European Commission

ENTEC

Energy Transition Expertise Centre

EU regulation for the development of the market for CO_2 transport and storage

Report – EU regulation for the development of the market for CO_2 transport and storage

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Prepared for
European Commission, DG ENER under contract N° ENER/C2/2019-456/ SI2.840317

Published: May 2023

PDF	ISBN 978-92-76-99419-0	doi: 10.2833/093881	MJ-05-23-015-EN-N

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This report was created by the Energy Transition Expertise Center (EnTEC), a think tank collaboration with DG ENER. The report draws on multiple sources, including Fraunhofer Institute for Systems and Innovation Research ISI, TNO and Trinomics. EnTEC are responsible to DG ENER for the conclusions and recommendations of the research. The information and views set out in this report are those of the author(s) and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein.

Acronyms used in this Report

Acronym	Description
BECCS	Bio-Energy Combustion Plants
BEIS	Department for Business, Energy and Industrial Strategy of the government of the United Kingdom
CA	Competent Authority
CAN	Canada
CAPEX	Capital Expenditure
CarbonSAFE	Carbon Storage Assurance Facility Enterprise
CBAM	Carbon Boarder Adjustment Mechanism
CCS	Carbon Capture and Storage
CCU	Carbon capture and utilisation
CCUS	Carbon capture, utilisation and storage
CEE	Central Eastern Europe
CEF	Connecting Europe Facility
CEPA	Canadian Environmental Protection Act
CfD	Contracts for Differences
CIF	Carbon Capture and Storage Infrastructure Fund
CIFIA	CO_2 Infrastructure Finance and Innovation Act
DACCS	Direct Air Carbon Capture
DKK	Danish Krone
DSO	Distribution System Operator
EC	European Commission
EEA	European Economic Area
EHR	Enhanced Hydrocarbon Recovery
ELD	Environmental Liability Directive
ENNOH	European Network of Network Operators for Hydrogen
EOR	Enhanced Oil Recovery
EPS	Emissions Performance Standards
ERR	Economic Regulatory Regime
ETS	EU Emission Trading System
EU	European Union
EUA	EU Allowances
EUR	Euro
FID	Final Investment Decision
FOAK	First-of-a-kind
GBP	Great Britain Pound
GCCSI	Global Carbon Capture and Storage Institute
GD	Guidance Document
GHG	Greenhouse Gas

Acronym	Description
GISZ	Gas Importation and Storage Zone
HER	Enhanced Hydrocarbon Recovery
HNO	Hydrogen Network Operators
IMO	International Marine Organization
IOGP	International Association of Oil & Gas Producers
IPCC	The Intergovernmental Panel on Climate Change
IRA	Inflation Reduction Act
IRR	Internal Rate of Return
ISO	International Organisation for Standardisation
JRC	Joint Research Centre
LC	London Convention
LNG	Liquid natural gas
LP	London Protocol
MRR	Monitoring and Reporting Regulation
MRL	Market Readiness Level
MRV	Monitoring Reporting and Verification
Mt	Million tonnes
MTPA	Million Tonnes Per Annum
NECP	National energy and climate plans
NEP	Northern Endurance Partnership
NEPA	National Environmental Policy Act
NGO	Non-Governmental Organization
NOK	Norwegian Krone
NRA	National Regulatory Authority
NZIA	Net Zero Industry Act
NZT	Net Zero Teesside
O&G	Oil and Gas
OBPS	Output Based Pricing System
OFGEM	Office of Gas and Electricity Markets
OPEX	Operational Expenditure
PCIs	Projects of Common Interest
PCSF	Post-Closure Stewardship Fund
R&I	Research and Innovation
RAB	Regulated Asset Base
RMM	Risk Mitigation Mechanism
RRL	Regulatory Readiness Level
SCALE	Storing CO_2 and Lowering Emissions
SRL	Storage Readiness Level
T&S	Transport and Storage
T&SCo	Transport and Storage Company

Acronym	Description
TEN-E	Trans-European Networks for Energy
TEN-T	Trans-European Networks for Transport
TPA	Third Party Access
TRL	Technical Readiness Level
TSO	Transmission System Operator
TYNDPs	Ten Year Network Development Plans
UIC	Underground Injection Control
UK	United Kingdom
UNCLOS	United Nations Convention on the Law of the Sea
US	United States
USA	United States of America
WFD	Waste Framework Directive
ZCH	Zero Carbon Humber
ZEP	Zero Emission Platform

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1 Introduction

1.1 Background

The internationally committed target set out in the Paris Agreement of keeping global average temperature rise between 1.5 and 2 °C requires drastic and rapid action, leveraging all available options. Moreover, the Paris Agreement also aims at achieving net-zero emissions, through a "balance between anthropogenic emissions by sources and removals by sinks". As asserted in the latest IPCC report, this implies that the CO_2 released into the atmosphere through human activity is compensated by an equivalent amount being removed, either through nature-based or technological solutions[1].

Among the identified strategies and tools, carbon capture, storage (CCS) and carbon capture and utilisation (CCU)[2] are experiencing a new political momentum. **CCS and CCU offer a variety of opportunities for emissions reduction, in particular, in sectors where other technology options are limited, such as in the production of cement, iron and steel or chemicals**, and to produce synthetic fuels for long-distance transport (i.e. aviation)[3]. Other applications of CCS and CCU include the production of low-carbon hydrogen, Direct Air Carbon Capture (DACCS) as well as its application to capture emissions from bio-energy combustion plants (BECCS). The latter two are considered negative emissions technologies.

The first CCU processing plants were operating in the Val Verde Area in Texas, capturing CO_2 and supplying it to local oil producers for Enhanced Oil Refining (EOR). Today, there are **35 CCS and CCU facilities** around the world with capacity to capture and store almost 45 $MtCO_2$ each year[4]. Over the years, CCS deployment has expanded to more regions and more applications. The first large-scale CO_2 capture and injection project with dedicated CO_2 storage and monitoring was commissioned at the Sleipner offshore gas field in **Norway** in 1996, which has now stored more than 20 $MtCO_2$ in a deep saline aquifer. For technical and commercial reasons, the CO_2 needs to be removed from the gas before it can be sold; a CO_2 tax on offshore oil and gas activities introduced by the Norwegian government in 1991 made the project commercially viable.

In **Europe**, a new momentum has been triggered by the political commitment in climate policy and expressed in the **European Green Deal** and the **European Climate Law**. In the Impact Assessment on "Stepping up Europe's 2030 climate ambition", the European Commission found that it is critical that CCS and CCU are deployed and tested at the industrial scale during this decade.

The industrial sector in Europe represents approximately one fourth of EU's GDP and provides about 50 million jobs. At the same time the European industry is responsible for producing more than 500 Mt of CO_2 emissions annually (including electricity and end-of life emissions). This represents around 14% of the EU's total emissions. The **deindustrialisation** of Europe due to mounting pressure for climate action would result in the loss of jobs, lead to diminished economic competitiveness, increased dependency on other global players, and would have other macro-economic ramifications.

[1] IPCCC, Climate Change (2022) Five options to halve emissions by 2030.

[2] CCS is the storing of captured CO_2 in geological formations, such as depleted oil and gas fields, to permanently prevent it from being released into the atmosphere. Regarding CCU, the captured CO_2 is converted into other compounds or products – such as raw material or feedstock for the production of chemicals, fuels, and others – instead of being stored underground.

[3] The International Energy Agency (IEA) Energy Technology Perspectives 2020 report.

[4] IEA (September 2022) Carbon Capture, Utilization and Storage Tracking Report, Available at: https://www.iea.org/reports/carbon-capture-utilisation-and-storage-2

In this context, for some sectors, CCS represents one of the available tools to support the **decarbonisation of industry** while preserving industrial jobs and delivering low-carbon, essential products like chemicals, steel and cement. In addition, when coupled to gas-to-power or hydrogen technologies, CCS could facilitate a stable, flexible and low-emissions source of power. Thus, CCS has an important role to play in industry but also in many other important areas of economic activity including generation of electricity and heat, and the production of hydrogen and synthetic fuels.

As part of the European Green Deal, the European Commission has announced new initiatives – such as the European Climate Law, the Hydrogen Strategy, the Industrial Strategy – and revised existing pieces of legislation, such as the EU ETS directive and TEN-E regulation. In addition, the Innovation Fund will provide around **EUR 38 billion of support from 2020 to 2030**[5] for the commercial demonstration of innovative low-carbon technologies, aiming to bring to the market industrial solutions to decarbonise Europe and support its transition to climate neutrality. All these initiatives are key to ensure that more CCS and CCU projects are deployed in Europe, overcoming current barriers and securing more announcements. These include the Longship project[6] and funding awarded at both national level and through the Connecting Europe Facility for Energy (CEF) programme to European CCS and CCU projects (Northern Lights, CO2TransPorts).

To support these recent positive developments and encourage more, a regulatory framework is necessary to tackle current market barriers and provide equal rules for a safe and cost-efficient development of CCS. Moreover, R&I activities should be continued to address technical challenges along the value-chain, reduce the costs of the technologies and improve efficiency. Social acceptance challenges remain and will require the action of a wide group of societal stakeholders to be addressed. Local administrators, NGOs, academia, and other economic stakeholders play a central role in increasing awareness of CCS and CCU and facilitating an informed debate around it.

1.2 Objectives

The objective of this study is to **analyse options for a regulatory framework to support the infrastructure for CO_2 transport and storage and business models in Europe**.

The existing CO_2 transport networks and storage sites in Europe are still limited, but it is important to understand where, when and how these CO_2 networks will grow in the coming decade to link emitters to storage sites. The Joint Research Centre (JRC) has been asked to develop such an estimate to indicate where and when potential networks might develop. In parallel (and in cooperation with the JRC project) the Commission wants to understand which regulatory interventions are required to support these networks and how these networks will be organised/financed.

5 At EUR 75/tCO_2, depending on the carbon price. Available at: https://climate.ec.europa.eu/eu-action/funding-climate-action/innovation-fund/what-innovation-fund_en

6 Longship is the Norwegian Government's full-scale carbon capture and storage project. It will be the first ever cross-border, open-source CO_2 transport and storage infrastructure network and offers companies across Europe the opportunity to store their CO_2 safely and permanently underground. Phase one of the project will be completed in mid-2024 with a capacity of up to 1.5 million tonnes of CO_2 per year.

Therefore, this project has four objectives:

1) Analyse regulatory options (and their limits) for CO_2 transport networks
2) Analyse regulatory options for CO_2 storage sites (beyond the current CCS Directive)
3) Analyse potential business models for the construction and operation of the CO_2 transport networks
4) Analyse the potential business models for the development and operation of the storage sites

1.3 Tasks and Approach

The work will be divided into two main work streams – **regulatory** and **market** analysis.

The regulatory analysis will assess whether there is a need for regulatory intervention at EU level, define the scope of the intervention and finally propose and assess the available policy options. The market analysis will provide data to estimate the current costs of infrastructure investments and to develop the business cases for CO_2 transport network and CO_2 storage operation.

The information and data necessary to carry out these two distinct assessments will be retrieved from both desk-based literature review as well as expert interviews, which will be organised at a later stage of the project.

The study is divided according to the following chapters and sub-chapters:

1) Introduction
2) Regulatory analysis: current regimes, challenges and opportunities
    a. EU regulatory landscape and existing policy initiatives
    b. Barriers to CCUS deployment
    c. Need for regulation
    d. Lessons learned from EU regulation of network industries
    e. Lessons learned from international CO_2 networks
    f. Regulatory considerations for transport and storage of CO_2
    g. Scoping the regulatory intervention
3) Market analysis
    a. Current situation
    b. Existing CCS value chains
    c. Technology market readiness
    d. Investment costs for CO_2 transport and storage (T&S)
    e. Investment Costs for CO_2 T&S
    f. Future CO_2 T&S development scenarios
    g. Business model options for CO_2 T&S
    h. Key Challenges Remaining for Business Model Development
4) Regulatory Considerations and Policy Recommendations

In order to compile this information, both desk research and stakeholder interviews were carried out. The latter have targeted experts and stakeholders across the CCS value chain, with the aim of capturing the various perspectives on these topics. These include pipeline and shipping operators, storage operators, emitters, CCS project operators, as well as public sector bodies, at national and regional level. A total of 20 interviews are carried out, based on an unstructured approach, providing questions for guiding interviews, while being flexible for the interviewees to raise their own topics and issues. The findings from the interviews are used to complement and address the gaps of the desk research.

2 Regulatory Analysis: Current Regimes, Challenges and Opportunities (T1)

2.1 EU Regulatory Landscape and Existing Policy Initiatives

In this section, we provide an overview of the legal regimes of relevance to CCS deployment in the EU. It is meant to highlight the state of affairs in terms of **regulatory practices** of CO_2 storage and transport, the **interlinkages** between the different regimes, as well as possible policy and regulatory **gaps**. The relevant legal and policy instruments for CO_2 transport and storage in the EU that make up this analysis are:

- International regimes and treaties;
- CCS Directive and guidance documents;
- EU ETS Directive;
- Environmental Liability Directive;
- TEN-E and TEN-T regulations; and
- Relevant funding schemes.

This overview is based on secondary legal and policy literature, official Communications from the European Commission as well as other official EU policy and legal documents. Moreover, the scope of this overview comprises international and EU legal, policy documents and treaties with a **direct implication** on (i.e. explicit mentioning of) CCS development.

International Regimes and Treaties

Preceding direct EU-driven and concerted efforts to regulate CCS, international agreements and frameworks were adopted, with the aim of providing guidelines for carbon transport and storage projects. Two principal ones deserve attention – the **London Protocol** and the **OSPAR Convention**.

The **London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter** is a framework comprising the London Convention itself and its 1996 Protocol (known as the London Protocol). The London Convention is one of the oldest global conventions to **protect the marine environment** from human activities. It has been in force since 1975 and has 80 contracting parties. The relevance of the London Convention to CO_2 storage is limited but important – it only applies to storage conducted from aircraft and vessels and platforms in the water column[7]. Consequently, it does not apply to storage under the ocean seabed or in its subsoil, or from a land-based pipeline. The London Protocol, which was developed in the 1990s to modernize and eventually replace the London Convention, entered into force in March 2006[8].

Legal provisions addressing marine pollution and the dumping of wastes at sea constitute potential obstacles to CCS development, since CO_2 sequestration could be included in the scope of "pollution" or "waste", and hence forbidden. The London Protocol has been amended in 2009 to allow for cross-border transportation of CO_2 for sub-seabed storage. Specific enabling conditions

7 International Marine Organization (IMO), London Convention (LDC, LC) and London Protocol (LP). Available at: https://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Pages/LDC-LC-LP.aspx https://www.imo.org/en/OurWork/Environment/Pages/London-Convention-Protocol.aspx

8 Ibid.

have been provided to reconcile CCS activities with the protection of the marine environment[9]. Ahead of full ratification, a provisional ratification in 2019 cleared this international barrier for CCS offshore[10].

The **OSPAR Convention** was established in 1992 by 15 Northern European States and the European Community and it is considered to be the most comprehensive and strict legal framework governing the marine environment. Following a 2006 report on ocean acidification, the OSPAR Commission acknowledged the need for CCS as part of an ambitious GHG reduction strategy. Therefore, OSPAR has first adopted a Decision to ensure safe storage of carbon dioxide streams in geological formations together with guidelines for risk assessment and management of storage of CO_2 streams in geological formations[11]. OSPAR has also adopted a Decision to prohibit the storage of carbon dioxide streams in the water column or on the seabed, because of the potential negative effects[12].

There are a number of **regional marine environment protection instruments** that will need to address the question of CO_2 storage in the future[13]. With the exception of OSPAR and the London Protocol, no decision has been taken as to whether these other regional treaties and conventions clearly apply to CO_2 storage because they do not mention CO_2 storage activities nor apply below the seabed[14].

The Environmental Liability Directive

International maritime agreements cannot be considered in isolation from EU and national law. The combination of international, regional and national regimes governing CCS is intended to constitute a coherent legal framework. Linked to the treaties explained above, EU regulation addressing issues of direct or indirect relevance for CCS operation came about with the **Environmental Liability Directive** (ELD)[15]. Generally, the Directive's objective is to establish a common framework for the prevention and remedying of environmental damage at a reasonable cost to society. In the context of CCS, this Directive complements the rules provided under the EU ETS.

Operators of CCS storage sites are obliged to prevent and remedy environmental damage associated with those sites (Articles 5, 6). Member States are required to take measures to develop financial security instruments and markets to enable operators to use financial guarantees to cover their environmental liability responsibilities (Article 14). Paragraph 2 of this article provides flexibility in the implementation, through a "gradual approach, a ceiling for the financial guarantee and the exclusion of low-risk activities". In this context, a gradual approach would entail the gradual introduction of financial security, either in terms of time, industrial sector scope or covered

9 Zhang, H. (2021) Regulations for carbon capture, utilization and storage: Comparative analysis of development in Europe, China and the Middle East. *Resources, Conservation and Recycling*, *173*, 105722.

10 IEAGHG Technical Review April 2021

11 OSPAR Decision 2007/02 on the Storage of Carbon Dioxide Streams in Geological Formations

12 OSPAR Decision 2007/01 to Prohibit the Storage of Carbon Dioxide Streams in the Water Column or on the Sea-bed

13 Other potentially relevant international treaties include: United Nations Convention on the Law of the Sea, 1982 (UNCLOS); Basel Convention on the Control of Transboundary Movements of Hazardous Waste (1989); Convention on the Protection of the Marine Environment of the Baltic Sea (1992, HELCOM); Convention on the Protection of the Black Sea against Pollution (1994).

14 University College London (UCL) Carbon Capture Legal Program

15 Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage.

liabilities[16]. According to Munchmeyer et al. (2009)[17], financial guarantee ceilings refer in practice to a guarantee of a certain level of indemnity or a level of fee for the financial security instrument (given that, generally, no financial guarantee would provide for unlimited liability).It also allows for the exclusion of liability on behalf of operators, where they are not at fault, are otherwise not negligent, or a force majeure exception is available[18].

There is, therefore, an **articulated interplay** between the ELD, the CCS Directive and the various national legal regimes. It has been noted that civil actions, as well as private injury, are covered under the civil law rules of each Member State and are not subject to the limitations set out in either the CCS Directive or the ELD. Other provisions in the CCS Directive affirm the operator's responsibility to carry out preventive and remedial action as required under the ELD. While acknowledging the need for improvements, the directive currently includes key elements, such as **interim losses** and **compensatory remediation,** which could prove very expensive for CCS projects in the long run[19].

In addition, according to some experts, there is some ambiguity in the clause added to the ELD by **Article 34** of the CCS Directive. Article 34 addresses the "**operation**" of storage sites pursuant to the CCS Directive, which places the operation of storage sites under the ELD's provisions. However, experts expressed concerns over the lack of clarity of what counts as "operation". The latter could either refer to the mere active operation, or the active injection, of a storage site, while it could also potentially include the whole life of a project, from site selection to post-closure transfer of responsibility to the competent authority[20]. Finally, the need was also stressed for clearer requirements in the directive with regards to the implementation of financial security provisions in Article 14[21].

The CCS Directive

In 2009, the EU adopted the Directive regulating the safe and environmentally sound geological storage of CO_2 – the CCS Directive[22]. It notably provides a regulatory framework for permitting the exploration of potential CO_2 storage sites and storage operations. It therefore focuses primarily on storage aspects, particularly the selection and characterisation of storage sites, the obtaining of exploration permits and of storage permits (application procedure, conditions, content, and the requirement for the Commission to review permits, and changes and withdrawal of permits). In addition, the Directive addresses the issue of third-party access – i.e. parties who do not control the relevant transport or storage infrastructure, to the CO_2 transport network and CO_2 storage sites (Article 21 of the Directive). In particular, Article 21 requires Member States to take the necessary measures to ensure that potential users are able to obtain access to the transport network and storage sites. For these cases, the Member States may allow operators to refuse third-party access

16 Tanja Munchmeyer, Valerie Fogleman, Leonardo Mazza, and Shailendra Mudgal. Implementation Effectiveness of the Environmental Liability Directive (ELD) and related Financial Security Issues. Bio Intelligence Service, Report for the European Commission (DG Environment), 2009.

17 Ibid.

18 Makuch, Z., Georgieva, S., & Oraee-Mirzamani, B. (2020) Innovative Regulatory and Financial Parameters for Advancing Carbon Capture and Storage Technologies. Fordham Environmental Law Review, 32(1), 1-45.

19 Weber, V. (2021) Regulation of CCS Storage Sites in Norway and Compliance with EEA Law. *SINTEF proceedings*, (7), 435-442.

20 Costa, H. (2019) Liability in Civil and Environmental Subjects for Carbon Capture and Storage (CCS) Activities in Brazil.

21 University College London (UCL) Carbon Capture Legal Program, Environmental Liability Directive. Available at: https://www.ucl.ac.uk/cclp/ccsliable-Europe-liabilitydirective.php.

22 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

where there is an incompatibility of the CO_2 streams with the required technical standards (i.e. differing standards of the purity of CO_2 streams). Finally, the Directive covers the legal requirements for operation, closure and post closure obligations.

Concerning **site selection and characterisation**, the Directive establishes that Member States shall conduct storage capacity assessments when allowing carbon storage in their territory. Ultimately, geological storage sites should only be selected in the absence of any significant risk of leakage as well as health and environmental risks.

Moreover, the Directive establishes that, provided positive storage capacity and risk assessments, explorations should take place only with an **exploration permit**. Monitoring of injection tests plans may be included in the exploration permits. The holder of a permit is the only party allowed to explore the potential storage area. Following an exploration permit, the Directive requires a **storage permit** in order to bring operations forward. Permits should be withdrawn if leakage or irregularities are detected. The responsible authority should either issue a new permit or close the storage site. Operational, closure and post-closure obligations should be defined at the certification stage. This should include monitoring and reporting requirements as well as remediation following any leakage. In addition, operators must provide financial provision to ensure that all terms of the Directive and the issued permit are adhered to.

The Directive is accompanied by four nonbinding **Guidance Documents (GDs)** which were released in 2011:

- GD1 – CO_2 Storage Life Cycle Risk Management Framework;
- GD2 – Characterisation of the Storage Complex, CO_2 Stream Composition, Monitoring and Corrective Measures;
- GD3 – Criteria for Transfer of Responsibility to the Competent Authority; and
- GD4 – Financial Security and Financial Mechanism.

The set of Guidance Documents aims to assist stakeholders in implementing the Directive across the EU. Below, we provide a brief summary of each GD and a few points of potential improvement gathered from secondary sources. The four GDs are currently under revision.

Guidance Document 1: CO_2 Storage Life Cycle Risk Management Framework

Risk management is an integral aspect of safe CO_2 storage. Risk management involves **the continuous and systematic assessments** of potential risks, such as containment and leakage, as well as uncertainties in the geological framework, models and performance assessments. The GD1 explicitly mentions risk management techniques with the aim of identifying, mitigating, and managing identified risks and uncertainties in order to ensure the safety of any CO_2 storage site. This guidance document aims to provide guidance on the overall approach for the Competent Authorities (CA) that is consistent with the needs of the CCS Directive[23].

In the form of recommendations for improvement, the recent report by Zero Emission Platform (ZEP) highlights several ways that GD1 can be updated[24]. In particular, more emphasis should be placed on the flow of information between operator and supervisor. Risk management methods should be discussed upfront with a clarification on the risk criteria (i.e. level of acceptable risks) that will be used in the process. One goal of the risk management process is to increase the trust of

[23] Implementation of Directive 2009/31/EC on the Geological Storage of Carbon Dioxide. Guidance Document 1: CO_2 Storage Life Cycle Risk Management Framework.

[24] ZEP, Experience in developing CO_2 storage under the Directive on the geological storage of carbon dioxide. Available at: https://zeroemissionsplatform.eu/wp-content/uploads/Experience-in-developing-CO2-storage-under-the-CCS-Directive-ZEP-report.pdf

various stakeholders in the safety of CO_2 storage activities. Therefore, more emphasis is needed on how to build trust with risk management.

Guidance Document 2: Characterisation of the Storage Complex, CO_2 Stream Composition, Monitoring and Corrective Measures

The **characterisation** and **assessment** of the potential storage site, storage complex and surrounding area are necessary for ensuring that a potential storage site presents no significant risk of leakage and any negative effects and risks to the environment and human health.

The GD2 recommends a series of assessments at increasingly detailed scales, commencing with regional assessments to basin-scale assessments, to more detailed exploration of specific site locations[25]. The document recommends the CA to take into account several considerations, resulting in requirements for the composition of the CO_2 stream, with the aim of ensuring that:

- the integrity of neither the storage site nor the relevant transport infrastructure are adversely affected;
- there is no significant risk to the environment or human health; and
- the applicable EU legislation is complied with.

The CA bears the responsibility of either direct monitoring, or through the site operator, of the injection facilities, the storage complex, and where appropriate the surrounding environment during the operational phase and after closure until the transfer of responsibility.

The GD2 also provides that corrective measures should be developed hand in hand with site and complex characterisation, modelling, risk assessment and especially monitoring and other risk mitigation measures. They are also linked to financial security and financial mechanism which may be used to meet the cost of implementing corrective measures.

Since the publication of the Guidance Documents, new storage options have emerged, e.g. storage in oceanic volcanic rocks (ophiolites) by mineralisation[26], and storage in depleted (underpressurised) gas reservoirs has gained momentum[27] relative to storage in saline formations. These options require specific characterisation, monitoring and measures which are not dealt with sufficiently in the current GD2.

Guidance Document 3: Criteria for Transfer of Responsibility to Competent Authority

This Guidance Document[28] addresses the various issues related to the transfer of responsibility for all legal obligations from the operator to the CA, and as such expands on the provisions in Article 18 of the CCS Directive. As noted in the directive, the key criterion that allows for such a transfer of responsibility is when the operator can show to the CA that all available evidence indicates that the stored CO_2 is (and will continue to be) completely and permanently contained.

It has been suggested to provide practical criteria for long-term stability, coherence between modelled and measured behaviour and leakage detection thresholds. Dry-run exercises for three

[25] Implementation of Directive 2009/31/EC on the Geological Storage of Carbon Dioxide Guidance Document 2 Characterisation of the Storage Complex, CO_2 Stream Composition, Monitoring and Corrective Measures

[26] Kelemen, P., Benson, S.M., Pilorgé, H., Psarras, P., Wilcox, J. (2019) An Overview of the Status and Challenges of CO_2 Storage in Minerals and Geological Formations. Frontiers in Climate 1.

[27] IEAGHG (2022) Criteria for Depleted Reservoirs to be Developed for CO_2 Storage, Technical Report 2022-01.

[28] Implementation of Directive 2009/31/EC on the Geological Storage of Carbon Dioxide Guidance Document 3 Criteria for Transfer of Responsibility to the Competent Authority

storage sites were performed in the EU funded project CO_2CARE from 2011 to 2013, which holds valuable information[29]. There is a debate on the correct use of terms like conformity[30] which requires some clarification in a revised version of GD3 and the approach to assessing site conformance may benefit future storage project operators and regulators[31].

Guidance Document 4: Financial Security and Financial Mechanism

This GD addresses Article 19 (Financial Security) and Article 20 (Financial Contribution) of the CCS Directive[32]. The guidance provides information and options that MS may choose to use in establishing an effective system for **financial security** (e.g. options for defining instruments or acceptable equivalents, criteria for issuers of financial security instruments). The guidance also describes options for determining the amount of the financial contribution to be made available by operators prior to transfer of their storage sites to their CAs, including similarities and differences with methods described for determining amounts of Financial Security. The guidance encourages MS to secure the payment of the Financial Contribution through the instruments and procedures described for Financial Security. Experts have highlighted the need to provide more clarity on the transfer of financial liabilities, how that should be covered and who can monitor this.

EU ETS Directive

At EU-level, the most important regime governing and providing guidelines for carbon emissions in the **EU Emission Trading System** (ETS). Installations from sectors included in this scheme must surrender, every year, a number of allowances representing the total amount of GHG emissions from that installation from the previous year. As a trading scheme, the EU ETS serves the objective of determining a price for **emission allowances** based on a limited amount of tradable certificates. It is considered amongst the cornerstones of EU climate policy and is the largest emission trading system worldwide.

The ETS Directive constitutes a crucial regulatory element for CCS, positioning it at the centre of the EU industrial decarbonisation strategy. The ETS Directive contains specific provisions for CCS, as it allows and accounts the subtracting of emissions that are captured safely and permanently stored, thus creating the basis for a business model for CCS. It therefore integrates the governing of CCS by providing a support system that incentivizes the capturing of CO_2, while streamlining it with the wider EU industrial decarbonisation policy. Most importantly, the Directive provides specific guidelines on the accounting of emissions during transportation between the capturing installation and the CO_2 transport network. The recent revision of the ETS Directive, among other changes, expands the activity of CO_2 transport for storage to any transport mode (from previously only by pipeline). The Monitoring, Reporting and Verification (MRV) rules are being updated to reflect these changes and clarify the monitoring, reporting and surrendering obligations for the different operators in the CCS chain (capture installation, transport operator, storage site).

29 Wildenborg, T., Bruin, G. de, Kronimus, A., Neele, F., Wollenweber, J. and A. Chadwick (2014) Transferring responsibility of CO_2 storage sites to the competent authority following site closure, Energy Procedia, 63, 6705-6716.

30 Oldenburg, C.M. (2018) Are we all in concordance with the meaning of the word conformance, and is our definition in conformity with standard definitions? Greenhouse Gas. Sci. Technol. 8, 210–214. Available at: https://doi.org/10.1002/ghg.1773

31 Barros, E.G.D., O. Leeuwenburgh, S.P. Szklarz (2021) Quantitative assessment of monitoring strategies for conformance verification of CO_2 storage projects, International Journal of Greenhouse Gas Control, Volume 110. Available at: https://doi.org/10.1016/j.ijggc.2021.103403

32 Implementation of Directive 2009/31/EC on the Geological Storage of Carbon Dioxide Guidance Document 4 Article 19 Financial Security and Article 20 Financial Mechanism

Emissions monitoring and reporting within EU ETS is regulated by Regulation 2018/2066, which sets out the detailed requirements applicable to capture, transport and storage installations in terms of monitoring and reporting of emissions, which form the basis of any compliance obligations for the different installations across the CCS chain. Accurate subtraction of emissions under the EU ETS depend on correct CO_2 measurements across the CCS value chain, including transportation from and to ships, as well as the accurate emission monitoring and reporting. Continuous measurement systems (i.e., fiscal metering) with uncertainties below 2.5% are required for reporting of captured CO_2 at the capture site.

Trans-European Networks for Energy & Transport (TEN-E & TEN-T)

The **Trans-European Networks for Energy (TEN-E)** is a regulation[33] that focuses on linking the energy infrastructure of EU countries. Cross-border energy infrastructure is a key enabler for the energy transition and is crucial to reach the targets set out in the Green Deal. This is why the TEN-E framework has been revised to align this Regulation with the European Green Deal objectives. The revised TEN-E framework enables for inclusion of both CO_2 storage and transport projects including dedicated pipelines for CO_2 transport and fixed facilities for liquefaction, buffer storage and converters of carbon dioxide in view of its further transportation through pipelines and in dedicated modes of transport such as ship, barge, truck, and train. Although the TEN-E covers liquefaction facilities, buffer storage and converters in view of transport by various modes it does not cover these modes themselves apart from CO_2 transport by pipelines (i.e. transport via ships, barges, trucks, and trains is not covered).

As part of the policy, three priority thematic areas have been identified, of which **a cross-border carbon dioxide network** is one of them, focused on the development of transport infrastructure for captured CO_2 from industrial installations.

On CO_2 transport, it is equally important that the EU legislation includes the full range of modalities such as ship, truck, train and barge as well as connecting and docking facilities. In the projects currently in development in Europe, shipping has been especially important. The **Trans-European Transport Network (TEN-T)** regulation[34] addresses the implementation and development of a Europe-wide network of railway lines, roads, inland waterways, maritime shipping routes, ports, airports and railroad terminals.

Compared to pipeline-based CCS projects, other transport modalities such as ship, barge, rail and truck do not have the same access to support and funding. The Zero Emissions Platform argues that the lack of support for multiple transport modalities results in **negative signals** and continued high investor risk, further hampering market development and project deployment[35].

Transport of CO_2 from industrial clusters or other emitters to storage facilities will require the development of new CO_2 infrastructure networks, including pipelines and shipping. The recent TEN-E revision delivered on key aspects of the CO_2S infrastructure, for example, by acknowledging storage. While welcomed as an important element in the future development of CCS, stakeholders have called for **further advancements** on the part of policy need to be made. In particular, experts

[33] Regulation (EU) 2022/869 of the European Parliament and of the Council of 30 May 2022 on guidelines for trans-European energy infrastructure.

[34] Regulation (EU) No 1315/2013 of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network.

[35] ZEP response to the adopted act: Proposal for a Regulation on guidelines for trans-European energy infrastructure and repealing Regulation (EU) No. 347/2013. Available at: https://zeroemissionsplatform.eu/wp-content/uploads/ZEP-comments-to-revised-TEN-E-regulation.pdf

welcomed the announced EU strategy on CCS and CCU, and hope that it will draw specific milestones and timelines, and the necessary incentives to develop at-scale CO_2-storage.

Funding Instruments

Currently, transport of storage via pipeline and storage projects themselves can access funding through the **Connecting Europe Facility (CEF)**. CEF is designed to facilitate investment into cross-border energy infrastructure projects that, under current regulatory and market conditions, are not commercially viable. Grants to contribute to the construction costs can, in some cases, be applied to fill in the gaps in commercial viability of the projects that are particularly relevant for the EU.

Part of the money raised by the ETS is reinvested into the **Innovation Fund**: it is expected to provide around EUR 38 billion[36] of support from 2020 to 2030, for the commercial demonstration of innovative low-carbon technologies, aiming to bring to the market industrial solutions to decarbonise Europe and support its transition to climate neutrality. The third call for projects was launched in November 2022.

In 2021, of the seven innovation projects granted funding during the first large-scale projects call, four target the scaling up of CCS, with beneficiaries in Finland, Belgium, Sweden and France. These feature projects in hydrogen, chemical, bio-energy and cement production[37]. During the second large-scale call in summer 2022, from the 139 application received, the Commission selected 17, of which seven include CCS and/or CCU technologies. These are located in Bulgaria, France, Germany, Iceland, Poland and Sweden (two projects), involving the sectors of cement (three projects), lime, chemicals and synthetic fuels[38].

While the Innovation Fund represents a necessary source of finance, critics argue that it has a major issue of oversubscription, with an extremely restricted number of projects accessing to actual funding. Given that the Innovation Fund is aimed at supporting demonstration of innovative low-carbon technologies, it is not an instrument designed to co-finance the first few generations of carbon capture plants. However, it was mentioned in the interviews that such an instrument is missing and would be crucial for providing low investment risk to investors.

Summary of the Analysis

As a **summary** of the above overview of existing legal regimes, we provide a table with the main information from each instrument, highlighting its scope and identified gaps.

[36] Based on current projections of emission allowances price

[37] European Commission, Innovation Fund, Large-scale calls. Available at: https://climate.ec.europa.eu/eu-action/funding-climate-action/innovation-fund/large-scale-calls_en

[38] Innovation Fund Second Call For Large-Scale Projects List Of Proposals Pre-Selected For A Grant. Available at: https://climate.ec.europa.eu/system/files/2022-07/LSC2_List_of_pre-selected_projects_6.pdf

Table 1: Summary Overview of CCS Legal and Policy Regimes

Regulatory or policy instrument	Type of instrument	Geo-graphical scope	Aspects of CCS addressed	Identified gaps
OSPAR Convention, London Protocol	Multi-lateral agreements	Inter-national	• OSPAR Convention provides guidelines for risk assessment and management of CO_2; it also prohibits storage of CO_2 in the water column or seabed; • London Protocol amended so to remove barriers to CCS, not recognised as waste.	
Environ-mental liability Directive	EU Directive	EU (European Economic Area (EEA) relevance)	• Establishing a common framework for the prevention and remedying of environmental damage; • The Directive addresses compensation claims in case of leaks caused by non-compliance	• Ambiguity of the present thresholds for actionable environmental damage that trigger enforcement action; • Lack of a compulsory security clause, with the aim of providing the ELD with mandatory insurance or financial security cover for ELD risks.
CCS Directive & Guidance Documents	EU Directive	EU (EEA relevance)	• It provides a regulatory regime for permitting of exploration of potential CO_2 storage sites and storage operations; • Four Guidance Documents were published to provide guidelines on implementation.	• With regards to risk management, more guidance should be provided on the flow of information between operator and supervisor; • General need for update, given recent developments, particularly with regards to storage options and technologies, currently not envisaged in the GDs; • Provide more clarity on the transfer of financial liabilities.

Regulatory or policy instrument	Type of instrument	Geo-graphical scope	Aspects of CCS addressed	Identified gaps
EU ETS Directive	EU Directive	EU	• The inclusion of CCS activities within the revised EU ETS means that emissions allowances need not be surrendered where CO_2 is successfully captured and stored; those emissions will be counted as "not emitted"; • Streamlines CCS with the wider EU industrial decarbonisation policy.	
TEN-E & TEN-T Regulations	EU Regulation	EU	• TEN-E is focused on linking the energy infra-structure of EU countries, and identifies CCS as a specific area of policy priority; • TEN-T addresses the implementation and development of Europe-wide networks.	• Compared to pipeline-based CCS projects, other transport modalities such as ship, barge, rail and truck did not have the same access to support and funding.
CEF, Innovation Fund	Funding instrument	EU	• These instruments are used to provide funding to, among others, CCS projects.	• Issue of oversubscription, only an extremely limited number of projects can access funding for works, all PCI projects can apply for co-funding for studies; • Limited to demonstration of new technologies.

2.2 Barriers to CCUS Deployment

Based on the above analysis, several barriers can be identified to the full deployment of CO_2 infrastructure, comprising **legal**, **financial** and **social factors**. Legal and regulatory barriers have been addressed so far as part of the gaps and shortcomings of existing regulation.

Generally, EU-level regulation should provide the set of guidelines to facilitate the deployment of CCS on the continent, while also making cross-border transport and storage legally and financially feasible. Given the long deployment times and large volume flows required for pipeline infrastructure, it is crucial that technical and regulatory coordination is adopted to facilitate flexible transport options (i.e. ship, rail, and road tankers). This required coordination can be achieved through an EU effort to ensure compatible and scalable infrastructure, as well as recognised standards.

Concerning **financial barriers**, the primary issue for private and commercial storage operators is the financial certainty over the return on investments. As addressed above, while funding instruments currently exist that allow finance access to CCS projects, there is still a significant funding gap to enhance CCS deployment. Current sources of funding are restricted to a limited group of projects, the majority of which tend to be in demonstration stage. Uncertainty over the financial viability of CCS projects could be mitigated through more widely accessible funding instruments.

Finally, a third important dimension of the existing barriers to the deployment of CCS is **societal acceptance**. While more difficult to conceptualize quantitatively and in a systematic way, societal acceptance for a given innovation is identified as one of the factors determining its success. A large literature addresses this issue, analysing the numerous examples where lack of solid socio-political support for a technology has delayed or hampered its introduction. It is pertinent to mention that the perceptions, views and concerns need not be based on facts but this does not make the concerns or perceptions any less valid or relevant. Commonly perceived risks are risks at the local and territorial level, but also risks that concern future generations and ecological and economic systems, as well as risks of making political decisions that do not improve climate protection in the long term. The most frequently mentioned risk perceptions in the studies relate to negative health impacts, especially for people living near CO_2 storage and transport infrastructure[39].

2.3 Need for Regulation

Regulatory models refer to the organisation of the different activities needed to provide a given service. Central to the definition of a regulatory model is the assignment of responsibilities (who makes the key decisions?) and the relevant procedures (how are these key decisions made?). In general, based on market theory, one of the key reasons for regulating energy networks is the potential emergence of natural monopolies. A natural monopoly arises when average costs decline over the range of production that satisfies market demand. It poses a challenge for competition policy, because the structure of costs and demand seems to make competition unlikely or costly.

In the case of CCS, there are several arguments in favour of a regulatory framework to support the deployment of this technology in Europe:

- Capture projects will depend on T&S for the long term. In early stages of development, it is likely that only a single T&S option might be available to capture projects. In the absence of regulation, capture projects will be placed at a disadvantage because the T&S provider might have an effective natural monopoly[40],[41]
- Given the disperse and different nature of emitters, differences in capture technologies, CO_2 purities and options for transport there is a need for standardisation and harmonisation across the CCS value chain which can be facilitated by regulation.

[39] Nielsen, J. A., Stavrianakis, K., & Morrison, Z. (2022) Community acceptance and social impacts of carbon capture, utilization and storage projects: A systematic meta-narrative literature review. *PloS one*, *17*(8), e0272409.

[40] Bellona Europa (2021) Models for Transport and Storage of Captured CO_2: A review of some options

[41] In theory, this can work both ways and if not enough capture projects come online, the effective natural monopoly could be on the capture site. However, given the decarbonization needs of emitters and in many cases limited options this scenario is unlikely.

- As a technology which has not yet reached its full deployment and market potential, CCS would benefit from regulation to provide direction and certainty to investors and developers.
- Key EU stakeholders have highlighted that there is a need for an EU regulatory framework for CO_2 transport infrastructure to support the development of non-discriminatory, open access and multi-modal CO_2 transport infrastructure across Europe.[42]

The table below provides an overview of key regulatory elements that require consideration for developing CCS infrastructure in Europe.

Table 2: Key Regulatory Elements to Consider

Network Regulation
Need for a network regulator and its potential role
Network planning
Third party access
Tariffs and revenue regulation
Full chain organisation and unbundling
Cross-border infrastructure development
CO_2 standards

It is important to stress that there is no single, most-optimal regulatory design choice that will fit all circumstances. The regulatory approach of choice will depend on variables such as the physical characteristics (location, proximity to storage sites), market maturity and even differences in regulatory and political culture of Member States.

In the EU, a common, regulatory framework should be in place to ensure harmonisation across Member States, and the adequate functioning of the internal market (if CO_2 is considered a commodity). However, the framework should be flexible, to provide room for Member States to account for their specific geographic, regulatory and cultural contexts.

2.4 Lessons Learned from EU Regulation of Other Network Industries

A review of approaches and best practice in regulating emerging network industries can provide helpful information and suggest relevant design elements in the context of the future regulatory framework for carbon dioxide transport and storage. In particular, the hydrogen sector, where the EU regulation precedes the development of the sector into maturity (as opposed to electricity and natural gas sectors, where the EU regulation was imposed on existing, well developed networks) might be of special interest. Furthermore, the general consensus is that regulatory issues associated with CO_2 transport are generally more likely to fall within the scope of existing regulatory frameworks related to areas such as oil and gas, mining, waste, health and safety, property rights and transport. On the other hand, CO_2 storage, presents more unique challenge for CCS regulation.

In considering regulatory options for CCS, an important question will be to consider the following options:

- Revise existing frameworks to cover CCS activities, or

[42] See Towards a European cross-border CO_2 transport and storage infrastructure – issue paper from the CCUS Forum working group on CO_2 infrastructure

- Develop a dedicated regulatory framework for carbon management infrastructure.

In the section below, we provide a short overview of key regulatory elements for hydrogen, natural gas and other relevant networks.

2.4.1 Regulation of Natural Gas and Hydrogen Networks

Current Gas Package

Currently, the natural gas sector is governed by the 2009 Third Energy Package, specifically the **Gas Directive**[43] and the **Gas Access Regulation**[44]. The Gas Directive was amended by Directive (EU) 2019/692[45] to extend the regulatory regime to interconnectors linking EU Member States to third countries. The Directive sets out authorisation procedures, technical rules, public service and customer protection obligations, rules for the monitoring of security of gas supply, and elements to support regional cooperation among other elements.

The Directive includes provisions on[46]:

- the unbundling of transmission systems and transmission system operators (TSOs), their designation and certification by national regulatory authorities (NRAs);
- the unbundling of transmission system owners and storage system operators. As an alternative to unbundling, Member States may opt to establish independent system operators;
- the unbundling of distribution system operators (DSOs) and their designation and task specification. It includes the option for Member States to designate closed distribution systems;
- the designation of storage and LNG system operators, as well as duties for these entities;
- third-party access to infrastructure; access to storage, to upstream pipeline networks, refusal of access;
- new infrastructure, market opening and reciprocity, and the possible designation of direct lines;
- retail markets, safeguard measures and the level playing field.

The Hydrogen and Decarbonised Gas Market Package

The proposed **Hydrogen and Decarbonised Gas Market Package**[47] provides direction and guidance for the development of the emerging hydrogen and decarbonised gas markets. The Package has the following main objectives:

- enabling development of **dedicated hydrogen** infrastructure and market;
- facilitating access of renewable and low-carbon gases to existing methane gas network;
- fostering network planning of electricity, natural gas and hydrogen;
- promoting consumer protection and engagement in renewable and low-carbon gas markets;

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[43] Directive 2009/73/EC concerning common rules for the internal market in natural gas

[44] Regulation (EC) No. 715/2009 on conditions for access to the natural gas transmission networks.

[45] DIRECTIVE (EU) 2019/692 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 April 2019. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.117.01.0001.01.ENG#:~:text=Directive%20(EU)%202019%2F692,(Text%20with%20EEA%20relevance

[46] Summary based on: Gunst, A. et al. for the Law Review (2022) The Energy Regulation and Markets Review: European Union. Available at: https://thelawreviews.co.uk/title/the-energy-regulation-and-markets-review/european-union

[47] Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal markets in renewable andnatural gases and in hydrogen. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0803&qid=1640002501099

- improving resilience and security of supply.

Given the lack of maturity of the hydrogen sector, there should be a **phased approach towards market and network regulation**[48]. The approach is based upon the proven regulatory principles as experienced in the electricity and methane gas sector with certain flexibility for the application of these principles until 2030. However, the main regulatory principles for mature markets after 2030 are defined upfront. This is done to create certainty for investors, as well as to prevent expensive ex-post regulatory interventions. Importance is attached to **regulatory convergence of initially dispersed network elements**.

The table below summarises some key regulatory elements under the Hydrogen and Decarbonised Gases Market Package with potential application for the design of CCS regulation and their proposed approach.

Table 3: Summary of Selected Regulatory Elements and their Proposed Approach under the Hydrogen and Decarbonised Gas Market Package[49] and Applicability to CCS Regulatory Design

Regulatory element	Proposed approach	Applicability to CCS regulatory design
Network and (large) Storage infrastructure regulation		
Legal mono-poly/mandate assigned to single H_2 Network Operator (HNO)	No legal monopoly required No explicit distinction between transmission and distribution within the proposal	No need for explicit distinction between transmission and distribution networks Single Network Operator could be charged for overseeing the networks
Planning of hydrogen network infrastructure	Periodic hydrogen network development reports required to guarantee that the H_2 network follows realistic demand prediction. HNOs should be in charge of the operation, maintenance, and development of the H_2 transport network, working closely with each other as well as other system operators. HNOs should establish regional cooperation within European Network of Network Operators for Hydrogen (ENNOH). HNOs shall cooperate to avoid restrictions to cross-border flows of hydrogen due to hydrogen quality differences	Network planning reports on CO_2 networks would allow for more realistic demand predictions, higher certainty Close cooperation with other network operators of CH_4 and H_2 to allow for synergistic planning (possibility of repurposing old pipes) Support regional cooperation to ensure smooth trans-border planning Common CO_2 standards should be established to support trans-border transport

[48] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal markets in renewable and natural gases and in hydrogen. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A804%3AFIN&qid=1640001545187

[49] Based on unpublished analysis by Trinomics 'Promotion of Hydrogen Value Chain and Open-access Network for Flanders'

Regulatory element	Proposed approach	Applicability to CCS regulatory design
Cross-border planning of hydrogen network infrastructure	ENNOH to be established. ENNOH to develop network codes as well as adopt and publish a non-binding ten-year network development plan biannually. In collaboration with other relevant market actors and their associations, ENNOH shall explore, build on, and integrate existing work experience with infrastructure design, development, and operation.	Long-term, network planning requirements for CO_2 networks would allow for more realistic demand predictions and certainty. Collaboration with other actors for capacity building and ensuring transfer of knowhow.
Network Third Party Access (TPA) rules	HNOs should provide regulated TPA. Negotiated TPA can be applied by MS during the transition period till 2030.	Similar TPA provisions could be also considered for CO_2 networks.
Network vertical unbundling	Ownership unbundling as the default option.	In addition to TPA, vertical ownership unbounding could be considered for the CCS value chain (capture from T&S or separation of capture, transport and storage)
Revenue and tariff setting for regulated network operators	Regulated tariffs as default, with bilateral negotiation under nTPA allowed until 2030. Commission empowered to adopt network code on harmonised tariff structure.	Regulated tariffs can be considered in the case of CO_2 networks to address (over)capacity planning
Isolated / geographically delimited clusters	Geographically confined networks with one entry point exempted from unbundling, TPA rules apply. Unbundling exemption ends in 2030, or if a renewable hydrogen producer requests access to the network.	Similar exceptions could be applied for CCS
Large-scale storage TPA rules	Regulated TPA from the start of the regulation on.	TPA for CO_2 storage should be considered
Certification	Mandatory system of certification for renewable and low-carbon gases.	Mandatory certification based on established CO_2 purity standards

One element to note under the Hydrogen and Gas Decarbonisation Package proposals is related to the integrated network planning and interaction between the electricity, gas and hydrogen sectors, in order to promote system integration. Inclusion of CO_2 transport considerations in some form of network planning (for instance based on the Ten Year Network Development Plans (TYNDPs), or the NECPs) could be a way to do so effectively and should be further considered. Including CO_2 networks in the planning would provide visibility into the overall infrastructure needs to transport electrons and molecules across the EU. It would support a better understanding of the expected infrastructure needs and investments (see section on network planning below). It could also support identifying potential gas pipelines that could be repurposed.

Further, the Package proposes assistance to Member States with implementation of the hydrogen provisions of TEN-E, as well as supporting delivery of the hydrogen components of the NECPs.

Given that CO_2 infrastructure is included in the TEN-E regulation and CCS has a chapter in NECP guidance document[50], a parallel mandate should be considered for CO_2 infrastructure.

2.4.2 Regulation of Electricity Networks

The Electricity Directive[51] focuses on establishing the European **internal market for electricity**. In particular, it sets out public service obligations for electricity undertakings, customer protection obligations, rules for the monitoring of security of supply by Member States, technical rules and the promotion of regional cooperation.

The Directive stipulates that transmission systems and TSOs must be unbundled from generation and supply because of the natural monopoly conferred by transmission and distribution ownership. Like in the case of the Gas Directive, Member States may opt to designate an independent system operator. DSOs must also be unbundled. In the case of both TSOs and DSOs, the unbundling process includes the transparency of their accounts to Member States or any designated authority.

Like in the case of the Gas Directive freedom of third-party access is established based on market opening and reciprocity, and direct lines to all eligible customers.[52] Generally, no additional elements with particular application to CCS regulation, other than those already described under the Gas and Hydrogen and Decarbonised Gas Market Directives were identified.

2.5 Lessons Learned from International CO_2 Networks

Interesting lessons can be drawn from regulatory regimes of third countries which are considered front runners in supporting and establishing CCS networks. Below, we shortly summarise some of the key elements in the **United Kingdom, United States, Canada** and **Australia**.

2.5.1 United Kingdom

In the United Kingdom, the **Energy Act 2008**[53] provides for a licensing regime that governs the offshore storage of carbon dioxide. It forms part of the transposition into UK law of the CCS Directive. The Carbon Dioxide Regulations of 2010[54] transpose many other requirements of the directive. The regime applies to storage in the offshore area comprising both UK territorial sea and beyond designated as a gas importation and storage zone (GISZ).

The **Oil and Gas Authority** is the licensing authority for offshore CO_2 storage since 2016, except within the territorial sea adjacent to Scotland, which Scottish ministers authorise. In addition to applying for a licence, developers must obtain a grant of the appropriate rights from The Crown Estate or the Scottish Crown Estate.[55]

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[50] European Commission (2022) Guidance to MS for updated NECPs 2021-2030. Available at: https://energy.ec.europa.eu/guidance-ms-updated-necps-2021-2030_en

[51] DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32019L0944

[52] Summary based on: Gunst, A. et al. for the Law Review (2022) The Energy Regulation and Markets Review: European Union. Available at: https://thelawreviews.co.uk/title/the-energy-regulation-and-markets-review/european-union

[53] Energy Act (2008). Available at: https://www.legislation.gov.uk/ukpga/2008/32/contents

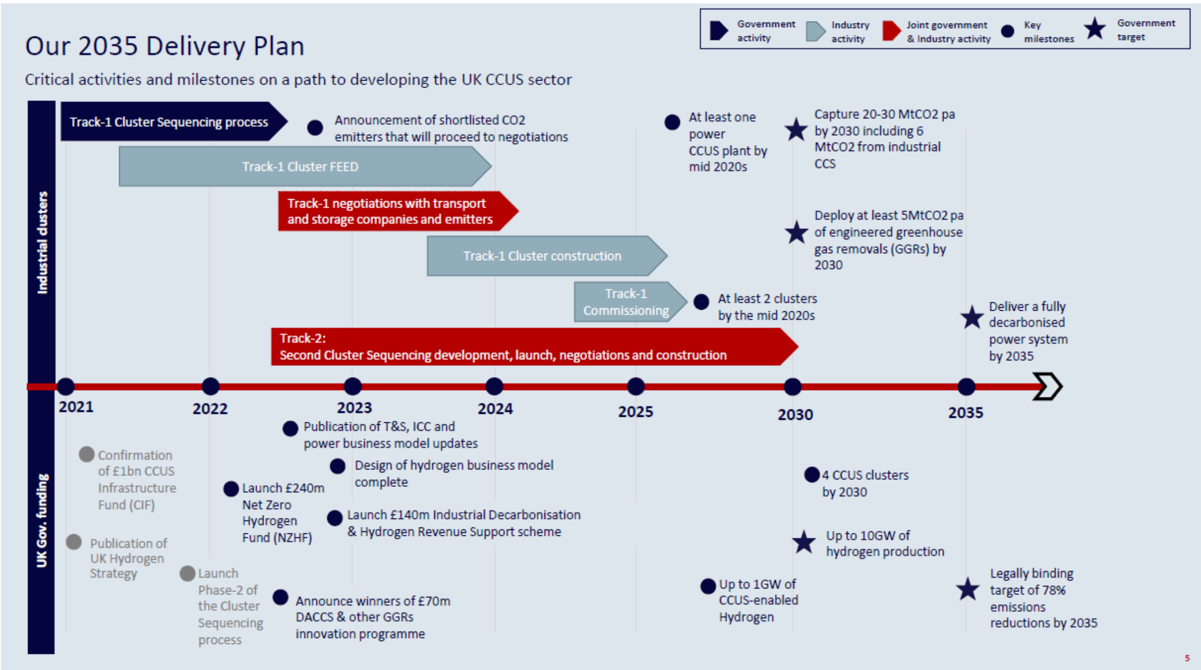
[54] UK Government (2010) The Storage of Carbon Dioxide (Licensing etc.) Regulations 2010. Available at: https://www.legislation.gov.uk/uksi/2010/2221/regulation/1/made

[55] UK Government, BEIS (2019) UK carbon capture, usage and storage. Available at: https://www.gov.uk/guidance/uk-carbon-capture-and-storage-government-funding-and-support

In October 2017, the UK government announced its new approach to CCUS in the **Clean Growth Strategy**[56]. Since then, the UK has set up a number of activities to support the deployment of CCUS. It established a CCUS Cost Challenge Taskforce and following the advice of the Taskforce it published the UK CCUS Deployment Pathway: An Action Plan.[57] The timeline for CCUS deployment together with key milestones are shown in Figure 1.

The **UK CO_2 transport and storage regulatory investment model** is based on an **economic regulation** funding model which includes precedents for other utility regulations. The key objective of this model is to unlock investments in T&S networks, enabling low-cost decarbonisation of multiple sectors and developing a market for carbon capture. The regulation is focused on regulating the revenue of T&S investors based on a User Pays model and oversight of T&S fees.[58] Based on the results of a public consultation, the role of the regulator will be assigned to the Office of Gas and Electricity Markets (Ofgem). The functions and duties of the regulator will be defined by law. These shall include provisions ensuring that a transport and storage company (network operator and asset owner) can finance its operations.

Figure 1: UK's CCUS Delivery Plan until 2035



2.5.2 United States of America

CCUS projects in the US have been historically developed with differences in approach or regulation depending on the State, as regulatory competence for CCUS is shared between **national and state**

56 Policy paper. Clean Growth Strategy: An ambitious blueprint for Britain's low carbon future. Available at: https://www.gov.uk/government/publications/clean-growth-strategy

57 UK Government, BEIS (2019) Clean Growth: the UK Carbon Capture Usage and Storage deployment pathway: An Action Plan. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/759637/beis-ccus-action-plan.pdf

58 UK Government, BEIS (2020) Carbon Capture, Usage and Storage: An update on business models for Carbon Capture, Usage and Storage

entities. Issues regulated at state level include property rights (onshore and offshore), transportation, pipelines, and economic incentives[59]. Several States have conducted work to identify priority CO_2 pipeline needs. Kansas, Louisiana, Maryland, Montana, Pennsylvania, Oklahoma and Wyoming have committed to creating and implementing the Regional CO_2 Transport Infrastructure Action Plan via the State Carbon Capture Working Group[60].

In 2022, the **California State Legislature** passed SB 905[61], a critical carbon capture legislation. SB 905 directs the California Air Resources Board to create a CCS programme with the objective of accelerating the deployment of carbon management technologies and ensuring they are deployed in a safe and equitable way. The bill still needs to be signed into law[62].

On a **Federal level**, an important development to provide support to CCUS was the introduction of the Storing CO_2 and Lowering Emissions (SCALE) Act in 2021[63]. The Act aims to support the development of critical CO_2 transport and storage infrastructure and to promote regional economic opportunities and job-creation over a 5-year authorisation period. The key objectives of the SCALE Act are to:

- establish a CO_2 Infrastructure Finance and Innovation Act (CIFIA) programme[64]. The current funding amount for the programme is USD 2100 million including loans and grants. The recipients could be state, local and public authorities.
- provide grant support for commercial geological CO_2 storage projects.
- support CCU by authorising the Department of Energy to provide funding for municipalities and states for procurement of CO_2-based products for infrastructure projects.
- support legal and regulatory authorisation for permitting Class IV[65] CO_2 storage wells[66]. Class IV storage wells were introduced under the Underground Injection Control Program to ensure a distinction between CCS activities and Class II rules for CO_2-EOR operations. The new regulatory framework established minimum technical criteria for geological storage operations, site characterisation, monitoring, post-injection site care and financial security.[67]

The table below provides an overview of **permitting requirements** for CCUS in the United States. Generally, the existing permitting requirements for CCUS mirror those permitting requirements for other industrial activities. A recent review by the Council on Environmental Quality Report

[59] Milieu Ltd for the World Bank (2016) MX TF Carbon Capture, Utilization and Storage Development in Mexico: Development of a regulatory framework for carbon capture, utilization and storage in Mexico.

[60] Council on Environmental Quality Report to Congress on Carbon Capture, Utilization, and Sequestration (2021). Available at: https://www.whitehouse.gov/wp-content/uploads/2021/06/CEQ-CCUS-Permitting-Report.pdf

[61] State of California (2021) SB-905 Carbon sequestration: Carbon Capture, Removal, Utilization, and Storage Program. Available at: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220SB905

[62] Clean Air Task Force (2022) California passes carbon capture and storage legislation, marking a pivotal move towards achieving its ambitious climate goals. Available at: https://www.catf.us/2022/09/california-passes-carbon-capture-storage-legislation-marking-pivotal-move-toward-achieving-ambitious-climate-goals/

[63] SCALE Act (Storing CO_2 and Lowering Emissions Act) Available at: https://www.iea.org/policies/13193-scale-act-storing-co2-and-lowering-emissions-act

[64] U.S. Department of Energy (2022) Carbon Dioxide Transportation Infrastructure. Available at: https://www.energy.gov/lpo/carbon-dioxide-transportation-infrastructure

[65] Under the Class I: Industrial and Municipal Waste Disposal Wells, Class II: Oil and Gas Related Injection Wells; Class III: Injection Wells for Solution Mining; Class IV: Shallow Hazardous and Radioactive Injection Wells, Class V: Wells for Injection of Non-Hazardous Fluids into or above Underground Sources of Drinking Water; Class VI: Wells used for Geological Sequestration of CO_2.

[66] IEA (2022) SCALE Act Storing CO_2 and Lowering Emissions Act. Available at: https://www.iea.org/policies/13193-scale-act-storing-co2-and-lowering-emissions-act

[67] GCCSI (2021) CCS in the Circular Carbon Economy: Policy & Regulatory Recommendations.

concluded that the Federal government already has a regulatory framework that can safeguard the environment, public health and safety as CCUS projects move forward. However, given the complexity of CCUS projects, identifying relevant permitting requirements that are broadly applicable to all projects can be difficult.[68]

Federal Safety Regulations for CO_2 Transport by Pipes[69]

The federal Pipeline Safety Act70 gives the U.S. Department of Transportation the responsibility to detail safety standards for the design, construction, operation and maintenance of CO_2 pipelines. However, the Department of Transportation has delegated this responsibility to the Pipeline and Hazardous Materials Safety Administration. At present, federal safety regulations encompass pipelines that carry supercritical CO_2 with high purity of around 90%, which is the quality used for EOR. No regulation for pipelines transporting CO_2 of lower concentration or form exist at the moment.

The **45Q tax credit**[71] constitutes an important incentive to promote CCUS in the US. Under the Inflation Reduction Act (IRA) of 2022, critical updates were made to the programme to further incentivise the use of carbon capture and storage.[72] The updated 45Q tax credit provides up to 85 US$/tonne of CO_2 permanently stored and 60 US$/tonne of CO_2 used for industrial applications that could include producing chemicals, provided emission reductions can be clearly demonstrated. The credit amount significantly increases for direct air capture technologies to 180 US$/tonne of CO_2 permanently stored and 130 US$/tonne of CO_2 when used.[73]

Another relevant initiative is the **Carbon Storage Assurance Facility Enterprise** (CarbonSAFE) by the Department of Energy-funded programme which fully develops large-scale (at least 50 Mt capacity) storage sites at key locations around the US, bringing them to a point where they are fully characterised, permitted for CO_2 injection, and available for commercial use.[74, 75] The table below provides an overview of the different project phases that the programme supports, their expected duration and activities to be undertaken at each of these phases.

[68] Council on Environmental Quality Report to Congress on Carbon Capture, Utilization and Sequestration (2021). Available at: https://www.whitehouse.gov/wp-content/uploads/2021/06/CEQ-CCUS-Permitting-Report.pdf

[69] Accufacts Inc. (2021) Accufacts' Perspectives on the State of Federal Carbon Dioxide Transmission Pipeline Safety Regulations as it Relates to Carbon Capture, Utilization, and Sequestration within the U.S.

[70] US 102nd Congress (1991-1992) Pipline Safety Act of 1992. Available at: https://www.congress.gov/bill/102nd-congress/senate-bill/1583

[71] See: Accelerating Carbon Capture and Extending Secure Storage through 45Q Act or the ACCESS 45Q Act. Available at: https://www.congress.gov/bill/117th-congress/house-bill/1062

[72] CATF (2022) Carbon Capture Provisions in the Inflation Reduction Act of 2022. Available at: https://cdn.catf.us/wp-content/uploads/2022/08/19102026/carbon-capture-provisions-ira.pdf

[73] Thielges et al. (2022) Committed to implementing CCU? A comparison of the policy mix in the US and the EU.

[74] U.S. Department of Energy, National Energy Technology Laboratory (2022). Available at: https://netl.doe.gov/carbon-management/carbon-storage/carbonsafe

[75] CATF (2022) European Strategy for CCS. Available at: https://cdn.catf.us/wp-content/uploads/2022/05/10050419/CATF_CCSEuropeStrategy_Report_final.pdf

Table 4: Supported Project Stages and Activities under the Carbon Storage Assurance Facility Enterprise Program[76]

Phase stage and name	Duration	Activities
Phase I: Integrated CCS Pre-Feasibility	12-18 months	• Formation of team • Development of feasibility plan • High-level technical evaluation of the sub-basin and potential CO_2 sources
Phase II: Storage Complex Feasibility	18-24 months	• Data collection • Geologic analysis • Analysis of contractual and regulatory requirements • Subsurface modelling • Risk assessment • Evaluation of monitoring requirements • Public outreached
Phase III: Site Characterisation and Permitting	< 3-years	• Detailed site characterisation • Submission of Underground Injection Control (UIC) Class VI77 permit for construction • CO_2 capture assessment • National Environmental Policy Act (NEPA) approvals
Phase IV: Construction	< 2.5 years	• Obtaining UIC Class VI permit to inject • Drilling and completion of injection and monitoring wells • Completion of risk and mitigation plans

[76] Based on: https://netl.doe.gov/sites/default/files/2022-05/IG-CarbonSAFE_20220512.pdf

[77] Class VI refers to wells used for geological sequestration of carbon dioxide. For more information see: https://www.epa.gov/uic/class-vi-wells-permitted-epa

Figure 2: Overview of Permitting Requirements for CCUS in the US[78]

Portion of the CCUS effort *	Authorization	Authorities that may require permits/permissions	Type of Agency**
	Land use	Local government, Federal Government (public lands)	City Council, Federal Land Manager (USFS, BLM, etc.)
	Discharges to surface water	State and/or Federal Government	State Department of Environmental Quality, U.S. Environmental Protection Agency
	Discharge of dredge or fill materials to waters of the U.S.	State and/or Federal Government	U.S. Army Corps of Engineers and or relevant State office (Florida, Michigan and New Jersey)
	Endangered species	State and/or Federal Government	State Environmental or Natural Resources Department, U.S. Fish and Wildlife Service, NOAA Fisheries
	Greenhouse gas reporting	State and/or Federal Government	State Environmental Department, U.S. Environmental Protection Agency
	Air permits	State and/or Federal Government	State Environmental Department, U.S. Environmental Protection Agency
	CO_2 pipeline safety	State and/or Federal Government	State and Federal Departments of Transportation
	Siting CO_2 pipelines	Local, State, and Federal Government	State Transportation Department or Utility Commission; Federal land management agencies
	Pore space ownership and mineral rights	Local, State, and Federal Government (if Federal lands)	Determined by State-specific law, Federal agency managing Federal Lands to be used
	CO_2 injection (and sequestration) permitting	State and/or Federal Government (some states have primacy for Class VI permitting)	State Environmental Department, U.S. Environmental Protection Agency

*denotes utilization, denotes capture, denotes transportation, and denotes geologic sequestration

**Federal responsibility is listed together with exemplary state and local governments (which vary depending on local context). For Tribal lands/sovereign nations, the Tribal government will have oversight.

[78] Council on Environmental Quality Report to Congress on Carbon Capture, Utilization, and Sequestration (2021). Available at: https://www.whitehouse.gov/wp-content/uploads/2021/06/CEQ-CCUS-Permitting-Report.pdf

2.5.3 Canada

Canada has several decades of experience with various components related to CCUS activities based on experience in the oil and gas sector. While there is no overarching piece of regulation on CCUS, regulatory competences of CCUS are shared between federal and province levels, similar to the US. The **federal government** has the power to regulate GHG emissions under the **Canadian Environmental Protection Act**, 1999 (CEPA)[79] which also includes, among other elements, federal funding for CCUS projects, projects on federal lands, and transboundary projects. The federal government, through the National Energy Board (NEB), regulates international and interprovincial aspects of the oil, gas and electric utility industries and has jurisdiction over interprovincial and international pipelines. On the other hand, **Environment Canada (EC)**[80] regulates international and interprovincial environmental impacts regarding CCUS such as federal air emissions, climate change, nature and pollution among others.

Canadian Provinces have a substantial amount of the constitutional authority to govern CCUS activities. Especially the Provinces of Alberta, British Columbia, and Saskatchewan have developed a CCUS regulatory framework during the last years based upon their oil and gas regulatory and legal framework.

In Saskatchewan, the **Boundary Dam Power Station** is the world's first and largest commercial-scale CCS project of its kind. In September 2021, the Minister of Energy and Resources announced the provincial government's key priorities to advance private sector investment in CCUS. One of the key initiatives looks into opportunities for CCUS infrastructure hubs and distribution models, including for the Regina-Moose Jaw Industrial Corridor to Southeast Saskatchewan and Greater Lloydminster areas.[81]

In 2010, Alberta amended its Mines and Minerals Act via the **Carbon Capture and Storage Statutes Amendment Act**[82] to declare that all pore space shall be owned by the province with the exception of that under federally owned lands. This amendment allowed the provincial government to accept the long-term liability for CO_2 storage. The province created a Post-Closure Stewardship Fund to ensure there are funds available to cover monitoring and possible remediation costs once the province assumes liability. CCS operators are obliged to contribute to the **Post-Closure Stewardship Fund**.[83]

[79] Canadian Environmental Protection Act (1999). Available at: https://www.canada.ca/en/services/environment/pollution-waste-management/understanding-environmental-protection-act.htmlhttps://www.canada.ca/en/services/environment/pollution-waste-management/understanding-environmental-protection-act.html

[80] Environment and Climate Change Canada. Available at: https://www.canada.ca/en/environment-climate-change.html

[81] Wildeman, J. (2022) Western Canada Leads the Way with Carbon Capture Utilization & Storage. Available at: https://www.mltaikins.com/energy/western-canada-leads-the-way-with-carbon-capture-utilization-storage/

[82] Carbon capture, utilization and storage – Overview. Alberta has committed $1.24 billion through 2025 to two commercial-scale carbon capture and storage projects. Available at: https://www.alberta.ca/carbon-capture-utilization-and-storage-overview.aspx#:~:text=Carbon%20Capture%20and%20Storage%20Funding,term%20liability%20for%20storage%20sites

[83] Milieu Ltd for the World Bank (2016) MX TF Carbon Capture, Utilization and Storage Development in Mexico: Development of a regulatory framework for carbon capture, utilization and storage in Mexico.

Alberta's Approach to the Transfer of Liabilities for CCS Projects[84]

In Alberta, all liabilities remain with the operator until the closure of the site and issuance of a closure certificate. The moment in which the transfer of liability occurs is at the issuance of a closure certificate by the minister. The certificate is issued "if the minister is satisfied" that the application is complete and accurate and if several conditions are met including, but not limited to:

- compliance with all monitoring requirements post cessation of injection,
- abandonment of all wells and facilities,
- compliance with surface reclamation requirements,
- the prescribed closure period has passed (the recommended period if of 10 years) and,
- the behavior of the captured CO_2 is stable and predictable with no significant risk of future leakage. The regulator and operator should agree on how the project will demonstrate that CO_2 is predictable and stable.

The transfer of liabilities from operator to the Crown encompasses statutory liability and their party tort liabilities of the licensee. The transfer of liabilities does not involve any scope expansion (the transfer does not involve additional liabilities).

Alberta's scheme contemplates that the operators should fund the transfer of the liabilities listed below through the Post-Closure Stewardship Fund:

1) any continuing post-closure monitoring
2) the statutory substitution liabilities (the Crown 'assumes all of the obligation of the lessee')
3) any suspension, abandonment and related reclamation or remediation costs associated with orphan facilities. Orphan facilities are those that fail to progress to the point of liability transferer (i.e. can be regarded as failed projects).

Third party tort liabilities are not included in the PCSF but remain with the province following the transfer of liabilities.

Alberta will determine the level of contribution to the Fund by each lessee on a project-by-project basis however, the funds paid into the PCSF are to be pooled amongst all PCSF payees. It is yet to be seen how to reconcile in practice favoring contributions assessed on a project specific basis on the one hand and on the other hand, pooling to reduce the contributions that would otherwise be payable by higher risk projects.

While some provinces, like Alberta, have created a fairly comprehensive CCUS regulatory regime, other provinces and aspects of the federal government's climate plan still require further developments. Among issues that should be highlighted are: the ownership of pore space, long-term liability for stored CO_2, a framework for how the reduction of GHG emissions will factor into the applicable Output Based Pricing System (OBPS), an off-set credit programme.

[84] Bankes, N. (2019) Alberta's approach to the transfer of liability for carbon capture and storage projects, Int. J. Risk Assessment and Management, Vol. 22, Nos. 3/4, pp. 311–323

2.5.4 Australia

While there is no overarching regulation to CCUS in Australia, a regulatory approach can be identified, consisting of a **mix of modification to pre-existing regulation for the petroleum sector and new, specific legislation**. There is a strong **differentiation between the approaches adopted for offshore and onshore storage** reflecting the different jurisdictions. The Commonwealth government has jurisdiction from three nautical miles offshore to the edge of Australia's continental shelf, while the states and territories have jurisdiction over CO_2 storage onshore and up to three nautical miles offshore.

The state of Victoria has been the first to support CCS development. **Victoria's Greenhouse Gas Geological Sequestration Act 2008**[85] regulates issues around storage of CO_2 including storage resource assessment, ownership of pore space, operational liabilities and financial security, site closure process and financial assurance of long-term site stewardship among others. In 2012, **Victoria's Offshore Petroleum and Greenhouse Gas Storage Act 2010**[86] came into force and in 2011, the associated Regulations. Victoria is the first state in Australia to have a comprehensive legislative and regulatory framework that provides for CCUS activities in both onshore and off-shore areas.[87] Queensland's regulation of CCS is described under the Greenhouse Gas Storage Act 2009.[88] Victoria and Queensland both leave liability with the operator post-closure.

On the other hand, Tasmania, New South Wales and the Northern Territory do not have specific CCS legislation. Western Australia had only just announced in 2022 that it will draft a Greenhouse Gas Storage and Transport Bill to facilitate CCS projects.[89]

2.6 Regulatory considerations for transport and storage of CO_2

Below the key regulatory considerations for CO_2 transport and storage are identified and discussed.

2.6.1 Transport

Pipelines

Providing proper commercial and regulatory framework for CO_2 transport will entail:

1) Network planning including defining the role of a regulatory authority
2) Organising the CCS full value-chain and considering unbundling
3) Choosing infrastructure's ownership structure

[85] Government of Victoria (2008) Available at: https://www.legislation.vic.gov.au/in-force/acts/greenhouse-gas-geological-sequestration-act-2008/013

[86] Government of Victoria (2012) Available at: https://www.legislation.vic.gov.au/in-force/acts/offshore-petroleum-and-greenhouse-gas-storage-act-2010/017

[87] Milieu Ltd for the World Bank (2016) MX TF Carbon Capture, Utilization and Storage Development in Mexico: Development of a regulatory framework for carbon capture, utilization and storage in Mexico.

[88] Queensland Government (2009). Available at: https://www.legislation.qld.gov.au/view/html/inforce/current/act-2009-003

[89] Government of Western Australia (2022) Available at: https://www.mediastatements.wa.gov.au/Pages/McGowan/2022/03/Draft-Bill-to-help-WAs-resources-industry-reduce-emissions.aspx

4) Providing access to the infrastructure including through Third Party Access
5) Tariff regulation
6) Specifying permitting issues
7) Considering CO_2 standards
8) Financing CO_2 networks (discussed under the market analysis section)

Network Planning

Network Planning is a crucial element, especially, at the early stage of CCS development given that planners will face uncertainty over volumes transported and pricing. In this regard, **a clear forecast of expected volumes and possible network corridors would be very valuable**. The EU's Joint Research Centre (JRC) published a study in 2010 on the expected trans-European CO_2 transport networks[90] and a follow up paper on the optimised deployment of a European CO_2 transport network in 2012.[91] However, after over ten years, these plans require updating. The JRC is currently working on these updates – which should bring much needed insights into the optimal design of infrastructure planning for CO_2 transport from emitters to storage sites.

The **European hydrogen backbone network could serve as a blueprint for the planning of the** CO_2 **transport network** as the same energy intensive industry players are often interested in being connected to hydrogen and CO_2 networks.

Network planning needs to **take into consideration that economies of scale for pipelines will translate into a preference for building pipelines with greater capacity** than required by initial projects – a challenge for initial investors (see section on access to infrastructure and tariff regulation). Volume risks based on uncertainty around the number of capture projects for transport and storage providers (T&S) could be mitigated/minimised, to an extent, by clusters of capture projects. Having a cluster of emitters located in one area would minimise the risk of any given emitter failing to fulfil the capture commitments. It would also allow to aggregate emissions volume.

Furthermore, deciding on **constructing new pipelines versus repurposing existing natural gas pipes** is an additional element for consideration during network planning. The cost of repurposing hydrocarbon pipelines for CO_2 transport are estimated to be much lower, just 1 to 10% of the costs of building new pipelines.[92] Thus, this should be an option that is prioritised when possible. However, without an oversight of all planned projects, it might be difficult, for individual projects to determine the cost-optimum investments – thus, a body tasked with these oversights would likely be required (see section on network regulator). Alternatively, a "soft-approach" encouraging information-exchange between network operators could be envisioned through a platform such as the European CCUS Projects Network[93], which consists in the voluntary knowledge-sharing among projects.

The **role and extent to which CO_2 transport by means other than pipelines will be expected plays an important consideration in network planning**. Thus, multi-modal transport should be considered in the planning. In particular, transport options involving transport other than through pipelines will play a role in connecting smaller and/or stranded emitters, which account for a substantial share of emissions in Europe.

[90] JRC (2010) The evolution of the extent and the investment requirements of a trans-European CO_2 transport network

[91] Morbee, J. et al. (2012) Optimised deployment of a European CO_2 transport network

[92] Benton C. and Silton B. for ADL Ventures. Repurposing Natural Gas Lines: The CO_2 Opportunity. Available at: https://adlventures.com/repurposing-natural-gas-lines-the-co2-opportunity/

[93] https://www.ccusnetwork.eu/

Furthermore, an understanding of the European storage potential including the development of onshore storage sites is an additional element to consider in planning. Views among stakeholders on the extent to which onshore storage will play a role in Europe differ. For example, in France, onshore storage could play an important role, and a model based on smaller volume, onshore sites has been described by stakeholders interviewed. **A European storage atlas updated periodically would facilitate the task of network planning**.

As mentioned above, taking inspiration from the Hydrogen and Decarbonised Gases Market package the idea of establishing **a requirement for network planning**, as for instance in the Ten Year Network Development Plans (TYNDP), or via reporting in the NECPs, could help in **providing a degree of certainty for investors**. Articles 51 and 52 of the Recast Directive on common rules for the internal markets in renewable and natural gases and in hydrogen (COM2021/803) can provide guidance on how such requirements could be set up. Article 51 focuses on network development and powers to make investment decisions. Under this article, transmission system operators are to submit TYNDPs based on existing and forecasted supply and demand to regulatory authorities in each Member State. These plans are to be updated every two years. Elements to be included in the planning are:

- main infrastructure to be built over the 10 years period;
- information on all the investments that have been decides and those to be executed in the next three years;
- information on infrastructure to be decommissioned;
- provide a timeframe for the investment and decommissioning projects;
- be based on a joint scenario framework developed between relevant infrastructure operations;
- be consistent with the results of the common and national risk assessment under Art. 7 of Regulation (EU) 2017/1938 on measures to safeguard the security of gas supply;
- need to be in line with the integrated national energy and climate plan and its updates, and with the integrated national energy climate reports submitted in accordance with Regulation (EU) 2018/1999 and support the climate-neutrality objective set out in Article 2(1), of Regulation (EU) 2021/1119.

Except for the provision related to the Regulation on measures to safeguard the security of gas supply, the remaining planning elements could be applicable and would be valuable for the planning of CO_2 networks. Given that the CCS market is just emerging, a shorter planning timeframe could be more appropriate. The idea of establishing such network plans was positively received by several stakeholders interviewed within the scope of this project.

Role of a Regulatory Authority and Network Operator

Closely tied to the question of network planning is the question of who should oversee this planning. Should this be the task of a designated, centralised body or, to the contrary, left completely unregulated and up to the discretion of different project contractors/investors?

The above elements of planning would be more easily implemented with the oversight of a regulatory entity in the form of a network regulator. Similar to the case of hydrogen, a single network operator could be charged for overseeing the networks. Provisions under chapter 10 of the Recast Directive on the Hydrogen and Decarbonised Gas Market could provide guidance. Article 70 on the designation and independence of a regulatory authority states that Member States should ensure that the regulatory authority is legally distinct and functionally independent from any other public or private entity. This should also be the case for a regulator of CO_2 networks.

In addition, a clear distinction and task division between the network regulator and network operator would be helpful. For example, in the UK, a Transport and Storage Company (T&SCo) acts as the operator and asset owner and is entrusted with the development, construction, financing, operation & maintenance, expansion and T&S network. In addition, they are responsible for the health, safety and environmental compliance of the T&S network.[94] On the other hand, the regulator, likely Ofgem, would be tasked with ensuring that the transport and storage company (network operator and asset owner) can finance its operation.[95]

Organisation of the CCS Full Chain and Unbundling

An additional aspect of regulation is how the full-chain structure should be organised. Different models could be imagined from complete unbundling of the transport and storage parts to the provision of CO_2 transport and storage by one company as a single service.

In the UK, a Transport and Storage Company (T&SCo) is responsible for overseeing both elements. The bundling of T&S as one service would decrease complexity for emitters who would only have to worry about contracting a single service rather than having separate agreements for CO_2 transport and CO_2 storage. The Longship project in Norway consists of two CO_2 capture projects (Norcem and Celsio) and one CO_2 transport and storage project (Northern Lights). In the case of Longship, the state acted as a guarantor for the risks related to the interface between the projects. The state, through the state-owned enterprise Gassnova, also coordinated and facilitated the development of the full CCS chain acting as a "project integrator".

On the other hand, stakeholders mentioned the possibility of multimodal transport acting as an intermediary with emitters having a long-term contract with storage operators and transport being contracted separately by the emitters. Unbundling transport from storage would provide increased flexibility for transport options. In this case, emitters could have several different contracts with separate transport operations, for example, for pipeline and ship-based transport. In the case of Porthos and Aramis, the CCS Projects in the Netherlands, transport and storage will be overseen by different operators. The different organisation of the CCS value chains in different projects and countries is described under the section **Existing CCS Value Chains** in the report.

The organisation of the value chain will also impact how liabilities are distributed across the CCS chain. As mentioned under the description of the ETS Directive, the ETS liability moves from one operator to another across the CCS chain.

Infrastructures Ownership Structure

Current CCS projects worldwide cover a complete range of ownership structures for T&S from 100% state or municipal ownership to 100% private ownership. The table below provides a list of different ownership models. The ownership structure will have an impact on the level of decision-making by a government and the direct control of infrastructure to meet government objectives.

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[94] UK Government (BEIS) (2021) Carbon Capture, Usage and Storage: An update on business models for Carbon Capture, Usage and Storage.

[95] UK Government (2022) Duties and Functions of the Economic Regulator for Carbon Dioxide Transport & Storage Networks: Government response to the consultation.

Table 5: Examples of T&S Ownership Structures[96]

Jurisdiction and Project	Ownership model
Netherlands	Entirely government and municipally owned (this is the case of CO2TransPorts) Aramis is partly privately, partly publicly owned)
Norway (Northern Lights)	Some state ownership by the participation of the state-owned Equinor
Denmark	Government takes 20% share in all storage projects
USA	Privately owned
UK	Likely that in the UK the transport and storage company will be entirely privately owned (this is not yet confirmed)

Providing Access to the Infrastructure

Issues of **third-party access** arise when **spare capacity exists in the** CO_2 **pipeline network** (or storage site) and optimising the use of this capacity becomes of interest. In such cases, the spare capacity may influence the market for CCS (e.g. through potential monopolistic behaviour among market players). If operators try to prevent potential new connectors from entering the market without any reasonable technical or economic grounds, implementing laws that set conditions by which operators are obliged to grant third-party access to CO_2 pipelines (and storage) should be considered. The design of third-party access regulation should be carefully considered to avoid disincentivising project developers from financing and constructing new pipelines (and storage).

Important elements to consider include[97]:

- The need to incentivise fast CCS infrastructure deployment while considering the ‘chicken and egg problem’ and relationship between capture investments and investments in sufficient storage availability.
- The number of actors and the volumes per actor to ensure the most cost-effective deployment with the highest climate impact by transporting and storing the largest volume of CO_2.
- The high entry cost for new market participants – the high costs of new infrastructure development and very high costs for site exploration create entry barriers for smaller players.
- Desirability to bring in smaller players – third-party regulation could lower market entry costs for new players.
- The necessity to provide incentives for first movers - the desirability of supporting new and smaller player market entry should be balanced by the need to incentivise that new infrastructure is built.
- Technical limitations of designing pipelines with optimal capacity – so that third party access can succeed, new pipeline capacity needs to be designed to match the CO_2 volumes of capture facilities. Issues regarding blending of different CO_2 sources and purity standards (see section on standards below) must also be considered.

One of the recommendations by the government of Alberta in Canada regarding TPA was to undertake some form of "open house" events where the operators can invite interested, other

[96] Own elaboration based on Bellona Europa (2021) Models for Transport and Storage of Captured CO_2 and with added information on Denmark.

[97] IEA (2010) Carbon Capture and Storage: Model Regulatory Framework

parties to assess potential customers and thus provide more information to correctly size the pipes.[98]

Article 21 of the CCS Directive already contains provisions on third-party access to transport and storage sites. The article states that Member States shall take necessary measures to ensure that potential users are able to obtain access, in a transparent and non-discriminatory manner, to transport networks and to storage site. This shall be done considering:

a) the storage capacity which is or can reasonably be made available within the areas determined under Article 4, and the transport capacity which is or can reasonably be made available;
b) the proportion of its CO_2 reduction obligations pursuant to international legal instruments and to Community legislation that it intends to meet through the capture and geological storage of CO_2;
c) the need to refuse access where there is an incompatibility of technical specifications that cannot be reasonably overcome;
d) the need to respect the duly substantiated reasonable needs of the owner or operator of the storage site or of the transport network and the interests of all other users of the storage or the network or relevant processing or handling facilities who may be affected.

Tariff Regulation

Appropriate price setting through e.g. tariff regulation can address the price risks associated with capital and operational expenditures especially given the importance of ensuring spare capacity considering the expected increase in CO_2 capture volumes over the 2030 and 2050 time-horizon.

Prices may consist of:

- commodity charge per tonne of CO_2 transported;
- capacity charge for a certain maximum flow rate paid irrespective of the volumes transported;
- a connection fee.[99]

The optimal price setting mechanism will depend on variables related to the chosen business model (see below) and type of financial support being received among others. For example, capacity charge can reduce the risks of variations in CO_2 capture volumes from a project, because the charge does not dependent on the volume transported. On the other hand, a connection fee can recover costs specific to an individual capture project, for example a smaller branch pipeline serving only that project.

Tariff setting should also be designed to address the incurred costs of transport (and/or storage) investors in overcapacity. Transport through pipelines and storage exhibit natural monopoly tendencies and capacity considerations will play an important role in determining the overall investment (building a pipeline with twice the capacity is much cheaper than building two pipelines, similarly, developing one larger storage place is cheaper than investing in two storage sites). Thus, ensuring a mechanism through which costs in overcapacity can be recovered will be crucial to incentivise investments. However, tariffs need not be the only way to address the issue of investments in overcapacity. Government subsidies targeting capacity costs or operational subsidies are another option to address this. Different business models such as depreciation of the **regulated asset base (RAB)** could also be applied. These are further discussed in the report section on market models.

[98] IEA Legal and Regulatory Frameworks for CCUS: An IEA CCUS Handbook

[99] Bellona Europa (2021) Models for Transport and Storage of Captured CO_2

Regulated tariffs could be set by a network regulator. They could be based on one or a combination of elements listed above. Alternatively, negotiated tariffs could be set based on bi-lateral negotiations between individual users of the network (and storage) and the operators.

An idea brought forward during stakeholder interviews was that of collective barning by emitter clusters with transport and storage service providers to determine a negotiated tariff based on committed volumes. During the negotiation, it could be possible to commit to larger volumes over time and thus minimise uncertainty over future volume.

Other Transport Modalities

The specific cost structure of network infrastructures frequently results in significant market power concentrated to its owner. Pipeline transport of CO_2 has large economies of scale, and so a tendency towards natural monopoly. Alternatives to transport by pipelines are being developed in the form of ships, barges, and trucks. Transport by pipelines is likely to be subject to only limited competition in the early years of CCS deployment.[100] However, although most of CO_2 transport is currently done via pipeline, the role of CO_2 transport by ship will become increasingly important – both maritime and inland rivers and canals. CO_2 transport by ship will be crucial to the operationalisation of CCS Projects of Common Interest (PCIs). Furthermore, other transport modalities such as rail and trucks must also be considered. These modes of transport can provide flexibility and allow access to storage sinks for disperse, smaller emitters not connected to pipelines. Multi-mode CO_2 transport is also imperative to ensure fair access to CCS for all Member States including those that are land-bound and where onshore CO_2 storage is not permitted. This issue was highlighted in the context of Central Eastern European countries where development of storage sites might take time and, in the meantime, access to international storage is not straightforward.

Though inclusion of all CO_2 transport modalities in the relevant legislation mention above is crucial to support a multi-mode and flexible transport of CO_2, dedicated CO_2 shipping regulation is likely not needed. Based on interviews, it seems like the existing regulatory framework for maritime transport is sufficient. For example, shipping CO_2 by barge is included in the UN charter for shipment of dangerous goods and is the regulation by which ship transport companies of CO_2 abide.

CO_2 shipping must be accounted for when setting up CO_2 standards (see section below).

Carbon Dioxide Standards

The need for CO_2 standards to facilitate CCS deployment across Europe is of crucial importance. Several considerations should come into play when establishing CO_2 quality standard. For example, if the CO_2 transport infrastructure is used to also transport CO_2 for the purpose of utilisation in addition to storage, this must also be considered. CO_2 standards will be crucial to ensure interoperability across the value chain, including different transport modes. Modular transport, using containers (tanks) carried by truck, train or ship, generally carries CO_2 as a refrigerated liquid under moderate pressure. In contrast, pipeline transport carries a continuous stream of CO_2 generally as a liquid or dense super-critical phase at high pressure and ambient or raised temperature. These two different transport classes, lead to two different treatments of CO_2 specification.[101]

[100] Bellona Europa (2021) Models for Transport and Storage of Captured CO_2

[101] Brownsort P. for the CCUS Projects Network (2019) Briefing on carbon dioxide specifications for transport.

A detailed analysis of CO_2 standards for shipping has been published by the Zero Emissions Platform and the Carbon Capture and Storage Association recently.[102] Key recommendations from the report were to establish a common standard for CO_2 temperature, pressure and composition. Adopting existing standards and guidelines for transporting liquefied CO_2 with CCS is also recommended.

Further, standards are crucial to ensure the viability of trans-national networks. In order to ensure compatibility between different Member States, such standards should be set at EU-level. The International Organisation for Standardisation (ISO) includes voluntary standards for CO_2 capture, transportation, and geological storage under the ISO TC 265.[103] These standards cover:

- Pipeline transportation systems (ISO/CD 27913)
- Geological storage (ISO/AWI 27914)
- Cross Cutting Issues – Flow assurance (ISO/DTR 27925)
- Transitioning from EOR to storage (ISO/AWI TR 27926)
- Key performance parameters and characterisation method of absorption liquid for post-combustion capture (ISO/AWI 27927)
- Performance evaluation methods for CO_2 capture plants connected with CO_2 intensive plants (ISO/AWI 27928)
- Transportation of CO_2 by ship (ISO/AWI 27929)

These standards could be used as a basis for establishing minimum standard requirements at EU-level. At present, the first mover projects, such as Northern Lights, tend to be standard setters.

Different components of the value chain are likely to have different interests when it comes to CO_2 standards. For emitters, providing CO_2 of high quality will come with a higher cost penalty, whereas for CO_2 transport higher quality standards imply lower risks and liabilities. Thus, a balance between cost effectiveness, safety and lowering liability should be sought after. During stakeholder interviews, establishing CO_2 quality standards based on minimum and maximum acceptable ranges was seen as a good solution to address this issue.

The technical specifications of such standards are beyond the remit of this report but should rather be set by a task force made of specialists and stakeholders representing different parts of the value chain.

2.6.2 Storage

The CCS Directive addressed to a large extent regulatory issues around CO_2 storage and associated liabilities. The European experience in developing CO_2 storage under the CCS directive has also been extensively described elsewhere.[104] Some regulatory issues identified include:

- Relatively lengthy permitting processes (between 18 months and 2 years)
- Need for better guidelines to support cooperation/interaction between Competent Authorities and operators/applicants
- Limited guidance regarding transfer from oil & gas operations to CO_2 storage operations in hydrocarbon fields

[102] ZEP/CCSA (2022) Network Technology Guidance for CO_2 transport by ship.

[103] https://www.iso.org/standards.html

[104] ZEP (2022) Experience in developing CO_2 storage under the Directive on the geological storage of carbon dioxide. Available at: https://zeroemissionsplatform.eu/wp-content/uploads/Experience-in-developing-CO2-storage-under-the-CCS-Directive-ZEP-report.pdf

- Options for risk-sharing and transfer of liabilities between the storage developers and the regulatory authorities could be reconsidered. The question on how private investors and governments could share long-term CO_2 storage risks should still be assessed. Options to consider include the establishment of a national fund for pooled liabilities for storage resources.[105]

Recent reports highlight the concern that the development of geological storage sites is falling far behind demand. Based on announced project timelines, there could be a 50% shortfall in developed storage capacity by 2030, even while Europe boasts an estimated 500 Gt of theoretical capacity for CO_2 storage. Storage sites generally take between 5 to 7 years to develop and permit, rely on detailed geological data, and require risky pre-construction investments, particularly for first mover projects with uncertain demand.[106] The Commission's proposal on the Net Zero Industry Act (NZIA), published on the 16th of March, 2023, establishes a target of an annual injection capacity of 50 Mtonnes by 2030.[107] This, target is very important in supporting the development of CCS as it creates certainty for investors as to the minimum CO_2 injection capacity they can count on. However, support for a positive business case for storage will still be very important in the case of many projects. A potential instrument to support the exploration and development of new storage sites could be based on mirroring the Carbon Storage Assurance Facility Enterprise in the USA which fully develops large-scale (at least 50 Mt capacity) storage sites at key locations and brings them to a point where they are fully characterised, permitted for CO_2 injection, and available for commercial use. Further considerations on de-risking investments in storage capacities are discussed in the Market Analysis section of this report.

Permitting

Chapter 3 of the CCS Directive is dedicated to establishing rules for CO_2 storage permitting. It contains rules for exploration permitting, storage permitting, applications for storage permitting, conditions for storage permitting, contents of the permits, review by the Commission of draft permits, changes, reviews updates and withdrawals of storage permits. However, most Member States have transposed the CCS Directive but have not yet developed a regulatory framework to govern the permitting process for CCS. This constitutes a barrier for CCS deployment, as regulators, administrations, operators and general public do not handle a clear compendium of rules and standards to follow. This lack of regulation affects even more to the onshore sites, which are usually surrounded by communities, industries, etc. that require the compliance of regulations to assure safe and controlled exploration and operation processes[108].

Furthermore, given the concern that storage capacity might not be sufficient as capture volumes increase in the future, there could be value in re-evaluating the permitting process to identify areas that could be streamlined and made more efficient.

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[105] Based on Towards a European cross-border CO_2 transport and storage infrastructure – issue paper from the CCUS Forum working group on CO_2 infrastructure

[106] CATF (2022) European Strategy for CCS. Available at: https://cdn.catf.us/wp-content/uploads/2022/05/10050419/CATF_CCSEuropeStrategy_Report_final.pdf

[107] European Commission (2023) Net Zero Industry Act. Available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_23_1665

[108] Carlos de Dios, J; Martinez R. (2019) The permitting procedure for CO_2 geological storage for research purposes in a deep saline aquifer in Spain. Available at: https://www.sciencedirect.com/science/article/abs/pii/S1750583619302555

2.7 Scoping the Regulatory Intervention

In the sections above, different regulatory elements have been identified and discussed. For each of these elements, the extent of regulation which is desirable is subject to further deliberation. The future regulatory framework for CO_2 T&S can range all the way from a highly regulated market to an unregulated one where business-to-business arrangements dominate. However, arguably, further regulatory guidance would be beneficial as the absence of dedicated regulatory attention for CCS can lead to uncertainty for market actors (see section that follows) that often need to operate across multiple countries and with extended time horizons. During interviews with market actors and other stakeholders, the prevalent view was that the aim should be to strike the right balance between providing further regulatory guidance and certainty while at the same time avoiding overregulation of the market too early, which could have negative effects on the development of the market.

The table below provides a summary of the different regulatory elements and options based on sections above. The table loosely groups the different options based on the extent of regulation that these would require, however it is important to highlight that this grouping is loose and not applicable to all elements.

Table 6: Summary of Regulatory Elements and their Level of Regulation

Regulatory element	No to low degree of regulation		High degree of regulation/oversight
Network Planning	No regulatory oversight Ad-hoc planning based on individual projects	Low to medium degree of regulatory oversight	High degree of regulatory oversight Integrated network planning including the development of network plans similar to the TYDNPs. Updated NECPs can constitute a good starting basis.
Network Operator	No designated Network Operator	Separation between network asset owner and system operator	Designated Network Operator is also asset owner
Ownership structure	Fully Private	Public-Private Partnership	Fully Public
Providing access to infrastructure/TPA	TPA based on CCS Directive, Art. 21	Negotiated[109] TPA	Regulated[110] TPA
Full chain organisation and unbundling	Complete unbundling/separation between capture, transport and storage	T&S bundled as one service	Capture, transport and storage are vertically integrated
Tariff regulation & infrastructure cost recovery	Business to business	Collective bargaining by clusters	Subsidy Profiling revenue Fixed price
Standards	No regulation on standards	Suggested range of CO_2 quality standards	Strict regulation of standards within the European Economic Area (EEA)

[109] Access is negotiated between parties on the basis of the publication of the main commercial conditions for use of the system.

[110] Access is regulated on the basis of tariffs and/or other published provisions and obligations for use of the network.

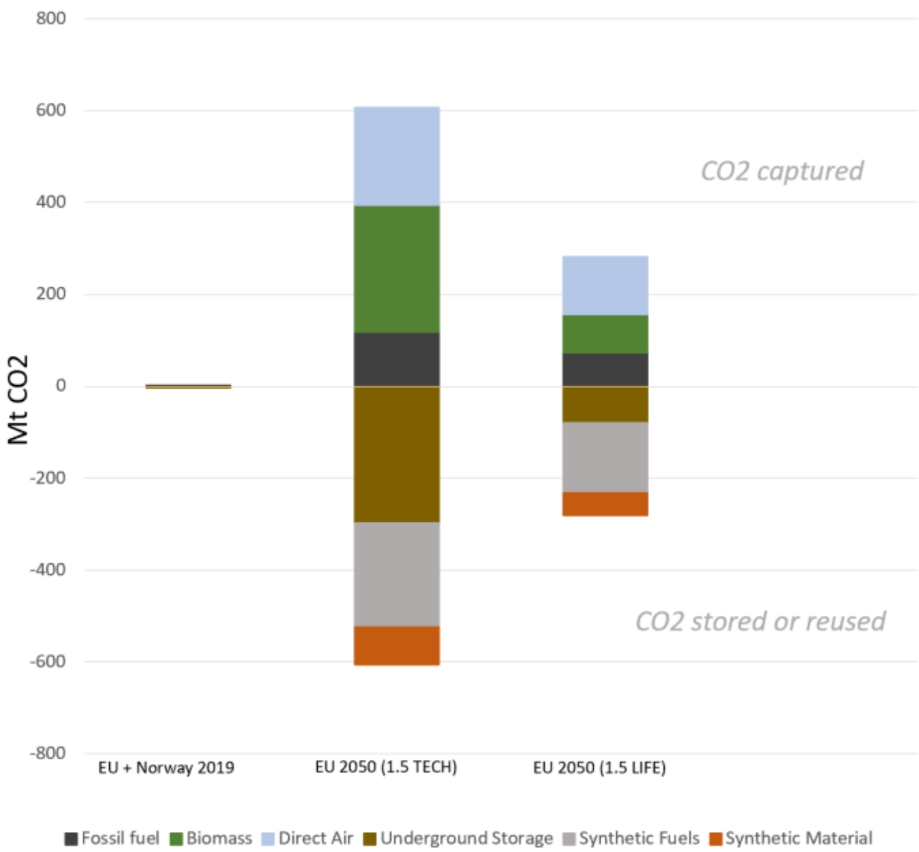
3 Market Analysis

3.1 Current Situation

The market for CCUS in Europe comprises of three main services: the capture, transport and storage of CO_2. This makes the economics and drivers of the developing CCUS market complex, and different to that of a purely commodity driven market (such as natural gas supply). A limited CO_2 commodity market already exists, e.g. where CO_2 is utilised in plastics, fuels, enhanced oil recovery and the food industry, however for the storage of CO_2 a different incentive is required. The development of commercial-scale CCUS will require different economic drivers, focused on avoiding emissions through, for example, putting a price on them as in the case of the EU ETS, rather than the inherent value of CO_2 as a product.

As shown in Figure 3, the potential for CO_2 utilisation is limited, used predominantly for the production of synthetic fuels. The focus of the IOGP report is on the market for providing CO_2 transport and storage purely as a decarbonisation service. However, it should be noted that the CO_2 usage market and the CO_2 storage markets are intertwined. For example, as incentives for storage increase, capture plants currently providing CO_2 for use may be encouraged to instead store their CO_2 and the availability of CO_2 for utilisation could therefore decrease. This of course also works vice-versa, if CO_2 users are willing to pay more than the cost to store CO_2 providers might have less incentive to join CCS projects.

Figure 3: CO_2 Storage and Utilisation Requirements to Meet the Commission's Climate Neutral Scenarios



Source: IOGP (2019)

The CCS transport and storage (T&S) market in Europe is still emerging, and is predominantly driven by the increasing price of emitting CO_2, via the EU Allowances (EUAs) and the associated emissions trading system (ETS). The cost of emitting CO_2 is increasing interest in providing services to permanently store CO_2 (and thus transport it). Currently the ETS price in Europe is still too low to incentivise CCS sufficiently and given the uncertainties currently involved with large-scale CCS deployment, and the economic uncertainties of a changing ETS price, deployment is also currently reliant on national incentives in addition to the ETS.

Note: The largest market driver for CO_2 *storage globally is currently for enhanced hydrocarbon recovery (EHR) projects, where the value is in the production and sales of the oil or gas produced by injecting and permanently storing* CO_2*. This is out of scope for this report.*

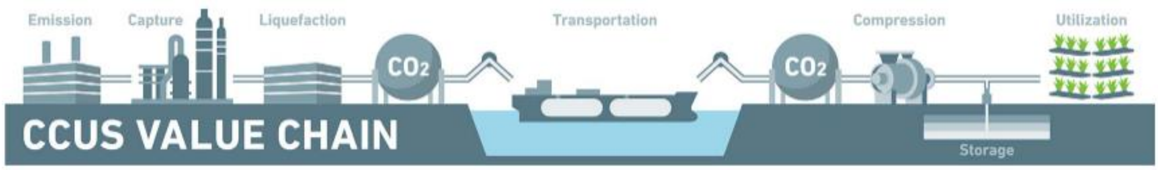
Another key market development for CCS in Europe is the expectation that CO_2 is likely to be transported between Member States, as not all countries have well developed storage potential. The type of cross-border commercial carbon management market that could emerge in Europe is still unclear. In this report the value chains and business models currently developing in various European countries are described to provide insight on the types of markets that are emerging. Key challenges and concerns from stakeholders have been reviewed to allow for an assessment to be made on the type of policy and regulatory support that could be developed in Europe to support these developing cross-border networks.

One of the biggest remaining questions in Europe is whether CO_2 T&S networks should be regulated or privately managed, and how this may impact the type of market, e.g. allowing open-access and allowing for market competition (preventing a monopoly).

3.2 Existing CCS Value Chains

A value chain is a business model that describes the full range of activities needed to create a product or service. The CCUS value chain comprises the same overall capture and transport elements whether it is eventually utilised or permanently stored. Although the economic driver behind the storage business model is somewhat complex, given that in this context CO_2 is not a commodity but rather a T&S service provided designed to prevent climate change, the value chain itself is relatively simple. As shown in **Figure 4**[111], the value chain comprises the capturing of emissions, their liquefaction and transportation and then compression for either storage or utilisation.

Figure 4: Diagram Showing Components of the CCUS Value Chain



Source: MHI (2022)

Especially, for the T&S value chain, the main variation in business model requirements come from the transport mode, whether shipping or via pipeline transport. The process of developing and operating stores remains relatively similar regardless of the type. Other than the investment

[111] Mitsubishi Heavy Industries Group (MHI) (2022) What is needed from CO_2 transport? Available at: https://solutions.mhi.com/blog/what-is-needed-from-co2-transport-an-essential-element-of-the-ccus-value-chain/

requirements to appraise the site, and potentially slightly different operational costs, in general the format of the business model will be the same. However, the business model for transport by shipping is very different to transport by pipeline. The key difference when developing shipping value chains is that there is less of a need for volume uncertainty to begin the project. Shipping is designed based on contracted volumes with emitters on a project by project basis. However, a pipeline comes with more direct location and volume constraints from its inception. The impact of this is discussed throughout this section. In this section the specific value chain for prominent CCUS projects across Europe are discussed in more detail.

3.2.1 Netherlands

Market Overview

No commercial CCUS projects have yet reached operational phase in the Netherlands. The CCUS market currently emerging in the Netherlands is partly driven by a 'push' from the increasing price of emissions via the EU ETS, and partly driven by a "pull" of additional subsidies from the government for early-mover projects. The SDE++ subsidy from the Dutch government provides a Carbon contract for Difference (CfD)-like subsidy to support the cost of CCUS operations, i.e. the subsidy will cover the cost for the project above the EU ETS price but will only run until 2035 as CCUS is considered a transitionary technology.

Capturing CO_2 from industrial emissions is a priority from the Dutch government. The 2019 Climate Agreement in the Netherlands led to a goal for industry to decrease its annual emissions of 14 Mt by 2030. CCUS has been identified as one of the necessary technologies to meet these ambitious targets. The Netherlands has the largest port in Europe, at Rotterdam, which accounts for EUR 45.6 billion or 6.2% of the added value of the Netherlands. The Port of Rotterdam is the largest petrochemical complex in Europe and as a result is responsible for 20% of Dutch greenhouse gas emissions[112]. Given both the significant impact on the economy and climate, the port has developed into the focus of CCUS developments in the Netherlands.

The two CCS projects under development at the moment are CO2TransPorts (the development around Rotterdam is called Porthos) and Aramis, where CO_2 will be transported offshore to the Dutch North Sea from the Rotterdam region. In both projects EBN and Gasunie are project members for the transport and storage services. Gasunie is a limited company, fully owned by the Dutch state, which manages the current gas transport network in the Netherlands. EBN is a natural gas exploration, production, transportation and sale company also fully owned by the Dutch Government. Through EBN the government represents 40% of the Dutch oil and gas production market. Gasunie and the regional network operators are public monopolists in onshore gas transmission and a major player in gas storage.

National Policy & Regulation

The policy support and introduction of the SDE++ have supported the Porthos business case and helped it reach its Final Investment Decision (FID) (at the time of writing this report, FID has been delayed having originally been planned for Q1 2023). All 4 emitters for Phase 1 of the project have signed contracts with Porthos, given they have more financial security now by securing funding for 15 years.

[112] Port of Rotterdam (2019) Building a Sustainable Port. Available at: https://www.portofrotterdam.com/sites/default/files/2021-06/factsheet-port-of-rotterdam-building-a-sustainable-port-en-2019.pdf

Regarding regulation, the EU CCS Directive has been transposed into Dutch National Law. Two storage permits have been secured for the Porthos projects and have recently secured an 'irrevocable' status which was required for the project's final investment decision to be taken in Q1 2023. There are currently no regulatory barriers in the Netherlands to deploying CCUS directly. However indirectly, major construction projects in general (which has impacted Porthos) are currently experience delays due to regulations on nitrogen emissions and the impact of soil extraction. An overview of the two Dutch project are given in Figure 6[113,114].

The current stance on CCUS from the Dutch Government is that it should be a business to business endeavour, between private entities, stimulated by the market. Industry parties are expected to take the lead, developing business models based on government subsidies and set T&S tariffs based on the market. The Dutch Mining Law requires operators to provide non-discriminatory third party access to a CO_2 network (based on the CCS Directive) and therefore a regulator for T&S services is not yet needed nor envisioned. The Ministry of Economic Affairs (EZK) will be the point of contact and the mediator should any complaints or problems regarding open third party access arise.

The development of Porthos and Aramis have varied slightly. For Porthos, there was an open season period for emitters to express interest in accessing and utilising a CO_2 T&S system. However, Aramis has been developed through more bilateral agreements. Through discussions with stakeholders it is apparent that this process of developing bilateral agreements is much less transparent. Many trying to access the market voiced the opinion that they preferred the open season model. Although open access will be required for the infrastructure associated with both projects, the open season process right at the start could provide what is perceived as a fairer process.

[113] Porthos Project website (Accessed November 2022) https://www.porthosco2.nl/

[114] Aramis Project website (Accessed November 2022) https://www.aramis-ccs.com/

Case Study: Porthos (& Aramis)

Consortium: Porthos Development C.V. is its own legal entity which will provide the transport and storage service. The consortium comprises:

Port of Rotterdam

Gasunie (a limited company, fully owned by the Dutch state, which manages the current gas transport network)

EBN (a natural gas exploration, production, transportation and sale company owned by the Dutch Government)

Product & Services: The project is based on permanent storage in the North Sea, with a local collection pipeline provided in the Rotterdam Port area. Capture is the responsibility of the emitters in the Port of Rotterdam area (currently Air Liquide, Air Products, ExxonMobil and Shell) and Porthos will provide the transport and storage services. Given the public nature of Gasunie and EBN the infrastructure developed is planned to be open-source to new customers in the future. The collection pipeline in the Rotterdam area will be oversized for this purpose.

2.5 Mtpa is planned to be captured and stored, from hydrogen production by Air Liquide and Air Products' hydrogen plants, and from the refinery emissions of Shell and ExxonMobil in Phase 1. However, the storage potential in the permits secured so far is much larger and the collection pipeline will have a capacity of 5 Mtpa.

The CO_2 transport service will be operated by Gasunie who will provide a local low pressure connection network between the emitters in the Rotterdam Port area. Storage will be provided by a separate operator, likely to be the previous oil and gas operator of the field, contracted under the Porthos entity. The Port of Rotterdam is part of the CO2TransPorts project which has been awarded a Project of Common Interest status under the 5^{th} PCI list.

The Aramis project is considered a Phase 2 to Porthos and will share transport infrastructure in the Rotterdam region but extended further offshore to increase storage capacity. EBN and Gasunie are again project partners and the business case, product and service are based on the same value chain. Shell and Total will be the storage providers but the offshore pipeline will be designed with overcapacity for open access to third parties in the long-term. Aramis has received the status of Project of Common Interest as part of the projects selected under the 5^{th} PCI list.

Figure 5: Schematic Overviews of the Porthos (left) and Aramis (right) CCS Projects in the Netherlands

Source: Aramis and Porthos project websites

3.2.2 Norway

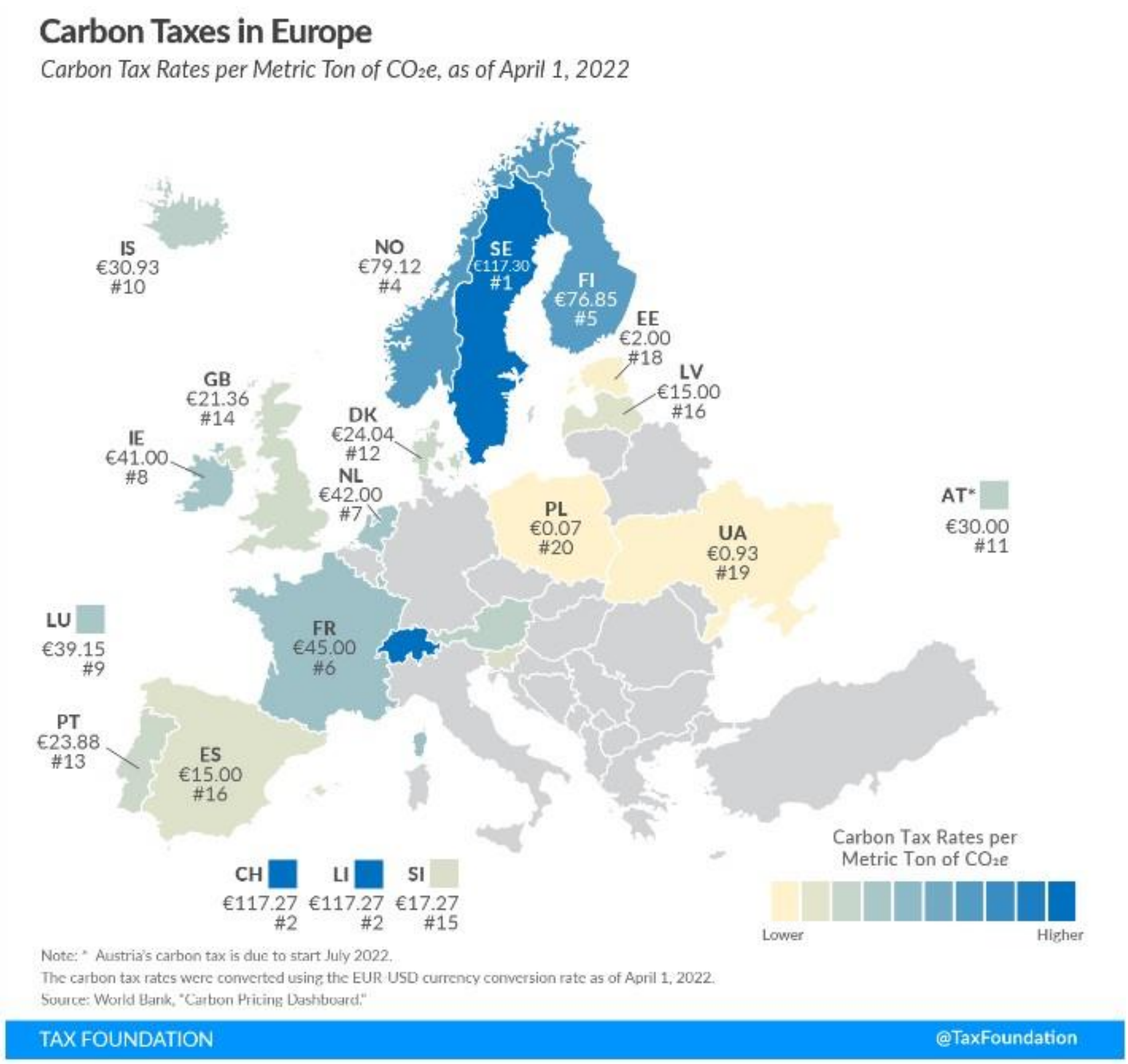
Market Overview

Norway has extensive experience in CCS project deployment, with the Sleipner project having been in operation since 1996. Norway is Europe's top petroleum producer and gas production is vital to the Norwegian economy with crude oil and natural gas accounting for 41% of exports and 14% of gross domestic product (GDP)[115]. Some of the gas produced from the Norwegian continental shelf has had a high CO_2 content leading to the CO_2 management projects (i.e. CCS) that have developed. The natural gas produced from the Sleipner West field "contained up to 9% CO_2, however, in order to meet the required export specifications and the customers' requirements, this had to be reduced to a maximum of 2.5%"[116]. This naturally high CO_2 content, along with Norway's particularly high carbon tax compared to the rest of Europe (see Figure 6), provided the business case to begin CCS deployment in Norway.

[115] Times Magazine (2021) Norway's Fossil Fuel Reliance is going to the Ballot Box. Available at: https://time.com/6096977/norway-fossil-fuels-election/

[116] MIT CCS Project Database (Accessed November 2022) https://sequestration.mit.edu/tools/projects/sleipner.html

Figure 6: Carbon Taxes in Europe as of April 2022



Source: Tax Foundation Website

Through the latest project called Northern Lights (the T&S element of the Longship project), Norway is now hoping to position itself as a storage provider for emitters across Europe. Northern Lights has recently signed an agreement with the Yara Sluiskil ammonia and fertiliser plant in the Netherlands to transport and store the captured CO_2 from the plant in Norway. This is the first cross-border agreement between business entities of its type, claiming to pave the way for international transport and storage of CO_2 as a commercial service.

National Policy & Regulation

The Norwegian government is a strong supporter of CCS developments. Two-thirds of the costs of the Longship project will be covered by the Norwegian government (approximately 25.1 billion NOK) and industry will pay the remaining third[117]. For many years, the government has supported

[117] Norwegian Government Website (Accessed November 2022) https://www.regjeringen.no/en/topics/energy/carbon-capture-and-storage/id86982/

the development of CCS technologies through programmes such as Gassnova, CLIMIT and Technology Centre Mongstad.

Regarding regulation, the EU CCS Directive has been transposed into Norwegian National Law. Two ministries are responsible for the implementation of the directive in Norway, The Ministry of Petroleum and Energy (for resource management) and The Ministry of Climate and Environment (for environmental issues). So far, the Norwegian government has awarded five licences related to CO_2 storage on the NCS. These are:

1) In 2019, an exploitation licence "Aurora" to Equinor in the North Sea (this is the storage location for the Northern Lights project project).
2) An exploration licence to Wintershall Dea and Cape Omega in the North Sea ("Luna project").
3) An exploration licence to Equinor, Horisont Energy and Var Energy in the Barents Sea (Polaris project).

In March 2023, two further licences in the southern part of the NCS were awarded.

4) An exploration licence awarded to AkerBP and OMV Norge ("Poseidon" project), and
5) An exploration licence awarded to Wintershall-DEA Norge and Altera Infrastructure ("Stella Maris" project).

Applications for further exploration licences have been submitted early 2023 by several companies. Hafslund Oslo Celsio has secured funding for their capture project at the waste incineration facility in Oslo.

Phase 1 of Longship will be completed in the beginning of 2025 (some delays due to the pandemic and the war in Ukraine). Phase 1 is fully booked after NL secured the first commercial heads of agreement with Yara in the Netherlands in August 2022, with the ambition of capturing 800.000 Mtpa from 2025.

As discussed in detail below under the section "Managing Liabilities", the risks of managing the project interfaces are the role of the state in Norway (via Gassnova). The tariff level is set through negotiations between Northern Lights and third-parties and is not regulated.

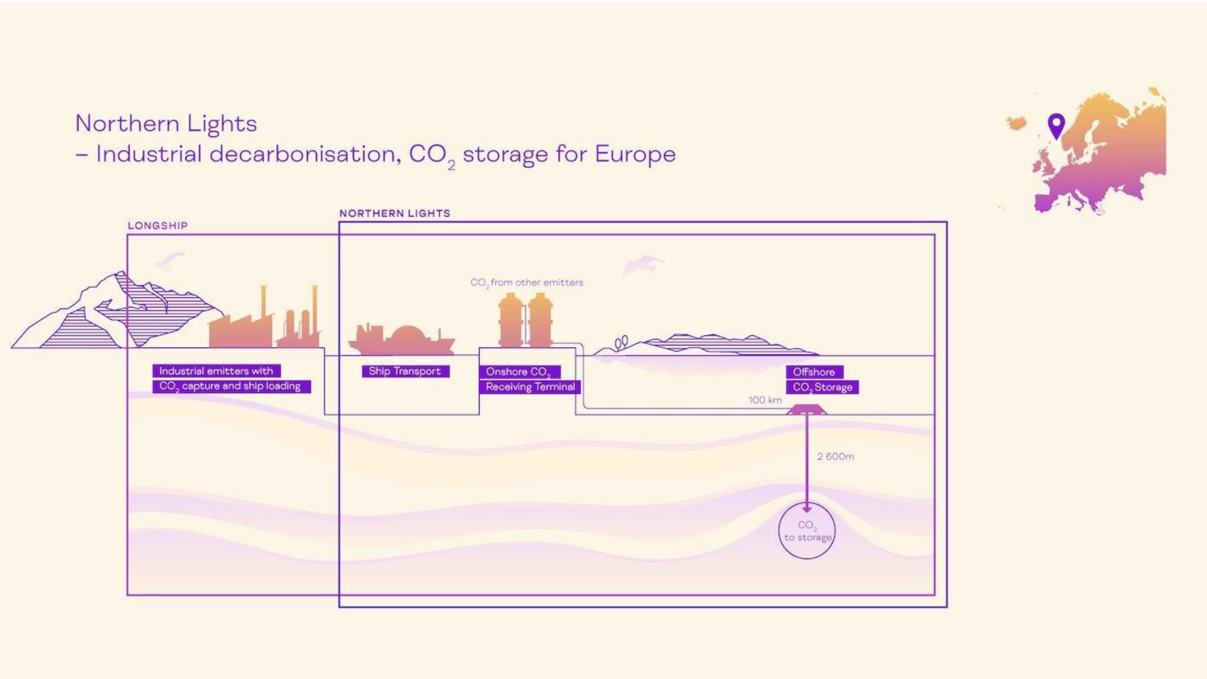
Case Study: Longship & Northern Lights

Consortium: Longship consists of two capture actors, Norcem Heidelberg Materials and Hafslund Oslo Celsio (earlier Fortum Oslo Varme), and one transport and storage actor, the Northern Lights consortium (made up of Equinor, Shell and Total). Each of the three actors has separate agreements with the government to avoid cross-chain risk. Overall responsibility for Longship resides with a steering group, made up of members from Gassnova and the Norwegian Ministry of Petroleum and Energy.

Product & Services: The Norwegian Government aims to implement carbon capture at Norcem's cement factory in Brevik as well as at Hafslund Oslo Celsio's waste incineration facility in Oslo. Northern Lights (Equinor, Shell and Total) is handling the transportation and storage of CO_2 on the Norwegian Continental Shelf.

Phase one of the project will be completed in the beginning of 2025 with a storage capacity of up to 1.5 million tonnes of CO_2 per year. Currently, 0.8 Mtpa are reserved for the two captures sites in Norway (Norcem cement factory in Breivik and the Hafslund Oslo Celsio's waste-to-energy plant). The remaining 0.8 Mtpa of phase one will be used by Yara in the Netherlands. The ambition of phase two of the project is to expand capacity to a total of 5 million tonnes. Northern Lights are engaging with emitters around Europe who are considering using the Northern Lights infrastructure as demand grows, allowing them to reach the full potential storage capacity of the site. Northern Lights has the status of Project of Common Interest as part of the 5th PCI list of projects. Furthermore, the project N-LiTES, as the successor of Northern Lights project, has applied for Project of Mutual Interest status (6th PCI list) (this is between EU MS and EEA states).

Figure 7: Schematic Overview of the Northern Lights and Longship CCS Project



Source: CCS Norway Website

3.2.3 United Kingdom

Market Overview

No commercial CCUS projects have yet reached operational phase in the UK. In 2015, the UK government cancelled its £1bn competition for CCS technology just six months before it was due to be awarded, which was a massive setback for the development of CCUS. In recent years, there has been a renewed push in CCUS developments, again incentivised by the government.

The UK is adopting a hub and cluster approach, aiming to decarbonize the highest emitting industrial areas first, such as the Liverpool Bay area and the Humber region. Clusters are seen as key hubs of local economic activity and an important part of the UK economy: "*They offer high quality jobs that tend to pay above the average UK wage and are key to local supply chains at the local economy. Industry that uses energy intensively, within and outside of clusters, has a value of around £150 billion to the UK economy (GVA)*"[118]. The decarbonisation potential of the Humber Cluster alone is 12.4 Mt per year, meaning the role CCUS could play in maintain the economy whilst also reaching climate goals is significant. The UK also has good storage resources in both depleted hydrocarbon fields and saline aquifers located in the North Sea and Irish Sea.

National Policy & Regulation

The UK Government set out goals for CCUS projects in the Ten Point Plan and the Energy White Paper, which were to capture 10 Mt of CO_2 by 2030 and establishing two "SuperPlaces" by the mid-2020s. Published in 2020, the government stated they would provide "£1 billion to support the

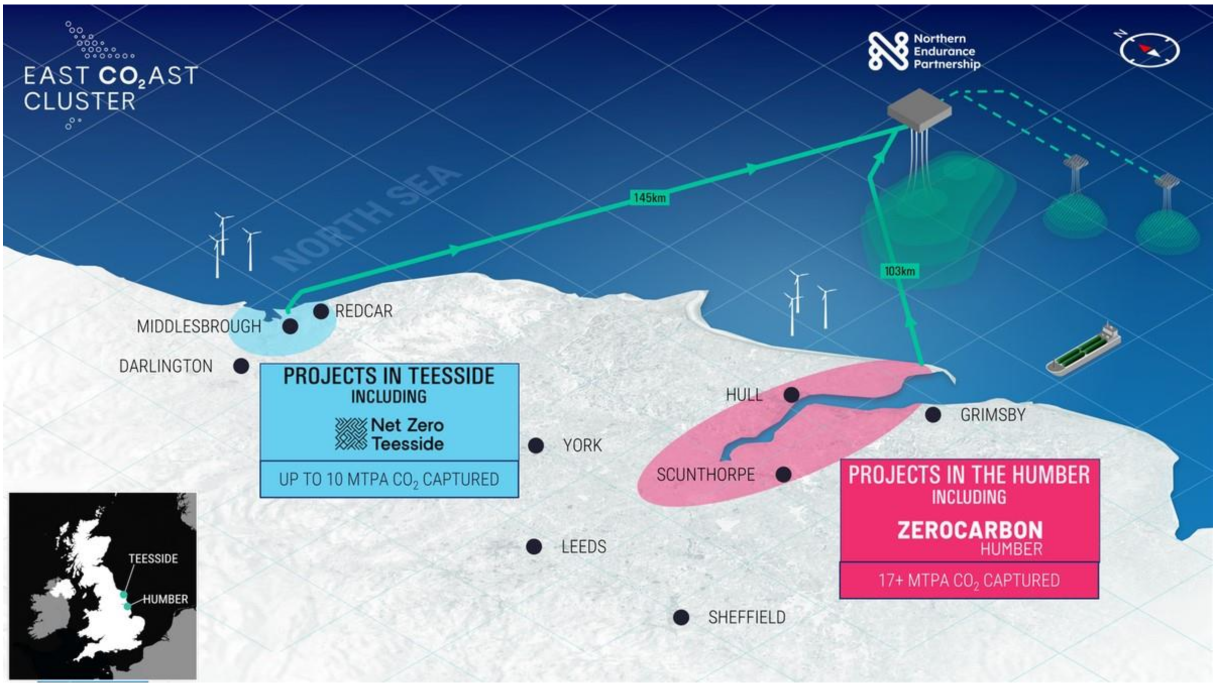
[118] UK Government InfoGraphic (2019). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/803086/industrial-clusters-mission-infographic-2019.pdf

establishment of CCUS in four industrial clusters, creating "SuperPlaces" in areas such as the North East, the Humber, North West, Scotland and Wales".

The Carbon Capture and Storage Infrastructure Fund (CIF) was first announced at Budget in March 2020, and its allocation of GBP 1 billion was confirmed at the Spending Review in November 2020[119]. The UK Government remain of the view that a private sector delivery model (initially supported by targeted forms of government support such as the CIF) is the preferred approach for the delivery of the CO_2 T&S network. The business models being developed in the UK are discussed in more detail below under the section "Business Model Options for CO_2 T&S" but in summary, the UK government has already provided support for the development of two transport and storage clusters with The HyNet (near Liverpool) and East Coast Clusters (in the East Midlands) confirmed as track 1 clusters through the government's CCUS cluster sequencing process. The Phase 2 competition for carbon capture projects that wish to connect to these 2 carbon dioxide transport and storage infrastructures is currently underway[120].

As discussed below in the section "Capital and Ownership", the UK government has decided to put in place an independent economic regulator to oversee the framework of economic regulation of CO_2 transport and storage (T&S), consistent with the approach in other regulated utilities. The Economic Regulatory Regime (ERR) – to be regulated by Ofgem – will set the regulatory framework, including revenues, outputs and incentives. Having spoken to various stakeholders this has been perceived as a very transparent process.

Figure 8: Schematic Overview of the Northern Endurance Partnership T&S Infrastructure and the Locations of the Teesside and Humber Clusters



[119] UK Government (2021) Policy Paper: The CCS Infrastructure Fund: an update on its design. Available at: https://www.gov.uk/government/publications/design-of-the-carbon-capture-and-storage-ccs-infrastructure-fund/the-carbon-capture-and-storage-infrastructure-fund-an-update-on-its-design-accessible-webpage

[120] Equinor Webpage (Accessed November 2022) https://www.equinor.com/news/uk/20220512-east-coast-cluster-carbon-storage-licences

Case study: Northern Endurance

Consortium: BP, ENI, Equinor, National Grid, Shell and Total form Northern Endurance Partnership (BP will be the operator)

Product & Services: The Northern Endurance Partnership (NEP) will develop offshore CO_2 transport and storage infrastructure in the southern UK North Sea. This infrastructure will serve the proposed Net Zero Teesside (NZT) and Zero Carbon Humber (ZCH) projects that aim to establish decarbonised industrial clusters in Teesside and Humberside. Together, this whole project is referred to as the East Coast Cluster.

The East Coast Cluster was named as one of the UK's first CCUS clusters following a successful bid in Phase-1 of the UK Government's CCUS cluster sequencing process in October 2021. In March 2022, 25 projects within the East Coast Cluster capture projects were shortlisted for evaluation within Phase-2 of the cluster sequencing process. This includes power, hydrogen and industrial carbon capture projects.

In May 2022, further storage licenses were awarded to Equinor and Bp beyond the Endurance field leading to a total storage potential of 1 billion tonnes of CO_2. The NEP project is aiming first injection from 2026, and by 2038 will be capturing and storing up to 23 million tonnes of CO_2 per year from a wide range of industrial and power projects on Teesside and the Humber.

3.2.4 Other Emerging Project Examples

Denmark

In recent years, there has been a renewed interest in CCUS in Denmark given a new political majority in the Danish parliament to enhance the development of CCS with the vision of developing Denmark as a regional hub for CO_2 storage. Two political agreements were entered into by the political majority in 2021. Firstly, a political agreement was reached making CCS legal and committing to a funding pool of more than DKK 16 billion (EUR 2.2 billion) for CCS and related activities. Secondly, the government intends to amend the Danish Subsoil Act to introduce pilot and demonstration projects and the possibility of state participation (previously project below 100,000 tonnes has special permitting requirements)[121].

Alongside the new government funding, an increased CO_2 tax is in development which will help incentivise CO_2 storage. In June 2022, Danish lawmakers agreed an increased carbon tax price of DKK 1125 (approx. EUR 151) by 2030, which will consists of a DKK 375 (EUR 50) fee on top of the projected 2030 ETS price of DKK 750 (EUR 100)[122]. Reduced prices of DKK 125 (EUR 16.80) have been set for emitters "with mineralogical processes", such as cement plants, to prevent production from moving outside of Denmark. Non-ETS emissions will be charged a DKK 750 (100 EUR) tax. The current carbon tax in Denmark is EUR 24 per ton of CO_2 which prevents CCS being profitable. There are also hopes within Danish industry for negative emission support for biogenic emissions sources, in the form of a negative CO_2 tax or carbon offset allowances.

[121] WSCO (2022) CCS – The Danish Perspective. Available at: https://uploads-ssl.webflow.com/6183d750c2a4a2d74e966763/6234496d3d8d9d691f51ec2c_CCS%20-%20the%20Danish%20Perspective%2C%20March%202022.pdf

[122] Reuters (2022) Denmark Agrees Corporate Carbon Tax. Available at: https://www.reuters.com/markets/commodities/denmark-agrees-corporate-carbon-tax-government-2022-06-24/

The Greensand Project is currently the most developed CCUS project in Denmark, currently in proof-of-concept pilot phase, and aims to store 1.5 Mtpa by 2025 and increasing to 8 Mtpa by 2030. This project alone could store 13% of Denmark's annual CO_2 emissions and with this project alone reach the government's CCS targets[123]. The Bifrost project will store 2-3 million tons of CO_2 per year from 2029-2030 and 10-15 million tons of CO_2 per year from 2030-2032. Other projects are emerging onshore as well such as the Danish Norne project, which expects to store 2.3 million tons of CO_2 per year by 2026 and 18.7 million tons of CO_2 per year by 2030, as well as the Ruby project which anticipates injection from 2027 with an injection capacity of 1 million tons of CO_2 per year increasing to 5-10 million tons of CO_2 per year by 2030.

The main emitters being targeted for CCUS in Denmark are waste incinerators, industry (largely cement) and combined heat and power plants.

Overall, approximately 37 billion DKK (5 billion EUR) has been set aside in total to achieve reductions and removals of 3.2 million tons of CO_2 per year from 2030.[124]

The regulatory framework in Denmark is currently given by the CCS Directive. The current regulatory barriers to CCS deployment are being investigated at a national level, e.g. regarding third party access and sharing liabilities, but no decisions have yet been taken. A government position on the regulatory framework for CCS is expected at some point in 2023.

Central and Eastern Europe

In many eastern European countries there is still no state support for CCUS, however European funds are starting to stimulate early-mover projects. For example, there is the new ANRAV CCUS project launched in 2022 by Heidelberg Materials, based in Bulgaria, which aims to develop one of the first CCUS clusters in Eastern Europe. It is fully funded by industries in the region of Varna and has received funding for the EU's Innovation Fund. As part of the project, emissions from the Devnya cement plant in Bulgaria are to be captured and transported to offshore permanent storage in the Black Sea (Galata Field).

The geography of the regions is also different to that of North-Western Europe with many large emissions sources located at larger distances from one another (not clustered) making shared transport infrastructure more difficult. The market is therefore less likely to develop using a hub and cluster approach. For example, in Poland, the Gdansk Region has the "EU CCS Interconnector" project and has potential capture projects 100s of kilometres apart feeding into the same collection point at the port area. This makes the market harder to stimulate when larger transport distances to storage sites are required.

3.3 Technology Market Readiness

CCUS is a proven and commercially ready technology, various capture technologies are at TRL 9 ready for more wide-scale deployment and transport and storage has already been proven. Although costs could benefit from being reduced in order to be more commercially viable this is most likely going to be done through the deployment of first-of-a-kind projects. The technological

[123] Project Greensand Website (Accessed November 2022) https://www.projectgreensand.com/en/hvad-er-project-greensand

[124] Danish Ministry for Climate, Energy and Utilities (2022) Status on CCS in Denmark. Available at: https://kefm.dk/Media/637995168833263248/Status%20on%20CCS%20in%20Denmark.pdf

readiness of numerous capture technologies as well as a summary for storage deployment, are provided in an annual report by the Global CCS Institute[125].

However, a key aspect of technology readiness currently having a market impact is the difference in project development time for a storage project versus a capture project. This concept is well captured in the idea of storage readiness levels[126]. As shown in Figure 9 storage sites can be thought of in the same was as TRLs, with a storage readiness level (SRL) 9 meaning a site is well developed and ready for injection. Storage projects can have long lead development times to reach SRL 9, depending on the data available prior to the storage development (up to 5-10 years). This is demonstrated in Figure 9 for various projects across Europe. Although ample theoretical storage capacity is available, to be ready for commercial CCS operations, significant time and financial investment is needed to progress a site from a low SRL to SRL 9 and be ready for injection.

Via the ETS and various CfDs, CCS is currently being stimulated in Europe focussing on the emitter's receiving funds, which would reach storage operators via the T&S tariff. However, storage sites need to be developed well before a T&S contract is ready to be signed. There is currently a lack of "bankable" storage being developed, meaning a mis-match is currently developing between the availability of permitted storage capacity and the storage demand from planned capture projects. This could lead to significant delays in a commercial CCS market developing. The recently announced (16/03/2023) target for 50 Mtonnes annual CO_2 injection capacity from 2030 under the Net Zero Industry Act is a very good step in addressing this issue.

Many countries have stated their CCS ambitions for 2030, and for these storage capacities to be available within that timeframe store development should begin now to allow for appraisal work to be undertaken in the next 5 years. Through the stakeholder interviews undertaken as part of this study it is clear that storage potential being underdeveloped is a key concern across the board. The newly announced target under the NZIA of 50 Mtonnes/yr of CO_2 injection capacity by 2030 is a welcomed initiative to address this issue. Although the planned First-of-a-kind (FOAK) projects in Europe (such as Northern Lights and CO2TransPorts) will help to shorten development timelines in the future (e.g. by streamlining future permit applications, or improving the appraisal process) by the time these projects are operational, significant work should already have started on the future storage potential in these regions to meet future storage needs.

[125] Global CCS Institute (2021) Technology Readiness and Costs of CCS. Available at: https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Technology-Readiness-and-Costs-for-CCS-2021-1.pdf

[126] M. Akhurst, K. Kirk, F. Neele, A. A. Grimstad, M. Bentham, P. Bergmo (2021) Storage Readiness Levels: communicating the maturity of site technical understanding, permitting and planning needed for storage operations using CO_2, International Journal of Greenhouse Gas Control. https://doi.org/10.1016/j.ijggc.2021.103402

Figure 9: Estimated Costs for Appraisal and Characterisation of Various Storage Sites Across Europe to Reach Various Storage Readiness Levels

	Country	Site	Type	Appraisal (M€) SRL 1–3	Characterisation and design (M€) SRL 4–7	Construction (M€) SRL 8	CO_2 storage capacity (Mt)	Source of data
Expenditure	UK	Goldeneye Field	DHC	3.2	48.8	NA	30 – 36	Peterhead CCS FEED Project (Shell, 2016a, 2016b,2016c)
	UK	Endurance (Bunter Closure 35)	SA	56.1		NA	233* – 2600†	White Rose FEED Project (National Grid, 2016b)
	UK	Hewett Field	DHC	0	12.7	NA	206	Kingsnorth FEED Project (E.ON, 2011)
	Norway	Sleipner Field	SA	1.6	< 2	10	> 42	(Torp and Brown, 2005)
	The Netherlands	P18-4 Field	DHC	0	2	36	8	(ROAD, 2018)
	The Netherlands	Q16-Maas Field	DHC	0	3	55	2	(ROAD, 2018)
Estimated costs	UK	Hamilton Field	DHC	0	29.3	NA	125	S-SAP (Pale Blue Dot, 2016)
	UK	Bunter Closure 36	SA	63.4		NA	280	S-SAP (Pale Blue Dot, 2016)
	UK	Forties 5	SA	125.7		NA	300	S-SAP (Pale Blue Dot, 2016)
	UK	Captain X	SA	37.8		NA	60	S-SAP (Pale Blue Dot, 2016)
	UK	Viking A Field	DHC	0	34.2	NA	130	S-SAP (Pale Blue Dot, 2016)
	Denmark	Gassum Formation	SA	5	85	365	240	Skagerrak/Kattegat report (Bjørnsen et al., 2012)
	Denmark	Vedsted§	SA	10		6	60	SiteChar assessment (Gruson et al., 2015)
	UK	Outer Moray Firth (Blake Field)	DHC +SA	28		255	100	SiteChar assessment (Gruson et al., 2015)
	Italy	South Adriatic	SA	43		25	10	SiteChar assessment (Gruson et al., 2015)
	Norway	Trøndelag Platform	SA	81		30	40	SiteChar assessment (Gruson et al., 2015)

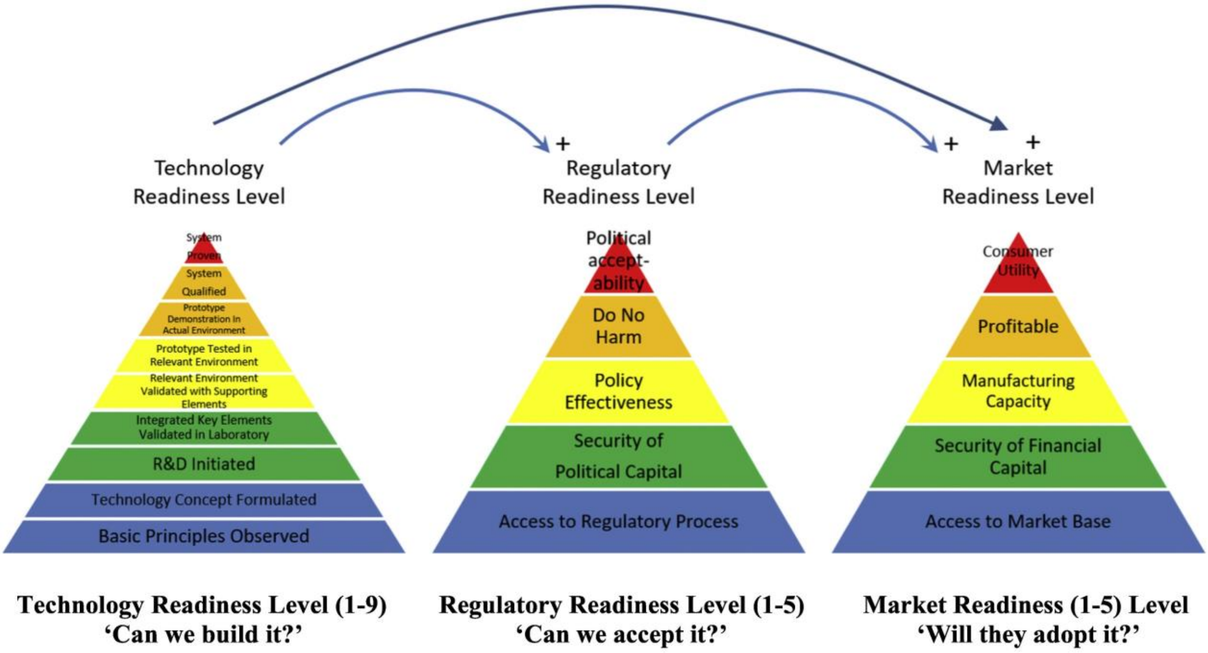
Storage types: DHC: Depleted hydrocarbon field, SA: Saline aquifer
* Theoretical storage capacity from the CO_2Stored database (www.co2stored.co.uk)
† Theoretical storage capacity from the White Rose FEED Project (National Grid, 2016b)
§ Onshore site

Source: Akhurst et al. (2021)

As summarised by Kobos et al., when looking at technology transitions towards market, after defining the technology readiness the regulatory and market readiness also needs to be assessed, as shown in Figure 9[127]. Even though a technology may be at the highest TRL possible, it will not reach market without regulatory support or a timely and sizable market adoption.

[127] P. Kobos, L. Malcynski, L.T. Walker, D Borns and G. Klise (2018) Timing is everything: A technology transition framework for regulatory and market readiness levels. Technological Forecasting and Social Change. Volume 137. 211-225

Figure 10: Pyramid Representations of Technical Readiness Level (TRL), Market Readiness Level (MRL) and Regulatory Readiness Level (RRL)



Source: Kobo et al. 2018

Although CCUS is at a high TRL, it is still an emerging technology in Europe and not yet in commercial deployment. In Europe, the regulations are therefore still developing alongside the market. It is not the case that there will be full "Level 5" regulatory readiness before the market can start developing. Instead, as these first-of-a-kind projects develop, the regulations and market will likely change with time. This first wave of projects will develop within their own market of high government involvement and subsidy support. Towards 2050, a market will likely develop into more private investment and less subsidy support. How this transition will occur and the regulatory support needed to support this transition is the main focus of this study.

Regulatory Readiness Level

In Europe, the CCS Directive and its implementation into national laws has made the first initial step into providing regulatory readiness for the deployment of CCUS. Referring to Figure 10, the Directive provides that initial access into the regulatory process. However, deployment in Europe has yet to reach commercial scale and numerous emitters have yet to be combined into one T&S system at scale. Policy is therefore still evolving and remains uncertain, although this also provides opportunities for it being shaped. Indirect incentives such as carbon pricing are being set at both national and EU level via the ETS but more direct incentives are needed. T&S infrastructure is likely to be shared by multiple users in an "industrial cluster" approach and cross-chain support is therefore needed. Regulatory enablement is building as more sites are permitted for storage and with this knowledge on risk management is improving.

To further answer "Can we accept it" (with reference to Figure 10), one of the main questions regarding financing projects and the associated risk is regarding the financial liabilities incurred by the EU CCS Directive. A study by the Zero Emission Platform[128] highlighted that the Directive also transfers full financial responsibility for potential incidents to the operator. This means that finances

[128] ZEP (2019) CO_2 Storage Safety in the North Sea: Implications of the CO_2 Storage Directive. Available at: https://zeroemissionsplatform.eu/wp-content/uploads/ZEP-report-CO2-Storage-Safety-in-the-North-Sea-Nov-2019-3.pdf

have to be secured to cover the costs for all potential eventualities for each individual project site before operation. The report emphasised that these securities need to be based on, and proportional to, the very low risk of leakage. "*Developing a proportionate approach to managing financial securities is an important step to encouraging greater private sector investment in CCS projects*".

During the stakeholder interviews, another element of "regulatory readiness" discussed was the potential to store CO_2 outside of the EEA. Article 12(3a) of the ETS Directive currently prevents any CO_2 being permanently stored at adequate sites outside Europe from receiving allowances. Some capture projects and shipping companies want to be ready to start CCS operations by 2025, but given that EEA stores are not currently readily available, many are now looking towards storage locations outside of the EU. The UK was highlighted as the most urgent given its proximity; however, given the increasing ETS price and the lower storage costs in some countries internationally, transporting even further afield benefit many companies looking to decarbonise in the short-term. To prevent stalling capture projects in Europe, and unnecessarily preventing them from decarbonising, amending the current EU regulatory framework to create equal access to comparable permanent CO_2 storage sites, irrespective of where they are located, would be beneficial.

Market Readiness

The key elements to any market being ready (as shown in Figure 10) are summarised below in the following steps:

1) Market Access

The first step is that companies need to be able to freely enter the market and access the transport and storage services. This is already supported in current EU regulations, with the requirement from the CCS Directive that third party access is ensured. However, one of the greatest limitations in the EU market currently, as already discussed, is that for an emitter to have access to the market there needs to be enough storage available. Currently the greatest threat in Europe to open third party access is a large competition emerging between emitters for access to small storage volumes. If T&S services are initially developed at overcapacity this will allow for a more open market.

Following the stakeholder interviews, it has become apparent in some areas of Europe that the CCS market currently developing has the potential to be dominated by larger multinational operators, for example those with the potential to both capture CO_2 emissions from their processes and also provide CO_2 storage. Although this provides the initial support and incentive to begin CCS in Europe at a commercial scale, it could lead to long-term difficulties for smaller companies to be able to compete in this market. Here, there is the need for national governments to either play a mediator role to ensure better access to the market and an even playing field for all emitters or allow for overcapacity of the network.

2) Security of Capital

Through the ETS and various subsidies most of the financial incentive for CCS is being placed on the emitter side of the chain. Overall our analysis has shown that in this emerging market the capital required can and has been raised through the incentive of avoiding increasing ETS prices and various subsidies to support the business models in development to construct and operate a site. The details of the financing of business models are discussed later in this report.

However, following stakeholder interviews as part of this study, one of the greatest hurdles for storage developers mentioned was the capital required to provide financial security for a storage site over the whole project lifetime. Currently, under the CCS Directive, the capital required to cover liabilities for a potential leakage can act as a deterrent for some projects. This is discussed later in the report under the section Financial Risk Management.

3) Service Capacity

A key element for a commercial market is having the ability to develop the service at the rate required to meet the capacity demand. Theoretically, the storage available across Europe has more than ample capacity to meet the storage needs required. However long storage lead times, especially regarding permitting, are limiting the number of CCS projects that can be brought online in the short term.

The target of 50 Mtonnes/yr of CO_2 injection capacity by 2030 established under the NZIA is a very relevant step in addressing this issue. This will prevent that only a limited number of projects can be brought online once the ETS price and numerous government plans currently being developed come into fruition and allow for a significant number of capture projects to be viable.

4) Profitability

The main difficulty in the developing markets for CCUS is that the revenue streams are not yet well established. All early mover projects in Europe are currently based on large government subsidies in various forms. However, for wide-scale commercial deployment business models need to become more robust, where revenue streams do not rely on subsidies. This will allow investors to have greater security and confidence in their investments. Policy is currently key in enabling viable revenue streams for the first wave of CCUS projects.

According to a recent analysis by McKinsey, globally "*the CCUS industry will require $130 billion per year from now until 2050*" and "*the required investment by 2050 is on par with global liquefied natural gas (LNG) ($120 billion per year), electric-vehicle (EV) charging ($140 billion per year), and hydrogen ($140 billion per year)*"[129]. To attain this level of investment, European companies will need to commit significant capital. Before this is going to happen at a commercial scale, more confidence will be needed on the risks associated with these investments. To move away from subsidy requirements, the market needs to change to allow CO_2 prices high enough that a product equipped with CCUS (such as cement) becomes cost competitive with its high-emitting equivalent. And until that happens secure long-term contracts are required to ensure that the difference needed to make these projects profitable is covered.

The business models and revenue streams that are currently developing in Europe given the current market and how these are likely to develop towards 2050 are discussed later in this study.

5) Customers Want to Utilise the Service

CCS is already seeing growing interest in Europe, and given the rising ETS price and increased support from national governments, the number of companies interested in deploying CCS will likely increase significantly (especially once initial projects in Norway, the UK and the Netherlands begin). One of the greatest challenges in the CO_2 T&S market is that the industry players, usually oil and gas majors, are more accustomed to a completely different market with higher risks but also higher returns on much shorter time frames. The revenue models for CO_2 T&S are different and with much lower profit margins than O&G majors are used to but with higher security of income over longer time-periods. As more financial incentives are placed on the emitters, towards 2030, there will be an increased need for support to provide similar incentives for large storage sites to take on the liabilities and risks associated with CO_2 storage.

[129] McKinsey (2022) Global Energy Perspective. Available at: https://www.mckinsey.com/industries/oil-and-gas/our-insights/global-energy-perspective-2022

3.4 Investment Cost for CO_2 Transport and Storage (T&S)

Many analyses have been conducted on the estimated costs of CO_2 transport and storage, with the GCCSI[130] providing one of the most recent global overviews and comprehensive literature reviews. The total cost of CCS consists of the costs of (based on report from GCCSI, 2021):

- CO_2 capture at the emission source – purifying CO_2 from a gas stream up to over 95% purity by volume.
- CO_2 dehydration and compression/liquefaction, depending on the transport method.
- CO_2 transport by pipeline, ship or mobile vehicle.
- CO_2 injection, and monitoring and verification of stored CO_2.

Costs for various components CCUS can be difficult to constrain and are highly project specific. The cost is driven by the size and location of the facility, with economies of scale being beneficial alongside small distances between the source and storage site. The most expensive part of the chain is the capture and compression of CO_2 ready for transportation, which is dependent on the CO_2 source composition and capture type.

For the purpose of this report, indicative costs are provided here following a 2021 report by the Danish Energy Agency and Energinet who published a systematic techno-economic analysis of the various CCS components including various capture, transport and storage technologies[131]. The information from this publication was used to provide some insight in the unit technical costs of the various components. In some cases, the data was modified so that they can be presented in a uniform manner. The numbers presented in Table 7 are not exhaustive but should give a reasonable impression of the costs involved. In practice, these costs are highly variable depending on the purity of CO_2 in the exhaust streams, the transportation distance and CO_2 mass. The reference year for the cost numbers is 2020, which implies that the more recent dramatic cost increase of materials and energy is not reflected in these numbers. Capture is the most costly component but could be much lower for high-purity streams. Storage offshore can be relatively expensive as well depending on the definition of the battery limits for storage and on opportunities for re-using existing infrastructure. The examples here are all new built. Transport costs depend on transport distance and mass of CO_2.

Table 7: Unit Costs in EUR/tonne CO_2 for the Main Components of the CCS Value Chain (Modified after Danish Energy Agency & Energinet, 2021)

CCS component	Examples	Unit costs (EUR/tonne CO_2)	Comment
Capture (PCC)	Boundary Dam (US)	49	Compression included
	Petra Nova (US)	28	Compression included
	Shand feasibility study (CA)	28	Compression included
	Klemetsrud CCS (NO)	55	Liquefaction and temporary storage included

130 Global CCS Institute (2021) Technology Readiness and Costs of CCS. Available at: https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Technology-Readiness-and-Costs-for-CCS-2021-1.pdf

131 Danish Energy Agency and Energinet (2021) Technology Data – Carbon Capture, Transport and Storage, 151p. Available at: http://www.ens.dk/teknologikatalog

CCS component	Examples	Unit costs (EUR/tonne CO_2)	Comment
Transport	Norcem CCS (NO)	46	Liquefaction and temporary storage included
	12" Onshore pipeline (250 km and 150 bar)	5	
	12" Offshore pipeline (180 km and 150 bar)	4	
	Seagoing ship (4,000 tonne CO_2, 16 bar and -26°C)	11	Excluding harbour fees and taxes
Injection & Storage	Onshore storage 1 Mtpa	13	NPV @ WACC, pre-FID and intermediate storage included
	Onshore storage 3 Mtpa	8	
	Onshore storage 5 Mtpa	8	
	Offshore storage 1 Mtpa	30	
	Offshore storage 3 Mtpa	21	
	Offshore storage 5 Mtpa	19	

Important Economic Factors

The most impactful cost components for different CO_2 T&S systems are going to be highly project-specific. For very long pipelines, it will be on the price of materials; and for underdeveloped stores, it could be the price of site development and appraisal. It is therefore difficult to constrain exactly where the biggest sensitivities would lie for various projects being developed across Europe. However, some important cost factors and their potential impact on CCS in Europe are summarised below.

Gas Price

One of the greatest uncertainties at the moment in Europe is the gas price. Fluctuating gas prices have an impact across the whole chain. For storage in depleted fields the lifetime of a field may become longer or shorter depending on how commercial hydrocarbon extraction is at various volumes. This in turn could delay access to certain storage sites. For the transport chain, material costs (such as the cost of steel) could vary significantly due to increasing energy costs and also fuel costs of running pipeline compressors or ships. And for the emitter side the cost of energy usage could impact the business model, for example if productivity decreases resulting in a lower CO_2 output. A detailed analysis of the predicted gas prices in Europe is outside the scope of this report but is a key element to consider when looking at CCS costs and business models towards 2030.

Materials: Access & Cost

The cost of materials, especially steel, will have a significant impact on the cost of transport infrastructure and across the full-chain. Material prices can fluctuate for a variety of reasons, for example increasing energy costs, but could also be impacted due to scarcity. For example, when supply chains were impacted during the pandemic.

Labour

Access to labour is also important when assessing costs. For example, in times of high oil or gas prices there is greater demand on the skillsets needed to develop CO_2 storage sites, which can lead to labour shortages in this more competitive, higher-wage market.

Project Delay

For the projects currently in development, one key uncertainty has been project delays. These have occurred for a variety of reasons, including delays in acquiring storage or environmental permits (e.g. the nitrogen crisis in the Netherlands impacting Porthos), political changes delaying funding for projects (or the 2015 CCS funding competition in the UK being cancelled by the government) or delays in signing contracts due to co-ordination failures. Given the small revenue margins and uncertainties in this market, project delays can have significant impacts on the costs and financial viability of early-mover projects.

In our stakeholder interviews, one of the key project delays frequently highlighted is the time taken to acquire a CO_2 storage permit. For example, in the Netherlands, the P18-2 storage permit for Porthos was applied for in February 2021, but a decision to permit the site was not made until July 2022. Although this was somewhat predicted for the first-of-a-kind project, the permitting process will need streamlining to allow for commercial-scale deployment and a large number of sites to be permitted towards 2030. Although it can be expected that the permit evaluation and assessment phase will become quicker as more applications are handled, some guidance for applicants would be beneficial on how permit applications should be handled with regard to timings expected for key decision gates.

Emissions Trading Scheme

The price of emissions allowances in Europe (EUA price) is highly volatile, as shown in Figure 11[132]. From the beginning of 2022 until 2 November 2022, the EUA price varied from less than 60 euros per tonne to more than 95 euros per tonne. However, the average ETS price tends to increase though as is shown in Figure 12[133].

Ariadne (2021)[134] reported a number of EUA price projections for 2030 from six models, five of which yield a price estimate in the range of approximately EUR 130 to 160.

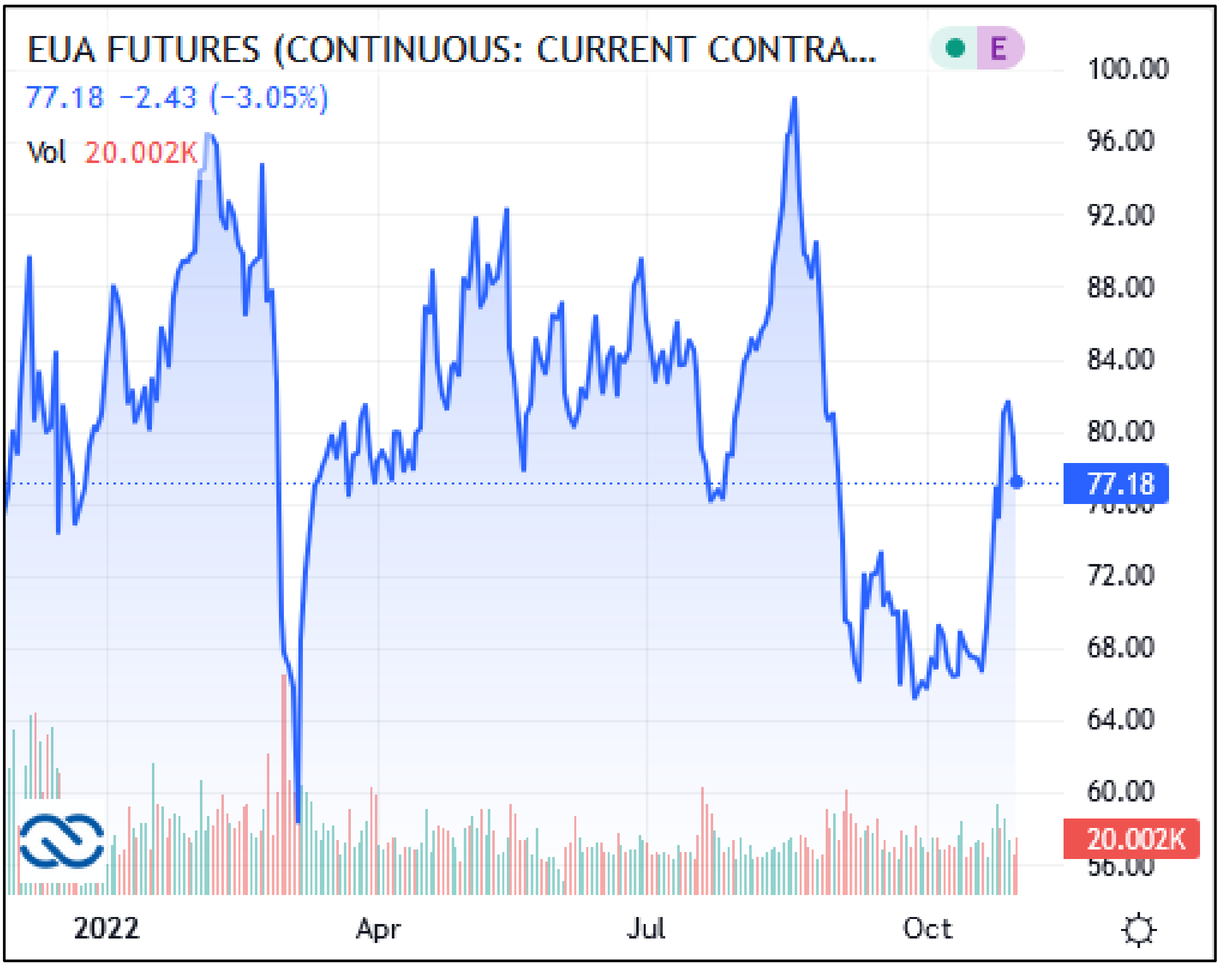
This implies that a significant share of the costs for CCS can be covered by the ETS carbon price, in particular, for the low cost low hanging fruit options. Additional funding like the Contracts for Difference is needed to make the CCS market stable and attractive for investors and project developers.

[132] Carbon Credits Website (Accessed November 2022), https://carboncredits.com/carbon-prices-today/

[133] ING presentation at Carbon Storage Dialogues on 13 Oct 2022. Available at: https://www.ebn.nl/wp-content/uploads/2022/10/Financing-of-CCS-dos-donts-and-other-insights_Ramon-van-den-Dungen_Peter-Paul-Ekelschot.pdf

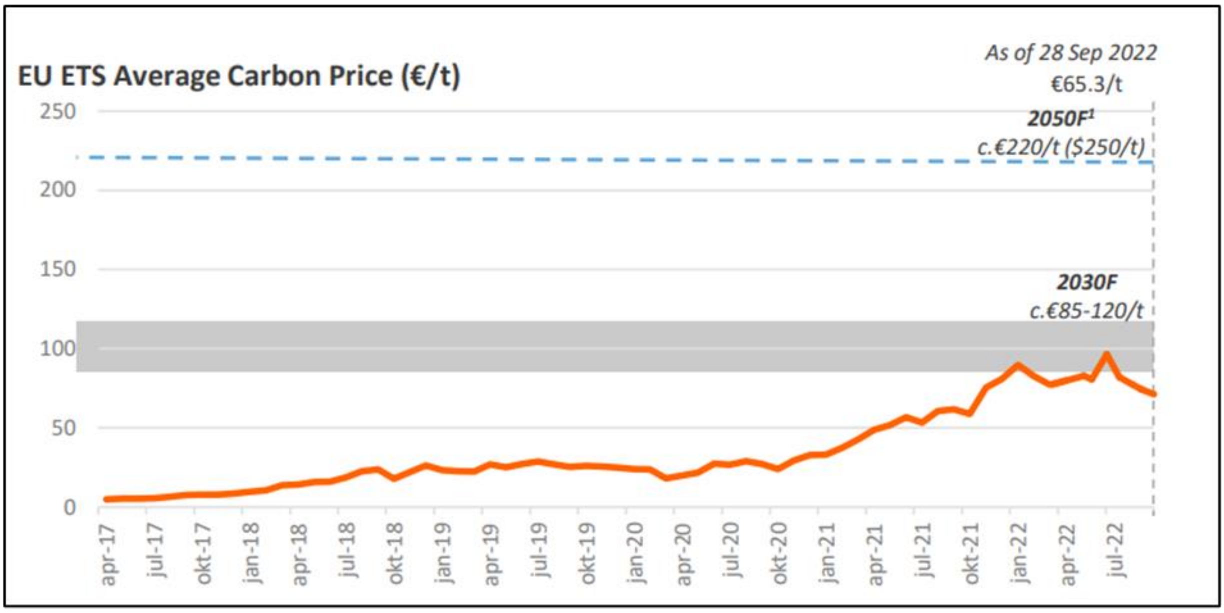
[134] Kopernikus-Projekt Ariadne Potsdam-Institut für Klimafolgenforschung (PIK) (2022) M. Pahle, J. Sitarz, S. Osorio (PIK), B. Görlach (Ecologic), The EU-ETS price through 2030 and beyond: A closer look at drivers, models and assumptions.

Figure 11: ETS Carbon Price Development in 2022



Source: Carbon Credits Website

Figure 12: Average Carbon Price Tends to Increase Since 2017



Source: ING (2022)

Although the ETS pricing is currently insufficient for a commercial market, the way it is developing alongside subsidies from local governments looks like a promising trend.

The Future: CBAM and Decline in Free Allowances

As long as the ETS price continues to trend upwards, the greatest impact towards 2030 will be the EU's planned decrease in allowances and the introduction of the carbon border adjustment mechanisms (CBAM)[135]. Through CBAM importers will pay a financial adjustment from 2026, buying carbon certificates corresponding to the carbon price that would have been paid, had the goods been produced under the EU's carbon pricing rules. This is to prevent the import of high emitting goods at a lower price than the decarbonised goods being produced within Europe under the ETS, i.e. the CBAM will mirror the ETS price (with the free allowances also fairly represented on import goods). The CBAM will initially apply to imports of the following goods:

- cement
- iron and steel
- aluminium
- fertilisers
- electricity.

As part of EU's "Fit for 55" package, the EU ETS is currently being reformed. In December 2022, the Council and the European Parliament reached a provisional political agreement on the ETS reform, which includes reducing the number of free allowances more each year than originally planned; previously 2.2% a year, and now with a target of 4.3% a year from 2024.

It is crucial that the extra funds made available within the EU by selling extra carbon certificates abroad and by lowering free allowances are used to fund decarbonisation technologies directly relevant to those impacted most by the changes. For example, the cement industry in Europe is unlikely to make the emission reductions required to meet the lowering of free allowances and not feel an impact. There are also significant cement imports into Europe. Therefore, this industry would greatly benefit if the extra funds raised went towards helping it to deploy CCS. Other decarbonisation solutions may not be as relevant and the impact of decreasing allowances while not supporting CCS could be significant. This could be particularly important in CEE regions where the different geographies and energy mix could make other solutions such as wind and solar less relevant.

T&S Tariffs

The T&S tariffs currently being defined in these early-mover European projects are given below in Table 8.

Table 8: Summary of T&S Tariffs

Project	CAPEX (for T&S)	Tariff (for T&S)
Northern Lights[136]	1025 Million USD (Approx. 40 USD/tonne if 1.5 Mtpa)	30-55 EUR/tonne

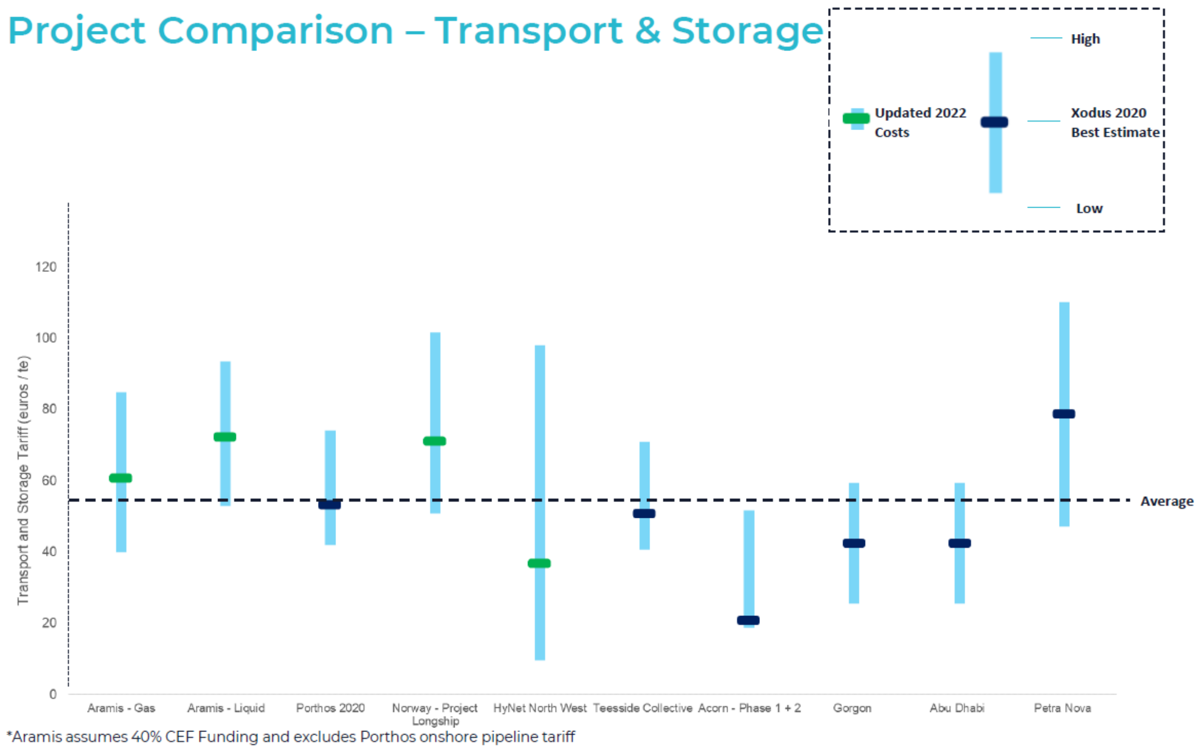
[135] Overview of EU's plans regading CBAM. Available at: https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3661

[136] Gassnova (2020) The Norwegian Full-scale Project. Available at: https://netl.doe.gov/sites/default/files/netl-file/20CCUS_Carpenter.pdf

Project	CAPEX (for T&S)	Tariff (for T&S)
Porthos[137]	24 EUR/tonne	49.2 EUR/tonne
Aramis[138]	Not disclosed	Approx. 50 EUR/tonne

As shown in Figure 13, the average tariff deduced by Xodus in their review was approximately 55 EUR per tonne of CO_2.

Figure 13: T&S Tariffs for Different CCS Projects



Source: Xodus (2022)

Example: Aramis Project

Xodus (2022)[139] evaluated the tariffs proposed by the ARAMIS JV based on a top-down assessment of other similar projects and a bottom-up assessment with in-house models. The ARAMIS related T&S infrastructure includes onshore pipeline transport (separate Porthos tariff), compression, offshore trunkline of 200 km and two storage sites. The analysis was done for gaseous and liquid CO_2 with an initial capacity of 5 to 7.5 Mtpa and a maximum capacity of 22 Mtpa. Costs for liquid CO_2 terminal and shipping were not considered.

The assumed ARAMIS tariff is 71.8 EUR/tonne (using a reference year of 2022), which is close to the Xodus bottom-up calculated tariff of 67.4 EUR/tonne CO_2. The Xodus calculations are based on different assumptions and consider higher Internal Rate of Return (IRR).

[137] Xodus (2020) Porthos CCS – T&S Tariff Review. Available at: https://zoek.officielebekendmakingen.nl/blg-947442.pdf

[138] Xodus (2022) Review of the Aramis Project. Available at: https://www.staten-generaal.nl/9370000/1/j4nvgs5kjg27kof_j9vvkfvj6b325az/vlutrvd2g2y4

[139] Xodus (2022) Final report – Public, Dutch Ministry of Economic Affairs and Climate Policy, L-400699-S00-Y-REPT-001, 19p. Available at: https://open.overheid.nl/repository/ronl-1b9c7525f0bd7faefdc6b427c2ea2471f14b1753/1/pdf/rapport-xodus-toetsing-en-opslagtarief-co2.pdf

With varying assumptions on costs the tariff for gaseous CO_2 varies between roughly between 40 and 100 EUR/tonne CO_2 and roughly between 50 and 110 EUR/tonne CO_2 for liquid CO_2, according to the Xodus report (2022). Note that the onshore transport costs are not included in the range mentioned for gaseous transport and storage, and that the range for liquid transport does not account for terminal and shipping costs.

The tariff numbers for ARAMIS were compared to the calculated pseudo-tariffs for other similar industrial CO_2 transport and storage projects in Europe and around the world, which resulted in an average tariff close to 55 EUR/tonne CO_2 and a total uncertainty range roughly between 10 and 110 EUR/tonne CO_2 (Xodus, 2022).

Xodus (2022) indicated that the market is very volatile since 2020 with a fourfold increase of the price for electricity rising with for electricity and more than 3 times increase of the steel price. This makes predictions of actual tariffs in the future even more uncertain.

3.5 Future CO_2 T&S Development Scenarios

In order to provide some context to the business models and regulatory considerations presented later in this report, the expected development scenarios for CCS in Europe towards 2050 are presented here.

Transport and storage scenarios were developed by JRC and published in 2010 based on transporting and storing emissions from the European power sector. The CO2Europipe project had partly similar objectives. In most assessments to date the main transport mode envisioned in Europe mainland was by pipeline. However, in the past 2 years shipping has seen a sharp increase in interest, with a lot of Western European capture projects planning to ship to North Sea storage projects from 2026.

Table 9: Overview of Future T&S Scenarios in Europe

<table>
<tr><th></th><th>Currently</th><th>2030</th><th>2050</th></tr>
<tr><td>Capture Projects</td><td>12 plants
Volume: Approx. 1 Mtpa</td><td>33 plants
Volume: Approx. 75 Mtpa</td><td rowspan="5">The JRC 2010 Scenarios expect 900 Mtpa of capture and storage capacity, with projects in 28 countries.

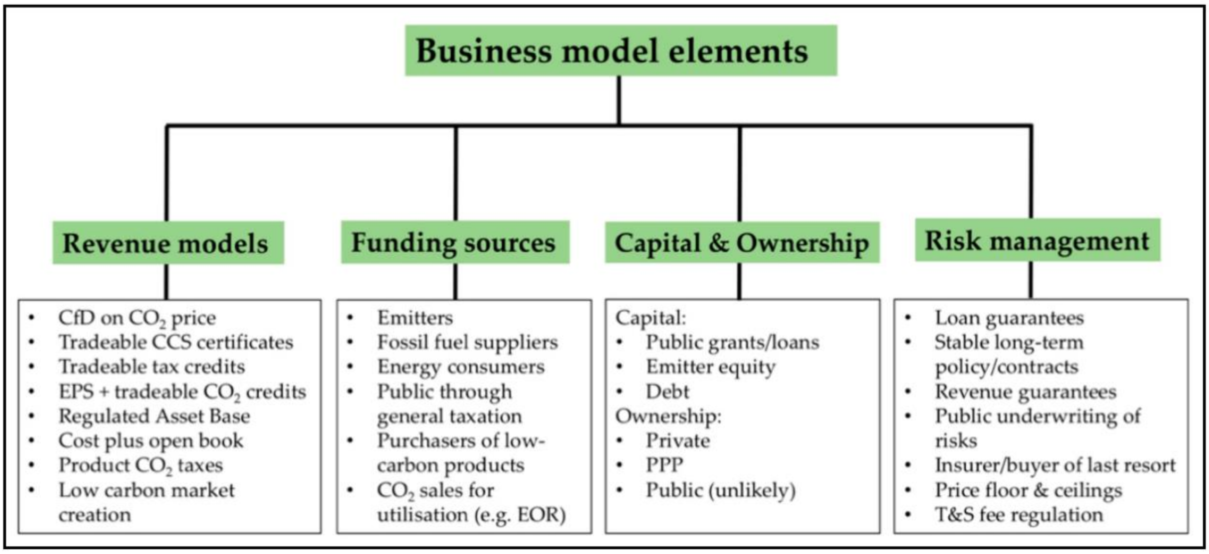
However, given current project development, their assessment of 272 Mt by 2030 is very unlikely to be realised and, hence, their 2050 scenarios may also be a large overestimate.</td></tr>
<tr><td>CO_2 Storage Projects</td><td>3 sites
Volumes: Approx. 1 Mtpa
Countries: Iceland and Norway</td><td>12 sites
Volumes: Approx. 53 Mtpa
Countries: Iceland, Norway, Italy, Netherlands, UK, Denmark</td></tr>
<tr><td>Operational CO_2 pipelines</td><td>3</td><td>12</td></tr>
<tr><td>Cross-border connections</td><td>0</td><td>3
(Germany, France, Belgium)</td></tr>
<tr><td>Countries with full-chain CCS projects</td><td>2</td><td>6</td></tr>
</table>

3.6 Business Model Options for CO_2 T&S

The design of CCUS business models needs to improve the confidence among investors to attract new activity in the market. As well as being cost efficient models should be mindful of proportionate cost and risk sharing between governments and the project developers. Ultimately, the business model for CCUS deployment in Europe needs to work towards being subsidy free in the long-term.

As shown in Figure 14[140], building a business case for CCUS can be divided into four main elements:

Figure 14: Elements of a CCUS Business Model



Source: Muslemani et al. (2020)

How each of these elements, and therefore the overall business model, is structured, will be defined at a national level and will vary from country to country or even regionally. This section of the report provides an overview of each of these elements (focussing on those that are most relevant in Europe), drawing on key case studies where these elements are currently being developed. This will allow for an overview of the options for different nations on how the business case may develop.

Revenue Models & Funding Schemes

In this section, the different approaches to revenues and funding are discussed together. Given that this is an emerging market, for most projects their revenue stream is currently heavily reliant on numerous funding scheme including subsides. Therefore, both are discussed here.

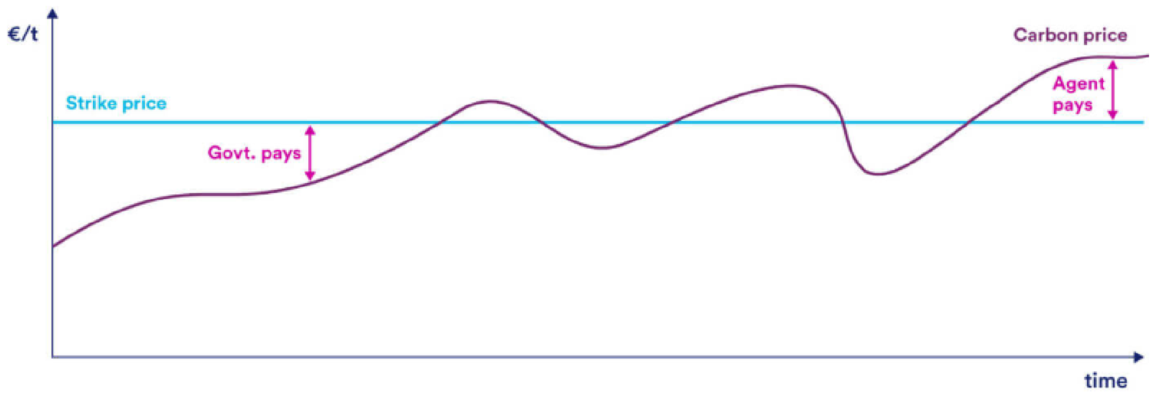
In Europe, to make up for the shortfall based off the ETS price alone, governments are helping to create viable revenue models by developing some for a subsidy usually through contracts for difference. The latter is the case in, for example, the UK, Netherlands and Norway. However, other models are available such as the tax credit approach currently being taken up in North America. However, through the stakeholder engagement taken up during this study it was concluded that the current market approach in Europe is suitable, although more guidance could be provided.

[140] H. Muslemani, X. Lang, K. Laesehage, J. Wilson (2020) Business Models for Carbon Capture, Utilization and Storage Technologies in the Steel Sector: A Qualitative Multi-Method Study. Available at: https://www.mdpi.com/2227-9717/8/5/576/htm

Contracts for Difference (CfDs)

A financial contract for difference (CfD) is a legally binding agreement, in which the difference between the price of an underlying asset at the start of the contract and the price when the contract is closed is guaranteed. In the context of CCUS, this refers to a guaranteed price for capturing CO_2 in relation to the ETS price. I.e. if the price of CO_2 emissions goes up, less investment will be provided and vice versa. The counterparty will usually be the government (or a government body). The concept of CfDs are shown schematically in Figure 15.[141]

Figure 15: Example of CfD Payments



Source: Clean Air Task Force (2022)

Currently, the price of European Emissions Allowances (EUAs) does not allow for low-carbon technologies (such as CCUS) to compete with higher polluting alternatives. CfDs allow for investor assurance that when the allowance falls below a pre-agreed strike price, the CfD will be triggered and make up the short-fall. The strike price will differ between and within industrial sectors given the varying costs as described earlier in the report. A strike price of €80 per tonne of CO_2 was recently allocated to the emitters supplying CO_2 to a large-scale CCS project in the Netherlands (Porthos)[142].

CfDs are being used in the UK and the Netherlands, CCS projects currently in development and likely to be the most utilised form of revenue in Europe for future CCS projects. As the EU ETS price increases, and the price of second-of-a-kind CCS projects decreases the required amounts to be paid by governments will become increasingly smaller. These provide revenue for the emitters, which will allow them to pay the tariffs needed for T&S costs. This is the same as with tax credits and certificates. CfDs are a key mechanism to support early-mover projects by allowing them to reach deployment by covering the 'uncommercial costs'[143].

The SDE++ scheme in the Netherlands is one of the most developed CfD schemes in Europe, and is discussed in more detail below[144].

[141] CATF (2022) Why Carbon Contracts for Difference could be the policy measure Europe needs to decarbonise industry. Available at: https://www.catf.us/2022/08/why-carbon-contracts-difference-could-policy-measure-europe-needs-decarbonise-industry/

[142] Port of Rotterdam Website (Accessed November 2022) https://www.portofrotterdam.com/nl/nieuws-en-persberichten/financiering-voor-co2-opslag-onder-noordzee-is-rond

[143] Bellona (2021) The Industrial CCS Support Framework in the Netherlands

[144] Trinomics (2019) Review of SDE++. Available at: https://trinomics.eu/wp-content/uploads/2020/02/Review-SDE-Methodiek.pdf

Case Study: SDE++ in the Netherlands

Contract for Difference Arrangement: The SDE++ scheme (translated as the Sustainable Energy Transition subsidy scheme) provides a 15-year CfD-like subsidy support covering the "uncommercial" cost of CCS operation. I.e. the subsidy provides the extra money for the cost of CCS deployment above the EU ETS price.

Pros: (Based on report by Bellona, 2021)

- The scheme is focussed on the maximum CO_2 reductions for the lowest price, rather than being a specific technology subsidy scheme.
- A second policy has also been implemented to supplement the SDE++, where the carbon tax will be slowly raised to 125 EUR/ton by 2030.
- Emitters do not have to purchase ETS allowances for CO_2 that has been captured and stored and any installation receiving SDE++ support keeps its free allowances under the EU ETS. This allows both the money saved from not having to buy ETS allowances and the money made by selling the allowances to be invested in the CCS project.
- Given the high EU ETS price currently, very little of the 2 billion EUR currently reserved by the Dutch government for these CCS contracts will actually need to be used if the price remains at this level.

Cons:

- Ranking projects and allocating funding based on 'effectiveness' of emission reductions is dependent on forecasts on high uncertainties and that needs to be better accounted for.
- The focus is on emission reduction to 2030, and longer-term technologies may miss out on subsidies.

Obligation & Tradeable CCS Certificates

CCS certificates can be awarded per tonne of CO_2 abated. Emitters could be obligated by law to ensure a certain amount of CO_2 is captured and stored, relative to a predefined industry benchmark. Certificates are awarded for storage and can be used to meet the obligation and traded freely and the obligations are increased with time to reach a long-term reduction trajectory.

This is somewhat being stimulated in Europe by the EU ETS 'cap-and-trade' approach, where allowances are granted for how much CO_2 can be emitted, beyond which they must pay a price for CO_2 emitted. If they deploy CCS, they can trade the allowances they have not used by avoiding emissions.

EPS & Tradeable CO_2 Credits

An Emission Performance Standard (EPS) sets minimum emission standards by which emitters must abide. The tradeable certificates function similarly to the obligation scheme and can be used to meet the standard.

Tax Credits

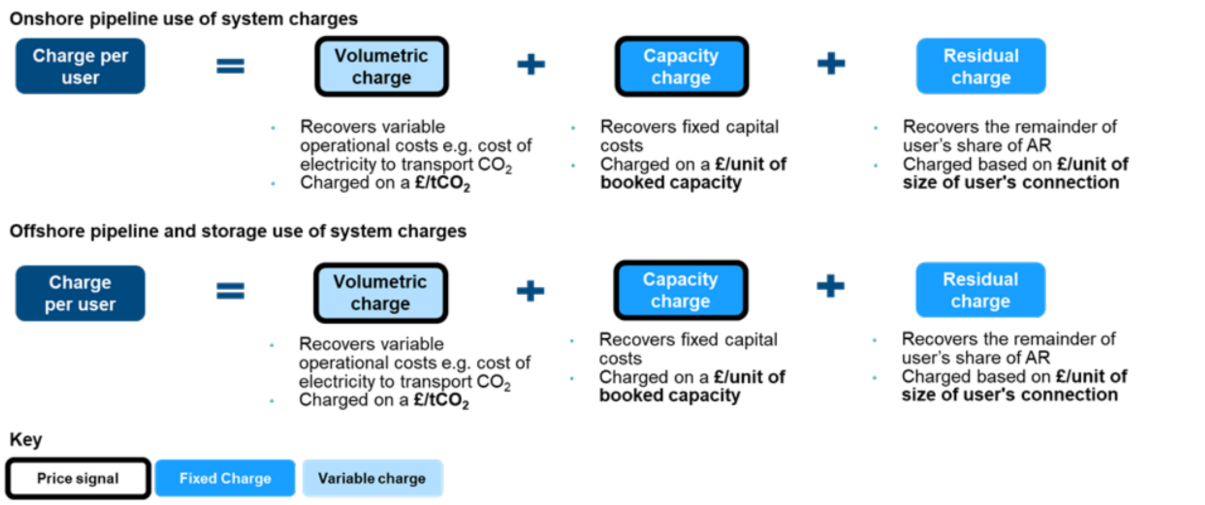
The same principle can apply to tax credits. This has been applied in the USA through the 45Q where industrial manufacturers that capture carbon from their operations can earn 50 USD per tonne of CO_2 stored permanently or 35 USD if the CO_2 is utilised.

Regulated Asset Base (RAB)

With regards to revenue for the T&S part of the chain, regulated asset base models (RAB) can be used to provide revenue. "*A RAB model is a type of economic regulation typically … used for monopoly infrastructure assets such as water, gas and electricity networks. The company receives a licence from an economic regulator, which grants it the right to charge a regulated price to users in exchange for provision of the infrastructure in question. To prevent monopolistic disadvantages, the charge is set by an independent regulator who holds the company to account to ensure any expenditure is in the interest of users.*"[145]

In the UK, RAB models have already been utilised for infrastructure projects such as nuclear power stations. They are utilising a similar model in their current business model plans for CCUS. Here a "user pays" system is planned where the T&S operator will collect fees paid by the users of the T&S network. The tariffs allowed to be charged to users will be set by an independent regulator and will be separated by onshore and offshore pipeline charges, as shown in Figure 16[146].

Figure 16: Proposed Structure of Charges for Use of T&S System in UK



Source: BEIS (2019)

Cost Plus Open Book

Cost plus contracts, which are also commonly referred to as open book or cost reimbursement contracts, are when *"a contractor is paid for all of their business-related expenses plus an additional predetermined profit."*[147] This means those that develop the infrastructure pass along the costs directly to their clients while still making a profit based on the agreed-upon fee or percentage. It is argued that these contracts offer clients a deeper level of budget and price transparency compared

[145] BEIS (2019) Business Models for Carbon Capture, Usage and Storage. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/819648/ccus-business-models-consultation.pdf

[146] BEIS (2022) Update to Business Models for CCUS T&S. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1045066/ccus-transport-storage-business-model-jan-2022.pdf

[147] CoConstruct Website (Accessed November 2022) https://www.coconstruct.com/blog/cost-plus-and-open-book-construction-contracts

to fixed price or lump sum contracts. Under cost plus open book, *"the emitter is directly compensated by the Government for all properly incurred operational costs and the emitter's capital investment is paid back with agreed returns."*[148]

Product CO_2 Taxes & Low Carbon Market Creation

Another way to create revenue is to put the price of CCS into the product itself. This way the end user consuming low carbon energy or low carbon products, such as cement, can provide some revenue to the project. It could also be that a market for low carbon goods is created by improving customer awareness by certifying low carbon products.

Overview of Funding Sources

The funding sources available in Europe have already been presented earlier in this report, but it is worth noting that funding could also come from other sources. Similar to revenue streams, funding sources can also come from the emitters and storage providers themselves, be passed on to consumers by creating a low carbon market or be subsidised by funding being provided by the government and tax payers, as summarised below:

Table 10: Overview of Funding Sources in a CCS Market

Producers	Consumers	Governments & Public
Based on the "polluter pays" principle, projects can be financed through obligations and taxes from: **Emitters and O&G companies**	To help distribute costs, consumers could also pay through: Energy Users Purchase of low carbon products CO_2 utilisation sales	Given the societal benefit of climate change mitigation and decarbonisation through CCUS deployment, funding could also be raised **through taxation.**

Capital and Ownership

The financial sector, industry and governments are all going to have to work together to develop the first CCUS projects in Europe. The capital cannot be raised through one entity alone and the financial liabilities and risks are too great to not be shared. Nearly all CCUS projects in operation are public-private partnerships with high levels of government support required both to share investment and risks. No projects currently developing in Europe are fully financed from state resources or from private sources.

In Europe, the most common business model for developing CCUS projects is through a joint Venture (JV) model. "*A joint venture is a business arrangement in which two or more parties agree to pool their resources for the purpose of accomplishing a specific task. This task can be a new project or any other business activity. Each of the participants in a JV is responsible for profits, losses, and costs associated with it*[149]"

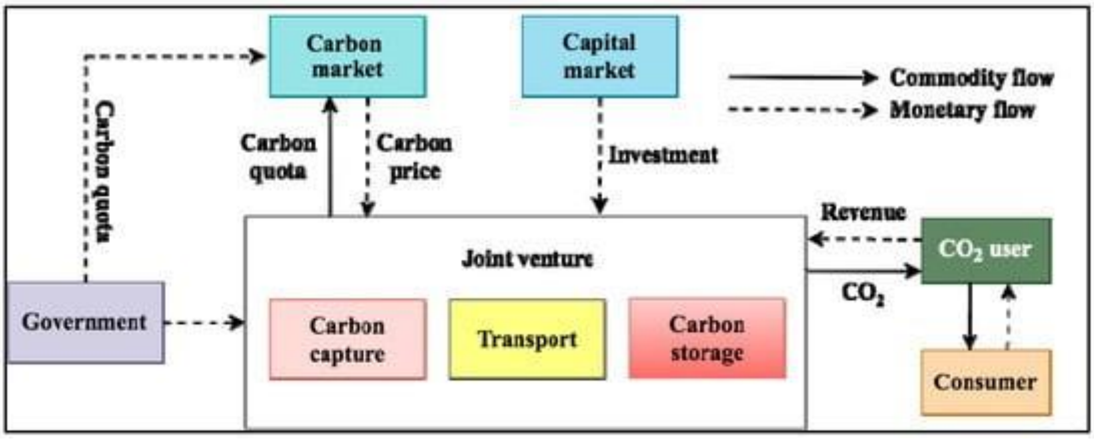
Earlier projects globally have been based on a more vertically integrated structure where the CO_2 capture company takes responsibility for the whole chain. However, current CCUS projects are forming more complex networks with more than one emitter in a collective hub. This has led to

[148] Jon Gibbons presentation at Group of Experts on Cleaner Electricity Systems 15th session Geneva, 5-6 November 2019, Palais des Nations, Salle XI. Available at: https://unece.org/fileadmin/DAM/energy/se/pp/ces/ge15_2019CEP/6_November/2_Jon_Gibbins_Financing.pdf

[149] Investopedia website (Accessed November 2022)

more joint venture projects where the emitter would be liable for capture costs and operations but the T&S network is managed jointly.

Figure 17: Joint Venture CCUS Business Model

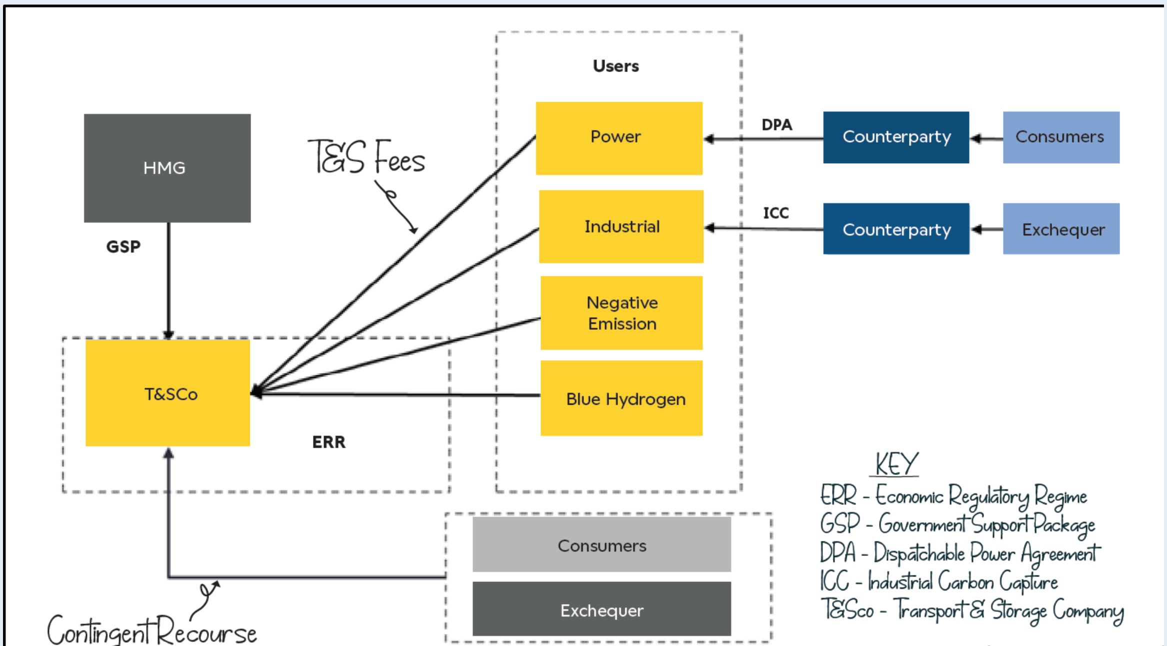


Source : H. Muslemani et al. (2020)

Case Study: UK T&S Business Model

The UK government is currently in the process of developing CCUS Business Models for their planned investments. They are of the view that a private sector delivery model (initially supported by targeted forms of government support) is the preferred approach for the delivery of the T&S network. The revenue stream is based on "User Pays" where users pay the T&S company a fee to transport and store CO_2.

The aim is to have an independent economic regulator that would oversee the framework of economic regulation of CO_2 transport and storage (T&S), consistent with the approach in other regulated utilities. The Economic Regulatory Regime (ERR) – to be regulated by Ofgem – will set regulatory framework such as revenues, outputs and incentives.



(Source: beis.gov.uk)

Responsibilities of the T&S Company:

- development, construction, financing, operation, maintenance, expansion, and decommissioning of the T&S network;
- ownership of the onshore and offshore transportation network, and obtaining relevant regulatory approvals for operation of onshore and offshore transportation and offshore storage sites;
- operation of the T&S network to ensure the operational parameters are within agreed specified limits, managing network access and performing network planning and administrative tasks (such as those set out in section 6 (Revenue Model));
- review of the CO_2 metering and compositional analysis equipment installed by the users at the point of connection; and
- ensuring that the transportation and long-term storage of CO_2 is safe, efficient, and compliant with defined requirements.

Financial Risk Management

Alongside a lack of incentive, one of the biggest barriers to a commercial CCS market developing in Europe is the absence of a low risk environment for investors. A guarantee of income needs to be secured before large CAPEX investments in CCS infrastructure can be made. Alongside securing a revenue stream it is also important that investors feel that the liabilities with such investments are also low, for example in the case of a technical problem that hinders the project.

Securing a Revenue Stream

Stable long-term policies and contracts are the key to beginning the investment process. In the Netherlands the Porthos project wouldn't have been able to take FID without the SDE++ and the CfD scheme being in place, which guarantees project funding for the next 15 years when required. This timeframe has proven to be successful from both an emitter and T&S perspective, where often emitters require shorter time commitments but T&S operators would prefer 15-20 year commitments.

In a CfD, a strike price is agreed. If other contract forms are used these contracts need to include some form of **price floor or ceiling**. For example the UK ETS will have a transitional Auction Reserve Price (ARP) of 22 GBP, which establishes a minimum price for which allowances can be sold at auctions[150].

In the UK, the main way revenue streams are being secured is by establishing an independent regulator and have the **T&S Fee Regulated** to guarantee a price for those wanting to access the network. Non-discriminatory access to transport infrastructure and storage locations is already required as part of the CCS Directive but for investor security a regulated fee can also be highly beneficial. In the Netherlands a tariff price has been pre-agreed with the emitters but the fee is not explicitly regulated. However, given that government owned bodies such as EBN and Gasunie are developing the infrastructure, they can play a direct role in making sure the fees remain reasonable.

Beyond these early-mover projects there could be the potential to move away from contracts focussed on length and instead move towards selling volume space. However, without large stores and networks already in operation this kind of model would be hard to support.

Need for Insurance to Reduce Financial Burden

In most commercial markets, as CCS projects develop, a market for financial insurers will develop alongside it. However, as it currently stands, there is no commercial insurance available and the CCS Directive has specific Financial Security requirements, which are covered in Article 19:

"Financial provision should be made in order to ensure that closure and post-closure obligations, obligations arising from inclusion under Directive 2003/87/EC, and obligations under this Directive to take corrective measures in case of leakages or significant irregularities, can be met. Member States should ensure that financial provision, by way of financial security or any other equivalent, is made by the potential operator so that it is valid and effective before commencement of injection." (CCS Directive quote)

[150] UK Government Website (Accessed November 2022) https://www.gov.uk/government/publications/taking-part-in-the-uk-emissions-trading-scheme-markets/taking-part-in-the-uk-emissions-trading-scheme-markets#:~:text=The%20UK%20ETS%20will%20have,not%20be%20successful%20at%20auction

Currently, this requirement is being handled differently by different national governments, as the requirements are relatively unclear. A recent study by ZEP[151] has highlighted that this financial provision should be strictly risk-based, given the low risk of leakage. Should a full financial provision be required for an unlikely worst-case scenario, the burden on storage operators will be too great.

This risk-based approach has been followed by the Porthos project. In EBN/TAQAs, CO_2 storage permit application for P18-2[152] they also conclude that the financial requirements of a cash deposit or bank guarantee are too large given the very low risk of leakage, and instead a form of insurance is proposed. They are in talks with an insurer broker to set up a specific tailor-made cover for CO_2 storage from international insurance companies. For Porthos, the State will be co-policyholder of this "all risks" insurance, so that the state can also make claims at any time on the policy. This process of setting up insurance is expected to be completed 8 months before the start of injection where a pre-determined credit rating will be defined in order to issue the insurance. The advice so far given by the insurance broker is that current indications are that the market is expected to be willing to insure the risk. The pricing of the insurance premium will be determined on this specific case, based on:

- the organisational and technical capabilities of the license holder;
- any portfolio of CCS projects of the permit holder;
- the environment and size of the storage reservoir;
- the depth of the storage / the subsurface; and
- the costs of acquiring greenhouse gas emission allowances.

An estimate has already been made of the predicted costs from the legal obligations, and probabilities of the issues arising have been calculated. Together the cost and probability of events occurring has been translated into a financial security requirement. A summary is provided below in Table 11.

Table 11: Estimated Financial Security Required by Porthos Project to Cover Insurance Policy (in million €)

	Year 1	Year 2	Year 3	Year 4	Year 5
Sure elements (referring to costs / activities that will occur in any case)					
Risk Management plan	0,6	0,6	0,6	0,6	0,6
Monitoring until handover from State	9,3	9,0	8,7	8,4	8,1
Financial contribution after handover	2,0	2,0	2,0	2,0	2,0
Dismantling and closing	31,5	31,5	31,5	31,5	31,5
	43,4	43,1	42,8	42,5	42,2

[151] ZEP (2019) CO_2 Storage Safety in the North Sea: Implications of the CO_2 Storage Directive https://zeroemissionsplatform.eu/wp-content/uploads/ZEP-report-CO2-Storage-Safety-in-the-North-Sea-Nov-2019-3.pdf

[152] Letter from TAQA/EBN to EZK (12.02.2021) Titled "Indiening Aanvraag CO2-opslagvergunningreservoirP18-2 TAQA/EB" Available on the RVO website.

	Year 1	Year 2	Year 3	Year 4	Year 5
Unsure elements (these are costs / activities that may never occur)					
CO_2 emissions rights*	1,2	1,9	2,7	3,5	4,7
Correcting measures	24,6	24,6	24,6	24,6	24,6
	25,7	26,5	27,3	28,1	29,2

In the UK T&S business models, a Government Support Package is planned to help support leakage risk which "*would offer protection to investors for specified remote high impact low probability risks that the private sector would not be able to bear at an efficient price or indeed any price…. These risks are defined leakage events of CO_2 from storage facilities and asset stranding. Our intention is for the GSP (if required) to be for very remote risks, for a finite period of time, limited in its response, and only for specific events.*" It is still being considered how the government might act as **an insurer of last resort** where commercial insurance is not available or inadequate.

However, if a few large stores in the North Sea are likely to provide a majority of European storage capacity, further guidance at an EU level would be beneficial to help support national governments providing this service. National governments alone cannot take on this insurer role for a large-scale commercial market to be viable. For example, to help stimulate numerous projects and countries working together to develop a form of protection & indemnity insurance.

It is also worth noting that long-term liabilities are also mainly being handled by the state in the US[153].

Liability Manager and Government Role

There are two main risks in the CCS business models, which currently prevent commercial deployment: the risks associated with price variations and the risks associated with uncertainties over volumes. The financial aspects have already been discussed, and many governments are already taking a role here by providing subsidies and CfDs. However, there are the remaining liabilities across the chain regarding volume certainties. For example, emitters need a guarantee they can dispose of their CO_2 and for T&S that they will actually receive CO_2. For many emitters a commitment period of a couple of years would be most appropriate, given economic uncertainties they cannot control. T&S operators on the other hand would require commitments on a 10-20 years timeframe to make a return on their large upfront investments.

Nearly all projects in Europe are tending towards a hub and cluster approach, separating the capture projects from the T&S networks. This is beneficial, as many capture projects are not willing to take on the liabilities of that part of the chain. However, there still remains the need for a clear risk-allocation system along the full CCUS chain in the joint venture projects. For this purpose, establishing an external body that could provide de-risking mechanisms before concluding commercial agreements between the full chain components would be beneficial[154]. For example, as

[153] A reference is provided by State Policy on CCS Database (ccsreg.org), which summarises the funding mechanisms and long-term liability status of various states undertaking CCS.

[154] This is discussed further in the Final report from the CCUS Forum working group on CO_2 infrastructure, who provided us with their report on 9th January 2023. Their final study will be published end of February 2023.

shown in the case study below, Gassnova has taken this external body role in Norway of managing the cross chain risk for the Northern Lights projects by organizing risk-based quality assurance of project deliveries and taking responsibility for developing and maintaining an overall project schedule. In the UK, this de-risking role is currently being undertaken by the government (i.e. through BEIS)[155] who have established 'Risk Mitigation Mechanisms' (RMMs) to mitigate risks (specifically associated with the revue model) to cover (inter alia) the timing mismatch of when planned capture projects connect to the T&S facilities.

For a completely decoupled system, also additional guarantees may be required, for example for the emitter to be sure they are working with a suitable storage provider, some form of storage guarantee is needed. Through the stakeholder interviews undertaken as part of this study, it became apparent that emitters do not feel comfortable joining projects before the store site is well developed and a storage permit has been secured. However, for stores to be permitted a commitment is often needed from the emitter side. Although ISO standards and permits are being developed and secured by various operators, a form of early certification scheme (e.g. based on the SRL levels previously mentioned in Figure 9) would be beneficial to provide security to emitters.

In most countries, a relatively "hands-on" approach has been needed from national governments to provide a mediator role between parties and ensure that risk is allocated across the full CCS chain and where unmanageable, provide measures to help mitigate, e.g. by taking the financial risk on themselves. In Norway and the UK, the government has helped connect specific emitters to the T&S system, running competitions, removing the responsibility (and liability) of emitters to directly working business-to-business with T&S operators.

[155] More on the UK approach can be found on the BEIS website: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1045066/ccus-transport-storage-business-model-jan-2022.pdf

Case Study: Norway and the Role of Gassnova

The Longship Project in Norway has been organised into separate individual sub-projects (based on capture transport and storage) but the company Gassnova (a state enterprise) takes on the co-ordination role of the whole framework. *"The different parties have only been responsible for activities within their areas of competence and business, while the state carries the full-chain risk." (CCS Norway website, Accessed November 2022)* The risks of managing the project interfaces are therefore the role of the state.

Although the project has been largely publicly funded, all facilities and infrastructure developed as part of Longship will be completely privately owned.

"Norcem, Hafslund Oslo Celsio and Northern Lights have each entered into agreements with the government providing state aid to the construction and first ten years of operation of the CCS-facilities. Reflecting the balance between risks and opportunities in these agreements, the state will bear approximately 84% and 73% of the expected cost of Norcem's and Northern Lights' projects, respectively, as well as 36% of Hafslund Oslo Celsio's project"

Gassnova's responsibilities:

- Development of the design basis for the CCS chain.
- Performing audits and verifications as needed.
- Technical ranking and evaluation of the capture projects.
- Performing health safety and environment (HSE) activities, including conducting the hazard identification (HAZID) and hazard operational study (HAZOP) for the interface between capture export terminal and ship for CO_2 transport, and the CCS chain carbon footprint.
- Organising risk-based quality assurance of deliveries (except the KS quality assurance).
- Developing and maintaining an overall project schedule.
- Coordinating the development of the interfaces between the various sub-projects, incl. management of a technical committee and an agreements committee.
- Advising and assisting MPE in commercial negotiations with the industrial partners.
- Analysing and managing project risk in line with recommendations given in NS-ISO 31000.
- Reporting to and preparing documentation for the project steering committee (led by MPE).
- Increasing the industrial partners' awareness of the risk of cross- subsidisation.
- Coordinating and leading the work on benefit realisation.

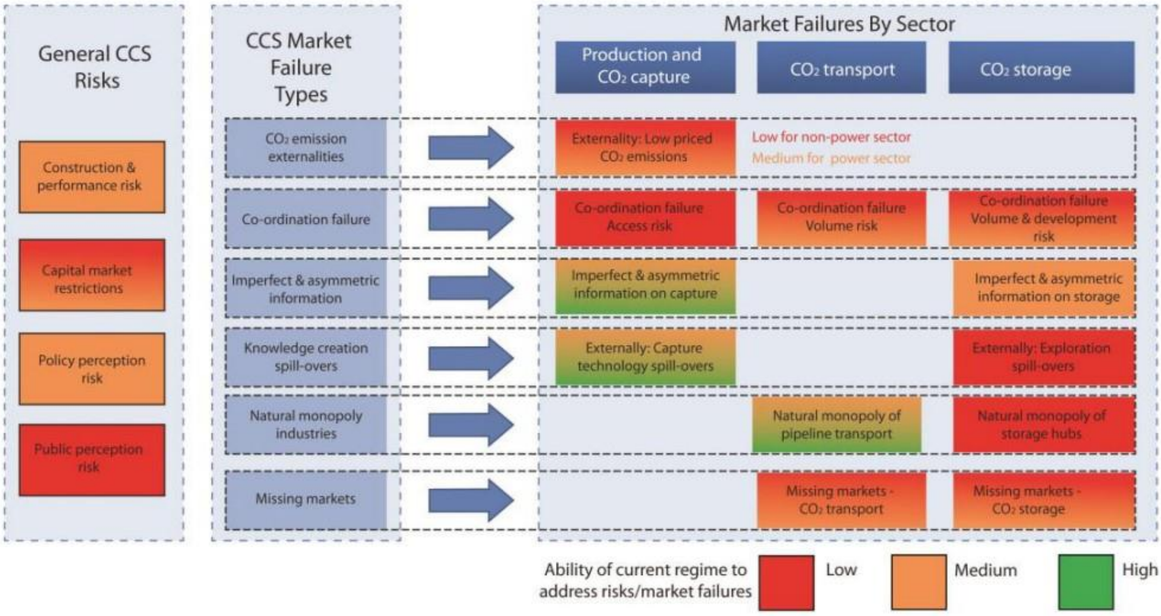
3.7 Key Challenges Remaining for Business Model Development

Given the current lack of commercial CCUS projects in Europe, it should be noted that there have been significant failings in market developments to support deployment to date despite a few early starters in the Norwegian offshore. The greatest failing has been in securing the investment for infrastructure developments. As a result, the projects currently in development are a combination of public-private partnership where clear infrastructure development policies and incentivisation schemes have allowed for more long-term project security and better risk profiles for private project investments.

In a paper on policy innovation for CCS deployment, Goldthorpe and Ahmad (2017) provided an overview of the common market failure by sector in the CCS value chain[156]:

[156] W. Goldthorpe and S. Ahmad (2017) Policy Innovation for Offshore CO_2 Transport and storage Deployment; Energy Procedia. V114

Figure 18: CCS market failures by sector



Source: Goldthorpe and Ahmad (2017)

Most projects in Europe have failed to date because the government support was not strong enough to provide the subsidies needed. For example, the UK Government Competition for CCS project funding was stopped in 2015 and the ROAD Project in the Netherlands never reached FID as the government support for CCS on coal sources waned.

First-of-a-Kind Projects Towards 2030

Through the very first projects currently in development (Northern Lights in Norway, Porthos & Aramis in the Netherlands, and the East Coast Cluster and HyNet in the UK) many lessons will be learnt, which will help progress the next wave of projects towards 2050. These early mover projects are already being designed with technologies that can be deployed within the next couple of years at mega-tonne scale and within a regulatory regime that has allowed for permitting of numerous storage sites. They are already close to becoming operational and the regulatory environment in Europe has not been prohibitive. However, for the next wave of projects the following short-term challenges still remain that will not be solved by initial deployment of these early-mover projects:

- **lack of storage capacity causing high competition**
  Although there is the regulatory requirement for open third party access and newly established storage targets under the NZIA, some emitters might still not have access to storage towards 2030. Many of the FOAK CCS projects in development are already 'sold-out' meaning they will not increase the storage potential for new capture projects coming online. This has already been seen in some projects which have been awarded funding through the Innovation Fund, where some have struggled to find storage on the order of the 4.6 Mt CO_2/year requirement. There is increasing concern that with the implementation of the CBAM and decreasing allowances towards 2026 there will not be enough CCS projects available regardless of the increasing price of the carbon market. Nevertheless, a large number of new candidate projects for the next PCI list represent storage capacity that is planned to become online towards 2030, in addition to what is currently being developed.

- **Reliance on subsidy competitions providing uncertainty**
For FOAK projects, the current ETS price will likely remain too low towards 2030 and some form of subsidy will be required. The current subsidy schemes are often competition based which provides uncertainty for many potential projects that the funding may not be available.
- **Not enough financial security to over-design capacity**
To benefit from economies of scale, the CCS networks being design towards 2030 would be best designed to accommodate future projects coming online. Given current market mechanisms focussing on stimulating the emitters to capture CO_2 many transport and storage operators cannot take on the financial burden of initially overdesigning their networks and increasing capital costs.
- **Lack of clarity on full-chain risk and need for a mediator role**
Some questions regarding suitable business models, contractual set-up and guarantees on revenue streams are likely to be answered during the current ongoing processes with various CCS project partners. However, for many emerging projects it is still unclear how to overcome this "chicken and egg" style problem of developing contracts and allocating the full-chain risk between parties. Therefore, a mediator role is beneficial with a clear remit, which could include inter alia: ensuring open and fair access to infrastructure, regulating fair tariff prices, providing an insurer of last resort and managing the interfaces between the capture, transport and storage elements.

Second Wave Projects Towards 2050

Once these FOAK projects are established towards 2030, the next challenge for a commercial CCS market will then be to move towards business models less reliant on government subsidy schemes towards 2050. Although the first wave of projects towards 2030 will provide some clarity, guidance at this stage would be beneficial on the following longer-term aspects:

- **European level guidance on network development plans**
During discussions with stakeholders it was highlighted that guidance is needed on an EU level on what the CCS development plan in Europe is. Which technologies or emissions sources will be prioritised? Where are storage and transport expected to be developed first?
- **Support for large-scale storage providers**
Given that large-scale storage could be provided in only a few Member States (but will benefit emitters across Europe), some support might be needed at a European level. Support is needed firstly regarding the liabilities taken on. Both the storage operator and the national government responsible for these stores taking on a disproportionally large part of the financial risk. Here, support or guidance is needed in the form of an insurance scheme. The CCS Directive currently provides limited guidance on how Financial Security should be managed proportionally to the low risk of leakage.
Secondly, support is needed to develop enough capacity and start appraising enough sites to ensure there is enough bankable storage within the next decades. Here, an understanding of where CO_2 transport networks are expected to develop towards 2050 would be beneficial.
- **Guidance for non-clustered emissions**
For countries and geographical areas far away from storage, but also more remote and not clustered emitters (e.g. some large emitters in the CEE region) some mechanism is required to increase the incentive to develop CCS. Currently, the extra costs associated with larger transport distances can be prohibitive.

4 Regulatory Considerations and Policy Recommendations

Based on the challenges that have been identified in this study for commercial CCS business development, a summary is provided here on issues identified where regulations and policy could play a role in speeding up the CCS developments. These recommendations have been made based on interviews with stakeholders and a literature review. Based on the current gaps that have been identified key regulatory and policy requirements are proposed which could support the CCS market to be established by 2030 and matured towards 2050. Overall we see emitters increasingly ready to invest in CCS but unsure about the transport and storage possibilities. And we see transport and storage operators hesitating with their investments and only investing in current needs and not in future needs for T&S capacities. Thus, leading to sub-optimal decisions and higher cost for industry and society. The recommendations are based around addressing these hurdles.

1) **Ensuring Adequate and Future-Proof Capacity for T&S Infrastructure to Allow Access for all Interested Emitters**

One of the key issues identified for CCS development in Europe is that, although there is a regulatory requirement for open access, the current **lack of storage capacity** is deterring emitters from investing in capture technologies given the limited access to storage sites which is often reduced to first movers only.

The "**chicken and egg" problem** which describes the fact that transport and storage developers do not want to invest in developing T&S infrastructure without firstly having emitters committed to supplying CO_2, whereas emitters do not wish to invest in capture technology without the required T&S infrastructure being already in place is a long standing barrier for the widespread deployment of CCS.

The first step to solving this problem is **stimulating initial overcapacity** in transport and storage facilities and ensuring there are public mechanisms and/or public support in place for **early mover projects to initially oversize their T&S infrastructure**. This will allow for better access to the infrastructure for emitters interested in CCS as an option to decarbonise in the future.

Whereas initial capital costs for transport infrastructure by pipeline are high, the marginal cost for CO_2 pipelines is relatively low. Therefore, initial **financial support targeted at the capital expenditure for oversized pipelines** can be used to lessen the revenue required by the T&S operator to recoup initial costs, allowing for the infrastructure to be initially underutilised whilst other projects get ready to join. Financial mechanisms should be designed to de-risk initial investments in pipelines with overcapacity. They could serve as a guarantee in case the expected CO_2 volumes do not come online within foreseen timeframes.

Public investments are justified considering they are for **developing a public good that will serve society at large** in the process of decarbonisation while maintaining European industry alive. Furthermore, given the limited options for decarbonisation available to sectors such as energy intensive industry there is already a large demand for T&S infrastructure foreseen towards 2030. By providing a mediatory body, such as a national government, either early infrastructure funding can be provided to allow for overdesign, or a guarantee could be provided should the infrastructure not be fully utilised as predicted. Our analysis has shown that T&S infrastructure is already developing too slowly. The IEA has predicted a 60 Mtpa shortfall by 2030. Even with the recently announced targets of 50 Mtpa by 2030, there is still a 10 Mtpa shortage in storage capacity. Helping to stimulate T&S infrastructure capacity beyond guaranteed usage will therefore be key and likely become a very strong accelerator for CCS.

Given the current high competition for T&S access there also needs to be some form of **support for emitters to be able to join existing initiatives**. The development of bilateral agreements without an open season process has allowed for some monopolisation in some countries for these initial projects as it has created a bias towards larger companies with greater incentives, such as those that can develop both capture and storage projects given their industry already operates both up and downstream.

Some stakeholders expressed interest in setting up more structured, but open, forums to help facilitate discussion. These forums should not be focussed on R&D topics but have a commercial setting to **bring emitters together with potential T&S operators**.

Some countries are developing their CO_2 transport networks in TSO structure, which will be regulated (e.g. the T&SCo model in the UK). In other countries, a TSO-like structure is indirectly developing, which is due to this being an emerging market with fewer industrial players. For example, Gasunie in the Netherlands, will be the only CO_2 transport operator involved in the first two early-mover projects, but the government plans to keep this an open market and keep tariffs unregulated. Given that this is an emerging market, there is a strong message that there could be over-regulation too soon, before large networks have been commissioned, let alone cross-border ones. However, there is some level of regulation that inherently comes with a TSO system.

Another issue regarding suitable storage capacity is the current restriction on having to store CO_2 within the EEA Amending the ETS Directive to allow storage outside of the EEA for example in the UK part of the North Sea, would benefit projects by opening up more storage capacity and allow access to early-mover T&S projects internationally.

2) **Support for Early Development of Large Stores**

It is likely that the North Sea will become a CO_2 storage hub, providing a majority of the storage capacity available for Europe, especially within the next decade when a target of 50 Mtpa of CO_2 injection capacity is to be reached as stipulated under the NZIA. Given that only a few countries have taken on most of the storage responsibilities, more support is required at a European level to ensure further development of storage sites and a level playing field across the EU.

In the case of storage, **financial support for early site exploration** and development of storage sites at key locations by bringing them to a point where they are fully characterised, permitted for CO_2 injection, and available for commercial use would **reduce technical risk, uncertainty, and the cost of commercial-scale saline storage projects**.

Given the long (5-7 year or more) development timelines greater incentives are required for storage operators or independent research organisations to appraise and characterise sites early, to allow for bankable storage capacity to be ready by the time capture projects are ready to enter the market. It would be highly beneficial for either the operator or independent teams to work their way through potential storage sites, using all available data, to deliver insight on the cost to a higher readiness level (SRL) ready to use, identifying the not-so-good or the very-expensive sites. It is clear that whatever the route, Member States with suitable storage reservoirs need to vastly scale-up storage developments.

Further, given the loosely defined requirements of the CCS Directive regarding Financial Security, large financial burdens are being put on operators before projects commence and are not being defined in line with risk (i.e. given the low risk of leakage, financial security requirements should be lower). Given that the storage will benefit all EU Member States, an **EU level insurance or guarantee scheme would be highly beneficial**, paid for by those accessing the projects.

3) **Further Regulatory Guidance on CO_2 Transport and CO_2 Certification at EU-Level to Ensure Harmonisation**

There is a general consensus on the **need for further regulatory guidance on CO_2 transport at EU-level**. The CCS Directive is mostly focused on CO_2 storage and does not provide sufficient detail on critical **regulatory elements for multi-mode CO_2 transport**. In order for CCS deployment to take place at a Pan-European level, transnational transport of CO_2 will be needed. Thus, there is a need to **provide guidance and harmonization** in order to ensure interoperability across member states. In this regard, establishing **CO_2 standards for transport** at EU level will be of crucial importance. As a minimum, these standards should specify CO_2 temperature, pressure, purity and composition, taking into account that each of the various elements of a transport and storage system may have specific requirements. A balance between cost effectiveness, safety and lowering liability should be sought. Establishing **CO_2 quality standards based on minimum and maximum acceptable ranges** is a good way to support standardization while maintaining flexibility. Flexibility will be particularly important especially in the early stages of CCS deployment before experience is obtained on optimal parameters.

4) **Decoupling T&S from Emitters**

As the CCS market moves towards commercialisation, it is likely to become more efficient to **decouple the emitters from the T&S network**. Especially with shipping development, it is easy to develop contracts that once the CO_2 leaves the emitters, its final destination is not relevant once the transport operator takes over responsibility. Under the updated ETS both transport and storage operators will have reporting obligations for their emissions including in case of leaks. Decoupling emitters from T&S can be an effective way of organizing the CCS full-chain regardless of this. This model will become particularly effective as larger transport networks develop, potentially connected to numerous stores, and cross-border transport of CO_2 begins. However, for this to be effective regulation is needed to standardise numerous elements of the chain, including, as discussed above, CO_2 quality standards for multi-mode transport, storage and potentially utilisation.

5) **European Vision**

In order to efficiently develop large-scale T&S infrastructure, there is the need for a clear **focus at EU level** on where the infrastructure is developing and where financing can be most effectively placed – both from a sector and country perspective. Some Member States would benefit from having EU-level support regarding their NDCs. Such support could be in the area of reaching both short and long-term goals, as well as in developing CCS in the context of member state needs, taking into account potential interconnection with services being provided in other countries.

The EU is best placed to oversee the **planning and development of a Pan-European network of CCS transport and storage**. To that effect, **requiring that CO_2 network plans** are developed by regulatory authorities in Member States and submitted periodically as, for instance, in the TYNDPs would facilitate the deployment of CCS across Europe. The plans must, of course, be linked to the expected developments of storage sites in Europe, and also take into account emitter clusters. The CCS planning that will be described by Member States in the updated National Energy and Climate Plans (NECPs) could serve as a starting point to inform this planning. It is important that the regulation for CCS be tailored to the unique characteristics and needs of CO_2, which is not an energy carrier, like other gases. Thus, whereas there are several lessons to be learned from regulation in other sectors, especially the hydrogen and gas ones, it is **important that the regulation for CCS be tailored** to encompass its specificities.

More clarity is also desired on where incentives will be placed, especially related to innovations like DACC/BECCS technologies, and in stimulating the development of a merit order for various technologies. The question that kept arising during our stakeholder interview was "What is the EU prioritising and how can we as industry partners best place ourselves?" The **EU must be unequivocally clear in its support for CCS** and the industry will follow.

There is increasing concern that CCS will not be available to many emitters in the short term and yet the impact of CBAM and decreasing allowances from 2026 will mean that they will be making increased financial contributions to the EU. The CCS community therefore feels it is essential to see these funds re-invested to provide more bankable storage potential and support emitters in their infrastructure planning.

6) **National Government Role**

Regardless of whether T&S systems are developing more business-to-business and privatised or more government regulated, overall, this study has shown there is the need for a **hands-on government role**. Alongside the role in infrastructure design (point 1) a role is also needed to **facilitate interface management across the whole chain and help mediate/ manage the cross-chain risks**. There is a current need in this emerging market for an external body that could provide de-risking mechanisms before concluding commercial agreements between the full chain components.

Governments should have a responsibility to prevent further project delays by establishing long-term financial security through their subsidy schemes and also providing guidance on streamlining storage site permitting.

National authorities will oversee the development of network plans requested by the EU and other important responsibilities that are crucial for supporting the deployment of CCS. As a consequence, they must address the need for increased capacity and staff having good knowledge of the key CCS topics.

7) **Support for the CEE Region**

Support is also required for emitters that are currently not located close to any storage sites. This is particularly relevant for the CEE region, that has high emissions (such as Poland) but where emitters are located at large distances from the storage hubs currently developing in the North Sea (unless on-shore storage becomes a reliable option, faster than anticipated now). There needs to be some form of mechanisms in place to make sure these **countries can progress their CCS projects without being penalised for being far away from storage hubs**.

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MJ-05-23-015-EN-N

Publications Office
of the European Union

ISBN 978-92-76-99419-0