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Towards a European cross-border CO_2 transport and storage infrastructure: Recommendations ahead of the EU Industrial Carbon Management Strategy

Report of the CCUS Forum Working Group on CO_2 Infrastructure

September 2023

EXECUTIVE SUMMARY

Reducing emissions by 2030 and reaching climate neutrality by 2050 is the main objective of EU climate action and the most important global challenge. There is evidence that carbon capture and storage (CCS) and some applications of carbon capture and utilisation (CCU) can effectively contribute to climate change mitigation efforts. These technologies are crucial for the decarbonisation of industry, in particular the harder-to-abate sectors – and enable carbon dioxide removal (negative emissions) which can balance out residual emissions – contributing to economic growth, sustaining current jobs, and creating new ones.

Recent developments in industrial carbon management testify to the strong momentum for CCS and CCU in Europe. While industry is ready to deploy, political support has not always been sufficient, leading to uncertainty and delays. At the same time, technical, regulatory, and economic challenges still hinder the development and scale-up of these technologies in Europe.

We welcome the establishment of the CCUS Forum which, through the established working groups, can identify the actions that are urgently needed to support the deployment of CCS and CCU to decarbonise industry. This paper identifies and describes the key technical, regulatory, and economic challenges to the development of a robust, non-discriminatory, open-access, cross-border CO_2 transport and storage infrastructure in Europe. It is critical that the European Commission responds to this paper with concrete measures, supporting European global leadership in innovative low-carbon technologies, in line with the objective to be the first climate-neutral continent by 2050.

The key findings and recommendations of this paper can be summarised as follows:

- A non-discriminatory, open-access, cross-border Europe-wide CO_2 transport and storage infrastructure, with unbundling between transport and storage, is crucial for Europe to reach climate neutrality.
- There is an urgent need for a fit-for-purpose EU regulatory framework for CO_2 transport infrastructure to complement the CO_2 Storage (CCS) Directive.
- The directive 2009/31/EC CO_2 storage (CCS) Directive is a good basis for CO_2 storage. This Directive's Guidance documents are being revised but the Directive itself should not, at this time, be opened for review.
- There is a need for clarity regarding the conversion of hydrocarbon fields from oil & gas operations to CO_2 storage reservoir operations in terms of liability.
- Interoperability is crucial for the development of the Europe-wide CO_2 transport and storage infrastructure. Standards/network codes are needed for CO_2 specifications, addressing the different technologies and segments of the CCUS value chain, also bearing in mind cost effectiveness considerations. The report of the CCUS Forum expert group highlights that safe transport of impure CO_2 streams is possible today and recommends the European Commission to develop a strategy and clear targets for a common European CO_2 transport network; develop as rapidly as possible a network code and standards for a multimodal CO_2 transport network in the EU/EEA; and to support and prioritise research in this field.
- Limited access to information is a barrier to CO_2 storage appraisal and characterisation. Access on a non-reliance basis to crucial (non-confidential) information in areas where CO_2 storage

sites can be permitted is a must to support the development of storage sites in Europe, and an integral part of a European Storage Atlas.

- Capacity building within competent authorities, efficient permitting processes and ensuring a sufficient number of permitting and licensing rounds is crucial. Early engagement – and ongoing interactions and discussions – between competent authorities and project promoters is vital to the success of CCUS projects.
- All relevant EU and national funding programmes should be adapted to maximise their potential to fund CO_2 infrastructure projects and to avoid 'chicken and egg' challenges along the value chain.
- There is a need to further clarify the legal basis for the export of CO_2 for offshore storage, linked to the London protocol application within the EU/EEA area, to enable large-scale development of CO_2 transport networks in Europe.
- It is important to resolve the EU-UK cross-border issues – enabling CO_2 captured in the EU and stored in the UK without having to submit emission allowances under the EU ETS, and vice versa – to ensure the development of a Europe-wide CO_2 market.
- Successful deployment of CO_2 capture, transport and storage at scale will depend on a proper allocation of liabilities and contracts between the entities operating along the value chain. Risk-sharing and transfer of liabilities between the storage developer and the regulatory authority/the state is key to balance risks and rewards and de-risk the needed investments, supporting project development.

It should be noted that experience is and will continue to evolve with early CCS and CCU projects. These projects will allow the identification of new challenges/barriers and it is important that the European Commission keeps engaging with industry players to create favourable conditions for the development and operation of these projects, along with civil society and the research and innovation (R&I) community. Similarly, different initiatives and programmes that are already in place should be reviewed as a way to identify possible learnings and best practices.

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1. Introduction

1.1 Scope

The objective of this paper is to provide clear recommendations to the European Commission (EC) on how to sustainably develop and deploy European CO_2 transport and storage infrastructure to reach climate neutrality by 2050. In this context, the report identifies key regulatory and technical challenges to be addressed to enable the development of an integrated CO_2 network.

The paper focuses on the CO_2 transport and storage components of the value chain (and not on capture), highlighting their technical, regulatory and economic dimensions. Recognising the efficiency gains of developing broad CO_2 markets, the paper takes a wider European perspective, rather than focusing only on EU Member States.

This paper does not attempt to describe, in detail, the challenges faced by each individual carbon capture and storage (CCS) and carbon capture and utilisation (CCU) technology. Similarly, it is recognised that, compared to CCS and carbon dioxide removal (CDR), CCU solutions involve more complex value chains, with implications for the planning of transport infrastructure. Nevertheless, all CO_2 flows – CCS, CDR, CCU etc. – need to be taken into account in infrastructure planning and development, which calls for continued investigation of the challenges and needs of different technologies. In addition, at the basis of infrastructure development must be a rigorous assessment of the contribution of the different technologies/projects to climate change mitigation, based on best available scientific evidence, a full life-cycle assessment (including energy use and end-of-life) and thorough carbon accounting, scalability potential within a relevant timeline, and relevance compared to counterfactual scenarios. Similarly, environmental and energy efficiency principles are to be preserved, ensuring that infrastructure development promotes the most efficient solutions for climate neutrality.

The working group (WG) on CO_2 infrastructure urges the EC to respond to this paper with concrete action, by filling in the policy gaps and by addressing the technical and economic constraints that hinder the development and scale-up of CO_2 transport and storage infrastructure.

1.2 Work process

The report is developed by the WG on CO_2 infrastructure, based on discussions and input received from a broad membership, including stakeholders from industry, energy, researchers, and environmental NGOs, as well as on existing work that reflects information and research (e.g., reports, studies). The report builds on the issue paper developed by the WG in December 2022[1], presented at the 2022 CCUS Forum Plenary (27-28 October 2022)[2].

To prepare this report, the WG held four meetings between July and November 2022, three thematic workshops – dedicated to the regulatory, technical, and economic dimensions respectively – in the beginning of 2023, and a final meeting in June 2023. The WG benefited from active and fruitful participation, reflecting the urgency of sustainably developing and scaling up CCUS in Europe.

[1] Available here.
[2] More on the European Commission's CCUS Forum here.

In addition, given the critical importance of standards/network codes for the CCS value chain, the WG established, in the beginning of 2023, an expert group to work on the technical components, e.g., CO_2 specifications.

The report should be seen as an integral part of the work conducted under the three CCUS Forum WGs, engaged by the EC. Notably, the WG on CO_2 infrastructure has coordinated with the WG CCUS Vision. The WG has also coordinated with and provided input to the EC technical and regulatory studies on CO_2 infrastructure by EnTEC and the Joint Research Centre (JRC) and the DNV review of the CO_2 Storage (CCS) Directive's Guidance Documents.

1.3 Statement of the challenge

Reducing emissions by 2030 and reaching net-zero greenhouse gas emissions by 2050 is the main objective of EU climate action and the most important global challenge. To achieve these objectives, urgent actions must be implemented, based on clear scientific evidence about the role of the different technology solutions. There is evidence that CCS can contribute to significantly reduce carbon emissions into the atmosphere, being employed in the majority of decarbonisation scenarios consistent with the 1.5°C and 2°C global temperature targets. Some CCU applications can effectively contribute to mitigation[3].

The findings of the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) working group III[4] show that:

- "CCS is an option to reduce emissions from large-scale fossil-based energy and industry sources, provided geological storage is available. When CO_2 is captured directly from the atmosphere (DACCS), or from biomass (BECCS), CCS provides the storage component of these CDR methods"
- "The deployment of carbon dioxide removal (CDR) to counterbalance hard-to-abate residual emissions is unavoidable if net zero CO_2 or GHG emissions are to be achieved. (…) CDR refers to anthropogenic activities that remove CO_2 from the atmosphere and store it durably in geological, terrestrial, or ocean reservoirs, or in products"
- "(…) not all end-uses are expected to be commercially electrifiable in the short to medium term {11.3.5}, and many will require low GHG liquid and gaseous fuels, i.e., hydrogen, ammonia, and biogenic and synthetic low GHG hydrocarbons made from low GHG hydrogen, oxygen and carbon sources (the latter from CCU, biomass, or direct air capture"
- "Carbon is a key building block in organic chemicals, fuels and materials and will remain important (high confidence). In order to reach net zero CO_2 emissions for the carbon needed in society (e.g., plastics, wood, aviation fuels, solvents, etc.), it is important to close the use loops for carbon and carbon dioxide through increased circularity with mechanical and chemical recycling, more efficient use of biomass feedstock with addition of low-GHG hydrogen to increase product yields (e.g., for biomethane and methanol), and potentially direct air capture of CO_2 as a new carbon source"

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[3] For a revision of the role of CCS and CCU in the EU decarbonisation scenarios, see: Butnar, I., Cronin, J., & Pye, S. (2020). Review of Carbon Capture Utilisation and Carbon Capture and Storage in future EU decarbonisation scenarios. UCL Energy Institute (part of the CCUS SET-Plan Implementation Plan work).
[4] Intergovernmental Panel on Climate Change (2022). Climate Change 2022: Mitigation of Climate Change.

- "Reducing emissions from the production and use of chemicals would need to rely on a life cycle approach, including (…) carbon sourced through biogenic sources, and, depending on availability, carbon capture and use (CCU), direct air CO_2 capture, as well as CCS".

The majority of European countries benefits from favourable conditions for CO_2 storage[5]. While the storage potential is large, Europe still needs to realise projects to meet the predicted demand from emitters[6]. The European Commission foresees that 30 projects in preparation will be able to store approximately 50 million tonnes per year by 2030 but emphasises that reaching climate neutrality will require at least six times more CO_2 to be stored per year by 2050[7]. At the same time, the European Commission proposal for a Net Zero Industry Act (NZIA)[8] sets out an annual CO_2 injection capacity target of 50 million tonnes by 2030, to be achieved through individual contributions from oil and gas license holders.

Recent developments are encouraging with Denmark[9] and the United Kingdom[10] recently awarding their first CO_2 storage licenses in the North Sea, including both saline aquifers and depleted oil & gas fields. The Norwegian Petroleum Directorate has also recently offered two new exploration licenses for CO_2 storage on the Norwegian continental shelf in the southern part of the North Sea a license for CO_2 storage in the North Sea[11], adding to the five licenses previously awarded in 2019 and 2022[12]. Furthermore, the world's first open-source CO_2 transport and storage infrastructure, Northern Lights[13] is expected to start operations in 2024 and is being built ready for expansion to accommodate increasing storage demands. In the Netherlands, the Aramis project[14] will allow several CO_2 storage sites to connect to its offshore transport backbone.

Developments in CO_2 storage infrastructure can also be seen in regions other than the North Sea. Recent project developments in the Mediterranean and the Black Sea lay the ground for significant offshore storage capacity in the rest of Europe. Furthermore, smaller, but still relevant onshore project initiatives are evolving and are expected to facilitate CO_2 abatement in landlocked regions.

Nevertheless, limited progress in storage development translates into difficulties for capture projects and vice versa. Notably, identifying storage options has been highlighted as a key hurdle for Innovation Fund projects.

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[5] Clean Air Task Force (2023). Unlocking Europe's CO_2 Storage Potential: Analysis of Optimal CO_2 Storage in Europe.

[6] Clean Air Task Force (2022). The gap between carbon storage development and capture demand.

[7] Presentations by DG CLIMA regarding the Innovation Fund and the Projects of Common Interest.

[8] Proposal for a regulation of the European Parliament and of the Council on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act) (here).

[9] Danish Energy Agency (2023). The Ministry of Climate, Energy and Utilities grants Denmark's first full-scale CO_2 storage permits in the Danish North Sea.

[10] North Sea Transition Authority (2023). Huge net zero boost as 20 carbon storage licences offered for award.

[11] Norwegian Petroleum Directorate (2023). Award of two new licences for CO_2 storage on the Norwegian continental shelf.

[12] Norwegian Petroleum Directorate (2022). Licenses for carbon storage.

[13] More information about Northern Lights on the project website.

[14] TotalEnergies (2021). Netherlands: TotalEnergies, Shell Netherlands, EBN and Gasunie Form Partnership to Develop the Offshore Aramis CO_2 Transport and Sequestration Project.

Referring to CO_2 utilisation, the Nova-institute has estimated that the global need for embedded carbon in chemicals and derived materials will increase to 1 Gt per year by 2050[15]. The Nova-institute further states that sharing, reusing, and recycling will play the main role in keeping carbon in a closed loop. The report adds that, as it is not possible to keep the entire carbon in a cycle, there is a need for alternative carbon sources that can be partially covered by CO_2. A rigorous and standardised carbon accounting methodology is a prerequisite when determining any technology's contribution to emission reductions.

The North Sea region benefits from neighbouring European industrial regions and ports such as Aberdeenshire, Amsterdam, Antwerp-Bruges, Dunkirk, Le Havre, North Sea Port, Rotterdam, Ruhr, the UK East Coast, and Wilhelmshaven. In recent months there has been a positive momentum for European CO_2 infrastructure projects with several key announcements, including the Wintershall Dea-Fluxys cooperation agreement on a cross-border CO_2 pipeline network connecting southern Germany and Belgium[16], an offshore pipeline 'heads of agreement' between Equinor and Wintershall Dea[17] to connect Germany and Norway, a new 1,000 km onshore pipeline project by OGE in Germany[18] to connect industries to the port of Wilhelmshaven, and 'heads of agreement' between Equinor and Fluxys to connect Belgium and Norway through an offshore pipeline[19].

Developments in international cooperation should also be noted, including the bilateral arrangements signed between Belgium and Denmark[20] and between Belgium and the Netherlands[21] to allow the cross-border transport of CO_2 for the purpose of permanent geological storage, the memorandum of understanding (MoU) between Denmark and the United Kingdom on cooperation in the energy transition, including CCUS[22], the joint declaration of intent between Denmark and Germany on CCUS cooperation[23], and the MoU between Norway and Belgium on energy-related cooperation including CCS[24]. These are a key steppingstone for the development of cross-border projects; notably, the bilateral arrangement between Belgium and Denmark allowed the kickstart of the pilot phase of the Greensand project[25], a clear landmark in CCS projects landscape.

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[15] Kähler, F., Carus, M., Porc, O. & vom Berg, C. (2021). Turning off the Tap for Fossil Carbon – Future Prospects for a Global Chemical and Derived Material Sector Based on Renewable Carbon. nova-Institute (Ed.), Hürth, Germany.

[16] Wintershall Dea (2023). Wintershall Dea and Fluxys jointly investigate options for transport of CO_2.

[17] Wintershall Dea (2022). Wintershall Dea and Equinor partner up for large-scale CCS value chain in the North Sea.

[18] OGE (2022). OGE and TES join forces to develop a 1,000 km CO_2 transmission system.

[19] Fluxys (2022). Fluxys and Equinor launch solution for large-scale decarbonisation in North-Western Europe.

[20] Memorandum of Understanding (MoU) between the Minister for Environment of the Flemish Region and the Federal Minister for the North Sea of Belgium and the Minister for Climate, Energy and Utilities of Denmark on Cross border transportation of CO_2 with the purpose of permanent geological storage.

[21] Memorandum of Understanding (MoU) between the Minister for Environment of the Flemish Region and the Federal Minister for the North Sea of Belgium and the Minister for Energy and Climate of the Walloon Region and the Minister of Economic Affairs and Climate Policy of the Netherlands on Cross border transportation of CO_2 with the purpose of permanent geological storage.

[22] GOV.UK (2023). Cooperation in the energy transition: UK - Denmark memorandum of understanding.

[23] Joint Declaration of Intent between the Federal Ministry for Economic Affairs and Climate Action of the Federal Republic of Germany and the Ministry of Climate, Energy and Utilities of Denmark on the Cooperation on Carbon Capture Utilisation and Storage (CCUS).

[24] Memorandum of Understanding (MoU) between the Government of the Kingdom of Norway and the Federal Government of the Kingdom of Belgium on Energy cooperation on the North Sea.

[25] INEOS (2023). INEOS led consortium announces breakthrough in carbon capture and storage.

This momentum will need to be preserved and enhanced through conducive regulatory conditions and EU and national/multilateral funding programmes. While the industry is ready to deploy at large scale, there is a need to put in place a robust, non-discriminatory, open-access, cross-border CO_2 transport and storage infrastructure that enables emitters to connect to sinks, as and where needed. In addition, the development of full-scale commercial projects will require all parts of the value chain to be operational which implies that the different components must be developed and implemented in tandem so that capture facilities can be confident that transport and storage facilities will be available and vice versa.

A robust CO_2 infrastructure network is key to enable the development of low-carbon and competitive industrial sectors, provide clean flexibility to the energy sector, and allow to unlock early large-scale volumes of low-carbon hydrogen and carbon dioxide removals. This integration implies that CO_2 infrastructure needs to be developed in parallel and in alignment with the necessary expansion of hydrogen and renewable energy infrastructure. Ports need to be equipped with means for handling CO_2, including CO_2 captured from exhaust gases of ships and need to be integrated into the CO_2 infrastructure to enable effective access to storage sites. Moreover, a CO_2 transport network can enable the supply of necessary CO_2 raw materials, for example, for the chemicals industry.

1.4 International perspective

The Communication on Sustainable Carbon Cycles published by the European Commission in December 2021[26] highlights the ambition to make the EU a leader in innovative low-carbon technologies and in CCUS, putting forward several proposals to create an internal market for capture, use, and storage of CO_2, supported by an open-access and cross-border transport network. At the same time, important political developments at the international level are bringing unprecedented support to CCUS technologies. For instance, in August 2022, President Joe Biden signed the Inflation Reduction Act[27], increasing the already available tax credits (known as 45Q) for CCS and CCU and for the capture of CO_2 via Direct Air Capture (DAC). While this represents a positive signal for the global development of CCUS, it should at the same time call on Europe to raise its support to unlock its potential to build industrial, economic, and political leadership in innovative low-carbon technologies in line with the objective to be the first climate-neutral continent by 2050.

[26] Communication from the Commission to the European Parliament and the Council Sustainable Carbon Cycles (here).

[27] Inflation Reduction Act of 2022.

2. The structure of the CO_2 infrastructure market

2.1 The CO_2 Storage Directive

The current legal basis for the storage of CO_2 in Europe is the Directive 2009/31 on the Geological Storage of carbon dioxide (hereinafter 'CO_2 Storage Directive')[28]which includes provisions on site selection and characterisation, conditions for permitting, as well as monitoring and reporting requirements to verify storage, including remediation obligations in case of leakage. It also includes some requirements on providing third-party access (TPA) to infrastructure. The EC publishes biannually reports on the implementation of the CO_2 Storage Directive[29] which highlights progress in EU Member States.

Experience with storage permit applications in the Member States and at EU level is currently evolving under the directive and its Guidance Documents. There is a clear consensus that the Directive itself should not be opened for review, however, some elements of the Guidance Documents could benefit from an update as highlighted in a recent ZEP report[30]. Notably, the Guidance Documents are currently being reviewed by the European Commission, supported by DNV. A first draft version of the updated Guidance Documents has been made available for stakeholder review[31].

2.2 The proposed Net Zero Industry Act

In March 2023, the European Commission put forward a proposal for a 'Net-Zero Industry Act' (NZIA) aimed at expanding the manufacturing capacity of net-zero technologies in the EU. The proposal recognises CCS as a strategic net-zero technology and CO_2 storage projects as net-zero strategic projects, eligible for streamlined permit-granting procedures. In addition, the NZIA sets out an annual CO_2 injection capacity target of 50 million tonnes by 2030, to be achieved through individual contributions of authorised oil and gas producers.

2.3 CO_2 transport infrastructure is crucial to connect emitters across Europe with storage

Some elements of the CO_2 Storage Directive cover CO_2 transport and the TEN-E regulation[32] focuses on CO_2 infrastructure development in a bottom-up process, via the development of projects of common interest (PCI). According to the TEN-E regulation, the selection process of cross-border CO_2 PCI candidates is based on a system-wide harmonised Cost-Benefit-Analysis methodology (CBA) established by the European Commission[33].

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[28] Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006 (Text with EEA relevance) (here).

[29] Reports on the implementation of the CO_2 Storage Directive (here).

[30] Zero Emissions Platform (2022). Experience in developing CO_2 storage under the Directive on the geological storage of carbon dioxide.

[31] More information can be found at the DNV website.

[32] Regulation (EU) 2022/869 of the European Parliament and of the Council of 30 May 2022 on guidelines for trans-European energy infrastructure, amending Regulations (EC) No 715/2009, (EU) 2019/942 and (EU) 2019/943 and Directives 2009/73/EC and (EU) 2019/944, and repealing Regulation (EU) No 347/2013 (here).

[33] Joint Research Centre (2023). Harmonised system-wide cost-benefit analysis for candidate cross-border carbon dioxide network projects: After Public Consultation 22 May 2023.

Rather than fragmented initiatives, there is a need to develop an overarching regulatory framework for CO_2 transport infrastructure with flexibility regarding implementation in Member States (this is further developed in chapter 4.1.1). The regulatory framework would support the development of a non-discriminatory, open-access, multimodal CO_2 transport network, would establish a clear legal and regulatory basis for planned projects, in particular for cross-border cooperation, and would enable coordinated CO_2 infrastructure planning, regional cooperation and harmonised standards on the transport part of the CCUS value chains (e.g., Monitoring Reporting and Verification, CO_2 quality specifications), in line with the CO_2 Storage Directive and the Monitoring and Reporting Regulation. This is further explored in the complementary report.

As noted above, most large-scale geological storage projects are currently concentrated in the North Sea, while CO_2 emitters are widely spread across Europe, including in hinterland areas far from the coast, requiring the development of corresponding storage capacity across Europe. Thus, there is a crucial need for European CO_2 transport infrastructure to connect dispersed emitters across Europe to storage facilities.

While technologies have reached a stage of maturity that allows the value chain to be implemented and operated, there are remaining challenges that can hinder the scale-up of CCUS to the levels that are needed for decarbonisation. The following chapters assess the main technical, regulatory and economic challenges faced by CO_2 transport and storage operators and proposes possible solutions. Importantly, while this report sought to be forward looking, it is important to note that experience is and will evolve with the ongoing and soon to start projects. These projects will allow the identification of new challenges/barriers and it is important that the European Commission keeps engaging with industry actors and leveraging on Europe’s science and innovation expertise to create favourable conditions for development and operation. Similarly, there is some experience on how to deal with some of the technical, regulatory, and economic issues identified. The different initiatives and programmes that are already in place should be reviewed as a way to identify possible learnings and best practices.

3. Technical dimension

This chapter presents the main technical barriers to large-scale deployment, focusing on the transport and storage components of the value chain. The chapter draws on WG discussions, notably, on the technical workshop held in February 2023 with the JRC, Fluxys and DNV, as well as on the findings by the CCUS SET-Plan Implementation Plan work[34].

3.1 Transport

CCUS projects, both cross-border and domestic, will rely on different modalities for the transport of CO_2 such as pipelines, rail, ships, barges, and trucks. While most of the CO_2 transport is currently done via pipeline, other transport modalities will become equally important (see boxes 1 and 2 below for an overview of ongoing work regarding CO_2 transportation).

The transport of CO_2 in a multi-modal, multi-origin, cross-border, fit-for-purpose and flexible open-access network will present technical challenges, as it will require handling CO_2 streams from different technologies and different sources[35]. Although initial transport projects and contracts will likely be between a given emitter and a specific sink, there is a need for standardisation of CO_2 specifications (gaseous and liquid), taking into account the different technologies and addressing matters such as composition, purity, pressures and temperatures, as well as standards for the design of pipelines, valves, ships, and other parts of the transport value chain (e.g., loading and off-loading). This will support interoperability and interconnections across Europe, across national borders and different transport modalities. As highlighted in a recent report[36], given the similarity between CO_2 phase behaviour and Liquified Petroleum Gas (LPG), existing standards for transport of LPG by ship can be a good starting point for liquified CO_2 and, potentially, for dual use shipping. Global standards are relevant for the application of CCS technologies to the exhaust gases of ships, which need to be able to unload captured CO_2 in ports all over the world.

Developing CO_2 transport networks will also involve dealing with complex issues such as liabilities for transport owners / operators, requiring entry/exit tracing of CO_2 sources and composition.

The development of CO_2 transport networks must consider connections to small and isolated emitters which are far away from CCUS/industrial clusters, as they account for a substantial proportion of global CO_2 emissions. As a direct connection to pipeline infrastructure may not be feasible for those emitters, viable alternatives can involve transporting CO_2 via low-pressure pipelines (in case of repurposed pipelines or unprocessed CO_2), truck or rail. While processing those CO_2 streams at central hubs (clusters) is likely to be an economically attractive option for small emitters and for CO_2 captured on board of ships, it also increases the transport challenges due to varying levels of impurities which leads to more complex phase behaviour of the unprocessed CO_2.

Box 1: JRC study on the evolution of a trans-European CO_2 transport network

[34] CCUS SET-Plan Implementation Plan work (2020/21): Report on key enablers and hurdles impacting on CCUS deployment with an assessment of current activities to address these issues, and CCUS Roadmap to 2030.
[35] Zero Emissions Platform (2020). A Trans-European CO_2 Transportation Infrastructure for CCUS: Opportunities & Challenges.
[36] Zero Emissions Platform & Carbon Capture and Storage Association (2022). Guidance for CO_2 transport by ship.

Following a mandate from the European Commission's Directorate General for Energy (DG ENER), the Joint Research Centre (JRC) is currently updating its study 'The evolution of a trans-European CO_2 transport network'. The study, which focuses on EU member states plus CO_2 storage options in the UK and Norway, will map optimal routes linking CO_2 sources to stores. By building a European sources-to-stores map, the study will provide a first indication of the potential routing of pipelines as well as of the potential volumes required for CO_2 transport by other transport modalities.

The report is expected to be published by the end of summer 2023.

Box 2: Developments on CO_2 transport by ship

CO_2 transport by ship is expected to be an essential component of the European transport network, with both inland and maritime shipping solutions having been identified by both cross-border and domestic CCS projects, including candidate projects to PCI/PMI status.

Recognising that further work is needed to describe the scope of CO_2 transport by ship in the future European transport market, the Zero Emissions Platform (ZEP) and the Carbon Capture and Storage Association (CCSA) set up a working group on CO_2 transport by ship which is developing a report to:

- Investigate the scope and trade routes for CO_2 transport by ship and their evolution over time, based on a European sources-to-stores map.
- Follow-up on interoperability and the work that is being done by the International Organization for Standardization (ISO), International Maritime Organization (IMO), and the Society of International Gas Tanker and Terminal Operators (SIGTTO), and identify potential elements that are not yet addressed by those organisations.
- Describe existing barriers to commercialisation and provide recommendations to address them.

The aims to provide companies, regulators, and decision-makers with greater certainty and facilitate the emergence of the market. So far, the work has resulted in the following early draft recommendations:

- European countries that are parties to the London Protocol to deposit a notice to provisionally apply the CO_2 export amendment with the International Maritime Organization (IMO) to enable cross-border CCS projects in Europe.
- Standardisation of ship-shore interface by the appropriate shipping organisation (SIGTTO), to enable compatibility, destination optionality and ultimately increase market competition.
- Standardisation of CO_2 specifications for shipping, liquefaction, and onshore storage to ensure compatibility and consistency between CCS projects *(see complementary report).* Acceleration of the cross-border CO_2 shipping transportation regulatory framework, including UK/EU/European Economic Area. Besides the ratification of the article 6 amendment to the London Protocol, progress could be achieved through country-to-country agreements and through mutual recognition and mechanisms for credits and liability transfer between the EU and UK ETS systems.
- Create the right business environment enabling multiple international CO_2 shipping providers to invest and offer services on a competitive basis.

- Develop effective safety and environmental footprint performance in early phases of CCS and CO_2 shipping as a pre-condition to License to Operate.

The report is expected to be published in autumn 2023.

3.2 Storage

This section describes current challenges regarding CO_2 storage, focusing in particular on:

- The types of storage
- The potential for CO_2 storage in Europe
- The stages of a typical CO_2 geological storage project

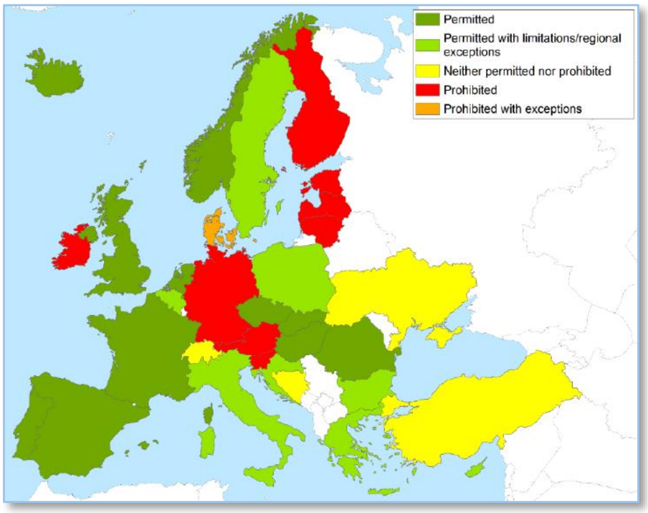

Figure 1 - Countries where CO2 storage is permitted and prohibited. Source: CO2GeoNet (2021). [State-of-play on CO2 geological storage in 32 European countries — an update](). Note: since the publication of the report, Denmark has changed its law, permitting storage.

3.2.1 Types of storage

A number of CO_2 storage options exist[37], such as storage in on- and offshore geological formations deep underground (including oil & gas fields and saline formations). When describing storage solutions, mineralisation should also be mentioned.

These options may operate under different timescales, present different characteristics, risk profiles, availability and implications for regulatory frameworks. It is important that these implications are duly considered, and that the regulatory approaches taken are in synergy with relevant EU pieces of legislation.

Deep saline formations or saline aquifers are expected to offer the largest CO_2 storage capacity[38]. These options are being explored in the North Sea, where Sleipner, Snøhvit, Longship, the UK East Coast Cluster and ACORN are either storing or planning to store CO_2 in saline aquifers.

Depleted oil & gas fields, especially in the North Sea have been and are being appraised by oil & gas operators and can be viable solutions to store large quantities of CO_2. Offshore storage is particularly suitable for countries where onshore storage is banned or may encounter public acceptance issues with onshore storage. In many European countries, mainly in the central, eastern, and south-eastern part of the continent, depleted and nearly depleted onshore oil & gas fields can offer early CO_2 storage solutions. The potential use of existing wells and surface facilities also presents cost saving opportunities for storage developers but can also raise issues related to the age of these facilities.

3.2.2 The potential for CO_2 storage in Europe, site appraisal and characterisation

[37] For an overview of types of CO_2 storage resources, see International Energy Agency (2022). CO₂ storage resources and their development: An IEA CCUS Handbook.

[38] Global CCS Institute (2022). Global Status of CCS 2022.

While there is no lack of potential for CO_2 storage in Europe, significant investments decisions are needed to transform this potential into marketable storage capacity. At the technical level, this involves supporting prospective storage promoters to swiftly identify suitable storage sites. Experience indicates that pre-competitive, publicly available, storage appraisal supports and increases the rate of the development of storage projects. Publication of a European Storage Atlas, providing detailed information on storage opportunities, will greatly support storage development. This can be supported by national initiatives, such as the storage atlas published by the UK and Norway.

The limited access to information has also been highlighted as a key barrier in site appraisal and characterisation. Thus, there is a need for competent authorities to outline a reliable pathway that enables the future storage operator to access non-confidential information and raw geological data required to undertake site appraisal activities (e.g., re-use of wells, well maintenance records, annulus pressure data, etc.).

While it is outside the scope of this work to identify a single best option to access crucial information for site appraisal, it is noted that this would benefit the development of storage sites in Europe and should be an integral part of a European Storage Atlas[39], to support investment decisions. The CO_2StoP database[40] provides pan-European coverage of CO_2 storage potential; however, as highlighted by a recent CO_2GeoNet report[41], new storage assessments and new data have become available in at least 25 European countries since preparation of the database and an updated and maintained European Storage Atlas would enable CCS project developers to identify storage resources for further appraisal and prepare for the development of larger storage capacities[42].

It is also noted that there are existing classifications systems aiming at reporting CO_2 storage resources and to understand the remaining actions that are required to advance from storage potential to stored CO_2. For example, the SPE SRMS[43] is a two-axis system (resource uncertainty and commerciality) following the approach taken by the oil and gas industry while the UNECE UNFC[44] is a more complex three axis system (economic and social viability, field project status and feasibility, and geological knowledge) applicable to all sorts of resources. Those classification approaches can be considered in the development of a European Storage Atlas.

3.2.3 The stages of a typical CO_2 geological storage project

Geological storage development is a prerequisite of the CCS value chain and is on average more time consuming than developing CO_2 capture. A geological storage project may take anywhere between 4 to 15 years to mature, involving many steps between inception and the start of injection, including the identification of storage resources, exploration and appraisal, licensing, signing up of emitters, and

[39] The ‘Storage Atlas’ concept is further developed in the CCUS SET-Plan Implementation Plan work (2022): Recommendations on the steps to establish a R&I Activity 4 European Storage Atlas.
[40] More information and maps with geological data can be accessed here.
[41] CO2GeoNet (2021). State-of-play on CO_2 geological storage in 32 European countries - an update.
[42] For more information on storage appraisal, see: Unlocking European CO_2 storage capacity: recommendations on the steps required to deliver target 7 of the SET Plan’s Implementation Working Group on CCS and CCU (2022).
[43] CO_2 Storage Resources Management System. Available here.
[44] More information about the UNFC system and UNFC documents available here.

securing transport connections[45]. Moreover, it is important to take into account site closure, including a clear understanding of regulatory and financial barriers and liabilities including after closure of site (stemming from the CO_2 Storage Directive and its Guidance Documents).

Building technical capacity and expertise within governments and competent authorities is crucial to streamline the licensing process and to the operationalisation of storage sites.

	Resource assessment	Design and development	Construction	Operation	Closure	Post closure
Timeframe (year)	2-6	1-5	1-3	20-50	Variable	10+*
Investment level	Medium to high	Medium	High	Low	Moderate	Very low
SRMS category	Prospective	Contingent to capacity	Capacity	On injection	Stored	Stored
Description	Process to identify and study CO_2 storage resources. Investment carries exploration risk since not every resource will be developable.	Project planning and design including FEED activities and permitting in advance of FID.	Post-FID activities, including site construction, connection to transport lines, expansion of MMV instrumentation and drilling of additional wells.	Period of time during which CO_2 is actively injected into the subsurface. This is commonly referred to as "on injection".	Period between cessation of injection activities and the granting of a closure authorisation.	Period of time after injection ceases where the CO_2 plume is still actively being monitored. Time during which site responsibility is transferred if applicable.

*Figure 2 - The stages of a CO_2 storage project. * Post-closure timeframes are jurisdictionally dependent and range from being unspecified to being over 50 years. Notes: FEED = front-end engineering design; SRMS = Storage Resource Management System. Assessment and development activities carry exploration risk and assessed resources may be defined as undevelopable or not commercially viable. Investment needs are relative to overall costs. Source: IEA (2022). [CO_2 storage resources and their development: An IEA CCUS Handbook]. Note: the figure, as shown here, depicts only part of the original figure in the IEA report.*

[45] For an overview of the regulatory landscape on CO_2 storage, see: Zero Emissions Platform (2022). [Experience in developing CO_2 storage under the Directive on the geological storage of carbon dioxide].

4. Regulatory dimension

This chapter focuses on the regulatory dimension, drawing on WG discussions, notably the regulatory workshop held in January 2023 with presentations from ENTSO-G and the Energy Transition Expertise Centre (EnTEC). The main conclusions and recommendations of the EnTEC study on the regulatory environment for CO_2 transport and storage infrastructure are presented in Box 3 below.

A stable policy and regulatory framework is key for the large-scale development of CCS and CCU within this decade. While industry is ready to deploy, the political support for the technology has not always been sufficient, leading to uncertainty and delays.

Box 3: EnTEC conclusions on a regulatory framework for CO_2 transport and storage infrastructure

The European Commission has commissioned a study from the Energy Transition Expertise Centre (EnTEC)[46] to analyse options for a regulatory framework supporting the development of the CO_2 transport and storage infrastructure as well as business models[47]. Notably, the study finds that emitters, despite being ready to invest in CCS, face uncertainties about the transport and storage possibilities. At the same time, transport and storage operators hold back on investing in future infrastructure capacity. The following key recommendations are presented, based on the identified challenges:

- Ensure adequate and future-proof capacity for transport and storage (T&S) infrastructure to allow access for all interested emitters.
- Support early development of large stores.
- Provide further regulatory guidance on CO_2 transport and CO_2 certification at EU-level to ensure harmonisation.
- Decouple the T&S network from emitters to ease contract development.
- Planning and developing infrastructure with a European Vision.
- National governments play a key role in streamlining project development.
- Support emitters that are located at large distances from storage hubs currently in development.

To support the development of CO_2 networks in an environmentally safe and secure manner, a best-available-technology approach (relevant to the risks associated with CO_2) is required (regulated by the Paris Agreement and the UNFCCC). Moreover, contracts between emitters, transport owners and operators, and storage and utilisation operators need to ensure a proper allocation of liabilities across the CO_2 value chain as well as tracking of CO_2 volumes.

The level of regulation will depend on the market, its maturity and size and may change over time while the network is developing. Developing a CO_2 network could be possible under different levels of regulatory intensity, reflecting the local/regional conditions. However, to prevent fragmentation, a minimum set of regulatory principles for CO_2 transport infrastructure such as transparent and non-discriminatory open access, should be established in the EU to provide Member States with a baseline

[46] Energy Transition Expertise Centre

[47] European Commission, Directorate-General for Energy, Bolscher, H., Guevara Opinska, L., Finesso, A. et al., (2023). EU regulation for the development of the market for CO_2 transport and storage.

to build on, while securing equal access and transparent cross-border transportation in order to support the internal market structure.

The first question to ask is if there would be a natural monopoly or not. For a pipeline network this would likely be the case, depending on competition from other transport modalities. The second question is if the monopoly would need to be regulated – for example with a regulated tariff and third-party access terms. Where tariffs for onshore pipelines are regulated at national levels, EU regulation should establish a common framework – like for natural gas. Ship or truck transportation could be fully commercial business depending on the local circumstances.

If the future CO_2 pipeline network would be regulated, there are two main options for open access and openly published procedures:

- nTPA - where the conditions are specifically determined by the infrastructure operators
- rTPA - where the conditions are determined by the National Regulatory Authority (if applicable, also for tariffs based on regulated revenues).

Different regulatory approaches can co-exist in the EU, reflecting the local/regional conditions. Gas Transmission System Operators (TSOs) are open to all options supporting CCS/CCU and CO_2 pipeline transport developments. As infrastructure operators, TSOs can enable the green transition, are fit to transport CO_2, and can take advantage of existing gas pipelines for CO_2 transport (not excluding build-up of new pipelines in duly justified cases).

Multiple storage sites are being developed across Europe and these will per definition compete with each other. The basis for competition on CO_2 storage is a Europe-wide market that is unbundled from the transport infrastructure. Consequently, access to storage should be based on publicly available tariffs from different storage operators in order to ensure the development of a competitive and efficient Europe-wide CO_2 storage market. Offshore CO2 pipelines should be compared with 'upstream pipeline networks' in the natural gas market and a EU regulatory framework should be comparably 'light touch'(with transparent, non-discriminatory access terms being in place.

Cross-border transport of CO_2 for offshore storage is regulated under the London Protocol of the International Maritime Organisation (IMO), namely, Article 6. Since 2019, a provisional solution (i.e., pending entry into force of the 2009 amendment to Article 6) allows CO_2 export for sub-seabed storage for countries that enter into bilateral IMO agreements. In the European Economic Area (EEA), a simplified process may apply, according to a recent analysis paper[48] published by DG CLIMA. Under this process, a notification to the IMO would be sufficient for the export of CO_2 for sub-seabed storage. However, the legal status and implications of the analysis paper, and which aspects that can still be dealt with via bilateral treaties in the EEA, must be clarified. Furthermore, incentives to ratify the 2009 amendment must be maintained, allowing its entry into force and enable CO_2 cross-border flows for offshore storage, also connecting countries outside of the EEA.

Legal frameworks should enable the development of a competitive and efficient Europe-wide market, by enabling access to storage opportunities across the EU, its EEA partners and the UK. As an example, the UK part of the North Sea has a large potential for CO_2 storage that can be an alternative competitive option for emitters in the EEA. In this context, the recognition of CO_2 exported to the UK for permanent storage under the EU ETS system (and vice versa) would facilitate CO_2 flows between

[48] Commission services analysis paper for the Information Exchange Group (IEG) under Directive 2009/31/EC. Available here.

the EU and the UK and unlock access to competitive storage options for emitters. The above-mentioned analysis paper maintains that the exception to surrendering emission allowances does not apply to EU ETS installations that export CO_2 for storage outside the EEA (e.g., the UK). Such a legal landscape could effectively create an obstacle to the development of a wider (European) market for CO_2 transport and storage and should be carefully assessed and further clarified.

4.1 Transport

4.1.1 A regulatory framework for CO_2 transport infrastructure

As stated in previous chapters, the European Commission should develop a regulatory framework for CO_2 transport infrastructure, focused on the development of non-discriminatory, open access and multi-modal CO_2 transport infrastructure with flexibility for the member states to adopt further regulation to accommodate national market developments and ownership models[49]. Such a regulatory framework would complement the CO_2 Storage Directive and establish a legal and regulatory basis for all planned projects, domestic and cross-border. This is essential to provide a degree of predictability for long-term investments.

A regulatory framework should include the following elements:

- *CO_2 infrastructure network operator*

  Deployment of new CO_2 transport corridors and networks would benefit from integrated planning and consultation processes, in a similar way to those established for the gas, electricity sectors (ENTOS-E and ENTSO-G) and to be established for the hydrogen sector based on the final outcome of the Hydrogen and Decarbonised Gas Package. An equivalent entity for CO_2 – incorporating emitters, transport providers and utilisation and storage operators and with a mandate to consider value-chain regulatory issues and make recommendations to the European Commission – would enable coordinated CO_2 infrastructure planning, network design, and facilitate cross-border cooperation, thereby supporting the deployment of new CO_2 networks. As an existing example, ENTSOG has shown long term experience in planning and preparation of network codes for gas transportation, and possible synergies should be investigated. This entity could address regulatory and permitting barriers and promote relevant standardisation across the value chain, including on CO_2 quality specifications and shipping of CO_2.

- *The CCUS Forum as an EU regulatory and stakeholder forum for CO_2 networks*

  The CCUS Forum can act as the body to take stock of the experience developed under a regulatory framework, in a similar approach to that of the Madrid Forum for Gas and the Florence Forum for Electricity. A joint approach to developing Forum Conclusions can be helpful in achieving transparent alignment on the work programme. The Forum would be well placed to provide recommendations to national and European policy makers, supporting progress on specific regulatory / policy challenges.

- *Integrated network planning*

[49] Zero Emissions Platform (2021). ZEP proposal for a regulatory framework for CO_2 transport infrastructure

An important element under the Hydrogen and Gas Decarbonisation Package proposals is fostering integrated network planning and interaction between the electricity, gas and hydrogen sectors, in order to promote flexibility and resilience in the EU energy system. Work to integrate the role and scope of CO_2 transport infrastructure into energy network development planning, such as the 10-year network development plans (TYNDP), could be undertaken as part of a regulatory framework for CO_2 transport infrastructure. This scope could cover both localised CO_2 grids (e.g., in coastal areas / ports) and cross-border / regional CO_2 backbone infrastructure.

As established by the TEN-E, network planning shall involve a participatory approach, whereby all relevant stakeholders, including CO_2 infrastructure stakeholders and civil society organisations, are invited to provide input through consultation.

- *Regional cooperation*

A regional approach for discussions around CO_2 infrastructure could trigger more efficient infrastructure cooperation and deployment, with a particular focus on integration between cross-border CCUS systems. This could be facilitated by the European Commission and policy makers in Europe, either under the CCUS Forum or as part of any new platform for CO_2 infrastructure, as included in the TEN-E regulation.

Planning and investment in infrastructure can be supported by regional development organisations, functioning as market makers, sitting between industrial CO_2 sources and CO_2 users and stores. Such organisations would coordinate development and take responsibility for risks[50].

- *Public perception and acceptability*

The development and construction of new, large and costly infrastructure often faces challenges regarding public acceptance. Mechanisms and best practices for inviting public consultation and integrating feedback into CO_2 transport infrastructure planning, including the development of guidance on public engagement and support for new and repurposed infrastructure, will be an important element of the broader policy framework and must be integrated into the scope of the CO_2 infrastructure network operator.

- *Flexibility of approach*

Experience in CCUS is evolving, with potential for innovation to drive efficiency, cost reductions and enhance integration. For this reason, regulatory flexibility – while prioritising environmental integrity – must be preserved, such that CO_2 infrastructure providers and operators are not faced with unnecessary complexity, investment gaps not covered by users or public policy, and costs that are detrimental to efficient project implementation. The regulatory sandbox approach under the Innovation Fund could serve as a testing ground for approaches that could then be supported more broadly under the regulatory framework for CO_2 transport infrastructure.

Moreover, it is important to ensure that an EU regulatory framework for CO_2 transport does not create barriers for projects that were initiated under a different legislative setting. Regulatory sandboxes – can also play an important role to encourage research and development. Costs for

[50] Bellona Europa (2016). Manufacturing Our Future: Industries, European Regions, and Climate Action.

this would be taken into account by the National Regulatory Authority as necessary infrastructure investment.

Regulatory support schemes could be envisaged also to cover the residual investment gap for operators and pipeline owners not covered by (initial) CO_2 users (e.g., via CO_2-connected funds facilities, like ETS allowance funds). Flexibility at Member State level might be required to address the funding gap (not restricted to public funding schemes – like ETS allowance funds or other supporting mechanisms – like CCfDs or CfDs).

- *Supporting delivery of Trans-European Network provisions on CO_2 infrastructure and NECPs*

  Recent integration of CO_2 storage into the TEN-E Regulation and incorporation of CCUS in National Energy and Climate Plans (NECPs) has helped to better support the role of CCUS in achieving decarbonisation targets in Member States and at the EU level. The Hydrogen and Decarbonised Gas Market Package contains provisions to assist Member States with implementation of the hydrogen provisions of TEN-E, as well as supporting delivery of the hydrogen components of the NECPs. Since CO_2 infrastructure is a part of the revised TEN-E regulation as well as a number of NECPs, a similar link should be established between the regulatory framework for CO_2 infrastructure and achieving the CCUS elements of the new TEN-E/ NECPs, in order to support successful delivery.

- *Facilitating sharing of best practices at EU level*

  The cross-border transport of CO_2 and the coordination of CO_2 streams from different sources brings about technical challenges. Facilitating the sharing of best practices at EU level is needed to address existing differences in technical requirements with regards to the construction and characteristics of pipelines for cross-border pipeline projects.

4.1.2 Multi-modality

CO_2 infrastructure projects require that all existing legislation – such as the TEN-E regulation, TEN-T Regulation and EU ETS Directive – have an adequate extended scope to prepare for the rollout of large-scale, shared CO_2 infrastructure. The EU Taxonomy recognises all modes of CO_2 transportation – pipeline, ship, barge, rail, truck. This outcome is critical and should be preserved and reflected in all revised relevant legislation, as it will allow near-ready CO_2 transport and storage projects to be realised and to create opportunities for numerous CO_2 emitters throughout the EU/EEA area to have access to low-cost decarbonisation pathways.

4.1.3 Standards/network codes

Developing a common understanding of specifications for CO_2 transport is crucial to ensure that the CO_2 transport network is safe, cost-efficient, interoperable, and accessible to industrial emitters of different sizes. The development of standards would thus complement the regulatory framework for the transport of CO_2.

Point-to-point connections, where large emitters are directly connected with sinks, can define their own specifications regarding the characteristics of the transported CO_2 (pressure, temperature, impurities, etc.).

Developing an open-access multimodal European transport network, on the other hand, requires an agreed international network code that specifies CO_2 characteristics for the different transport modes. Requirements related to permanent storage must be considered if they exceed the requirements of the transport infrastructure (for instance, regarding allowable impurities). The specification of CO_2 characteristics should provide the lowest possible costs, taking into account the entire chain from capture to storage as well as different CO_2 applications. Specifications should be based on verified knowledge and must be stricter when scientifical evidence cannot provide sufficiently accurate answers to ensure safety.

With this in mind, the European Commission has set up an expert group on CO_2 specifications in early 2023 to complement the work of the CCUS Forum working group on CO_2 infrastructure and provide clear recommendations on specifications for CO_2 transport. Recognising that existing standardisation bodies like the International Organization for Standardization (ISO) are well placed to establish standards, the objective of the expert group was to:

- provide clear recommendations on specifications for CO_2 transport, focusing on CO_2 composition, pressure, purity and temperature;
- summarise the knowledge base on which stakeholders can base their convergence efforts for a network code;
- identify potential knowledge gaps and recommend research efforts, leveraging on previous work[51].

The recommendations and findings of the expert group can be found in the complementary report of the CCUS Forum expert group on CO2 specifications.

4.2 Storage

As noted in chapter 2.2, the European Commission's proposal for a NZIA introduces an annual CO_2 injection capacity target of 50 million tonnes by 2030. While this is crucial to the development of CO_2 storage capacity in Europe, there is a strong consensus that the NZIA should be carefully amended to ensure that the storage injection capacity objective can be achieved. This for instance means, first of all, adopting a value chain approach so as to ensure that the CO_2 capture and transport infrastructure are developed in parallel with storage to avoid the so-called 'chicken and egg' challenge. This would mean including CO_2 transport and considering CO_2 capture and transport in addition to CO_2 storage as net zero strategic projects with facilitated provisions regarding infrastructure planning and permitting.

In addition, the development of the CCS market in Europe would benefit from further long-term predictability, going into the post-2030 period, the NZIA could help to facilitate this by including the possibility to set new CO_2 injection capacity targets for the period post-2030. This should be done in

[51] See, for example, IOGP (2022). Gap analysis of standards and guides for carbon capture, transport, and storage.

close consultation with stakeholders and building on the findings of the impact evaluation of the initiative.

As described in chapter 3.2 above, different types of on- and offshore storage sites exist and their different characteristics, risk profiles, and availability must be duly considered under the regulatory framework.

Regulatory challenges related to storage concern both EU and national legal frameworks. The following paragraphs describe the challenges that have been identified and reflect the evidence gathered in a recent ZEP report[52].

Permitting processes tend to be quite lengthy and complex in most EU member states, usually taking between 18 months and 2 years (compared to 6 to 9 months in the UK). Besides providing guidelines to speed up permitting – while maintaining environmental safeguards – the EU can improve the current permitting procedures by striving to provide a timely opinion for Member States' licensing decisions.

In addition, there should be an increased number of regular permitting and licensing rounds in Member States to increase the potential for storage site development and support the achievement of the CO_2 injection capacity objective set out in the NZIA.

More guidance is also needed on the transfer from oil & gas operations to CO_2 storage operations in hydrocarbon fields. There might be an incompatibility between operators' preference for rapid removal of an oil and gas platform, due to high maintenance costs and/or regulatory requirements, on the one hand, and the desire to adapt multiple platforms, pipelines, and wells for CO_2 storage service in an orderly manner, on the other. Notably, guidance is needed on transfer of liabilities as well as on the role of the different stakeholders – competent authorities, owners, and future developers – during the transfer process.

There is also a need for clarity about converting producing hydrocarbon fields to CO_2 storage reservoirs. While early CO_2 storage projects in (offshore) depleted hydrocarbon fields start injection after the end of oil or gas production, there may be advantages in merging the tail end of hydrocarbon production with the first phase of CO_2 injection in cases where this is an option (not including EHR). For access to new geological CO_2 storage capacity, it could be helpful to assess the synergies and potential mutual relevance of the EU Hydrocarbons Licensing Directive[53] and the CO_2 Storage Directive, supporting access to information and site characterisation, and provide clarity regarding the risk allocation between the oil & gas and storage operators.

Early engagement between competent authorities and project promoters is needed to provide clarity (e.g., on the required level of detail in the interim documents/plans, including the criteria for the demonstration of permanent storage which should be agreed with operators on a case-by-case basis) and guidance where needed, avoiding misunderstandings and delays. Moreover, ongoing interactions and discussions between project operators and competent authorities have been identified as critical to the success of CCS projects.

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[52] Zero Emissions Platform (2022). Experience in developing CO_2 storage under the Directive on the geological storage of carbon dioxide.

[53] Directive 94/22/EC of the European Parliament and of the Council of 30 May 1994 on the conditions for granting and using authorizations for the prospection, exploration and production of hydrocarbons. Available here.

Financial securities for storage sites can vary considerably depending on the interpretation of regulations and can be particularly prohibitive for smaller operators. It is crucial to assess how private investors and governments could share long-term CO_2 storage risks. A number of countries (e.g., the UK and Norway with the Longship project) have developed options that enable risk-sharing and transfer of liabilities between storage developers and regulatory authorities. Possible avenues that could be pursued include national funds for pooled liabilities for storage resources, international funds for cross-border transport liabilities, creating a post-closure company, and insurance systems, based on a robust and independent review of risks.

The ongoing review of the CO_2 Storage Directive Guidance Documents provides an opportunity to address these issues and challenges. Moreover, there is an opportunity to share learnings and identify best practices from licensing procedures that have already been conducted. Building knowledge and capacity within competent authorities will also be crucial to streamline project development.

5. Commercial models and considerations on funding mechanisms

This chapter draws on the discussions held in a workshop dedicated to business models and funding frameworks, held in February 2023, with presentations from the Netherlands and IOGP Europe framing those discussions.

5.1 Commercial models

CCUS value chains typically include multiple separate business entities such as industry emitting, capturing and processing CO_2, infrastructure operators transporting CO_2 (whether through pipelines or by other modes), operators managing interim storage (e.g., ports), entities aggregating CO_2 flows from multiple emitters, CO_2 storage operators and CO_2 users. Successful deployment of CCUS at scale will depend on the ability to put in place commercial solutions that balance risks and rewards along the full value chain, underpinning and de-risking the needed investments.

When developing commercial models and de-risking measures, there are two key commercial risks that should be carefully considered: *price risks* and *volume risks*. These risks are explored in the subsequent sub-chapters.

5.1.1 Price (variation) risks

For CO_2 emitters, the value of capturing, transporting, and storing CO_2 largely depends on the alternative cost of emitting CO_2. The costs of emitting CO_2 have historically been relatively low (aided by free allocation of EU ETS allowances), thus not driving sufficient investment in CO_2 capture. However, prices have increased and become more volatile over the past years. De-risking the investment in CO_2 capture suggests the need for business models which can guarantee stable revenue streams over longer time periods, e.g., a possibility for emitters to enter carbon contracts for difference (CCfD) with an entity which can assume the corresponding price risk and guarantee investors stable returns on their investments. Such entity could be at Member State or EU level.

Similarly, companies transporting and/or storing CO_2 typically require some form of long-term commitment to guarantee their revenues and thus be able to invest in the corresponding infrastructure. Since long-term agreements can be commercially difficult to achieve, there is as in any market, an interest for and from aggregating stakeholders – that takes on risk by entering into a contract with the transport or storage operators on behalf of CO_2 from emitters – to engage.

5.1.2 Volume (certainty) risks

CO_2 emitters that wish to invest in CO_2 capture and linked processing facilities will likely require certainty over the possibility to dispose of the captured CO_2 over the lifetime of the emitting asset. The emitters may, at the same time, not possess the certainty to guarantee the supply of captured CO_2 over a period longer than a few years, due to circumstances outside of their own control. This may result in a mismatch, where emitters are only able to commit for shorter periods than those required by investors in transport and storage infrastructure. Entities in the value chain (e.g., an aggregator) that are exposed to this mismatch risk may find the need to establish de-risking mechanisms with external bodies before concluding commercial agreements with emitters, transport companies and/or storage operators.

These de-risking mechanisms can be set up in many different ways, where the default option is to let each component of the value chain develop a market-based hub/pool/exchange to connect and secure demand and supply. One other option – similar to the EU Energy Platform – includes the role for a fit-for-purpose regulated entity to take on the main commercial risks and be in charge of de-risking individual businesses: contracting CO_2 emitters to create demand, transport companies to underpin their investments, and storage operators thereby underpinning their investments.

5.2 Funding mechanisms

Funding mechanisms need to address the different commercial risks along the value chain and over the projects' lifetime. There are already several existing EU funding mechanisms that can contribute to the development of a European CO_2 transport and storage infrastructure network[54]. It is crucial that these funding mechanisms – and additional funding and de-risking mechanisms yet to be established – are coherent and coordinated both across funds and between the EU and national levels, for targeted and efficient deployment[55].

5.2.1 Existing funding mechanisms

The EU ETS Innovation Fund is the most relevant EU funding programme for CO_2 infrastructure projects, with many such projects already being funded through both its small- and large-scale calls. The Connecting Europe Facility (CEF) is also a key EU funding instrument supporting the development of cross-border energy and transport infrastructure projects. The TEN-E regulation and CEF funding has already proved instrumental in financing pioneer midstream CO_2 transport infrastructure (e.g., terminals in Antwerp, Ghent, part of Northern Lights). In addition, Horizon Europe provides funding for technologies at an early stage of development, including specific calls for CO_2 transport and storage demonstration projects, specific CCS and CCU industrial applications, and DACCS and BECCS[56].

While the Innovation Fund can fund CCS and CCU projects through its general call topics, investors in these technologies would benefit from separate funding windows. This would simplify the application process and avoid timing issues when establishing back-to-back contractual rights and obligations between the different actors in the value chain. Introducing the possibility of sequenced funding for CCS projects should also be considered to address 'chicken and egg' challenges – i.e., to enable the development of CO_2 transport and storage infrastructure so this can be ready for usage by CO_2 capture projects. This upfront investment can protect large-scale investments in CO_2 capture projects, as also noted by the EnTEC study mentioned earlier in the report.

The description of innovation, as an eligibility criterion, could also be broadened to recognise innovation beyond the technology itself, by considering the application of technologies to different sectors, commercial / value chains and regions.

Given the critical need for CO_2 storage and the experience collected from Innovation Fund calls, the European Commission should assess other funding possibilities for infrastructure projects, particularly

[54] Bellona Europa (2018). An industry's guide to climate action.

[55] The Just Transition Platform, managed by DG REGIO, which includes working groups relevant to CO_2 infrastructure, can provide a good basis for such coordination. More information about the Platform can be found here.

[56] The Horizon Europe Work Programme 2023-2024 can be consulted here.

during this year's mid-term review of the Multi Financial Framework and the future preparation of the post 2027 EU funding programmes. Other funding programmes, such as the LIFE Programme, the Modernisation Funds, regional ERDF Programmes and Next Generation EU Funds (distributed by Member States' Recovery and Resilience Plans), should also enable the possibility to fund CCS and CCU projects.

There can also be lessons to be learned from successful funding mechanisms for other low-carbon technologies. Examples include the Hydrogen Bank and the new competitive bidding mechanisms included in the Innovation Fund. The evaluation of those initiatives and learnings could prove useful in establishing the suitability of supporting CCS and CCU projects through equivalent mechanisms.

At the same time, it is important to recognise that Member States will have a very important role to play in supporting CCS and CCU projects through their own support schemes, where also CCfD models can be explored. Coordination between national and EU level support schemes is crucial and can be addressed through EU legislation in order to make the most of potential synergies.

5.2.2 Additional funding /de-risking mechanisms

De-risking long term revenue streams for investors along the CCUS value chain beyond the initial projects phase and thus supporting a fast scale up requires measures which address both price (variation) risk and volume (certainty) risks. Tools that can successfully achieve this include CCfDs, private-public partnerships, blended financing schemes and project development assistance funding.

5.2.3 Liability risks

CO_2 and related liabilities need to be clearly defined and clarified across the different entities along the value chain. In particular, it must be ensured that liabilities are transferred once CO_2 injection operations cease. Uncertainty on liabilities can create commercial risks and consequently increase costs to investors. Referring to the CO_2, liabilities and allowances under the EU ETS must all be aligned, including, where appropriate, the development of optimised or new financial security instruments.

5.2.4 Other funding considerations

The European Commission should support cross-border transport of CO_2 to enable access from emitters in one country to storage sites in another, thereby supporting the fast scaling up of CCUS value chains. Hurdles associated with multi-country funding and/or state aid guidelines should be reviewed and adjusted to allow and facilitate the creation of cross-border value chains.

Support learnings from initial projects, for example, by providing incentives for the funding of first-generation infrastructure projects to develop targeted research on open questions so as to support the economics and environmental benefits of next generation infrastructure.

The development of business models and potential tariffs should reflect the different risks and conditions along the CCUS value chain. For instance, in the case of remote sites it will be important to ensure that the decarbonisation remains possible at an affordable cost for emitters.

Experience developed with financing tools outside of Europe (e.g., the US 45Q) can also provide important insights that can feed into the development of financing mechanisms in Europe.

6. Guidance for Governments and NECP revision

The most recent Guidance[57] published by the European Commission in December 2022 provides clear guidance for Members States to include capture, transport and storage of CO_2 in their National Energy and Climate Plans (NECPs). Draft NECPs cover energy and climate plans to 2030[58], whereas long term strategies cover the period until 2050[59]. It is notable that CCUS is included in fewer NECPs than long term strategies. Strategic development of European transport and storage infrastructure for CO_2 could help bridge this emerging gap between expected need for storage and current projects[60] and provide the required step change in the deployment of these technologies. In this context, the working group welcomes the inclusion in the latest European Commission Guidance for updated NECPs 2021-2030[61] of a section, recommending to Member States to include in their updated NECPs the efforts planned towards capture and storage of CO_2.

To complement this process, it will be crucial to focus on building capacity at the national, regional, and local level, as well as on awareness raising among national and regional administrations. Capacity building of competent authorities will be crucial to mitigate current and potential future bottlenecks as well as to reduce unnecessary delays as more CCS projects come into play. This includes staff recruitment and staff training on CCS. National governments and competent authorities need to ensure that sufficient resources are built up to work on new CO2 storage applications linked to the CO_2 storage injection target proposed in the Net-Zero Industry Act. This process should also ensure that the CO_2 Storage 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.

Raising awareness and understanding of the technology is crucial. The IPCC Sixth Assessment Report, 'Climate Change 2022: Mitigation of Climate Change' stated that the public is largely unfamiliar with CCUS, and that strong local resistance can contribute to the cancellation of CCS projects.

Limited incentives to accelerate societal support represents another significant risk. Member States, European policymakers and all relevant stakeholders must collaborate to ensure that there is a robust understanding of public perception regarding the development of storage infrastructure and that acceptability is not threatened by false perceptions or confusion. Opposition from local communities represents a legal risk that should be taken into account. Therefore, early engagement with local communities by trusted and reputable entities raising awareness and reinsuring the public on the CCUS technologies could help improve public perception and understanding of CCUS.

[57] European Commission (2022), Commission Notice on the Guidance to Member States for the update of the 2021-2030 national energy and climate plans here.
[58] More information about the NECPs and the Member States' NECPs can be found here.
[59] More information about the long-term strategies and the Member States' national long-term strategies can be found here.
[60] The Carbon Sequestration Leadership Forum (2021). 2021 Carbon Sequestration Technology Roadmap.
[61] European Commission (2022). Communication and annex - Guidance to MS for updated NECPs 2021-2030.

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8. Glossary/Definitions

BECCS – Bioenergy with carbon capture and storage refers to the combustion or conversion of biomass with carbon capture and storage. Depending on the total emissions of the BECCS supply chain, carbon dioxide (CO_2) can be removed from the atmosphere.

CCS – Carbon capture and storage refers to the capture (separation) of carbon dioxide (CO_2) from various sources, followed by its transport and injection into a suitable underground geological formation for the purposes of permanent storage.

CCU – A process in which carbon dioxide (CO_2) is captured and the carbon then used in a product.

CCUS – Carbon capture, utilisation and storage encompasses the suite of technologies used to capture, transport, utilise, and store CO_2, including CCU, CCS, BECCS, and DACS, for the purposes of emissions reduction or CO_2 removal from the atmosphere.

CDR – Carbon dioxide removal refers to anthropogenic processes which remove CO_2 from the atmosphere and durably store it in geological, terrestrial, or ocean reservoirs, or in products. Also referred to as negative emissions.

Cluster – Multiple carbon dioxide emitters geographically located near each other, sharing CO_2 transport and storage infrastructure.

CO_2 Storage Directive – Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006 (Text with EEA relevance).

DACCS – Direct air carbon dioxide capture and storage is the separation of CO_2 from ambient air followed by permanent geological storage. DACCS is a CO_2 removal technology, provided value chain emissions are accounted for.

Isolated emitters – Carbon dioxide emitters that are distant from CCUS/industrial clusters, ports, and other CO_2 transport modes.

LCA – Life cycle assessment, a methodology to evaluate the environmental impacts of a product or process throughout its life cycle.

Open access / third-party access – in accordance with Chapter 5 of the CO_2 Storage Directive, open access or third-party access is here conceptualised as the guarantee that "potential users are able to obtain access to transport networks and to storage sites for the purposes of geological storage of the produced and captured CO_2" and that such access "shall be provided in a transparent and non-discriminatory manner".

Technology-based removals (also called engineered removals) encompasses technologies such as DACCS and BECCS, as opposed to nature-based removals.

ANNEX 1: Working group members

Members of the CCUS Forum working group on CO_2 infrastructure include stakeholders from industry, energy, utilities, technology and equipment suppliers, researchers, and environmental NGOs. This report benefitted from the active engagement and the input of these various members, who kindly contributed with their useful comments and materials. Some of the contributing organisations listed below also contributed to the report of the CCUS Forum expert group on CO_2 specifications.

Co-chairs

- Bellona Europa
- International Association of Oil & Gas Producers (IOGP)
- Zero Emissions Platform (ZEP)

Contributing organisations

- AB Achema
- Agora Energiewende
- Air Liquide
- Air Products
- Airfix
- Aker BP
- Aker Carbon Capture
- Altera Infrastructure
- ArcelorMittal
- Association of the Austrian Cement Industry
- AxcelFuture
- Baker Hughes
- Bastas Cement
- Bellona
- Bellona Deutschland
- BKC MAKINA AS
- Bond Beter Leefmilieu
- bp
- BrinkmannGroup
- British Geological Survey
- Carbon Capture Cluster Copenhagen
- Carbon Clean
- Carbon Gap
- Carbon Limits
- carboneer
- carbonengineering
- CarbonGeo/ CCUS Norway
- Carmeuse Europe
- CCS management/MOL

- Carbon Capture & Storage Association
- Cefic
- CEMBUREAU
- Centre for Energy and Natural Resources Innovation and Transformation
- Confederation of European Waste-to-Energy Plants
- Chevron
- Ciaotech
- CIMPOR/ATIC
- CINEA
- Clean Air Task Force
- Clean Energy Ministerial
- ClientEarth
- CO2 Management AS
- CO2 Value Europe
- CO2GeoNet
- Coalition for Carbon Capture
- Confederation of Norwegian Enterprise
- Corporate Department of Regulations and Public Affairs
- Crédit Agricole Corporate and Investment Bank
- CRH
- CVE
- Czech Geological Survey
- Danish CCS alliance
- Danish Energy Agency
- Danish Ministry of Energy and Climate
- DanishShipping
- Dansk Fjernvarme
- DC & P GmbH
- Department of Climate Change, Energy, the Environment and Water (Australia)
- Directorate-General for Climate Action (European Commission)
- DGMK e.V.
- Dioxycle
- Dow
- Drax
- E3G - Third Generation Environmentalism
- EBN / Aramis project
- EBRD
- EcoEnergy
- European Energy Research Alliance (EERA)
- EFTA Surveillance Authority
- eFuel Alliance
- EIB
- enagas

- Endrava
- Eni
- ENTSOG
- EPCM Global Engineering
- Equinor
- Equinor & Offshore Norway CCS Forum
- ERCST
- ETH Zürich
- EuLA - The European Lime Association
- EUROFER
- Eurogas
- EUROPA Danismanlik
- European Parliamentary Research Service
- EUTurbines
- Evida
- ExxonMobil
- ExxonMobil Low Carbon Solutions
- fetsa
- Flemish Energy and Climate Agency
- Fluxys
- FSR
- Galiboff
- Gas Infrastructure Europe
- Gassnova SF
- Gasunie
- General Electric
- GEOMAR Helmholtz Centre for Ocean Research Kiel
- German Energy Agency (dena)
- German Federal Minsitry of Economic Affairs and Climate Action
- German Institute for International and Security Affairs (SWP)
- Germanwatch
- Global CCS Institute
- Göteborg Energi
- grtgaz
- Heidelberg Materials
- Heirloom Carbon
- Holcim
- Horisont Energi
- Innovation Norway
- Institute of Building Materials Research / RWTH Aachen University
- Interconnector Limited
- IOM Law
- Istanbul Technical University

- Italcementi
- Izmir Institute of Technology
- Izmir Katip Celebi University
- Johnson Matthey
- European Commission’s Joint Research Centre (JRC)
- KBR
- Klaipėdos nafta
- Klimarepublik
- Konya Technical University
- Korean Embassy
- MCi Carbon
- Middle East Technical University
- Ministry of Climate and Environment of Poland
- Dutch Ministry of Economic Affairs and Climate Policy
- Dutch Ministry of Economic Affairs and Climate Policy
- Ministry of Environment and Spatial Planning of Slovenia
- Ministry of Transport of Baden-Württemberg
- Mission of Norway to the EU
- Mitsubishi Heavy Industries EMEA
- nabu
- NABU NRW
- Negative Emissions Platform
- Neptune Energy Germany
- Nippon Gases
- Norsk e-Fuel AS
- Norsk Hydro
- North Denmark EU Office
- Northern Lights
- Norwegian Energy Partners
- Norwegian Ministry of Petroleum and Energy
- OGE
- OMV Petrom
- Open Grid Europe
- PGS
- PNO
- Port of Aalborg
- Port of Gothenburg
- Porthos
- Prime marine
- Renova
- Repsol
- Return Carbon
- RHI Magnesita

- RITE
- Romanian National Agency for Mineral Resources
- romgaz
- Ruhr University Bochum
- RWE
- RWE Generation SE
- Sandbag Climate Campaign
- Shell
- Sia Partners
- Silesian University of Technology
- SINTEF
- Sivas Cumhuriyet University
- Snam Spa
- South Scania Waste Company
- Stockholm Exergi
- Svante
- Swiss Federal Office for the Environment
- Swiss Federal Office of Energy
- TANECS Engineering Consultancy Inc
- Teréga
- TES-H2
- Danish Ministry of Climate, Energy and Utilities
- The Energy House
- The Norwegian Ministry of Petroleum and Energy
- TNO
- TotalEnergies
- Tree Energy Solutions
- Tübitak Mam
- Uniper SE
- University of Belgrade - Institute of Chemistry, Technology and Metallurgy
- University of Manchester
- University of Stavanger
- University of Western Macedonia
- VDZ
- VDZ Technology
- Wien Energie
- Wintershall Dea
- Wintershall Dea Norge
- Wintershall Noordzee
- WiseEuropa
- WWF EPO
- Yara
- Yıldız Technical University - Economics Department