminatory. This approach towards the build out of CO_2 transport networks prevents inefficiencies with a holistic view of the overall CCUS market, avoiding lock-insdue to decision-making based on individual business interests.

→ **Common standards, along with cross-border cooperation on network planning will be required for CO_2 infrastructure.** There is a need for common CO_2 standards to be in place to support cross-border CO_2 transport. Standardisation should address aspects such as composition, purity, pressures, and temperatures, as well as standards associated with the design of pipelines, valves, ships, and other parts of the transport value chain (e.g., loading and off-loading). This level of standardisation will bolster interoperability across Europe supporting multiple transport modalities.

For the network plannin, cross-border cooperation among the TSOs is required. However, this will depend upon the scale of cross-border infrastructure needed and whether this should be considered from a pan-EU perspective or selected regional developments. It will be important to ensure close cooperation with other network operators of natural gas and hydrogen to allow for synergistic planning to facilitate coordinated decision-making for repurposing existing infrastructure or building out new pipelines, and encouragement of regional cooperation to ensure smooth cross-border planning. However, this will depend upon the scale of cross-border infrastructure needed and whether this should be considered from a pan-EU perspective or selected regional developments. It will be important to ensure close cooperation with other network operators of natural gas and hydrogen to allow for synergistic planning to facilitate coordinated decision-making for repurposing existing infrastructure or building out new pipelines, and encouragement of regional cooperation to ensure smooth cross- border planning.

→ **Define a suitable regulatory framework for CO_2 transport and storage.** CO_2 transport infrastructure embodies natural monopoly characteristics with large economies of scale and treating it as a competitive sub-sector would raise additional challenges due toa lack of alternative options and thereby creating market barriers for future market entrants. Storage sites and transport by ship are also likely to be subject to only limited competition, especially in the early years of CCUS deployment. This dependence of capture projects on one or two transport and storage providers means that some form of regulatory oversight is necessary.[28]

The future CO_2 transmission network should be accessible to any emitter who wants to transport their CO_2 to safe storage sites. Hence, ensuring open access CO_2 transportation infrastructure is key to accelerate CCUS deployment. The proposed approach between negotiated TPA and regulated TPA in the Hydrogen and Decarbonised Gas Market Package is an equally sound approach for CO_2 networks and storage. The package states that hydrogen network operators should provide regulated TPA, while allowing Member States to apply negotiated TPA during a transition period. Similar TPA provisions should also be considered for CO_2 networks and storage.

There are also uncertainties regarding the policy and regulation of CO2 storage and it is important to ensure sufficient CO2 storage capacity is made available and access conditions are non-discriminatory, transparent and open. Guidelines on streamlining permitting and licensing processes, clustering environmental permitsas well as increasing permitting processing capabilities should be prioritised to avoid bottlenecks for project development. A key aspect requiring de-risking is the end-of-life treatment of storage sites and ownership of liability. The CCS Directive touches upon this aspect and requires the operator of the storage site to conduct monitoring, reporting, and corrective measures after closing as well as responsibility for sealing the storage site and removing the injection facilities. However, it is unclear whether there would be an option for a subsequent transfer of storage site liability to a governmental body. Governmental support and clarity through risk-sharing and liability transfers will help developers to manage long-term risk and investment decisions. Potential options that have been put forth include the establishment of a national fund for pooled liabilities for storage resources.[29]

→ **Require Member States to declare the planned role of CCUS in their national energy and climate plans.** The role of CCUS (including

28 Bellona (2021). Models for Transport and Storage of Captured CO_2. [Link]

29 ENTEC (2023). EU regulation for the development of the market for CO_2 transport and storage. [Link]

carbon removal) should also be articulated under Members States' National Energy and Climate Action Plans (NECPs) to provide market players visibility on future market opportunities such as domestic storage developments or potential CO_2 volumes available for export across countries. This can be done by focusing on capacity building at all levels in order to mitigate current and potential future bottlenecks as well as reducing unnecessary delays as the number of projects increase. National governments and local authorities need to ensure that sufficient resources are in place to work on new CO_2 storage applications linked to the CO_2 storage injection target proposed in the NZIA. This process should also ensure that the CCS Directive is implemented effectively at the national level. The forthcoming update of the guidance documents and the capacity-building workshops that are planned for 2024 should also provide a good basis for coordinated implementation.

→ **Promote voluntary markets**. Although demand for carbon removal has the potential to significantly drive the growth of the voluntary market, price volatility as well as doubts over credit quality and climate impact from the current market setup act as barriers. The proposed Carbon Removal Certification Framework is the first EU-wide voluntary framework to certify high-quality carbon removals. Once it enters into force, it can help the development of carbon removal projects such as BECCS and DACCS, which are deemed permanent sources of storage in the proposed instrument. Voluntary markets, in combination with quantifiable and verifiable milestones for CCUS toward 2050 can stimulate the demand for carbon removals.

4.2. Financial support schemes

→ **Develop support schemes that cover the entire CCUS value chain.** Predictable revenue streams for CCUS projects over the long term are key to kick-starting and de-risking the market. Market players such as emitters, storage operators, and transportation network developers and operators need to be offered support schemes that can help them manage price variations and volume risks. Emitters want to ensure the transport and storage infrastructure exists to remove their CO_2 volumes, while transport and storage operators need certainty of the volumes to transport and store. To help with the high upfront CAPEX, the EU and Member States could support investors with activities in the feasibility stage of projects or by offering longer-term commitments with tariffs paid for certain agreed capacities. For strategic locations, dedicated funding couldbe provided to mature large-scale (>100 $MtCO_2$) storage sites and bring these to 'injection-ready' status, potentially with a tender process to develop target storage capacities by key dates.[30]

Public funds are necessary to stimulate the deployment of infrastructure and facilitate emitting industries to transport their CO_2 for permanent storage or sustainable use. A potential option for support scheme could be to create a state fund guarantee to address counterparty and project risk that exists with

30 CCUS Forum (2022). A Vision for Carbon Capture, Utilization and Storage in the EU. [Link]

long-term contracts between infrastructure and emitters. These projects are also highly capital-intensive and CAPEX funding would be needed to de-risk their profiles. The fund could cover the gap in case of delayed implementation of the CO_2 capture solution with the state paying the transport and storage operators for the missing revenue. Additionally, business models or instruments that can guarantee stable revenue streams for emitters such as CCfDs can allow for risk-sharing with the government as the counterparty. The EU Innovation Fund and CEF-E could also provide funding specifically for CCUS projects and mitigate timing issues that are likely to prevail in back-to-back contractual rights and obligations between emitters, transporters and storers. However, there is a risk that there may not be sufficient funding available as the number of applicant projects increases and therefore, this risk should be addressed in advance through solutions such as increasing the CEF-E budget and others.

De-risking measures to support viable business models for CO_2 storage should be defined. For example, the EU and Member States could support investors with activities in the feasibility stage of projects, as well as with the development of a European storage atlas, as proposed by the CCUS Forum.[31] For strategic locations, dedicated funding could be provided to characterise and mature large- scale (>100 MtCO2) storage sites and bring these to 'injection-ready' status, potentially with a tender process to develop target storage capacities by key dates.[32] Funding gaps will exist beyond the initial project phase and coordinated EU and Member State funding will help increase the availability of funding for CCUS projects. In this regard, IPCEIs represent a further effective mechanism to ensure active commitment from Member States. Similar to hydrogen, CCUS will play a key role in the decarbonisation of the EU and many projects will require cross-border collaboration, which would make CCUS an ideal candidate for an IPCEI.

→ **Consider defining specific incentives for biogenic CO2 to support carbon removal.**

When biogenic CO_2 is captured and permanently stored, CO_2 is permanently removed from the atmosphere (i.e., negative emissions). On the demand side, for example, recognising CO_2 emissions avoidance from biogenic CO_2 can create demand for biogenic CO_2. Recognition for biogenic CO_2 can be given for activities included in the EU ETS, like chemical or paper industries. On the supply side, financial incentives for biomethane producers to capture, purify and sell biogenic CO_2 can support its ramp-up.

31 CCUS Set-Plan (2022). Recommendations on the steps to establish a R&I activity 4 European Storage Atlas. [Link]

32 CCUS Forum (2022). A Vision for Carbon Capture, Utilization and Storage in the EU. [Link]

Annex

Extended list of CCUS projects

Project Name	Key Project Characteristics	Success Factors	Project Setup
Aramis 	• Located on Maasvlakte in the Port of Rotterdam. • Planned to store 22mtpa by 2030 and planned to be operational in 2026-2027. • The transport and storage ability will provide hard-to-abate industries reach their climate goals. • The CO_2 will be stored in depleted offshore gas fields, deep under the North Sea. • Based on an 'open access' philosophy so that other industrial customers and storage fields can be added incrementally to the system.	• Strong collaboration between both public and private stakeholders. • Political and public support.	Partnership between two state-owned corporations Energie Beheer Nederland (EBN) and Nederlandse Gasunie, and the private companies TotalEnergies and Shell.
German CO_2 Transportation Infrastructure 	• The planned CO_2 transport network will transport 18.8 million tonnes of CO_2 in the future. • The CO_2 transportation currently supports OGE projects including WHVCO2logne, Delta Rhine Corridor and the Elbe estuary and Rhenish coalfield clusters. • The aim is to quickly develop the export options in Wilhelmshaven, Rotterdam and Antwerp/Zeebrügge.	• Collaboration between business and stakeholders across the CCUS value chain. • Strong political support.	Owned and operated by OGE.
Grand Ouest CO_2 "GCOC2" 	• GOCO2 aims to capture CO_2 from industrial sites, transport it by pipeline to the Saint-Nazaire maritime export terminal and then to permanent geological storage areas. • With an estimated capacity of 2.6 million tons per year by 2030, GOCO2 is the largest decarbonisation project in Western France in terms of the volume of CO_2 captured and transported. • It could eventually transport and export up to 4 million tons per year of CO_2 in 2050, or more than 75% of the industrial emissions of the Great West of France. • Fully integrated into the local ecosystem, the project will partly benefit from existing infrastructure within the GPMNSN.	• Strong support from Région Pays de la Loireand Grand Port Maritime de Nantes Saint-Nazaire (GPMNSN). • In line with the French CCUS Strategy (France 2030) and ADEME's call for projects "Low Carbon Industrial Areas".	Partnership between Elengy, GRTgaz, Heidelberg Materials, Lafarge, Lhoist and TotalEnergies.

Project Name	Key Project Characteristics	Success Factors	Project Setup
Korskro Biogas Plant 	• Biomethane plant in operation since 2019. • Processes 500,000 tonnes of biomass annually. • Carbon capture unit enables 16,250 tonnes of biogenic CO_2 to be capture and utilized annually. • Biomethane production of 49 million m^3.	• Contributes to the circular economy by sourcing waste within 25km of the plant and supplies the food & beverage industry as well as the gas network. • Reduces shortfall of CO_2 required during summer months.	Wholly owned by NGF Nature Energy (now a subsidiary of Shell).
Belgian Open Access CO_2 Infrastructure 	• The Antwerp@C CO2 export terminal capacity will amount to 2,5 Mtpa (with the ambition to reach up to 10 Mtpa by 2030) and commissioning date is 2026. • Ghent Carbon Hub Marine terminal capacity amounts to up to 6 Mtpa. • The Ceapipe project will capture CO2 from emitters and bring it to safe storage sites in the North Sea Its transport capacity will amount to 20 to 40 Mtpa and will be ready for commissioning before the end of the decade.	• Funding support from the Connecting Europe Facility (CEF).	Antwerp@C CO2 Export Hub project will be carried out by Fluxys, Air Liquide, and the Port of Antwerp Brugge; Ghent Carbon Hub project will be carried out by Fluxys, North Sea Port, and Arcelor Mittal.
Pycasso (Pyrenean CO_2 Abatement through Sustainable Sequestration Operation) 	• Full chain CCUS project located in existing onshore site whereby mutualised CO2 (biogenic and fossil fuel CO2) can be transported using pipelines and ships. • Objective is to start the project in 2030 and capture up to 6Mt of CO2 from 2035 (up to 3Mt of biogenic CO2). • Can serve permanent storage projects or valorisation. • Providing biogenic small emitters with opportunity to contribute to decarbonisation by producing negative emissions or creating additional revenue.	• Strong political support from French government. • Project included in the national CCUS strategy. • Extensive public consultation and involvement.	Led by Teréga, Repsol and Lafarge.

Project Name	Key Project Characteristics	Success Factors	Project Setup
Ravenna CCS 	• Set to be the first application of the full capture, transport and storage chain in Italy.[33] • Planned to capture and store 25,000 tonnes of CO_2 per year during Phase 1 with start-up in 2024, scaling up in Phase 2 up to 4 million tonnes per year in 2026. • Gathering hub located in Ravenna collecting CO_2 both in gaseous and liquid phase from hard-to-abate clusters both in Italy and abroad. • Ravenna Hub is able to receive CO_2 via pipeline, ship, truck and train. • Offshore storage in offshore depleted reservoirs in the Adriatic Sea. • Future expansion phases starting from 2030 with a capacity injection that gradually reaches up to 16 million tonnes per year.	• Industry collaboration. • Local community involvement and public disclosures helped with the strong public support for the project.	Joint venture between Eni and Snam.

33 The CCUS Hub, Ravenna CCS [Link]

CCUS policy landscape in selected EU Member States

Belgium has prioritised the development of CCUS policies and strategy with the aim of becoming a frontrunner in the CCUS landscape. The National Recovery and Resilience Plan supports a legal framework for CCUS including cross-border infrastructure for CO_2 transport. The government of Flanders has approved a first draft law on CO_2 transport in April 2023. The law is currently being reviewed but no major adaptations to the law are expected and the anticipated publication date is in October 2023. Similarly, the Walloon government has approved a draft CO_2 transport law and both the Flanders and Walloon governments are seeking to negotiate with Norway to develop CO_2 transport and storage potential in the Norwegian Continental Shelf.

Denmark is focusing on becoming a regional CCUS hub, with an emphasis on CO_2 storage. The government has made the development of CCS a legal requirement and committed to a funding pool of more than €2.2 billion. The regulatory framework is driven by the CCS Directive and policies relating to TPA and liability transfer are being discussed. A government position on the regulatory framework for CCS is expected at some point in 2023. To improve the business case for CCS, the Danish government also intends to increase the CO_2 tax to €151 per tonne of CO_2 by 2030 with exceptions for key industries to prevent them from moving production outside the country. Denmark may also consider a negative CO_2 tax or carbon offset allowances resulting from biogenic emission sources.

France launched a public consultation on its proposed national CCUS strategy. The strategy highlights the best geographic locations for CCUS, such as where the Pycasso project has been developed. For storage, the strategy includes funding for the assessment of new storage sites in France. The French government will launch calls for tenders in 2023 and 2024 for emitters as well as provided support in the form of state guarantees to de-risk carbon capture projects. For transport, the strategy anticipates mechanisms to de-risk the development of the infrastructure through a regulated framework and a state fund to compensate delays or default on the capture component (e.g., if the emitter's carbon capture project's implementation is delayed).

Partially in response to the support introduced by the Inflation Reduction Act (IRA) in the United States, **Germany** is focusing on strengthening its industrial outlook and accelerating industrial carbon removals through a heavily funded subsidy programme for CCfDs. After a preparatory phase in June 2023, the government plans to introduce CCfDs to provide industrial companies with investment certainty for decarbonisation projects, including carbon capture. The 15-year-long CCfDs are intended to be awarded to companies that can decarbonise their production facilities at the lowest cost.

In the **Netherlands**, capturing CO_2 from industrial emissions is a priority for the government and there is a push for industry to decrease its annual emissions by 14 Mt by 2030. The Dutch CCUS market has been developing because of increasing EU ETS prices and the Stimulering Duurzame Energieproductie en Klimaattransitie scheme (SDE++) which acts as a carbon contract for difference mechanism. SDE++ covers the cost of CCUS projects above the EU ETS price and to date, the policy has supported the Porthos project in developing a business case and being close to reaching Final Investment Decision (FID). The customers of the project have been awarded €2.1 billion in funding as a budget reservation, which constitutes the maximum amount that may be paid over 15 years. The actual figure will be significantly lower due to increasing EU ETS prices and subsequent subsidy decreases. The funding will cease at the point when EU ETS prices surpass CCUS unit costs.