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Demonstrating a Refinery-adapted cluster-integrated strategy
to enable full-chain CCUS implementation - REALISE

D4.3: Analysis of socio-political considerations of CCS

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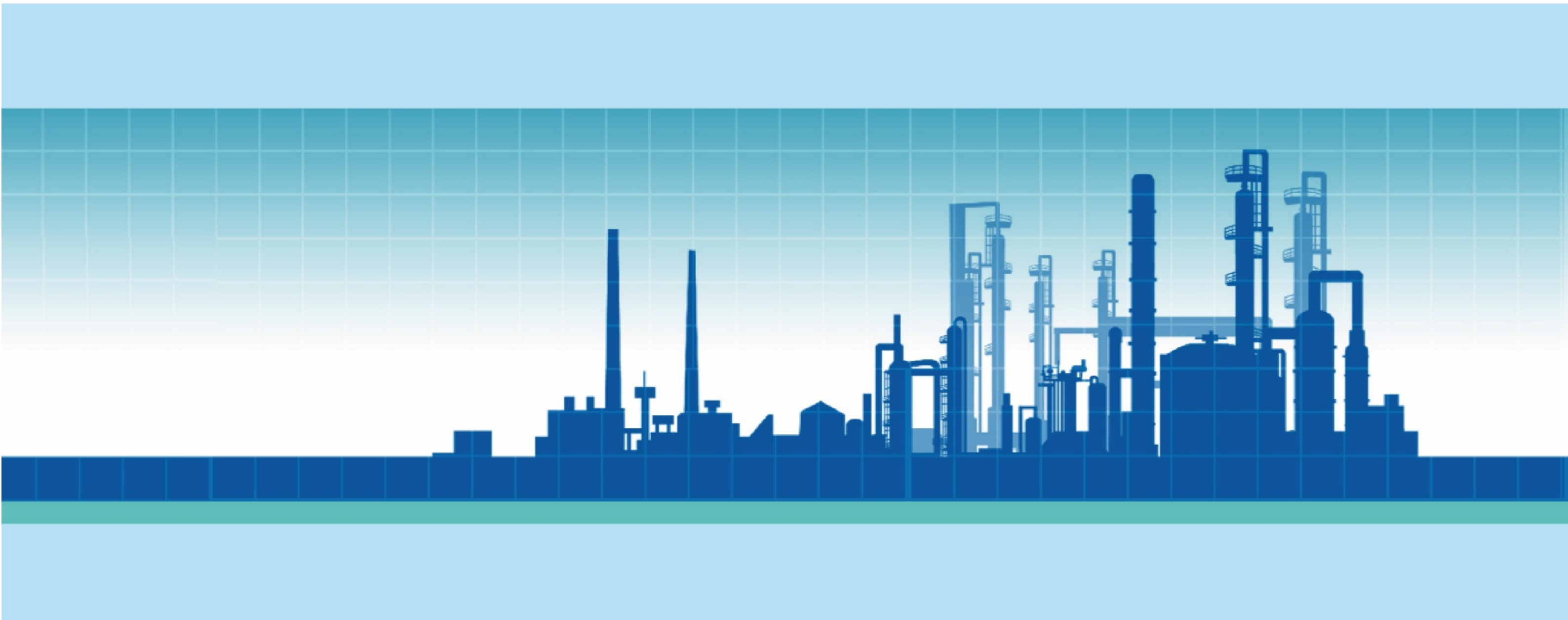
Global CCS Institute



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Document History

Revision History

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1	17/10/22		
2	23/11/22	Industry stakeholder workshop feedback and refinery transport methods included.	Angus Gillespie
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Authorisation

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Disclaimer

Executive summary

As part of the REALISE project, this report reviews:

- the management of socio-political risks in carbon capture and storage (CCS) projects
- policy and regulatory frameworks that enable or incentivise investment in CCS
- financing options for CCS projects
- CO_2 capture technologies specifically relevant to refineries
- barriers and policy considerations relevant to the transport and storage of CO_2.

The report also develops an indicator of the readiness of refineries for the application of CCS and applies it across European refineries.

<u>Management of Socio-Political Risk</u>

The CCS industry is relatively small, but several examples of socio-political risks have already caused problems during development. Over the past ten years, at least 87 recorded cases of CCS projects were abandoned at some point between their design and construction phases. Socio-political risks played at least a contributory role in around 5% of those abandonment decisions.

A clear lesson from previous experience is that socio-political risks should be managed with the same rigour as all other significant risks and this management should commence at the conception of the project. This will involve including socio-political risks in the project's risk management framework and the availability of deep community engagement, social science, and external engagement expertise. Failure to do so is a failure to manage a risk that can, and has, caused the complete failure of projects, even where they were sound from a commercial or engineering perspective.

<u>Policy & Regulatory Frameworks</u>

The successful deployment of CCS at refineries is contingent upon the presence of enabling policies that are designed to overcome broader CCS market failures. These market failures are not specific to CCS within any particular industry or sector, including refineries, so it follows that enabling policies will support refineries by default. Importantly, however, policies must place a sufficient value on CO_2 captured to ensure there is a business case for investing in CCS at refineries.

From the point of view of CCS investments, enabling policies must deliver the following:

- Place a sufficient value on captured CO2 to overcome revenue risk. Applying CCS to any industrial facility incurs significant additional capital and operating costs. Unless there is a financial return from CCS to the project owner, the investment will not be made.

- Overcome the cross-chain risk. CCS projects that have a single source connected to a single storage facility pose an important risk to investors because the unavailability of either component can cripple the entire value chain. This can lead to significant loss of revenue, making investment in such projects high-risk.

- Manage long-term storage liability. While the risk of leakage during the operation or post-closure phase of a CCS facility is diminishingly small, it is not zero. Although a private investor may manage this risk while a CCS facility is operating, it will be impossible for businesses to bear this risk for an indefinite period beyond post-closure.

- There are well-established policies and mechanisms that have been implemented that have enabled investment in commercial CCS projects. They include carbon pricing, or payment for each tonne of CO_2 stored, capital grants or other forms of government support or risk sharing for essential CO_2 transport infrastructure, and legislated mechanisms for the transfer of some forms of liability for stored CO_2 from the operator to the state once certain criteria are met. These are all broadly applicable to CCS at refineries.

Law and regulation similarly plays a crucial role in supporting the deployment of CCS projects. The development of CCS-specific legal and regulatory frameworks, as well as the removal of legal barriers to the technology, will be critical to ensuring more widespread deployment. CCS-specific regulatory frameworks will enable the development of CCS applications across a wider variety of technologies and locations, including projects linked to refineries.

Finance

The availability of affordable finance for CCS is critical. Debt financing from commercial banks for CCS is currently difficult due to the immaturity of the CCS industry compared to other industries for which banks have a long history of lending. There are a range of green bonds, sustainable bonds/social bonds that are a potential financing option for CCS at refineries, subject to an assessment, on a case-by-case basis, as to whether the CCS project complies with eligibility requirements of the particular bond. National import export credit agencies can also provide debt finance, loans, lines of credit or bonds as well as insurance and guarantees to support CCS projects, in support of national companies seeking to export goods or services.

Refinery Readiness Indicator

The suitability or readiness of a refinery to have CCS retrofitted to the plant depends on many factors. A Refinery Readiness Indicator was developed and applied to European refineries. It is a benchmarking tool that provides an indication of how close a refinery is to being "CCS Ready" compared to other refineries. The Indicator uses seven criteria, each with an appropriate weighting, to calculate the Refinery Readiness Indicator Score for each refinery.

1. Policy and Regulation
2. CO_2 partial pressure and total CO_2 emissions
3. Distance to geological storage resource and transport mode (ship and/or pipeline)
4. Regulations for transport of CO_2, both domestic and transboundary
5. Potential to form a CCS hub, considering other nearby CO_2 sources
6. Location Cost Factor
7. Presence of other active CCS projects in the host country

Overall the highest-scoring refineries are large (>2Mtpa CO_2), adjacent to suitable storage and in a country with an enabling environment for CCS.

The following high-level messages are clear:

- Strong policy and regulatory frameworks create an enabling environment for CCS deployment
- The larger refineries (>2Mpta CO_2) are the highest-scoring, offering the lowest costs per tonne of CO_2
- Access to adjacent and viable storage formations promotes the highest score; however, longer distances to better storage also improve the overall result

The five highest scoring refineries were:

1. Shell Nederland, The Netherlands
2. BP Scholven, Germany
3. PCK Schwedt, Germany
4. PKN Orlen, Poland
5. ENI Taranto, Italy

CO_2 Capture Technologies for Refineries

Refineries are complex industrial plants with small, lesser complex plants still having many varied CO_2 emission sources. There are three major sources of CO_2 in refineries; process heaters and boilers, FCCs and power generation (utilities). Although hydrogen production only accounts for approximately 2% of refinery emissions, the flue gas that is produced has a significantly higher CO_2 concentration than other sources in a refinery (15 – 99%).

There is a range of technologies available to capture CO_2 from these sources. Post-combustion carbon capture covers a range of specific technologies that fall into the category's liquid solvents, solid adsorbents and membranes.

Pre-combustion carbon capture refers to removing CO_2 from hydrocarbon fuels before combustion, typically through the generation of hydrogen as the fuel for combustion.

Oxy-fuel combustion is the third method for carbon capture. The nitrogen that is approximately 80% of the air commonly used for combustion serves to dilute flue gas CO_2 content to less than about 15% for process heaters, boilers and other thermal heat recovery systems. Post-combustion capture processes are designed to separate the relatively dilute CO_2 from the bulk flue gas nitrogen. In oxy-combustion processes, the bulk nitrogen is removed from the air before combustion in an Air Separation Unit (ASU). The fuel is burned with a mixture of oxygen (from the ASU) and recycled flue gas to control the combustion temperature in the absence of nitrogen. The resulting combustion products will have CO_2 content of about 90% or greater.

The selection of appropriate technologies for a given application should consider the typical partial pressure of CO_2 in a point source, the volume (tonnage) of CO_2 from that point source, and the relative availability and cost of energy sources (heat and electrical).

Within a refinery environment, it is essential that planning for staged deployment of capture projects is undertaken. Refineries have a range of point sources with varying costs and scales, and it is likely that these would be deployed in separate stages rather than as a single, integrated project.

Given the economics in most plants, it is likely that larger-scale capture projects would be deployed on the SMR and/or FCC units in stage one, then progressively working up the marginal abatement cost curve as resources are available.

CO_2 Transport and Storage

CO_2 can be transported through a combination of four modes. Listed alphabetically, they are pipelines, rail, road, and waterways. Of these modes of transportation, pipelines are the most versatile, used extensively worldwide to distribute and transport oil and gas. Using roads or rail to transport CO_2 requires additional capacity planning and potential debottlenecking since these modes are also used to transport people, freight, and other types of cargo. The transport of CO_2 through waterways, especially international waterways, has unique requirements. Planning for staged deployment of capture projects at a refinery is essential, and transport design should be considered in unison to ensure the most suitable transport design and method selected. It is likely in Europe that a combination of transport methods will be applied for refinery, and other CO_2 sources, to transport CO_2 to a suitable storage location.

The provisions of the London Protocol could influence projects where transporting CO_2 through waterways is a requirement. Only eight countries (Contracting Parties) have ratified the agreement. However, a provisional application of the amendment to Article 6 of the London Protocol was agreed to in 2019 at the 14th Meeting of the Contracting Parties. Countries with plans to transport CO_2 internationally can proceed but have additional requirements to liaise with the International Maritime Organization (IMO).

There are several business models relevant to the transport and storage of CO_2. Government policy has a significant role in enabling the development of the necessary infrastructure, just as it did in other industries such as electricity and telecommunications, water distribution, renewable energy, road and rail. Examples of policies or business models applicable to CO_2 transport and storage include the following.

1. Regulated Asset Base (RAB): In this model while the asset is owned by the State, private companies manage and operate the infrastructure. However, investment decisions are managed by a regulatory body. The private company receives payments for services provided to customers while also receiving incentives (subsidies, tax benefits) from the government to ensure the continuity of operations.

2. Public Private Partnership (PPP) or Private Finance Initiative (PFI): The government invites tenders for infrastructure projects. A consortium between a public-sector entity and private companies is set up as a separate company. This company carries out all stages of the project, from initiation, selection, and design, to execution and operation. Through a contract, it receives revenues for services provided to customers or receives performance-based payments from the public-sector entity for managing the infrastructure.

3. Contract for Difference (CfD): Used in the power and utility sector, this structure is a financial contract awarded through an auction. The energy generator that wins the contract is guaranteed a revenue stream for the contract's duration by providing a difference payment and providing long-term revenue certainty (Low Carbon Contracts Company, 2022)(Low Carbon Contracts Company, 2022)(Low Carbon Contracts Company, 2022). This guaranteed revenue stream can provide a basis for financing capital-intensive projects like CO_2 transport and storage.

4. Cost Plus: These financial contracts are used for capital-intensive projects. In this financial arrangement, project developers are paid for project expenses in addition to an additional payment for executing the contract (or a profit margin).

5. Waste sector type contract: These contracts are like other contracts common in the waste management sector. Project developers are paid for the units of CO_2 they can inject and store, or CO_2 sold for EOR.

6. Hybrid models/contracts: The models and contracts described above can be used in combination depending on the complexity of the project.

Conclusion

The application of CCS to European refineries can reduce annual emissions of CO_2 by many millions of tonnes. The successful execution of a CCS project requires a robust and effective risk management process that includes socio-political risk. Some early CCS projects failed as a direct consequence of ineffective management of socio-political risk.

CCS is an immature industry that materially contributes to a significant public good - a stable climate. Government has a critical role in establishing the policies and regulations to create a business case for private sector investment in this critical technology. There are several examples of policies and regulations that have successfully supported CCS investments around the world that are applicable to European refineries

There are no fundamental technical barriers to the retrofit of CCS to refineries. A range of CO_2 capture technologies to suit the variety of gas streams created by refineries is commercially available. Large gas streams with higher concentrations of CO_2, such as from hydrogen production, are lower cost and should be the first to benefit from CCS.

The transboundary movement of CO_2 by ship must comply with the specific requirements of the London Protocol. Parties to the protocol wishing to import or export CO_2 must advise the International Maritime Organisation that they will comply with those requirements. CO_2 transport also requires infrastructure such as pipelines and port facilities. Government has a role in supporting the development of this infrastructure which is essential to meeting ambitious climate targets.

Acronyms

Acronyms used in this report are listed below:

ADB	Asian Development Bank
AUD	Australian Dollars
CCS	Carbon capture and storage
CO_2	Carbon dioxide
CPL	Capture Projects Ltd
DECC	Department of Energy and Climate Change
E-PRTR	European Pollutant Release and Transfer Register
Eksfin	Export Finance Norway
ENGO	Environmental Non-Governmental Organization
ESG	Environmental, Social and Governance
ETS	Emissions trading scheme
EU	European Union
EXIM	Export–Import Bank of the United States
GBP	Green Bond Principles; British pound sterling
Gt	Gigatonnes
ICMA	International Capital Market Association
ICSA	International Council of Securities Associations
IEAGHG	International Energy Agency Greenhouse Gas
IFC	International Finance Corporation
KBPSD	kilo-barrels per stream day
KEXIM	Export–Import Bank of Korea
MCPP	Managed Co-lending Portfolio Program
METI	Ministry of Economics, Trade and Industry
Mtpa	Million Tonnes Per Annum
Tpa	tonnes per annum
NOK	Norwegian Kroner
SBP	Social Bond Principles
SSE	Scottish and Southern Energy
UKEF	United Kingdom Export Finance
USD	United States Dollars
WBG	World Bank Group

Table of Contents

1 A review of the management of socio-political risks in CCS projects

1.1 Summary

As part of the REALISE project, this section examines how socio-political risks have been managed, successfully or otherwise, in previous CCS projects. The learnings from this review will be used as an important input to producing a practical risk assessment framework for socio-political issues in CCS projects.

Socio-political risks are considered at the broadest level, covering the three dimensions of the "triangle of social acceptance" – society in general, the market and the local community.

The CCS industry is relatively small, but there are already several examples of socio-political risks having caused problems during development. Over the past ten years, there have been at least 87 recorded cases of CCS projects that were abandoned at some point between their design and construction phases. Socio-political risks played at least a contributory role in around 5% of those abandonment decisions.

Potential stakeholder management learnings and best practices were reviewed in case studies of five CCS projects; Barendrecht, White Rose, Peterhead, Zerogen and Tomakomai. These projects' experiences were explored through a brief summary of the project details and main learnings as well as common graphics to illustrate the impact of socio-political events and decisions on the project's prospects.

Unsurprisingly, the quality of stakeholder management evident in CCS projects has expanded and improved over the last decade as the number of global operational facilities grew. CCS developments were sometimes viewed as technical, and sometimes legal, processes. As companies with major capital project experience planned CCS installations, their own internal project development practices helped raise standards. Several governments have emphasised maximised knowledge management as a condition of their support for CCS projects. That, along with the intensified academic interest that comes from more CCS activity, has created a valuable catalogue of accessible advice and working tools to manage socio-political risks.

Most stakeholder concerns arise from the safe storage of CO_2 rather than its capture at the source industrial plant. That implies refinery-based CCS projects are no less, and no more, likely to incur socio-political risks than other industrial CCS facilities. When major stakeholder issues emerge, these are commonly from local communities rather than national forces such as, for example, when orchestrated by ENGOs. The continued and increasing association of CCS with fossil fuels by some activists could make that scenario more likely.

Some case studies showed examples where minimal stakeholder management was planned or undertaken. Given the very low proportionate cost of this element of risk management (maybe less than 1%[1]) it could prove false economy to reduce work based on costs alone.

[1] Stakeholder engagement work was estimated as accounting for 0.6% of the overall Zerogen CCS project budget (p66, "Zerogen IGCC with CCS, A Case Study", State of Queensland, 2014)

The best examples involve the engagement work commencing at, or even preceding, the start of standard CCS project development work.

Socio-political risk management can be viewed as a deliverable or as a process. Rather than simply make a binary choice between the two, socio-political issues should be managed with the same respect as technical and operational CCS project risks. The growing range and richness of templates and checklists available to guide stakeholder management in CCS projects should be treated as prompts for best practices and not to short-circuit efforts. The more applied the risk identification work, the easier it should be to develop mitigation efforts. Over-reliance on checklists can encourage simple mechanical assessments.

A workshop with relevant risk experts and CCS project managers was held in October 2022 in Cagliari, Italy, to progress this case study review work. The active and productive discussion made several observations on stakeholder management actions, checklists and templates.

1.2 Introduction

As part of the REALISE project, this report examines how socio-political risks have been managed, successfully or otherwise, in previous CCS projects. The learnings from this review will be used as an important input to producing a practical risk assessment framework for socio-political issues in CCS projects.

Managing socio-political risks is a well-understood topic across project management and a broad range of related business and academic literature is readily accessible. Learnings from, and guidance on, managing such risks for CCS projects is, however, less researched. This report helps address that gap in the context of supporting refinery CCS plans in the REALISE project.

The work is based on an initial literature review to produce a practical understanding and definition of socio-political risks. With that guidance on scope, the relevant issues are considered for CCS projects, firstly on the basis of general principles and then, with the help of several project case studies, using common applied themes and insights. The report concludes with a discussion of the main learnings and recommendations for managing socio-political risks for future CCS projects.

The Global CCS Institute is well placed to compile this report. The combination of over ten years of project experience and its proprietary project database allows it a unique insight into how socio-political risks have been managed in both failed and successful CCS projects over the past ten years. Indeed, the Global CCS Institute published a CCS Communication and Engagement Toolkit Ashworth, Rodriguez, et al., 2011) in 2015 to help CCS project managers in managing such issues. Five CCS projects were used as case studies for this report, each with different perspectives on managing socio-political risks that ultimately caused the cancellation of three of them. These are:

- Barendrect, The Netherlands – cancelled in 2010
- White Rose and Peterhead, UK – cancelled in 2015
- Zerogen, Australia – cancelled in 2010
- Tomakomai, Japan – successfully completed in 2019

While White Rose and Peterhead were both cancelled due to the same event, reviewing their different management approaches is revealing and instructive. Publicly available reports, listed in the bibliography in Appendix A, were used for each of the case studies, augmented on occasion with interviews with key managers and proprietary research material of the Global CCS Institute.

1.3 Working Definition of Socio-Political Project Risks

The concept of managing socio-political risks, often referred to as stakeholder management, is a recognised cornerstone of professional project management. Its standards and best practices continue to grow and improve, especially in helping steer those managing the development of the largest, highest profile and often most potentially controversial capital projects. Activities that attract most opposition, sometimes fuelled by increasingly well-funded and organised activists, have tended to develop the best practices in managing socio-political risks. Examples include very large civil engineering projects (e.g. major new roads or utility infrastructure that cause disruption) as well as nuclear, and increasingly any thermal, power generation stations. One could expect CCS developments to join such activities with the most need for professional stakeholder management practices. An academic tool, the “triangle of social acceptance”, has been developed that helps identify policies or technologies likely to have the greatest need for stakeholder management. A graphical version of the main criteria is shown below (Wüstenhagen et al., 2007).

The underlying premise of the triangle is that overall social acceptance of technologies comes from three dimensions: the market, covering general comfort with the technology amongst investors and consumers; general society that covers support amongst broader, more indirectly affected groups, such as industry, policy makers and the public; and the community, covering the local acceptability of actual projects. Results can vary and differ geographically. CCS projects are likely to be most impacted in general by socio-political issues and site-specific community support. Relative to wind and solar developments, that appear more inherently accepted by all stakeholder groups, CCS project developments merit closer attention to, and management of, socio-political issues.

Figure 1. Triangle of Social Acceptance.

For the purposes of this study, socio-political risks are considered at the broadest level, covering the three dimensions of social acceptance shown above. That allows interchangeability of use of the terms socio-political risk management and stakeholder management. It is important to consider the basic definitions as a foundation for reviewing CCS projects’ experiences and developing guidance for future projects. Socio-political risks are defined as political decisions, conditions or events in the region, country or market in which a project is investing, that impact on operations or earnings. They are a form of non-technical risks that emerge from the views, and ultimately decisions, of individual, groups or bodies – identified as stakeholders. That is in turn defined as a person, group or organisation that has an interest or concern in a project and can affect, or be affected by, its outcomes. Fundamentally, effective management of socio-political risks aims to understand, and then actively manage, the assessment of the project results from the perspective of each stakeholder[2].

To be successful, stakeholder management has to be approached with a genuine interest in, and a willingness to be accommodating of, external parties' views and needs of the project. Ultimately, that success comes from achieving a sense of mutual trust. The typical engagement approach of the late 20th century, sometimes described as driven by the "DAD" principle – Decide, Announce, Defend – created a level of dogma that undermined any sense of trust. Modern approaches to stakeholder management are considerably more open and adaptable.

An important feature of socio-political risks is their general lack of upsides for the project. They are predominantly characterised by creating disadvantages, from additional costs and/or schedule delays, when issues emerge but offering no symmetrical cost reduction or schedule acceleration when mitigated. Much like the basic needs, or hygiene factors, in the Maslow hierarchy of needs[3] and Herzberg theory of motivation[4], socio-political satisfaction has no real benefits for a project but risks considerable downsides when absent.

1.4 Socio-Political Risks in CCS Projects

Although, in relative terms, the CCS industry is at present small, there are already several examples of socio-political risks having caused problems during development. There are 30 large CCS facilities in operation today[5]. Over the past 10 years, however, there have been at least 87 recorded cases of CCS projects that were abandoned at some point between their design and construction phases. Research for the report suggests socio-political risks played at least a contributory role in around 5% of those project abandonment decisions.

It is probably fair to suggest that standards of stakeholder management in CCS projects have improved over the last decade or so. That is partly the result of increased awareness of the need to address continuing civil society concerns around CCS, especially when consolidated into organised opposition, and partly due to the internalisation of learnings from examples of relatively poor socio-political risk management. The likelihood of organised resistance to CCS projects might grow as several Environmental Non-Government Organisations (ENGOs) have adopted positions that oppose CCS on the grounds it preserves the role of fossil fuels in the global energy mix. In response, CCS project developers generally now approach stakeholder management in a more sincere and pragmatic manner. Topical advice, support and guidance is available from several CCS bodies (Ashworth et al., 2011)

Scope remains, nevertheless, to identify potential stakeholder management learnings and best practices from previous CCS projects from case studies. These illustrate possible

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[2] Definitions derived from "Stakeholder Management: An Approach in CCS Projects", MDPI, November 2018
[3] See an explanation of the Hierarchy of Needs here
[4] See here for a basic explanation of the Herzberg work
[7] The Global CCS Institute CO2RE Database, accessed 19 September 2022.

practices to both avoid and to adopt. The next two sub-sections therefore summarise CCS projects' experience with socio-politicial risk management to underpin the identification of empirical findings, and advice, for CCS project developers. Along with a brief summary narrative of, and learnings from, each CCS project's experience, common graphics are used to illustrate the combined impact of socio-political events and decisions on the project's prospects.

1.5 Review of failed CCS projects due to socio-political risks

1.5.1 Barendrecht

Name:	Barendrecht
Project type:	Onshore depleted gas reservoir
Source:	Pernis refinery
Capture:	Pre-combustion at hydrogen manufacturing unit
Volume:	0.8mln tonnes p.a.
Dates:	July 2007 to Nov 2010

The Netherlands government announced a tender process for two CCS demonstration projects in March 2007. In response, Shell submitted an application to transport CO_2 from the hydrogen manufacturing unit[6] at its Pernis refinery around 20km to store in a retired natural gas reservoir in Barendrecht, a suburb of Rotterdam. Towards the end of the year, Shell applied for the necessary planning permits from the Barendrecht city council, which triggered formal council discussions on the CCS project. At this point, Shell appeared to approach the consultation process as a purely technical task with no social evaluation of Barendrecht, or references to Dutch climate policy, *etc*. The strength of support for CCS from the national government, as well as Rotterdam, that had described CCS as a core piece of the Rotterdam Climate Initiative, perhaps gave false indications of general public support.

The need for a formal environmental assessment prompted the organisation of two public meetings in 2008, one in February and one in April. The first event attracted around 60 people and, according to some reports, the poor preparation by both private and public representatives, as well as absence of national government, created local suspicion that over the next few months developed into ever stronger opposition. A key trigger point for initial community concerns reportedly arose from a poorly drafted sentence in the environmental report commissioned by Shell from a contractor. Its conclusion included wording that …"we could claim policy is needed to forbid storage of CO_2 in populated areas" (Feenstra et al., 2010). Despite then explaining that was not necessarily desirable, this "damning sentence" was often quoted by opponents. Safety concerns were exacerbated by the perceived silence of national government, delays in (and general mishandling of) Shell's answers to questions and the local media focus on such concerns that further built suspicions.

After the strength of community feeling shown at the second public meeting, the city council asked the project developers to stop communicating directly with the community as the information was having a more negative impact on the project. A new consultation and communications body (BCO_2) was formed in mid-2008 that included municipal and national government representatives but excluded Shell and the project developers. A cross-party political coalition was formed within the council to build and organise stronger opposition.

[6] CO_2 was already transported to local greenhouses and soft drinks manufacturers.

Several additional research tasks were also undertaken over 2009, largely by BCO_2, from technical storage reviews to health impact (including from stress) assessments. The next public meeting in April 2009 attracted a relatively hostile audience of around 1,100 people. Shortly afterwards, the city council voted against the project.

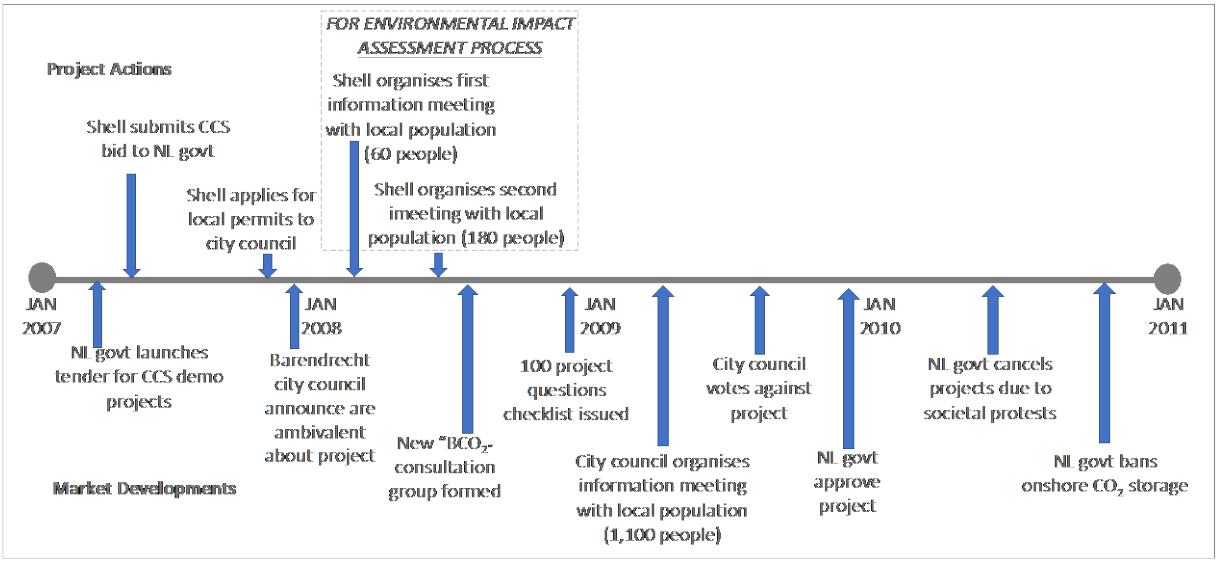


Figure 2. Timeline of Barendrecht CCS project events.

Controversially, and despite the provincial council adding its opposition to the project, the national government chose to overrule both the municipal and provisional governments to initially approve the Barendrecht CCS project in December 2009. The scale of the political fallout and local opposition attracted considerable media interest. Finally, after a fractious period of intense opposition, much of it organised by the "CO_2 is No" campaign, and media focus, the Netherlands national government overturned its approval in November 2010, citing societal protests as the reason for the reversal. To further appease the activists, now opposing CCS in general and not just at Barendrecht, the national government later introduced a temporary moratorium (since lifted) on onshore CO_2 storage.

One form of typical stakeholder map is shown below to summarise the related (and inferred) Barendrecht insights. Only a subset of all stakeholders (the most relevant) is shown. Colour coding indicates levels of support, as probably expected at the launch of the project (shown by subscript^0) and experienced at the end (with a subscript^1).

Figure 3. Indicative stakeholder map for Barendrecht CCS project.

The most striking observation is the change in stakeholders' sentiment towards the CCS project that, almost universally, turned to opposition. While there was no fundamental change in the extent of individual levels of influence, the amplified strength of aggregate opposition had a major impact on its ultimate cancellation. Also notable is that, in general, national (and indeed international) ENGOs remained relatively sanguine on the project. This was an example of genuinely coalesced and strong local community opposition rather than something "orchestrated" by an external body. Finally, although not shown by a stakeholder map, the project developer's ability to effectively manage the relative positions of individual groups was handicapped by its exclusion from the formal consultation body, BCO_2.

Several important observations emerge from the experience of the Barendrecht CCS project:

- There was virtually no socio-political project risk management process, with no analysis of local views and needs and little evidence of active stakeholder management. The project development process seems to have been considered a relatively routine technical and legal task.

- The developers probably over-relied on national and regional political support for CCS as proxies for local sentiment and so did not foresee the opposition and its consequences.

- Exclusion from the formal consultation process (managed by BCO_2) removed the majority of opportunities for the project developer to directly build local trust.

The next two abandoned CCS projects that are examined (White Rose and Peterhead) offer several insights for stakeholder management as they were both ultimately cancelled for the same reason – the withdrawal of funding for the UK government's CCS competition. The extent of public sharing of project information after the cancellations (a condition of government support) allows a more detailed review of socio-political risk management than is usually possible. The contrast in management approaches between the two CCS projects is illustrative in the search for learnings.

1.5.2 White Rose

Name:	White Rose
Project type:	Offshore saline aquifer
Source:	Drax power station
Capture:	Post-combustion at 448MW oxy-fired coal powered turbine
Volume:	2mln tonnes p.a.
Dates:	Oct 2012 to Apr 2016

Capture Projects Ltd (CPL) was formed[7] to partner with National Grid and propose a new CCS project based on capturing CO_2 from a new-build oxy-fired coal generation station at the Drax facility in North Yorkshire in England. It was submitted as a candidate for funding under the UK government's CCS Commercialisation Program (referred to as the CCS competition) in Q4, 2012. CPL was advised, along with Peterhead, it was one of two CCS projects that would be advanced in the CCS competition. As part of that support, funding for the FEED study (for which Genesis was commissioned) was awarded in early 2014. In parallel with the UK CCS competition, White Rose applied for co-funding from the NER300 scheme operated by the EU ETS to support climate technologies from the sale of retained EU emission allowances. At around the same time as the FEED funding award from the UK government, CPL were advised by the EU they would receive €300 million towards project costs, so long as the UK government provided (at least) matching finance.

The UK government Department of Energy and Climate Change (DECC) managed the ongoing detailed negotiations around contractual terms, including power-related Contract for Differences (CfDs). Contractual and commercial sensitivities restricted the degree of collaboration with the Peterhead CCS project team. This helped produce contrasting approaches to stakeholder management. In general, the White Rose risk register was very biased towards technical and legal issues. Only one of the top 50 FEED stage risks identified could be described as socio-political in nature and even that "project protesters causing disruption to project site" (White Rose Project, 2016) was relatively transactional rather than prompting mitigation by means of stakeholder management. That risk did not survive in the listing of the project's top 25 key risks. CPL did, however, express an intention to develop a stakeholder management plan once the project's construction phase began which, unfortunately, did not happen. Still, through the FEED stage of development, White Rose did not display any structured management of its socio-political risks.

Political developments in the UK government's Treasury caused the demise of the White Rose CCS project. To the surprise of both CCS project teams, as well as DECC, the Treasury removed the £1bln ringfenced for the CCS competition in November 2015. The official reason given by the UK government was that CCS technology costs remained prohibitively high without strong evidence of imminent cost efficiencies. Unofficially, several anecdotes at the time suggested the Treasury considered £1bln for an "unloved technology" as an avoidable cost commitment as it searched for reductions in spending.

DECC closed-out the prospects for White Rose CCS project in April 2016 when it explained it could not give planning consent as, without the CCS competition funding and the associated EU NER300 support, there was insufficient confidence in the funding of the project. Some elements of the White Rose CCS project have been retained as part of the Zero Carbon Humber CO_2 infrastructure consortium that is presently bidding for UK government support.

[7] Included three established companies: Alstom, BOC Group and Drax Group

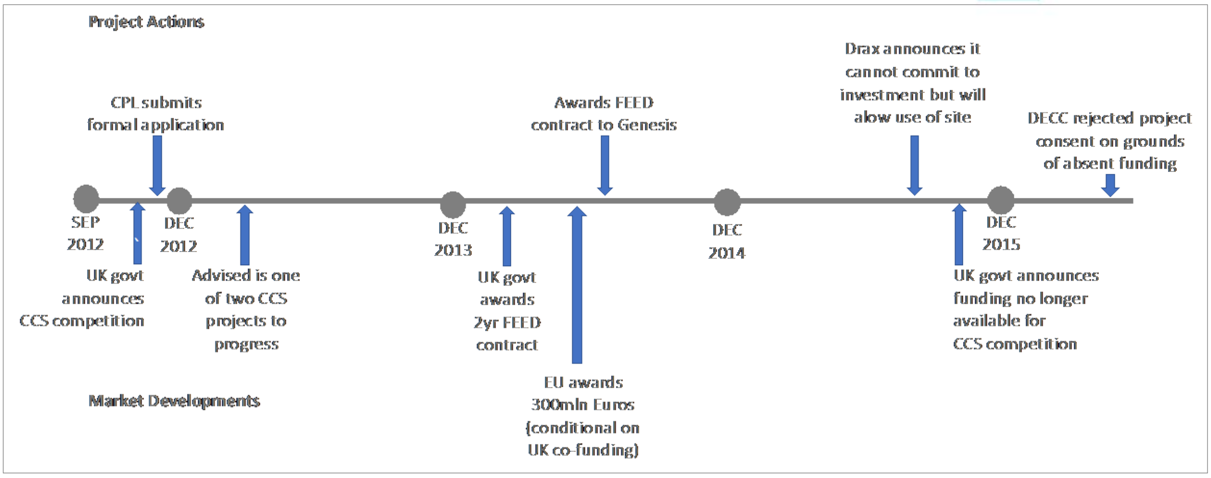


Figure 4. Timeline of White Rose CCS project events

Figure 5. Indicative stakeholder map for White Rose CCS project.

Unlike Barendrecht, there was no indication of any issues of low trust, suspicion, etc. with either the local community or councils. Instead, both the local councils (North Yorkshire County and Selby District) appeared strong supporters of the CCS project, and especially its economic benefits. While the absence of project social analysis makes it impossible to know the real reasons for the local community's neutrality, it could be postulated that the confinement of activities to traditionally industrial locations, as well as the proposed use of offshore CO_2 storage, avoided the "trigger points" shown at Barendrecht. Again, there was no evidence of the ENGO community having any material impact on the project.

The critical role of, and therefore risks associated with, the support of the UK Treasury was overlooked. Ironically, it's very late interest – based only on the scale of budget – was both negative and sufficient to stop the project's progress. Even in retrospect, other than to engage with the Treasury, or push DECC to do so, to emphasise the advantages of the CCS project and so reduce the risk of withdrawal of financing, the ability to mitigate the actual impact of that lost funding looks near impossible.

Several observations related to the White Rose CCS project's experience with socio-political risks emerge:

- No stakeholder management was planned until construction started. While that might have avoided some relatively minor costs, it might also have missed some immature but emerging issues.

- There was a lack of socio-political issues in the project's risk registers. That might have been due to an oversight in turn caused by low consultation during risk identification or not adhering to recognised processes that "force" consideration of these issues.

- Considering the calamitious impact of lack of Treasury support, while managing the consequences (i.e. lost funding) may look impossible, some actions could have been taken to reduce the likelihood of that event occuring. Differentation between unmitigated and mitigated (or residual) risk could have proved helpful for prioritisation and management.

1.5.3 Peterhead

Name:	Peterhead
Storage:	Offshore depleted gas reservoir
Source:	Peterhead power station
Capture:	Post-combustion at 385MW gas powered turbine
Volume:	1mln tonnes p.a.
Dates:	Oct 2012 to Nov 2015

Scottish and Southern Energy (SSE) operate a gas fired power station at Peterhead, a traditional fishing port and, in recent years, oil and gas supply location. Two CCS projects have included the Peterhead power station. The first, abandoned in 2007 due to continued government permit delays, involved BP transporting the CO_2 to the redundant Miller field. The second emerged in 2012 in partnership with Shell, planning to store the CO_2 in another depleted offshore natural gas field around 100km away in the central North Sea, Goldeneye.

As with White Rose, the Peterhead project team were advised in early 2013 that it was one of the two preferred projects under the UK government's CCS competition. In contrast to White Rose, however, Shell had launched a stakeholder management program in Peterhead ahead of government support being confirmed. A relatively sophisticated three-stage consultation process was adopted during 2014 to allow for sufficient feedback loop for issues to be addressed as well as understood. Shell and SSE created a local information centre and, at its peak, had the equivalent of five full-time employees working on community issues, including a CCS public engagement manager seconded part-time from the Global CCS Institute.

Compared to CPL at White Rose, Shell had considerable global experience in building, or at least closely managing the construction of major capital projects for the energy sector. It had (and has) many internal project processes guided by the "Shell Control Framework" for its flagship projects that prioritised risks, the seniority of their management and how they are monitored. Importantly, the framework distinguished "non-technical risks" that helped identify socio-political issues. At the risk identification stage, a relatively expansive consultation followed the TECOP mnemonic[8] to encourage a broad capture of potential risks. Considering the absence of this approach by Shell at Barendrecht, one can only speculate that the low budget and/or perceived routine nature of that project avoided the need to follow the same risk management practices.

The Peterhead CCS project did not apply for co-funding from the EU NER300 fund. Shell and SSE started FEED work in February 2014 and completed that within one year. The risk management process matured throughout this period. The pre-FEED risk register shows that eight of its 50 risks were socio-political in nature. Each issue was appraised on multiple criteria to track it on the project Risk Assessment Matrix (RAM) that assigned its level of supervision. The risk register differentiated pre and post mitigation assessments. Reviewing the final socio-political risks, one can suggest that, although loss of UK Treasury support was not listed, three risks (Scottish independence, interim election results and legislative changes) did imply the same consequential loss of funding.

The announcement of the withdrawal of UK Treasury funding for the CCS competition effectively signalled the end of the Peterhead CCS project. Unlike White Rose, there was no opportunity of an alternative revenue stream from the EU NER300 fund and so, just weeks or months short of taking its Final Investment Decision (FID), the project was cancelled. Peterhead power station remains in operation today, without any plans for CCS, albeit at reduced capacity and in a balancing rather than mid-load generation role.

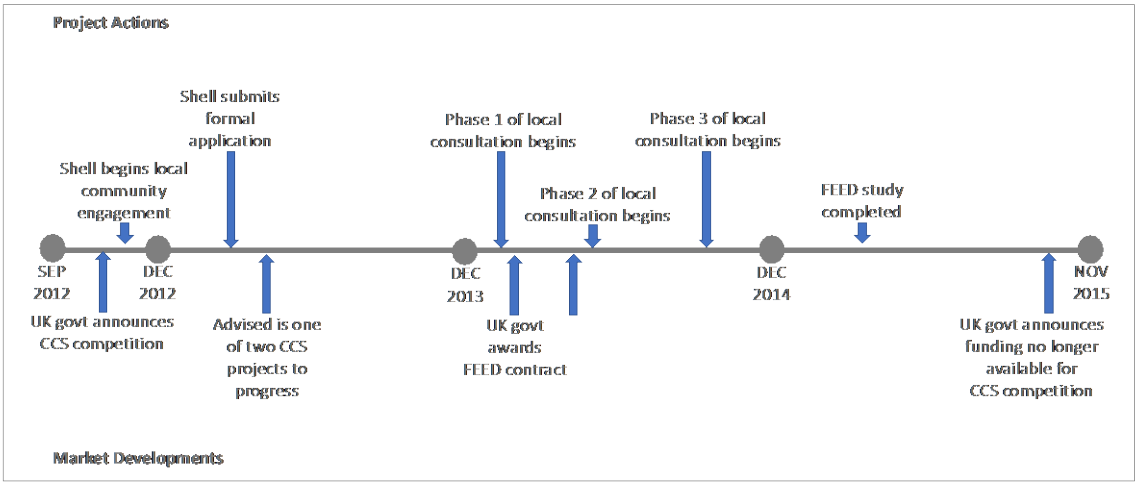


Figure 6. Timeline of Peterhead CCS project events

[8] Covers Technical, Economic, Commercial, Operational and Political forms of risk

Figure 7. Indicative stakeholder map for Peterhead CCS project

The indicative stakeholder map for Peterhead is, naturally, very similar to that for White Rose. The only differences are the absence of the EU as a stakeholder and the strength of (the earned) support, rather than indifference, of the local community. The extent of engagement by Shell embedded local support but did not insulate it from the impact of the overall CCS competition being cancelled.

Given the same ultimate demise, contrasting the intensive attention to socio-political risk management by the Peterhead team with the relative absence of work by White Rose raises an interesting, albeit hypothetical, question about which approach was best. While the planned later start of stakeholder work at White Rose avoided Peterhead's pre-FID costs, in terms of the overall budget[9], that is a minor saving. Perhaps Shell's practices would have proven a better investment in building a more solid base of support, but White Rose could have made the same progress with an approach that only absorbed resources from the construction phase. The issue remains speculative.

Looking for socio-political risk management learnings for this report, the following observations arise:

- The high quality of management arose mainly from Shell's own governance requirements that reflected its experience in managing major capital projects.
- Another possible explanation for the maximum effort applied by Shell is the sensitivity to how poorly it managed the same risks in the Barendrecht project, just two years earlier.
- The three-stage consultation process maximised the scope for feedback loops to satisfy stakeholder grievances or suggestions.

[9] Stakeholder engagement work was estimated as accounting for 0.6% of the overall Zerogen CCS project budget (p66, "Zerogen IGCC with CCS, A Case Study", State of Queensland, 2014)

- While its output was impressive, the extent of effort considerably exceeded any regulatory needs and, given the outcome, produced no benefits compared to White Rose who did very little.

- Sharing project learnings was a condition of participation in the CCS competition. The Shell literature includes many accessible examples of best practice systems, processes and documentation for future CCS projects.

1.6 Review of leading practices in CCS projects' management of socio-political risks

1.6.1 Zerogen

Name:	ZeroGen
Storage:	Onshore aquifer
Source:	Central Queensland power station
Capture:	Pre-combustion at 400MW IGCC coal powered turbine
Volume:	2mln tonnes p.a.
Dates:	Mar 2007 to Dec 2010

The Australian state of Queensland is rich in black coal resources. The mission of the Zerogen CCS project was to …"accelerate the development and deployment of low emissions coal technology at a cost to preserve Queensland's competitive advantage in power generation with black coal" (Ashworth, Rodriguez, et al., 2011)(Ashworth, Rodriguez, et al., 2011). It was a CCS development for a new Integrated Gasification Combined Cycle (IGCC) coal-powered generation station. The genesis of the concept can be traced to early 2006. Its prospects, and associated work, accelerated with the December 2009 inclusion of Zerogen in the Australian government's shortlist of four flagship CCS projects.

After initial consideration of a phased (pilot then demonstration scale) development, the addition of Mitsibushi Heavy Industries (MHI) to the partnership in 2007 led to the final concept, based around a (net) 440MW IGCC one-stage demonstration plant design, being agreed in June 2008. Shell provided much of the expertise on subsurface, CCS integration and general project management issues. Suitable aquifers were eventually identified for CO_2 storage around 270km away in the Surat basin.

The quality and extent of CCS related stakeholder management and community engagement in Zerogen is often cited as best practice. Work with local communities started in 2006 and lasted through to the project's cancellation at the close of 2010. Stakeholder management was regarded as a fundamental project activity rather than a discrete deliverable. The depth (as well as dynamic nature) of the research supported the development of the Zerogen Stakeholder Analysis and Communications Plan that evolved as a "living document", continually adapted to reflect the needs of both the CCS project and locals as well as to be a reliable focus of communication with community groups.

The success of the socio-political work in producing a living document maximised its practical value in appeasing, or retaining the satisfaction of, stakeholders. Rather than simply report findings, it provided detailed (and workable) insights into the underlying reasons for those observations. Similarly, the work periodically summarised the main "pitfalls" that most deserved reactions. Again, those were described in workable forms such as, for example, deteriorating relations with landowners or frequent reports of a lack of awareness of project developers. Such diagnoses helped the feedback work stages.

The final review of Zerogen, organised by Queensland in 2014 (Garnett et al., 2014), highlighted many technical and commercial learnings. The majority revealed the many problems, mostly reflecting the first-of-a-kind nature of a power-based CCS plant and the many issues in identifying a suitable CO_2 storage site. Almost exceptionally, however, the quality of stakeholder and engagement work was praised.

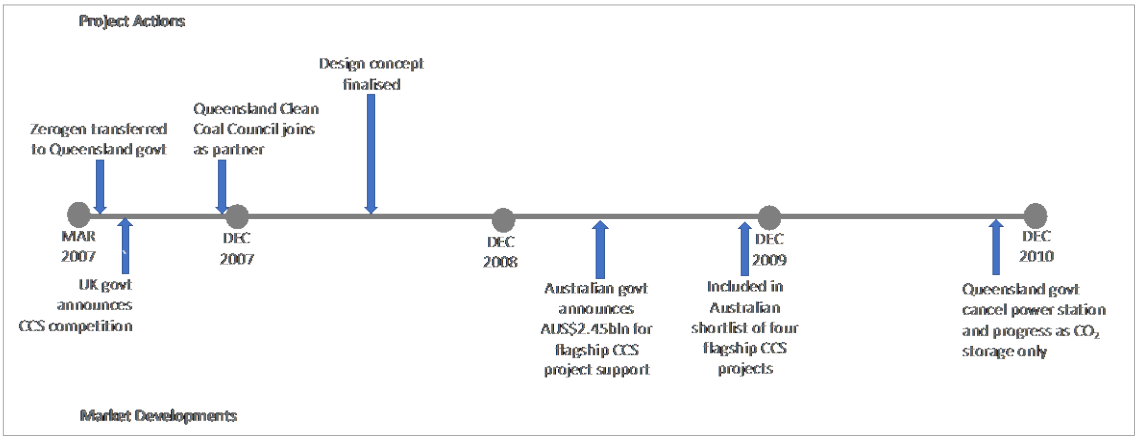


Figure 8. Timeline of Zerogen CCS project events

Figure 9. Indicative stakeholder map for Zerogen CCS project

Compared to the preceding projects' stakeholder maps, that for Zerogen is relatively uneventful. It basically reinforces the success of its management work. Looking at the graphical representation, and as with Peterhead's work, the extensive (maybe even excessive?) work on socio-political issues effectively made "green stakeholders even greener" rather than necessarily shifted their positions. The possible help from that achievement will never be known as the CCS project was cancelled ahead of construction and so the value of understanding the socio-political risks, with impacts for which the stakeholder management actions mitigated, was unproven.

The key socio-political observations related to Zerogen's approaches are:

- From the beginning of its work, stakeholder management was treated as a project process and not a one-off deliverable. Besides helping establish its credibility, this allowed planning and communication of a dynamic activity with ongoing monitoring and feedback loops.

- Effective feedback work was helped by the highly-operational nature of how key socio-political risks were identified and monitored throughout the period of the project. That needs ongoing engagement with operational staff to correctly describe and diagnose underlying issues.

- Probably reflecting the extent of government support and engagement, the depth of post-event academic and industrial reviews and searches for learnings has been impressive. The quality, as well as the open accessibility of its output, maximises its knowledge management value.

1.6.2 Tomakomai

Name:	Tomakomai
Storage:	Offshore aquifer
Source:	Hokkaido refinery
Capture:	Pre-combustion at hydrogen manufacturing unit
Volume:	0.1mln tonnes p.a.
Dates:	Oct 2011 to Dec 2019

Under the supervision of the Ministry of Economics, Trade and Industry (METI), the Japanese government reviewed 115 potential locations for a national CCS demonstration project between 2008 and 2011. The Tomokomai application was informed it had been selected in mid-2011. Its concept was based on transporting CO_2 captured from the hydrogen manufacturing unit at Idemitsu Kosan's Hokkaido refinery to near (4km) shore aquifers under the Tomokomai bay. The CCS-35 consortium had been formed to promote, and then build, the Tomokomai CCS project. Its name reflected the 35 local businesses, including the local industrial and fishery associations, that joined with the municipal government to develop the project. CCS-35 had existed since early 2010. Chaired by the local mayor, its original mission of CCS-35 was to secure METI support for the Tomokomai CCS project and to inform citizens, both locally and across Japan, on the needs and benefits of CCS.

Partly reflecting the CCS-35 mission statement, stakeholder management, especially public engagement and education, had a core role in the project's work from the beginning. Another, perhaps more important reason, for focusing on socio-political issues was the timing of METI's confirmation of Tomakomai's selection, coming just a few months after the Fukishima earthquake and nuclear incident. That merited additional effort to assure the public of the safety of CO_2 storage and especially its resilience to, and research that it does not cause, earthquakes. The initial social analysis that characterises professional stakeholder management was important in identifying specific sensitivities and important audiences. Earthquake risks and impacts on local fisheries emerged as focus interests and young people were most eager (and in need of) education on the case for CCS as well as its component processes.

Similar to Zerogen's work, the Tomakomai CCS project managed stakeholder engagement as a fundamental process that started before, and continued throughout, its operational period. CCS-35 emphasised the interactive nature of its work and the critically important feedback loops. Realising, for example, the sensitivity to earthquake risks and fishery impacts, the project shared baseline measure for both issues, then tracked and reported these over the period of CCS operations. Likewise, several TV documentaries on CCS were broadcast to reach younger audiences across Japan and live, publicly accessible, video streams were relayed from the CO_2 compression and injection construction sites.

Ironically, a major earthquake did occur, around 30km from the CO_2 storage location, in September 2018 during the CO_2 injection period. Guided by the risk register, the project team took prompt action to assure local communities. The standard earthquake monitoring data set was shared almost immediately to underwrite the resilience of operations, in terms of both the immediate suspension of injection and security of residual CO_2 storage. Just a few weeks later, a meeting of independent experts to review the data and actions was organised to further assure the public and interest groups of the ongoing safety of the CCS demonstration project.

Figure 9. Indicative stakeholder map for Tomakomai CCS project

The Tomakomai CCS project came to a successful culmination in December 2019 when METI announced the original target of 0.3 million tonnes of CO_2 storage had been achieved and injection activities would therefore end. Monitoring work will continue.

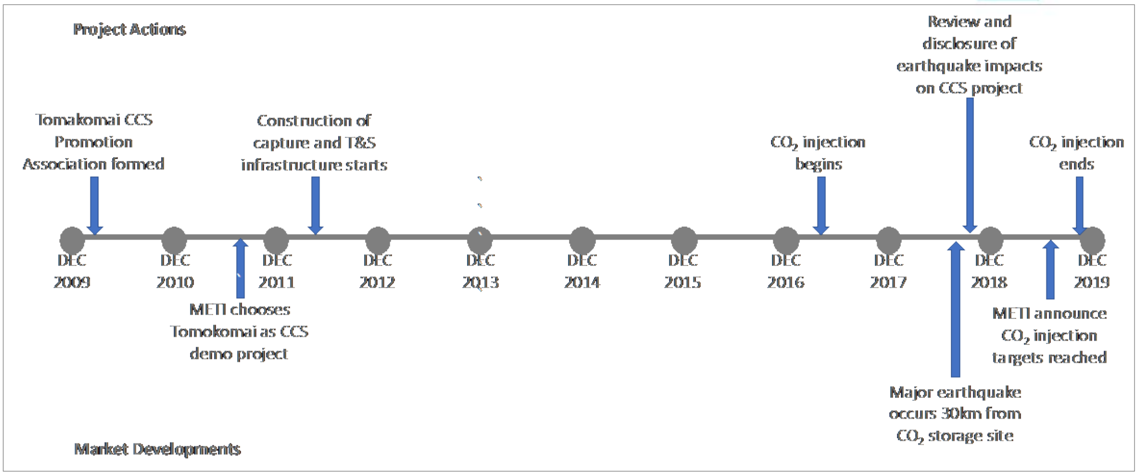


Figure 10. Timeline of Tomakomai CCS project events

As with Zerogen, the Tomakomai stakeholder map appears basic, static and uneventful. Nevertheless, as with Maslovian and Herzberg hygiene factors, however, general stakeholder satisfaction is conducive to stability and preferable to the loss of support if issues emerge. Especially for Tomakomai, where comprehensive stakeholder management helped steer the project through one of the major risks (an earthquake) actually occurring, the lack of any disruption to operations or stakeholder support was an achievement.

Several observations arise from the Tomakomai stakeholder management experience:

- The importance of stakeholder management was recognised, and codified into the mission statement, from the beginning of the project. Its relevance and priority was never questioned.

- It was important that the ongoing stakeholder analysis and monitoring was described in an operational manner that helped identify resolution options in the process feedback loops.

- The extent and breadth of CCS-35, effectively the project's steering committee, helped internalise the interests of many stakeholders. That contributed to the sense of trust in the CCS plans and so helped minimise many socio-political risks.

- As with any effective risk management process, as well as risk identification, the socio-political risk analysis developed provisional recovery options if the focus event did occur. That helped the speed and success of how Tomakomai managed the earthquake incident.

1.7 General Insights for Subsequent CCS Project Plans

This section offers some general observations and implications, related to socio-political risk management in CCS projects, that arise from the preceding case studies review. These are contextual rather than applied in nature and support the more functional guidance in Section 6 that deals with actual recommendations.

1.7.1 Trends in management

Unsurprisingly, the quality of stakeholder management evident in CCS projects has expanded and improved over the last decade as the number of global operational facilities grew from eight in 2010 to 30 in 2022. As Barendrecht showed, CCS developments were sometimes viewed as technical, and sometimes legal, processes for which permits rather than socio-political support (or at least ambivalence) were the defining signals of success. Poor experiences challenged that working assumption. Likewise, as more companies (especially from oil and gas) with major capital project experience planned CCS installations, so their own internal project development practices – that included structured stakeholder management – helped raise standards. That influence of major project processes is particularly evident in the contrasting approaches to socio-political risk management in the White Rose (by CPL) and Peterhead (by Shell) projects.

Several governments have emphasised maximised knowledge management as a condition of their support for CCS projects. The UK and Canada in particular have thus encouraged its project partners to publish details of its key project development processes, including stakeholder management, and key learnings. That, along with the intensified academic interest that comes from more CCS activity, has created a valuable catalogue of accessible advice and working tools to manage socio-political risks.

1.7.2 Scope of management

The case studies suggest most stakeholder concerns arise from the safe storage of CO_2 rather than its capture at the source industrial plant. That might reflect trust with the CO_2 capture process or, more likely, the relative invisibility of that stage of CCS activities. Either way, for the REALISE project, that implies refinery-based CCS projects are no less, and no more, likely to incur socio-political risks than other industrial CCS facilities. The post-capture CO_2 infrastructure appears to elicit the majority of community concerns. This could prove important for refineries considering CCS designs that use third-party CO_2 transport and storage services, such as with many hub and cluster concepts. The success of the CCS plans could rely extensively on the stakeholder management abilities of the infrastructure operator. Even if not involved directly in that element of risk monitoring, it is important to ensure an adequate level of attention.

A notable feature of the case studies is that, when major stakeholder issues emerge, and excluding the example of withdrawal of funding support for White Rose and Peterhead, is that these are commonly from local communities rather than national forces such as, for example, when orchestrated by ENGOs. The ENGOs have, until now, been relatively benign towards CCS projects. That could, however, change in future. Referring back to the triangle of acceptance (see p5), if the bias of stakeholder concerns moves from community acceptance to more general socio-political acceptance, that could attract more ENGO-led opposition and even ENGO orchestrated community resistance. The continued and increasing association of CCS with fossil fuels by some activists could make that scenario more likely, a trend that could raise particular issues for refinery-based CCS projects.

1.7.3 Intensity of management

White Rose and Barendrecht show examples where minimum stakeholder management was planned or undertaken. The three other case studies showed where efforts were more extensive. Given the very low proportionate cost of this element of risk management (maybe less than 1%; see (Ashworth, Rodriguez, et al., 2011) it could prove false economy to reduce work based on costs alone. That does not necessarily mean aspiring to the standards of Zerogen or Tomakomai but it does imply taking a methodical approach and, as a minimum, undertaking the initial social analysis stage. Done professionally, that could indicate the importance and/or urgency of active mitigation work. The best examples involve the engagement work commencing at, or even preceding, the start of standard CCS project development work.

The next choice for CCS project managers is how to consider socio-political risk management, as either a distinct deliverable or as a fundamental development process. Peterhead tended to approach it as a task while Zerogen and Tomakomai viewed it as a process. Rather than simply make a binary choice between task or process, perhaps the best advice is to treat socio-political issues with the same respect as other more conventional technical and operational CCS project risks.

Finally, the growing range and richness of templates and checklists available to guide stakeholder management in CCS projects should be treated appropriately. That means using these for exhaustiveness to prompt best practices in both individual risk and collective process management and not as a means to reduce efforts and short-circuit the need for diligent reviews, actions and monitoring work. As Tomakomai exemplified, the more applied the risk identification work, the easier it should be to develop mitigation efforts. Achieving that level of operational pragmatism needs and deserves focused risk analysis while, on occasion, over-reliance on check-lists can encourage simple (and dangerous) mechanical assessments.

1.7.4 Scrutiny of management

Besides the uninterrupted delivery of the underlying project, successful stakeholder management is sometimes judged by the relatively absent, or at least passive, role of the media. An additional external source of assessment of how stakeholders' interests are managed has emerged and strengthened in recent years; the Environmental, Social and Governance (ESG) investor community. The ESG sector is a strengthening source of guidance to a similarly expanding number of ethical investors. Weak attention to socio-political risks at either corporate or project levels, especially of an environmental nature, can result in poor ESG ratings. That, in turn could restrict access to, or at least the cost of, private project finance. Conversely, strong ESG performance and ratings could help project sponsors' prospects of being included in the growing number of green, socially responsible and ethical investment funds.

Consideration of ESG interests will be most important for the largest organisations and most high profile projects, especially those with an environmental impact, such as new CCS facilities. If the expected continued growth in ESG influence does emerge, for the best proponents of stakeholder management, that could help bring new upsides, in the cost and availability of more attractive private project finance. For CCS project developers with such needs, that could be a stronger incentive than merely achieving a neutral media assessment.

1.8 Recommendations

For ease of reference, the applied learnings on socio-political risk management are presented below as a list. As much as possible, these are shown chronologically rather than necessarily in order of importance. This list will be amended and strengthened after the planned workshop.

1. Treat socio-political issues as would other risk elements: Full integration with prevailing systems to manage operational and commercial risks could be the simplest way to encourage thoroughness. That could help address the choice of "process vs. deliverable" as stakeholder management would follow common practices. Leading practice risk management systems will use some form of rating and subsequent Risk Assessment Matrix (RAM)[10] to allocate accountability for prioritising and managing individual socio-political risks.

2. If proven, use internal risk processes or those of main contractors: Similar to the previous point, adoption of stakeholder management will be helped when it is based on familiar existing company systems and processes. Again, integration and normalisation of socio-political risk management is the objective. If the organisation commissioning the CCS owner is inexperienced in major capital projects, it can instead consider using the risk management processes of the main Engineering, Procurement and Construction (EPC) contractor.

3. Review best practices and use associated templates: It is becoming easier, because of both project numbers and open-sharing, to access key learnings from preceding CCS project developments. Stakeholder management is a separate component of those reviews. Several CCS organisations and previous best practice reports exist to facilitate valuable reviews and suggest replicable check-lists and templates. This report could be useful in that respect.

4. Communicate importance of stakeholder management, externally and internally: Emphasising the role of managing socio-political risks signals its importance to both internal teams, managing the process, and external stakeholders, with whom a productive dialogue is needed. Integration with prevailing corporate processes reinforce the same message internally. More orthodox forms of communication might be merited to reach and assure external stakeholders.

5. Follow a circular process of "analyse – diagnose – feedback – monitor": The best risk management processes are based on iterative cycles; the same can be done for socio-political issues. Approaching the task in this way encourages more pragmatism in describing and actioning risks from its beginning. It also tends to help consider stakeholder management as on ongoing project process and not a one-off, more static report.

6. Always plan social analysis at or before the project start: Regardless of whether stakeholder management is approached as a process or deliverable, the value of a robust baseline analysis of the project's key groups and socio-political issues is indisputable. That focused investigation could avert potentially disruptive blindsides.

[10] See Appendix 8.1 for a graphical example of a typical project RAM system

Also, more practically, it enhances the quality of monitoring work to detect and diagnose changes during the project's development phases.

7. Engage broadly during risk identification stage: Some leading examples of socio-political risk management have emerged from challenging corporate norms and beliefs at the earliest stages. In turn, that has been helped by actively including diverse interests to identify risks. Besides the final CCS operator, standard identification workshops and processes could extend to contractors, local authorities, previous CCS project developers, CCS organisations and academic experts. For a relatively small investment in diversity, unexpected insights (that can still be later discarded if not validated) could prove valuable in the ongoing stakeholder management process.

8. Consider internalising key stakeholders: At least for the identified most critical external bodies, or people, including them in some form of supervisory board – with a genuine opportunity to influence the project's direction, if not choices – could help build stronger working relationships.

9. Describe pre-mitigation and residual risk status: Reflecting the best practice "bow tie" general risk management model that addresses both pre-event mitigation and post-event recovery, taking time to describe (and quantify) residual risks enhances the speed and effectiveness of recovery if the underlying event does occur. Describing residual risks also promotes a deeper, more practical understanding of issues.

10. Formulate mitigation options in an operationally-friendly form: The main purpose of this is to ease the possible conversion to action and so make feedback loops more effective. Witnessing their concerns being addressed is the best route to building stakeholder trust and support. Another benefit is that producing an actionable mitigation narrative encourages internal consultation with operational teams and so a more robust outcome.

11. Identify and contribute to contiguous socio-political risk management: The trend towards fragmentation of the CCS supply chain and emergence of separate, but interdependent, operators of CO_2 capture and CO_2 infrastructure could lead to the neglect of some cross-chain socio-political risks. A refinery CCS project could, for example, be threatened by stakeholder concerns with its CO_2 storage issues, that are managed by a separate hub and cluster operator. While professional stakeholder management should encourage inclusivity (see 7 above), CCS developers should actively promote a more fully integrated supply-chain approach to socio-political risk management.

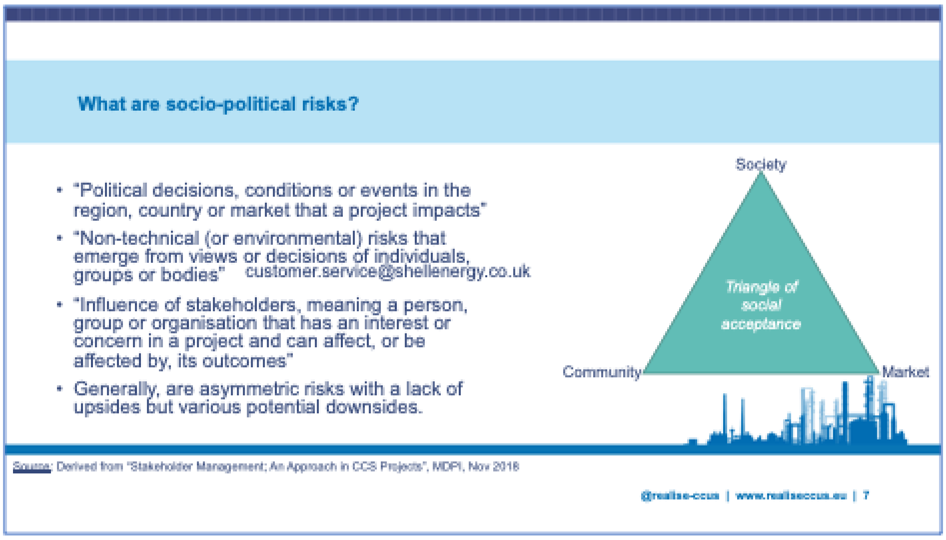
12. Consider sharing practices and findings with ESG community: As discussed at Section 5.4 above, new and strengthening sources of scrutiny of stakeholder management could come from the ESG sector. Evidence of best practices and/or achieving breakthrough solutions with stakeholders could be powerful testimonies for ESG investors. Proof of project actions to substantiate ESG-related targets is always sought by ESG advisors. Their inclusion in, for example, the narrative of a project sponsor's Sustainability Report is a valuable validation of an organisation's strategy.

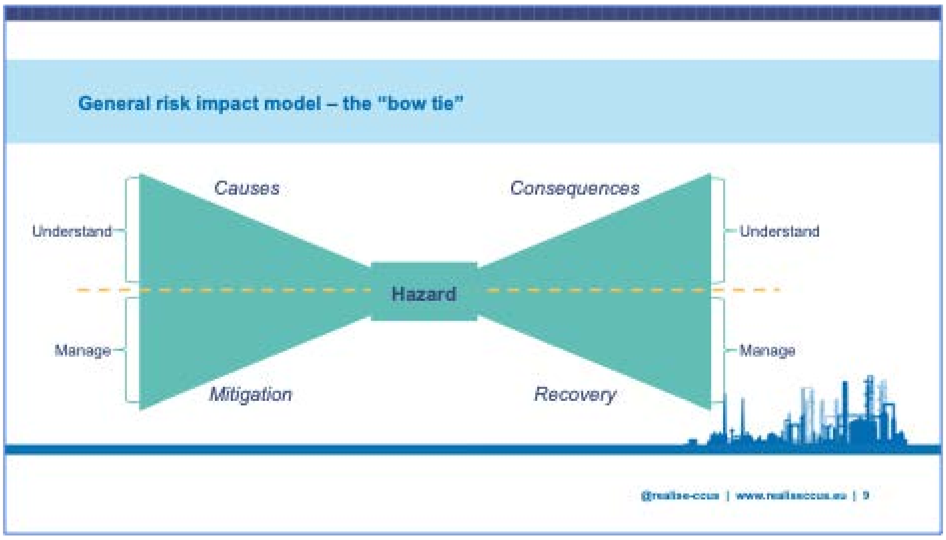
1.9 Workshop based peer review process

A joint face-to-face meeting of REALISE project partners in Cagliari, Sardinia in mid-October 2022 was used to test the main conclusions and results of the preceding report. Over a three-hour session, using a combination of in-person and online media, the main findings were summarised to an audience of around twenty project partners and industry club members as well as invited experts[11]. Later discussions were also arranged with additional subject matter experts to further test the workshop discussion. A selection of checklists and templates to help future CCS project partners manage socio-political risks were shared and tested at the workshop and in subsequent expert meetings. Feedback from the audience was actively encouraged and incorporated. This section summarises the workshop process and outcomes.

1.9.1 Workshop material

The opening part of the workshop was used to explain the general concept of socio-political project risks. This helped participants reach a common level of understanding. Following this, the application of socio-political risk management in CCS projects was explained and the empirical evidence from CCS projects' experiences reviewed in this report was examined. A PowerPoint pack was used to illustrate the key points. An example of the most helpful and impactful slides is shown underneath.





[11] The additional experts reflected a range of industries activities, including investment banks, public sector bodies, leading EPC contractors for CCS projects and major integrated primary energy producers.

Summary of CCS projects' SP risks and opportunities (from April 2021 report)

	Observation	Effect	Mitigation
Zerogen	Treated SP risk mgt as process not deliverable	Supports ongoing professional attention and management	• Use existing risk mgt process
	Open sharing of post-project learnings	Encourages use of insights	• Post investment review • Transparency (internal, external)
Barendrecht	No structured SP risk process	Likely to cause inadequate attention and/or management	• Use existing risk mgt process
	Mis-read local support	Likely to miss sensing of emerging issues	• Stakeholder mapping • Use existing risk mgt process
	Exclusion from community consultation	Missed opportunity to inform and/or manage stakeholders	
Tomakomai	SP focus embedded in mission statement	Supports ongoing professional attention and management	• Communicate and reinforce importance of process
	Stakeholders involved in steering committee	Encourages early sensing of emerging issues	• Stakeholder mapping • "Internalise" critical stakeholders

Summary of CCS projects' SP risks and opportunities (from April 2021 report), cont'd

	Observation	Effect	Mitigation
White Rose	SP mgt only started at construction stage	Risks inadequate understanding and/or attention	• Start early • Use existing risk mgt process
	Lack of SP issues on project risk register	Risks inadequate attention and/or management	• Use existing risk mgt process
	No quantification of "residual" SP risks	More difficult to prioritise issues	• Robust quantification process
Peterhead	SP mgt guided by internal project processes	Raises general standards	• Use existing risk mgt process
	Maximised SP risk mgt feedback loops	Encourages active mitigation	• "Analyse– Diagnose – Feedback – Monitor"
	Considerable SP effort for low "relative" benefit?	Risks disproportionate use of resources	• Robust quantification process • Calibrate to other risks

Key SP-related findings

Insights

- Strengthening ESG function has increased scrutiny of SP issues
- Quality of CCS projects' SP risk management continually improves
- Storage rather than capture projects attract most SP-related scrutiny
- Most SP issues arise from local rather than national sources
- Best practice treats SP risk management as ongoing process rather than deliverable
- SP risk mgt is relatively inexpensive

Learnings

1. Treat SP risks like other project risks
2. Use existing internal risk management processes
3. Review best practices and templates
4. Communicate importance of SP mgt
5. "Analyse – Diagnose- Feedback – Monitor"
6. Plan SP analysis at start of project
7. Engage broadly at SP risk identification stage

8. Consider internalising key stakeholders
9. Describe mitigation and recovery issues
7. Operationalise mitigation options
8. Support contigious SP risk management
9. Share SP practices and findings with ESG teams

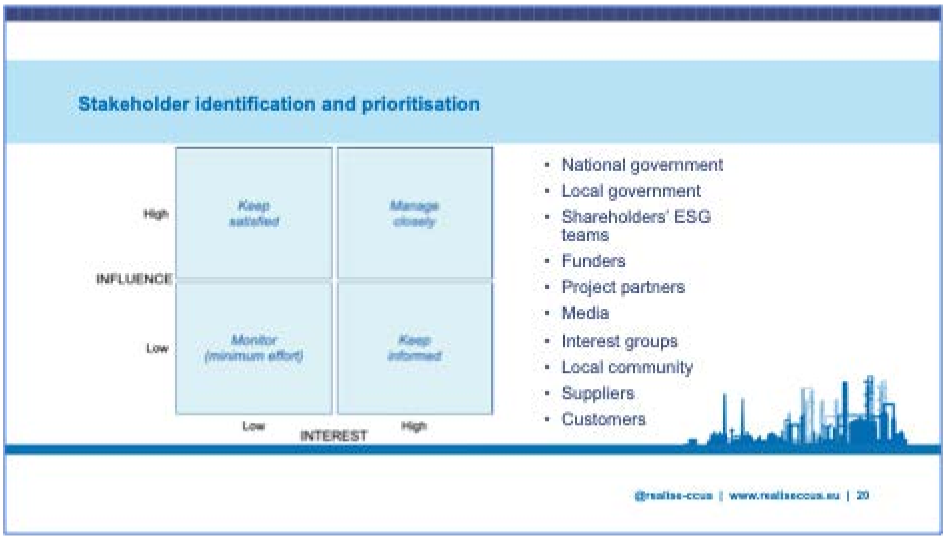
1.9.2 Workshop review outcome

An active and productive discussion followed the summary of socio-political risk management in general and the experience of CCS projects in particular. Reference to companies' stakeholder management actions, successful and otherwise, in all forms of major capital project development was valuable in exemplifying best (and bad) practices[12]. Amongst the most significant points raised in plenary were;

- There is considerable scope to improve the integration of socio-political issues with other, more conventional hazards in project risk registers. Stakeholder management is often managed separately.
- Associated with the previous observation, technical staff should be routinely included in ongoing discussions of stakeholder risks for both identification and management purposes.
- An acknowledgement that, to be effective, stakeholder analysis has to begin as early as practical. It needs to evolve as project information and data improves rather than be suspended until "all the answers are known".
- Relative to other forms of energy projects, CCS remains a new concept for many people. That can especially increase the sensitivity of local communities. Project developers need to be more transparent, patient and overall "educational" in their communication to allay natural suspicion of novel energy technologies.
- Relationship managers must show true sincerity in their approach to stakeholders to earn critical trust levels. Best practice should avoid old-fashioned, sometimes manipulative, "PR management". Using the term stakeholder engagement, rather than management, would help emphasise the need for feedback loops.
- The needs and expectations of socio-political risk mitigation work must be shared broadly to ensure all staff – as well as contractors – remain aligned.
- Disgruntled staff or contractors can be a key source of stakeholder risk and so deserve active inclusion in management programs.
- Although very simple, the "bow-tie process" should be closely followed to ensure more comprehensive consideration of stakeholder management risks.

Three examples of checklists and templates to support future management of CCS projects' socio-political risks were shown and discussed. The audience were invited to comment on the value of this material and offer their suggestions for improvement. These slides are replicated underneath.

[12] One example that proved particularly valuable, and repeatedly used, was the stakeholder management approach of Shell during the development of the Corrib gas processing facility in Northwest Ireland during 2005-2010.


Stakeholder identification and prioritisation
High
INFLUENCE
Low
Keep satisfied
Manage closely
Monitor (minimum effort)
Keep informed
Low
INTEREST
High
National government
Local government
Shareholders' ESG teams
Funders
Project partners
Media
Interest groups
Local community
Suppliers
Customers
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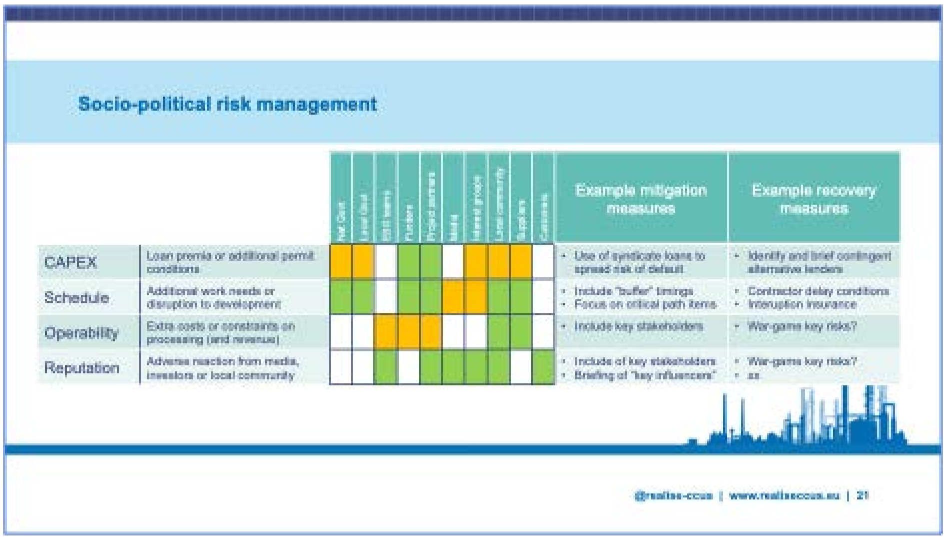
Socio-political risk management
Example mitigation measures
Example recovery measures
CAPEX
Loan premia or additional permit conditions
Use of syndicate loans to spread risk of default
Identify and brief contingent alternative lenders
Schedule
Additional work needs or disruption to development
Include "buffer" timings
Focus on critical path items
Contractor delay conditions
Interuption insurance
Operability
Extra costs or constraints on processing (and revenue)
Include key stakeholders
War-game key risks?
Reputation
Adverse reaction from media, investors or local community
Include of key stakeholders
Briefing of "key influencers"
War-game key risks?
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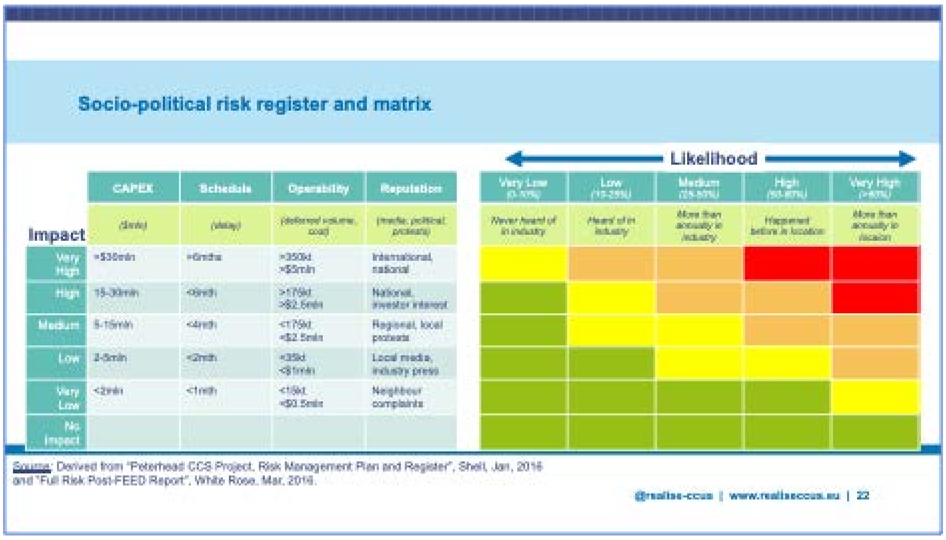
Socio-political risk register and matrix
Likelihood
Impact
CAPEX
Schedule
Operability
Reputation
Very Low
Low
Medium
High
Very High
Never heard of in industry
Heard of in industry
Happened before in location
Very High
High
Medium
Low
Very Low
No Impact
International, national
National, investor interest
Regional, local protests
Local media, industry press
Neighbour complaints
Source: Derived from "Peterhead CCS Project, Risk Management Plan and Register", Shell, Jan, 2016 and "Full Risk Post-FEED Report", White Rose, Mar, 2016.
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The rich discussion that followed included the following observations;

- It is best to offer a limited and small number of suggested tools, such as those shown above, rather than overwhelm project managers. There were no notable omissions from the short-listed three templates that were discussed.
- One organisation has adapted its stakeholder mapping tool to include "networking capacity" that acknowledges individuals' relative ability to mobilise others (e.g., via social media) that could intensify their impact on socio-political risks.
- It is imperative that the impact and likelihood criteria used in the risk assessment matrix (the last slide above) are adapted to reflect actual CCS project characteristics. That helps both the ownership and accuracy of risk mapping.
- Associated with the previous point, there was a view that there still is as much value in the structural methodology encouraged by the templates as in the precision of specific risk ranking criteria.
- The three templates should be periodically reviewed as well as used in a consistent and complementary manner to get their full value.

1.9.3 Options for further work

Based on the Cagliari workshop and the subsequent expert discussions, there appears to be scope to continue to explore the practices of socio-political risk management in CCS projects. There is an appetite, if not indeed a need, for additional research on;

- Testing the emerging hypothesis that most CCS-related socio-political risks arise from infrastructure and storage rather than capture activities and tend to mainly emanate from local community reactions.
- Identifying practical means to improve projects' general project risk management practices and processes to assure adequate integration and assimilation of socio-political issues.

2 Review of policy and regulatory frameworks

2.1 Summary

As part of the REALISE project, the purpose of this section is to review applicable policy and regulation currently in place across the CCS value chain.

Several key messages can be taken away from the review of policy and legislation in this section for consideration for future CCS project developers and Governments.

- The successful deployment of CCS at refineries is contingent upon the presence of enabling policies that are designed to overcome broader CCS market failures. These market failures are not specific to CCS within any particular industry or sector, including refineries, so it follows that enabling policies will support refineries by default. Importantly, however, policies must place a sufficient value on CO_2 captured to ensure there is a business case for investing in CCS at refineries.

- Law and regulation similarly plays a crucial role in supporting the deployment of CCS projects. The development of CCS-specific legal and regulatory frameworks, as well as the removal of legal barriers to the technology, will be critical to ensuring more widespread deployment. CCS-specific regulatory frameworks will enable the development of CCS applications across a wider variety of technologies and locations, including projects linked to refineries.

- CCS market failures, as well as broader barriers to investment, translate to a set of hard to reduce investment risks. If these risks are not properly managed and allocated to the parties best suited to bear them, there will not be investments in CCS at refineries. This section identifies these hard to reduce risks as follows:

    - **Revenue risk**

      A revenue risk exists because of an insufficient value placed on CO_2 captured by a CCS facility. It is up to government to place a sufficient value on CO_2 through a robust policy instrument. This report has identified several ways in which policies have addressed this risk.

    - **Cross chain risk**

      CCS projects that have a single source connected to a single storage facility pose an important risk to investors because the unavailability of either component can cripple the entire value chain. This can lead to significant loss of revenue, making investment in such projects high-risk. The report identifies how this can be overcome if governments provide a robust policy response to support investments in shared transportation and storage networks.

      Long term storage liability risk

      While the risk of leakage during the operation or post-closure phase of a CCS facility is diminishingly small, it is not zero. Although a private investor may manage this risk while a CCS facility is operating, it will be impossible for businesses to bear this risk for an indefinite period beyond post-closure. The report examines the legal and regulatory measures that have been implemented to manage the long-term storage liability risk around the world and government should take steps to assist project owners manage long term liability risk. This may include the transfer of some types of liability to government subject to limitations and meeting performance requirements.

- Policies to incentivise CCS investments have been found to be wide-ranging, but they each achieve the same goal of addressing CCS market failures. i.e., placing a sufficient value on CO_2, reducing the interdependency risk that arises across the CCS value chain, and managing long term liability associated with the geological storage of CO_2.

- We found that few countries' legal and policy frameworks are sufficiently robust to fully support CCS deployment at a commercial scale. Amongst the jurisdictions reviewed, the UK, Denmark and Croatia represent the most advanced frameworks, signalling strong and conducive regulatory environments for projects, as evidenced by the projects in development in some of these countries.

- While each has differing mechanisms to place a value on CO_2, the UK and the Netherlands have both embraced the hub and cluster model, whereby CCS is being incentivised at the level of industrial hubs and clusters. This is particularly important as hubs and clusters not only reduce costs but also substantially reduce investment risks.

- Other countries in the EU have not made significant strides beyond what is already being provided by EU-level policies. Notably, the successful deployment of CCS in these countries relies mostly upon the EU CCS Directive and the EU ETS to manage CO_2 storage and to place a sufficient value on CO_2 respectively.

- While these can be effective policies for some applications of CCS, they are not industry specific, and crucially, they do not enable CCS investments at refineries without additional policies that must be developed at the local level.

- Similarly, the legal and regulatory frameworks of the majority of the EU states, currently only incorporates the EU CCS Directive's framework for regulating CO_2 storage at a broad and high level. Beyond this, most EU countries have not added further detail or have left discrete aspects of CCS projects unaddressed. This is further exacerbated by the national restrictions on CO_2 storage within legislation in several EU countries. The EU thus lags behind countries such as the UK in providing the regulatory certainty and clarity that project operators have often cited as necessary to boost investor confidence and incentivise deployment.

- For China and South Korea, CCS policies are still in their early stages of development and significant work to create an enabling environment for CCS investments remains. These countries are still at the stage of developing their policy framework for managing CCS market failures, specifically to enable investments from the private sector.

- In the absence of CCS-specific legal and regulatory frameworks in both China and South Korea, the development of such legislation is imperative. Both countries may draw from the experience of other jurisdictions worldwide that have developed advanced regulatory models, as well as understand how legislation in these countries may have enabled or inadvertently blocked projects. A complex and lengthy process, which will require the input of a diverse range of stakeholders, urgency underpins the development of legislation in both countries, if CCS projects are to play a role in achieving climate targets.

2.2 Introduction

The purpose of this section is to review applicable policy and regulation currently in place across the CCS value chain.

The first part of this section provides a review of existing policies, legal and regulatory frameworks to support the deployment of CCS at refineries across the EU, UK, China, and South Korea. This review includes a general overview of the different policies applicable to CCS, followed by an assessment of the different CCS-specific legal and regulatory frameworks for each jurisdiction.

To provide a high-level understanding of how CCS projects have been deployed globally, market failures and broader barriers to CCS investment are examined. Key recommendations to overcome CCS market failures are then outlined, serving as the basis upon which policies that have successfully supported the deployment of CCS are examined.

The sections conclusion comprises a gap analysis across legal, policy and regulatory environments for the deployment of CCS at refineries. This gap analysis categorises countries' level of response across several key categories, namely:

- Legal and regulatory framework that addresses the CCS project cycle
- CCS-specific policy framework addressing barriers to investment and market failures
- Policy instrument that places a sufficient value on CO_2
- Government support for hubs and clusters
- Capital support for CCS project development

Countries are grouped according to the gap analysis, with key policy and regulatory interventions subsequently recommended for each group of countries.

A key factor that should be noted from the outset is that the market failures, barriers to investment and policy, legal and regulatory frameworks identified in the report were found to be applicable in the context of all types of CCS projects located across the regions surveyed, including refineries. Thus, the conclusions and recommendations resulting from the review and gap analysis are not necessarily specific to one type of operation and will be applicable to all types of CCS operations, including those linked to refinery operations.

2.3 Review of policy and regulatory frameworks

2.3.1 Overview of policy options employed by governments to incentivise the deployment of CCS.

Well-designed policy may provide the conditions that are necessary for making CCS a commercially viable proposition. A robust policy framework will include policies which support minimising costs, provide stable revenues and allocate risks efficiently. This ultimately enables the efficient operation of the CCS value chain, facilitates resource mobilisation from the private sector, and helps to deliver climate mitigation targets cost effectively.

The relative merits of different policy mechanisms depend on the context in which they are deployed and the specific barriers and market failures they are intended to address. From the point of view of CCS investments, enabling policies must deliver the following:

- Place a sufficient value on captured CO_2.
- Overcome the cross-chain risk
- Manage long term storage liability

The following section will provide an overview of the types of policies adopted by governments to incentivise deployment in the jurisdictions surveyed for this report. It is important to note that there are very few policies that specifically target CCS at refineries. This is because CCS comprises a broad range of technologies and applications, and policies to support the deployment of CCS implicitly supports its deployment at refineries. Crucially, however, the value on captured CO_2 must be high enough to overcome the costs and generate a sufficient return on investment at refineries. The value on captured CO_2 is referred to throughout the report as a measure of a policy's effectiveness for CCS at refineries.

2.3.2 The European Union

With the exception of the Netherlands, the EU Emissions Trading Scheme currently remains the key policy instrument incentivising emissions reductions through CCS, across all 28 of the EU's member states.

The EU Emissions Trading Scheme (EU ETS) is the world's first and second-largest greenhouse gas emission trading scheme which operates across 31 countries (the 28 EU Member States plus Iceland, Liechtenstein and Norway). CCS is explicitly included as an activity that is covered by the EU ETS. The scheme requires the operator of an installation to surrender pre-allocated allowances to account for the release of emissions. Where operators can show that emissions have been successfully captured, transported and stored, according to the EU CCS Directive, operators are not required to surrender allowances. Any subsequent leakage of CO_2 requires the member state to purchase and surrender allowances, at current market rates, to account for the emissions that have been released. The cap on GHG emissions and the ability to buy emission allowances incentivises companies to invest in technologies that cut emissions, such as CCS technologies.

There is limited policy support for CCS deployment, in addition to that afforded by the EU ETS, within the majority of the EU's member states. One reason for this may be attributed to the fact that CO_2 storage is prohibited in several countries, including Austria, Estonia, Germany and Slovenia due to the unsuitability of the onshore subsurface in these countries for CO_2 storage. However, some countries such as Germany, Denmark, and Sweden, have also established CO_2 taxes and provided historic support for CCS in terms of RD&D and knowledge sharing efforts, indicating potential support for CCS.

The Netherlands currently remains the only country within the EU with concrete measures, in addition to its participation in the EU ETS, to support the deployment of CCS. The government of the Netherlands, in its Coalition Agreement of 2017, has indicated that CCS could contribute around 80 per cent of annual CO_2 emissions reductions that would be needed in industry to achieve the 2030 emissions reduction target (Government of the Netherlands, 2017). Notably, in recognition of the role CCS could play in these areas, the Government has allowed CCS projects to qualify for funding under the Renewable Energy Grant Scheme (SDE++), an operating subsidy to cover the additional costs of the climate mitigation technology for a period of 12 to 15 years (Netherlands Enterprise Agency, 2020).

In 2021, the Government of the Netherlands also introduced a CO_2 tax on industrial emitters covered by the EU ETS (Dutch Emissions Authority, 2021). The CO_2 tax, which recognises the EU ETS alone was insufficient to achieve the goals of the Paris Agreement, removes the uncertainty around the price on CO_2 emissions, and increases the effective carbon price. It is anticipated that the tax will improve the financial viability of climate mitigation measures like CCS.

In addition to these incentives, the government of the Netherlands is also involved with the advancement of the PORTHOS project, a CCS hub project that will collect CO_2 captured from a range of companies and store it via centralised transport and storage infrastructure, located around the Port of Rotterdam. The Porthos project is a Joint Venture between Energy Behera Nederland (EBN), Gasunie and the Port of Rotterdam Authority, all of which are State Owned Enterprises (SOEs). SOEs can potentially borrow at lower interest rates than commercial organisations, helping to bring down the effective cost of capital of projects.

Despite the limited policy landscape for CCS deployment within the EU, several member states have pledged emissions reductions that are aligned with the ambitious economy-wide emissions reduction target that the EU and its member states. Moreover, commitments to achieve net zero emissions by 2050 are also gaining momentum within the EU, with several countries, including France, the Netherlands, Germany and Spain also incorporating these targets within legislation to ensure accountability for mandated targets. These commitments, alongside the recognition of the role of CCS for reducing emissions at the lowest cost in many of these countries' long-term strategies to achieve climate targets, may spur the uptake of supportive policies for CCS in the near future.

2.3.3 The United Kingdom

Following its recent departure from the EU, the UK has taken active, separate measures to support the deployment of CCS.

The UK Government's Ten Point Plan, published in November 2020, sets out its ambition to capture and store 10 million tonnes of CO_2 per annum by 2030. To achieve this, the Government has committed to establishing CCUS in two industrial clusters by the mid-2020s, and in four industrial clusters by 2030. The Government has also proposed the establishment of the first net zero emissions industrial cluster by 2040.

The Ten Point Plan led to the development of the UK Industrial Decarbonisation Strategy, which was launched in March 2021. The new strategy will see £171 million put towards hydrogen and CCS projects. The dedicated £171 funding is part of a larger £1 billion investment, largely aimed towards decarbonising government owned buildings (UK Department of Business Energy &Industrial Strategy, 2021).

In terms of capital support for construction, the UK Government has committed to spend up to £1 billion on the deployment of CCS up to 2025 under its CCS Infrastructure Fund. The rules of the scheme, and the broader business models to support CCS, are still under development (UK Department of Business Energy &Industrial Strategy, 2020).

Up until the end of 2020, large industrial and power sector emitters in the UK were subject to the EU ETS. On 31 December 2020 the UK officially left the EU ETS and established its own UK ETS, which commenced operation from 1 January 2021. CCS operations are currently covered under the UK ETS (The Government of the UK, 2022).

These measures, alongside the UK's legal commitment to reach net zero emissions by 2050 and a range of other measures currently in development, indicate an increase in momentum for CCS in the UK and its role as part of meeting net-zero emissions by the middle of the century.

2.3.4 China

China's policy landscape for CCS remains limited, with its support primarily centred around direct investment in CCS projects through State Owned Enterprises. All three of the commercial-scale CCS facilities in operation in China have been developed by SOEs. These are the Sinopec Qilu Petrochemical CCS project, CNPC Jilin EOR, and Karamay Dunhua Oil Technology EOR projects.

China has also adopted an INDC stating that it plans to support research and development and commercialisation of low carbon technologies, such as carbon capture utilisation and storage, and to promote the use of technologies to utilise CO_2 for enhanced oil recovery and coal-bed methane recovery.

Moreover, for the first time, China's Five-Year Plan from 2021-2025 (its fourteenth) includes large-scale CCUS demonstration projects and in May 2021, the Ministry of Ecology and Environment (MEE) announced support for the construction of large-scale, all-chain CCUS demonstration projects in free trade zones (Chinese Communist Party, 2021).

In addition to these CCS-specific commitments, China launched a National Emissions Trading Scheme (ETS) in 2021. The ETS links regional, pilot-scale trading schemes and initially covers emissions from the power sector. Over time, the scope is expected to expand, eventually covering a total of eight sectors including petrochemical, chemical, building materials, steel, nonferrous metals, paper, and domestic aviation. The National ETS is currently the largest in the world. While CCS activities are not currently covered by the scheme, a CCS methodology to enable the eligibility of emissions reductions conducted through CCS under the scheme is in development.

China also recently announced that it will aim to hit peak emissions before 2030 and achieve carbon neutrality by 2060. To achieve these targets, the government has indicated its intent to increase its NDCs by adopting new policies and measures. In light of these developments, the outlook for future policy support for CCS technologies in China remains positive.

2.3.5 South Korea

The government of South Korea has indicated its commitment to significant greenhouse gas reductions, through its recent announcement targeting the achievement of net zero emissions by 2050. Despite this, the current policy landscape for CCS in South Korea remains underdeveloped.

South Korea has previously recognised the role of CCS towards achieving its climate targets. Significant RD&D efforts towards CCS have been conducted by various government agencies, including several announcements within national policy documents. The Nationwide CCS Masterplan (2010-2019), for example, committed to raise US $2.3 billion for CCS activities.

South Korea has also supported two CCS test plants, funded by the country's state-owned utility provider. In addition, the country has also pursued a variety of international CCS knowledge sharing initiatives.

2.3.6 Status of CCS-specific legal and regulatory frameworks

Law and regulation have proven an important feature of the wider policy response to CCS deployment, in many jurisdictions worldwide. Early assessments of the technology's feasibility cited the absence or perceived unsuitability of existing law and regulation as a significant barrier to widespread investment deployment of CCS. While several features in particular were consistently highlighted, including, access and rights to the pore space and liability issues arising from long-term storage, the absence of more holistic regulatory frameworks proved a frequently cited obstacle.

The past decade has witnessed significant legislative intervention in many countries, which has resulted in the development of several CCS-specific regimes, aimed at regulating the entirety or aspects of the CCS process. Policymakers and regulators in several in jurisdictions across Europe, North America, Asia and Australia have now introduced legislation to enhance their existing regulatory regimes or have enacted stand-alone regulatory frameworks to support the technology's deployment.

For those seeking to deploy CCS in these jurisdictions, in a refinery setting or otherwise, it is these CCS-specific regimes that will ultimately determine roles and responsibilities and regulate many aspects of the project lifecycle. In those nations where CCS-specific legislation has yet to be considered or implemented, operators and regulators will be required to determine the legality of these operations under existing regimes governing, amongst others, environmental protection, planning, land use, mining and energy activities.

2.3.7 Assessment model

To assess the ability of individual nations to regulate CCS activities, for the purposes of this study, the Global CCS Institute has sought to rely upon the national assessments undertaken in the compilation of the CCS Legal and Regulatory Indicator (CCS-LRI).

The Institute's proprietary assessment model seeks to determine the 'comprehensiveness' of an individual jurisdiction's legal and regulatory framework in regulating a CCS project throughout the CCS project lifecycle. The assessment focuses upon several key assessment criteria, which comprise issues that are likely critical to the regulation of a CCS project, through its planning and operational stages and beyond into the post-closure phase. The five core assessment criteria consider the:

1. Clarity and efficiency of the administrative process under the legal framework for applying for and obtaining regulatory approval for CCS projects.
2. Comprehensiveness of the legal framework in providing for all aspects of a CCS project, including siting, design, capture, transport, storage, closure and monitoring.
3. Extent to which legal and regulatory frameworks provide for the appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes.
4. Provision for meaningful and effective stakeholder and public consultation.
5. Management of liabilities associated with closure, monitoring and accidental releases of stored CO_2.

In addition to these five core conditions, a further wider set of secondary, sub-criteria are also considered as part of the assessment. The sub-criteria are aimed at exploring a country's legal and regulatory regime and approach to these core themes in greater detail.

To further complement the assessments, the Institute also examined a wide-range of relevant literature, including academic publications, industry reports, government documents, conference proceedings and web-based resources, to gain a further understanding of existing domestic regulatory regimes and indication of proposed approaches to the future regulation of the technology.

The following sections and appendices detail these country-specific reviews, with brief summaries of the regulatory assessment undertaken for each nation to-date.

2.3.8 EU Member States and United Kingdom

A critical aspect of the EU's regional policy response to CCS, has been the development of a comprehensive legal and regulatory framework and the removal of discrete legal barriers to the technology's deployment, within the broader body of EU environmental and energy legislation. The European Commission and the EU Member States (including the UK as a former Member State) have played an important role in the design of early CCS legal frameworks and, the development of some of the first legal and regulatory responses to the novel challenges posed by aspects the technology.

The EU Storage Directive ("the Storage Directive") provides the foundation for the Commission's legal and regulatory response to the technology (European Commission, 2009). Together with several consequential amendments made to wider pieces of EU environmental legislation, including the EU Emissions Trading Scheme (EU ETS) and Waste Framework Directives, the Directive remains the principal instrument for regulating CCS activities. The Directive is discussed in greater detail, in the following section.

EU law obliges Member States to implement a Directive's requirements and provisions, however, it does not detail the means of application. In accordance with these requirements, Member States were therefore afforded a limited discretion as to how to implement the Storage Directive's requirements in their national legal and regulatory models. The Directive has been transposed by all the EU Member States, and the UK government, into their national legal regimes.

2.3.8.1 Overview of the EU Storage Directive

The EU Directive offers an early example of a CCS-specific legal framework that deals with many aspects of the technology, throughout the project lifecycle and within the context of climate change mitigation. The Directive was enacted as part of the EU's wider climate and clean energy policy objectives, while also aiming to ensuring the protection of the environment. In this context, the Directive removes several potential legal barriers to CCS activities and clarifies the status of the technology under a number of wider EU Directives and Regulations, including those relating to waste and water.

In developing a regulatory model for CCS, the Commission has utilised several pre-existing legal instruments to manage some of the risks associated with the capture and transport elements. Amendments were made to the integrated pollution prevention and control (IPPC) Directive (now incorporated within the Industrial Emissions Directive) to bring capture installations within the scope of that Directive's provisions, while amendments to the environmental impact assessment (EIA) Directive mean that both capture and transport activities are now within that Directive's scope.

Other legal instruments, which are primarily aimed at minimizing and managing risks to the environment, have also been amended by the Directive to explicitly include or exclude activities relating to CCS processes. Amendments to the Environmental Liability Directive (ELD) mean that storage activities are included within Annex III of the ELD and therefore attract strict liability provisions. Similarly, amendments made to the Directive implementing the EU Emissions Trading Scheme (EU ETS) removes the obligation to surrender allowances under the scheme, where CO_2 is captured, transported and stored in accordance with the storage Directive.

The Storage Directive sets out a comprehensive CCS-specific regulatory framework, which includes requirements for the permitting of exploration and storage activities, monitoring and reporting obligations, liability and financial security provisions and a process enabling the closure and long-term stewardship of storage sites. The capture and transport aspects of the CCS process are to be addressed by wider European legislation and the Member States' existing legal and regulatory frameworks.

The Storage Directive applies to the geological storage of CO_2 in the "territory of the Member States, their exclusive economic zones and on their continental shelves"; however, Member States retain the right "not to allow for any storage in parts or in the whole of their territory". The discretion afforded to Member States has been reflected in their national-level implementation of its requirements.

2.3.8.2 Review and observations

The detailed results of the assessment of each of the EU Member States' legal and regulatory regimes under the Global CCS Institute's CCS-LRI, are included in Appendix C of this report. The review, however, enables several conclusions to be drawn as to the status of CCS-specific legislation within the EU and in particular, the regulatory frameworks that would support CCS operations across the entirety of the CCS project lifecycle.

The analysis conducted by this study reveals the significant impact of the EU Storage Directive upon national legal regimes. Notwithstanding national approaches to the implementation of the Directive, the widespread transposition of its requirements has resulted in the establishment of a solid foundation for the regulation of the technology in many Member States. The adoption of the Directive has led to a largely similar approach to the permitting of CCS operations, with regulators in many instances now capable of awarding various licences, permits and leases to undertake activities throughout the project lifecycle. In addition, transposition had also required Member States to consider their approach to issues such as liability and the post-closure management of CCS operations.

The impact of the Directive's transposition may be seen in the assessment results, however, there remains some disparity amongst the Member States as to the complexity of their regimes and their ability to fully-support a CCS project. The assessment clearly identifies a disparity between nations that have developed highly detailed, comprehensive regulatory models and others which have chosen a broad, high-level implementation of the Directive's requirements. In several instances, this is coupled with weaker provisions that would be applicable to CCS activities, throughout the project lifecycle. The result is that the majority of European nations have been classified under the CCS-LRI as Band B nations, indicative of countries that have CCS-specific laws or existing laws that are applicable across parts of the CCS project cycle.

The assessment reveals the detailed and advanced of regulatory models developed by some nations in the region. The United Kingdom, Denmark and Croatia, have all implemented comprehensive legal and regulatory models that implement the requirements for the Directive and in some instances go-beyond its provisions to offer highly supportive regulatory regimes. The UK's CCS-specific regime is particularly thorough and is capable of dealing with the majority of issues likely to arise throughout the CCS project lifecycle. An example of this detail is the UK's approach to liability and the conditions necessary for transferring responsibility for a storage site.

The UK's CCS regime allows for the transfer to a competent authority of "*any leakage liabilities incurred by the licence holder prior to termination of the licence*", upon the termination of a licence. The broad definition of 'leakage liabilities' under the UK Regulations, to mean "*any liabilities, whether future or present, actual or contingent, arising from leakage from the storage complex to which the relevant licence relates and includes liabilities for personal injury, damage to property and economic loss*" suggests a far broader scope than the transfer provisions found in the Directive.

In several instances, Member States have introduced greatly restrictive legal and regulatory framework for the technology. Notwithstanding their obligation to transpose the requirements of the Directive, the discretion afforded to Member States '*not to allow for any storage in parts or in the whole of their territory*', has been taken up in some countries. During the transposition of the Directive several Member States have placed restrictions upon domestic storage activities, as a consequence of this provision, highlighting in turn their limited geological capacity, a preference for offshore storage, or a desire to limit storage activities in time and capacity.

2.3.9 China and Republic of Korea

The legal and regulatory regimes in both China and the Republic of Korea ("Korea") are currently underdeveloped and yet to offer a clear means for regulating the entirety of the CCS project lifecycle. While both nations have expressed interest in developing and enhancing their regulatory frameworks for the technology, there have been limited steps taken to-date to improve their domestic regimes.

Further detail of both countries current approach to the regulation of CCS activities, is provided in Appendix C.

2.3.9.1 China

At present, there is not a dedicated CCS-specific legal and regulatory regime in China, of the type seen in the EU and other jurisdictions around the world. The Global CCS Institute's assessment of China's national legal regulatory environment, as part of the CCS Legal and Regulatory Indicator (CCS-LRI), revealed it had very few CCS-specific or existing laws that are applicable across parts of the CCS project lifecycle.

Notwithstanding this position, there are existing regulatory systems governing oil and gas activities which may have potential application to CCS projects. Project proponents wishing to undertake a CCS project using these provisions will be required to apply for a series of permits and approvals from several government bodies. It is likely that they will also have to comply with existing national standards regarding the construction, transport and operation of industrial activities. It is likely that some of these permitting processes will overlap, however some sources report that about 50 clearances or permits alone, are required prior to the construction of a power plant.

Wider environmental and planning legislation will likely apply to CCS activities, with an Environmental Impact Assessment (EIA) a necessary requirement to the approvals process. In the absence of a CCS-specific legal framework, a number of regulatory gaps with respect to CCS projects must be addressed. These include, but are not limited to:

- CO_2 transport and trans-boundary movements
- Technology information and technology development guidelines
- Site selection
- Storage site characterisation
- Public consultation requirements
- Liability provisions governing the operational lifecycle of a project.

2.3.9.2 Republic of Korea

Korea has not developed a dedicated regulatory framework for CCS, nor are CCS activities contemplated in many of the country's wider existing regulatory regimes. As a result, Korea has been included in Band C of the Institute's CCS-LRI, indicative of a country with few CCS-specific or existing laws that are applicable across parts of the CCS project cycle.

Notwithstanding this, wider environmental legislation, particularly in the context of the country's implementation of the 1996 London Protocol, will be applicable to CCS activities. The recognition of CCS within national environmental legislation, extends its application to CCS projects. There is not, however, a clearly integrated overarching framework covering all aspects of the CCS project-cycle.

Korea's existing regulatory processes may, in some instances, be applicable to CCS operations. Legislation governing the planning and siting of major infrastructure operations, conservation and the permitting of energy-related activities do not currently contemplate CCS activities. As a result, there is considerable uncertainty surrounding their application and the exact nature of their impact upon CCS operations.

2.4 CCS Market Failures

Market failures occur when the operation of the free market does not maximise society's welfare i.e., a net social welfare loss. For example, rational decisions made by individual firms to maximise financial performance may conflict with the best interests of broader society.

CCS faces significant market failures, as well as broader barriers to investment. To overcome these, a robust policy framework must be implemented for the private sector to deploy CCS at refineries and beyond. Five broad market failures exist across the CCS value chain; these are illustrated in Figure 11.

These market failures directly affect the business case for CCS by reducing the expected return from projects relative to alternative options, including not investing in emissions reductions altogether:

- CO2 emissions externality → Revenue risk

- High capital cost → Lack of commercial financing
- Coordination failure → Cross-chain risk
- Legal barriers → Long term storage liability

It is up to governments to introduce policies to overcome these market failures by managing the hard to reduce risks that they engender. Below, we discuss these market failures and how they have been overcome through policy mechanisms, thereby supporting CCS projects towards positive FID.

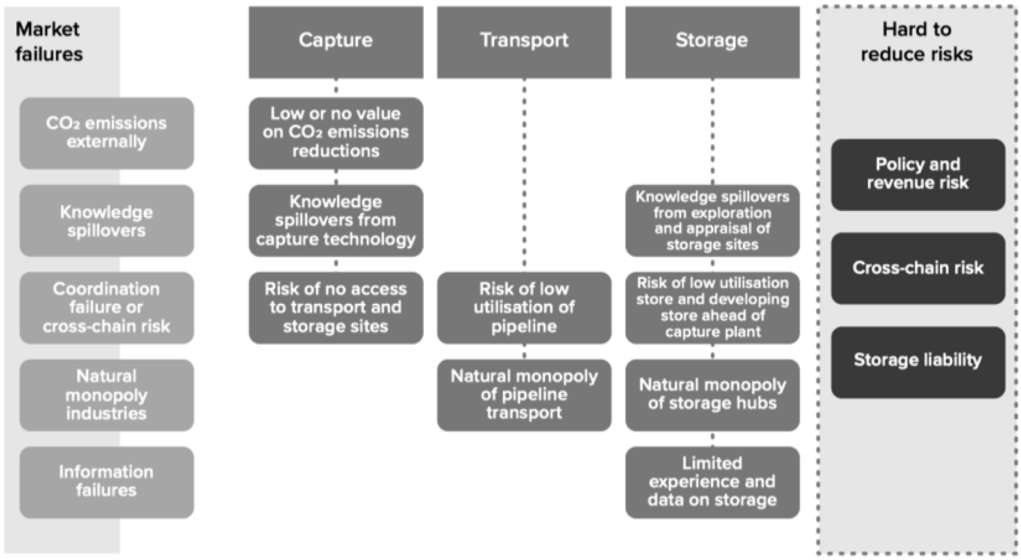

Figure 11 Market Failures[13] and broader barriers to investment occur across the CCS supply chain. Government plays the role of managing hard to reduce risks.

2.4.1 CO_2 emissions externality

Across the spectrum of climate change solutions, the most prominent market failure takes the form of a negative externality, known as the greenhouse-gas or CO_2 emissions externality. CO_2 emissions are a side-effect of economically valuable activities, which, if left unabated, will adversely affect society. The market failure – the overproduction of CO_2 – occurs because there isn't an economic reason for businesses and consumers to reduce their CO_2 emissions.

If businesses and consumers account for the cost of avoiding their emissions as part of their broader economic decision-making process, then the market failure no longer exists. To achieve this, government policies that place a value on avoiding emissions can be

[13] Adapted from Policy Priorities to Incentivise Large Scale Deployment Of CCS (https://www.globalccsinstitute.com/wp-content/uploads/2020/04/TL-Report-Policy-options-for-CCS-investment-digital.pdf).

implemented. Examples of such policies are carbon taxes, emissions trading schemes, emissions performance standards, among others. These create a price signal for emitters, which can lead to investments in technologies such as CCS.

For a potential CCS project developer, the main impediment to investment is often the lack of a clear and compelling CO_2 price signal that places a sufficient value on emissions reductions. Without this, the likely absence of a robust business case means the developer lacks the incentive to incur the costs of constructing and operating the capture plant. Policy instruments that have supported CCS projects towards positive FID have placed a sufficient value on the capture of CO_2. Examples of these are provided below.

2.4.2 Tax Credits

One proven example of a policy that provides a financial reward for CCS is tax credits, which have been an important enabler of the seven commercial CCS facilities that have commenced operation in the USA since 2011[14]. In the USA, tax credits are issued under section 45Q of the Internal Revenue Code. The credits can be used to reduce a company's tax liability or, if they have no tax liability, can be transferred to the company that stores the CO_2 or can be traded on the tax equity market. Tax credits have the benefit of being well established in the context of climate change mitigation in the USA, having been used to drive significant investment in renewables over the past two decades. They provide a predictable, effective revenue stream for each tonne of CO_2 stored (or utilised). Table 1 shows the current tax credit values under the 45Q tax credit policy.

Table 1. 45Q tax credit values in each year (US$/t$CO_2$)

Method for handling captured CO_2	2021	2022	2023	2024	2025	2026	Post-2026
Dedicated geological storage	36	39	42	45	47	50	Indexed to inflation
CO_2-EOR	24	26	28	31	33	35	
Other CO_2 utilisation processes	24	26	28	31	33	35	

The additional revenue from tax credits (once granted, third parties can purchase these at market value) has allowed investments across various CCS projects in the US.

[14] Note that two of these facilities have since suspended operations

2.4.3 Regulatory Requirement

Mandate-based regulations — such as meeting the requirement of an emissions performance standard — place an implicit value on avoided CO_2 emissions. Potential CCS investors may interpret a regulatory requirement as the cost of doing business.

2.4.3.1 Gorgon, Australia

Gorgon's project's sponsors recognised the need to reduce CO_2 emissions from the LNG project in Australia and included CCS in its Environmental Impact Statement. The Western Australian Government's approval of the project subsequently included a mandatory condition to inject at least 80% of the reservoir CO_2 produced by the gas processing operations. Gorgon has a dedicated CO_2 storage facility and is expected to store approximately 4 million tonnes of CO_2 per year. The additional cost of CCS was manageable in the context of the overall project, adding less than 5% to the total project costs.

2.4.3.2 Boundary Dam, Canada

The main driver of the SaskPower Boundary Dam coal-power station CCS facility in Saskatchewan, Canada, was a federal emissions performance standard introduced in 2011. The cost of generation after the CCS retrofit was similar to the cost of building a new NGCC power plant; the alternative means to meet the standard.

2.4.4 Cap and Trade Programmes and Baseline and Credit Schemes

A cap and trade, also known as an emissions trading scheme (ETS), works by having a fixed limit placed on the total emissions – the cap – that can be allowed from a given industry or even the whole economy. The cap is split into allowances, each permitting company to emit one tonne of CO_2, which are distributed to companies for free or through an auction. The allowances are transferrable, so companies can decide whether to contain their emissions, which can be done through direct investments in low carbon technologies or purchase additional allowances from other companies. By their nature, cap and trade schemes will reward the most cost-effective forms of mitigation first.

A baseline and credit scheme works in much the same way as a cap-and-trade scheme. Key to their difference is the absence of a fixed limit on emissions in a baseline-and-credit scheme. Instead, polluters that reduce their emissions more than they otherwise are obliged to can earn credits. These credits can then be sold on to others who need them to comply with regulations they are subject to.

In California, USA, the Low Carbon Fuel Standard or LCFS is a baseline and credit scheme that is designed to decrease the carbon intensity of California's transportation fuel pool. To be able to access the Californian transportation fuel market, oil refineries are incentivised to reduce the carbon intensity of their products. By using CCS, refineries are able to meet the standard set by the LCFS and potentially also generate credits. Since the market value of LCFS credits are worth upwards of US$200, this places a sufficient value on the capture of CO_2 at refineries, making it viable to invest in CCS.

2.4.5 Carbon Tax

A carbon tax creates a value on CO_2 from avoided emissions. It creates an incentive to invest in CCS if the cost of avoiding emissions is lower than the tax penalty. In 1991, the Norwegian government introduced a carbon tax of $50/t$CO_2$, sufficient to incentivise the Sleipner project's development. The same policy led to the later development of the Snøvit project.

2.4.6 High capital cost

Large-scale CCS projects are capital intensive, with an average cost of around $600 million for every 1 million tonnes of CO_2 emissions avoided. Despite several projects reaching positive FID and others entering the CCS projects pipeline, perceived investment risks have made it challenging for standalone CCS projects to attract debt financing. Instead, most CCS projects were funded through corporate finance, i.e., by large corporations and state-owned enterprises (SOEs). Notwithstanding this, financial support from governments – mostly in the form of capital grants – has played an essential role in supporting many CCS projects to reach a positive FID.

Private investors need financial incentives to invest in CCS. For a project to achieve positive FID, its return on investment must achieve a threshold known as the hurdle rate. The hurdle rate tends to increase with an investment's risk profile, so CCS projects may initially struggle to attract investors. This creates a barrier to CCS investments, which can be overcome if capital grants are used to reduce the project's risk profile.

Capital support from government is most effective when used to meet the cost of the most high-risk components and phases of CCS projects, bringing down the overall risk profile and capital requirement for private investors. Grant funding also mitigates the first-mover cost disadvantage by effectively rewarding early investors for the first-of-a-kind project knowledge.

Grant support has also been used to fund the construction of CO_2 transport and storage networks, to address the cross-chain risk that affects capture plant developers. This approach was adopted in Canada for the Alberta Carbon Trunk Line, which, ahead of its 2020 launch, received C$558M from the Alberta and Canadian governments for the C$1.2B project.

2.4.6.1 Funding Programmes

In North America, where projects tend to be developed and owned by the private sector rather than state-owned enterprises, government-led initiatives have taken the form of funding programmes. These are part of a broader strategy to enable CCS deployment in parts of the economy where the technology is most needed.

2.4.6.2 Canada: Alberta Program and Federal Government Capital Grants

The Pan Canadian Framework on Climate Change has set an ambitious target to reduce national emissions by 30% from 2005 levels by 2030. Each province has relative freedom in how to reduce its emissions inventory, except for coal-fired power generation. Canada's 2012 update to the Environmental Protection Act required new coal plants (and existing plants over 40 years old) to comply with an emissions limit of 420 tonnes of CO_2 emitted per GWh of electricity produced.

In Alberta, the government recognised its economy and emissions are both heavily tied to the oil and gas sector and to trade-exposed heavy industries. It decided on a CCS strategy to shield these sectors from climate-related risks. In 2008 it launched a C$2 billion CCS Fund to support large-scale projects. Four awards were made in 2009; two reached positive FID and are now in operation - the Shell Quest project and the Alberta Carbon Trunk Line project. At the federal level, Natural Resources Canada's Clean Energy Fund (2009-2014) budgeted C$205M for funding CCS projects, mostly spread across the Shell Quest and Alberta Carbon Trunk Line projects. The Government of Canada has also provided direct grant funding of C$240M towards the Boundary Dam project.

2.4.6.3 Shell Quest: De-risking through high subsidies and demonstration

The Shell Quest CCS facility near Edmonton, Alberta, is attached to a hydrogen production unit at the upgrader facility. It has been operational since 2015. It is a vertically integrated project that injects the captured CO_2 into a geological formation for permanent storage. In 2008, Shell Canada, along with its Athabasca Oil Sands Project joint-venture partners, received grant funding from the Government of Alberta's CCS Fund to develop Quest. Additional grant funding was obtained through the federal government's Clean Energy Fund. The overall proportion of direct grant funding amounts to some 64% of project costs. The Alberta government also awards carbon credits to the project on a performance basis at a ratio of two credits for every tonne of CO_2 sequestered. The combination of significant capital grants and a secure revenue line obtained from carbon credits was a sufficient incentive for the project to reach positive FID.

2.4.6.4 Alberta Carbon Trunk Line: De-risking through infrastructure investments in shared transportation

Situated in the province's industrial heartland, the Alberta Carbon Trunk Line (ACTL) is the world's largest capacity pipeline for carrying anthropogenic CO_2, capable of transporting up to 14.6M tonnes of CO_2 per year. The project involves multiple project partners. The pipeline connects two emitters, North West Refinery and Nutrien, to a storage operator, Enhance Energy. The CO_2 is compressed and transported by Wolf Midstream. Enhance Energy uses CO_2 for EOR. The 240km pipeline is oversized to allow additional emitters and storage operators to connect over time and connect to other oil fields and storage sites.

This operating model – known as a hub and cluster model – directly addresses one of CCS's so-called "hard to reduce" risks, the interdependency or cross-chain risk. It also allows project partners to benefit from economies of scale, reducing the cost of transport and storage of CO_2. However, the first investors in the transport and storage network face all the costs and risks of a "single source, single sink" business model until others join the network, which exposes them to the original cross-chain risks. This is a significant barrier but can be overcome if public sector capital support is made available. The role of the Alberta government was to ensure that the ACTL could be oversized at no additional cost to private sector partners. To achieve this, the Alberta and federal governments provided capital grants of C$495m and C$63, respectively, allowing project partners to reach FID based on CO_2-EOR revenues.

2.4.6.5 Boundary Dam

While emissions regulation mainly drove the Boundary Dam project, it was also supported by a C$240 million grant from the federal government, covering around 22% of its initial projected costs. This grant, coupled with the sale of CO_2 for EOR, combined to create a project with a Levelised Cost of Electricity (LCOE) equivalent to building a new NGCC plant.

2.4.7 USA: Department of Energy Funding Program: De-risking through the provision of capital subsidies

Like Canada, the US has also built a climate strategy that includes CCS. The US has the highest number (fourteen, or half the total) of operational CCS projects in the world and some of the largest. While the 45Q tax credit plays a vital role in generating revenue for CCS projects, capital support was also necessary. Capital grants are made available through the U.S. Department of Energy (DOE), which administers the Clean Coal Power Initiative (CCPI) that requires project developers to provide a minimum 50% cost-sharing. Three large-scale CCS projects, Air Products SMR, Illinois Industrial and Petra Nova, received grant support from the DOE to advance towards a positive FID.

2.4.7.1 Air Products SMR

Air Products SMR is a post-combustion CCS project. Air Products partnered with Denbury Onshore to capture and use CO_2 from existing steam methane reformers. The project was helped by the relatively low-cost transport because of its proximity to an existing Denbury pipeline, the Green Pipeline. This allowed the project to sell the CO_2 to oil fields in eastern Texas. It received US$284M in grant funding as a contribution towards the overall capital cost of US$431M.

2.4.7.2 Illinois Industrial

The Illinois Industrial plant produces bioethanol from corn. Since a relatively pure stream of fermentation CO_2 is produced in this process, the cost of capture is very low. The significant costs were compression and transportation of the CO_2, which was also low as a legacy academic study had previously installed that infrastructure. The project reached positive FID with significant grant support; it received a $141 million investment from DOE, matched by over $66 million in private-sector cost share from the investor, and receives 45Q tax credits for revenue generation.

2.4.8 Cross-chain risk

CCS facilities may involve one source, one sink, and one pipeline. There is a significant cross-chain risk for all members of the value chain in a disaggregated business model. For example, if the industrial source of CO_2 ceases operation, both the pipeline operator and the storage operator will have no customers and no revenue. This risk is a significant barrier to investment and manifests, ultimately, as a higher cost of capital and higher project costs.

Alternatively, CCS facilities may adopt a vertically integrated full-chain business model rather than a disaggregated model. This allows the operator to optimise the entire CCS value chain but requires the operator to be competent across a broad range of activities. For example, steel or cement makers typically do not have expertise in geological storage of CO_2. While this approach may suit a small group of emitters, it doesn't overcome the cross-chain risk; if one facility is unavailable, the others will not operate. The most effective approach is a hub and cluster model, which utilises a shared transport and storage (T&S) network (Figure 12).

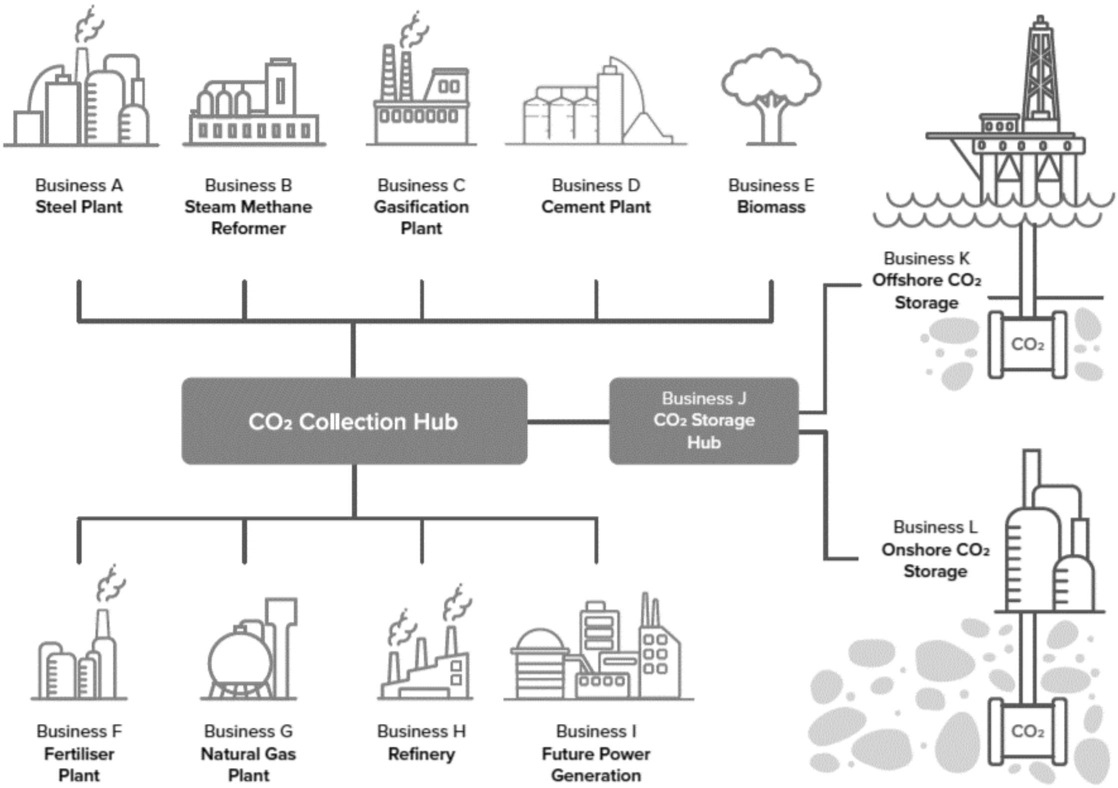

Figure 12 Hub and cluster disaggregated business model[15]

Emissions intense industries such as steel, cement and fertiliser production often exist in clusters due to the local availability of necessary resources such as fossil fuel feedstocks, a skilled workforce or infrastructure such as port and rail. These industrial clusters provide an opportunity to create CO_2 transport and storage networks, allowing multiple CO_2 sources access to common CO_2 transport and storage infrastructure. Transport and storage networks reduce the cross-chain risk by creating multiple customers for the operators of the CO_2 transport and injection business and multiple CO_2 storage service providers for industrial CO_2 sources. They offer much greater levels of operational flexibility than dedicated single source – single sink facilities, and therefore help to reduce operational risk.

It can, however, be challenging for the private sector to invest in shared T&S networks. Storage operators may have significantly constrained balance sheets, and lower tolerances to risk compared to capture plant operators. For example, one party may be a large corporation with a very strong balance sheet and a strategic interest in CCS, justifying the acceptance of a higher level of risk. Other parties may not have the same incentives or balance sheet strength and may be more risk averse. Further, the first investors will still face all of the cross-chain risk until others join the network. This is a barrier to the hub and cluster model unless guarantees are provided for revenue during the early stages of development.

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15 Adapted from Global CCS Institute (2019). Available at: https://www.globalccsinstitute.com/wp-content/uploads/2019/04/TL-Report-Policy-prorities-to-incentivise-the-large-scale-deployment-of-CCS-digitalfinal.pdf

One approach to overcome this is the Regulated Asset Base (RAB) model, whereby a legally binding license with periodical regulatory review of long-term tariffs is utilised. All investments are valued and costs are recovered from consumers under regulation. Consumers end up covering the risks, which in turn shelters investors from exposure to them, thereby enabling investments. In spite of these measures, it may be necessary for governments to make the initial investment in the T&S infrastructure under the RAB model. This would help establish the T&S for an anchor customer. Over time, the network can be expanded to service growing demand. Once the hub and cluster model has begun to mature, government may eventually choose to sell it off for a profit.

2.4.9 Long term storage liability

The risk associated with long term storage liability poses a significant barrier to investment in CCS. Even if the probability of leakage from a storage resource is very small, the impact of the risk is very high. If there are no limitations set on the liability, the storage operator is liable for all the costs associated with a future leakage. These costs include the cost of actions to stop the leakage, any damages claimed by parties because of the leakage, and any fines or sanctions, including the purchase of emissions allowances at the price in effect at that time.

To mitigate the risk of long-term storage liability, governments must implement a robust legal and regulatory framework that clarifies operators' potential liabilities. For example, the Australian government has implemented a framework where the storage operator bears the risk of liability during the operational phase of the facility, and for a specified period post-closure. This approach recognises that the risk of leakage is highest when CO_2 is being injected into a geological formation, but reduces immediately upon closure of the site, whereupon it continues to fall over time. As such, the risk that is accepted by government is very small and continues to get smaller during the post-closure period.

2.5 Conclusions and recommendations

2.5.1 Policy and legal and regulatory gap analysis

The jurisdictions considered in this report vary in terms of how they have addressed legal and regulatory issues and policy actions necessary for supporting the large-scale deployment of CCS. Table 2 below, provides an overview of the extent to which the policies and regulatory regimes, in each of the countries examined, may support the deployment of CCS.

Table 2. Summary of existing policies supporting CCS in the EU, the United Kingdom, China and South Korea.

Policy Element	Absent or Ineffective	Marginal	Effective
Comprehensive legal and regulatory framework addressing the CCS project cycle	South Korea, China	Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovenia, Slovakia, Spain, Sweden	Denmark, Croatia, Netherlands, United Kingdom
Strong CCS-specific policy framework addressing barriers to investment and multiple market failures in the context of CCS	South Korea, Austria, Estonia, Latvia, Slovenia	Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Finland, France, Germany, Hungary, Ireland, Italy, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia, Spain, Sweden, China	United Kingdom, Denmark, Netherlands
Policy instrument places a sufficient value on CO_2	China, South Korea	Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovenia,	UK, Netherlands

Policy Element	Absent or Ineffective	Marginal	Effective
		Slovakia, Spain, Sweden	
Government support for hubs and clusters	Austria, Belgium, Bulgaria, China, Cyprus, Czech Republic, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovenia, Slovakia, South Korea, Spain, Sweden	Italy	United Kingdom, Netherlands

2.5.2 Strong and conducive environments for CCS deployment: the UK, Netherlands, Denmark and Croatia

At present, the United Kingdom, the Netherlands, Denmark and Croatia are clear leaders, when compared to other nations surveyed for this report, in terms of their legal and regulatory response to support the large-scale deployment of CCS. The assessment of Denmark, the UK and Croatia's legal and regulatory environment in particular, under the Global CCS Institute's proprietary 2021 Legal and Regulatory Indicator, categorises these countries as Band A nations. A categorisation that suggests that these nations possess particularly detailed and advanced regulatory models.

A strong and supportive policy environment for CCS projects can also be seen in the United Kingdom and the Netherlands, further illustrated by the CCS projects currently in various stages of development in these countries. Strong commitments to achieving net zero emissions by 2050, together with explicit recognition of the crucial role of CCS in delivering the required emissions reductions to achieve targets, has led to the establishment of accompanying policy packages and strong legal and regulatory measures to facilitate the technology's deployment, in both nations.

The government of the Netherlands, for example, is planning to set aside grant funding amounting to €2.1 billion under the SDE++ subsidy scheme for the Port of Rotterdam CO_2 Transport Hub and Offshore Storage (Porthos) project in the Netherlands

In the UK, several industrial CCUS hubs and cluster projects will receive £171 million under the Industrial Decarbonisation Strategy, which is one of several capital and construction support mechanisms established in the UK to incentivise projects. The Government has also launched a policy bank – UK Infrastructure Bank (UKIB), mandated to deliver £22bn of infrastructure finance – to co-invest with the private sector to enable and accelerate the delivery of UK projects, including CCS.

The UK government has also outlined CCS business models for both power generation and industry, all of which place a sufficient value on capturing CO_2 to cover CCS costs and also generate a sufficient return on capital investment. This ensures that investment in CCS is well supported and is viable across many sectors where it is needed.

These initiatives, as well as the government's hydrogen and carbon capture and storage targets[16] send strong signals to industry, which has led to several projects being announced over the past two years.

2.5.3 The European Union: Inadequate policy and legal and regulatory response to advance CCS

Despite the implementation of the EU CCS Directive across the EU member states, the Institute has identified a disparity between these countries, which have implemented the Directive's provisions broadly at a high level, and countries such as the UK, the Netherlands, Denmark and Croatia, which have established advanced, highly detailed and comprehensive regulatory frameworks. As a result, the majority of European nations have been classified under the CCS-LRI as Band B nations, indicative of countries that have CCS-specific laws or existing laws that are applicable across parts of the CCS project cycle.

The policy environment amongst most of the countries in the EU also broadly reflects policy mechanisms and commitments at the EU level, such as the EU ETS and the EU's joint economy-wide emissions reduction target. The EU ETS covers many sectors, but the prevailing price of an emissions credit is not yet sufficiently high to incentivise CCS investments across refineries. Additional drivers include the EU's funding mechanisms, namely the EU Research and Innovation Programme, and the Innovation Fund. These mechanisms are designed to support low-carbon projects, including CCS, through capital grants. In the EU, only the Netherlands and Denmark[17] at this stage have separately established policy incentives to incentivise CCS projects, in addition to existing EU mechanisms. An example of this is the Port of Rotterdam CO_2 Transport Hub and Offshore Storage (PORTHOS) project in the Netherlands. At its core, the project is aimed to mitigate the cross-chain risk for capture facilities, whereby emitters are able to connect to a shared transportation and storage network. To facilitate the development of the network, the European Commission has proposed to cover € 102 million of the project costs, which total € 405-500 million.

To support the development of capture facilities, the SDE++ scheme is to cover the difference between companies' total costs and savings. Companies that participate in PORTHOS will not be required to pay EU ETS allowances, which is their main incentive for investing in CCS. Such a model instils confidence in lenders, making it possible for businesses that choose to take advantage of the network to raise capital from the private sector.

Domestic policy mechanisms to support CCS are yet to be established across most countries in the EU, which is likely due to the varying degrees of support for the technology in these

[16] Five gigawatts of hydrogen production and 10m tonnes of carbon capture a year by 2030
[17] The Netherlands' CO_2, tax, SDE++ subsidy scheme and ambitious climate targets cemented in legislation indicate a strong policy environment for CCS projects. Denmark is another example of a conducive policy environment for CCS, having established legislated climate targets and a CO_2 tax.

nations, in line with national policy priorities and circumstances. In countries such as Austria, Estonia and Slovenia, regulations currently restrict CO_2 storage, due to the lack of sufficient onshore storage capacity in their territories. Germany has adopted a cautious approach in supporting CCS, with restrictions currently in place in 5 federal states on the underground storage of CO_2. Various reasons underpin these restrictions, including prioritising the use of underground resources for geothermal energy, energy storage and mining and due to environmental and tourism concerns. National restrictions in this manner pose challenges for the deployment of CCS projects, including refineries, in these countries.

In the absence of strong domestic policy commitments to incentivise CCS amongst many of the EU's individual member states, the Institute's has categorised them as countries with an inadequate policy environment for CCS.

2.5.4 Varying degrees of policy uncertainty and significant limitations to existing legal and regulatory regimes: China and South Korea

The Institute's review has also revealed the need for government to establish legal and regulatory frameworks and policy mechanisms to support CCS in both South Korea and China. While both countries have acknowledged the potential of CCS to achieve their net zero emissions targets, there remains few examples of formal policies incentivising the technology's deployment, including the development of a dedicated legal and regulatory framework for CCS. Both countries are thus included in Band C of the Institute's CCS-LRI, indicative of countries with few CCS-specific or existing laws that are applicable across parts of the CCS project cycle.

Recent developments, however, suggest there is growing policy support for the technology in both China and South Korea. In China, for example, the launch of the national emissions trading scheme and inclusion of support for large-scale CCUS demonstration projects within major policy documents for the first time, signals the growing significance of the technology and the potential for further support mechanisms for CCS in the future. Similarly, South Korea's historic RD&D efforts for CCS as well as the recent announcement to achieve net zero emissions by 2050, suggests that there may be positive policy mechanisms to support CCS in the near term.

2.5.5 Recommendations

The following section provides key recommendations for the jurisdictions surveyed for this report, in light of the policy, legal and regulatory gap analysis conducted in Section 3.1. Once again, it is re-iterated that these recommendations are applicable to all types of CCS projects, including refineries, located in these regions.

- The United Kingdom, Netherlands, Denmark and Croatia Offer important models, within the region and internationally

The more widespread deployment of CCS will mean that early movers in the space, will have developed market supply chain capabilities. These capabilities can translate into opportunities for export of hardware and services to the neighbouring countries and beyond. Such opportunities can include:

- CCS technologies that have been developed locally can be exported abroad either
- Countries with large enough storage resources may provide the transportation and storage of CO2 as a service

- Specialist financiers, including export credit agencies, may partner with local technology providers to provide turnkey solutions abroad

Early movers in the CCS space will be those best positioned to avail these opportunities. To facilitate this, governments have the potential role of supporting countries to increase their level of CCS readiness through bilateral programmes and other such initiatives.

2.5.5.1 Additional, domestic policy incentives may build upon and compliment wider EU initiatives

As a standalone mechanism, the EU ETS provides sufficient incentive for CCS investments in some industries but is still insufficient for several others, including CCS at refineries. Irrespective of the technology applied, CCS will significantly increase the energy footprint of a refinery, thereby increasing its costs. Estimates suggest that the cost of capture per tonne of CO2 at refineries will be higher than the €40 to €50 mark, which is the prevailing price range of allowances at the time of writing this report.

In anticipation of a rising EU ETS price, governments can implement local policies that provide additional incentives – such as a price mechanism to support the EU ETS – to bring forward CCS investments at refineries. Financial incentives, such as such as capital grants and concessional loans can also be used in conjunction to these policies. Such arrangements may persuade emitters to bring forward their CCS investments to take advantage of lower cost opportunities.

2.5.5.2 The need for flexible and dynamic legal and regulatory models

Clear and well-defined law and regulation, as established in these countries, has resulted in greater confidence and proven critical in supporting early project deployment, as demonstrated by the several projects in these countries which have been aided by supportive models of regulation.

However, as the number of CCS projects across various industries and sectors grow and new technological developments relating to CCS come onboard, it may well be the case that further refinement of legal and regulatory regimes will be necessary, to ensure they offer sustained policy support and a complete regime which addresses previously unforeseen risks and contingencies, for the operational phase of projects.

This is because the most progressive models have ultimately required further development and clarification to resolve any remaining issues and the challenges of practical implementation. An example is the experience of the CarbonNet project in Victoria, Australia. The presence of a comprehensive legal and regulatory regime at the Commonwealth level and in the State of Victoria, at the inception of the CarbonNet project, enabled the project to progress. The project's permitting and viability, however, was delayed by uncertainties surrounding the regulation of storage operations which 'straddled' both Commonwealth and state territorial waters. The failure to address this issue in a timely manner led to considerable uncertainty for the project and illustrates perfectly, the critical role of law and regulation in enabling project deployment.

Similarly, the Norwegian Northern Lights project has faced similar challenges, with the London Protocol, the EU CCS Directive and the EU Emissions Trading Scheme Directive, all presenting challenges to the project's viability in recent years. The transboundary focus of the project and the project's reliance upon the shipping of CO_2 to the proposed storage site, posed considerable challenges under the international and regional legal status quo. The project's experience again highlights that, new technological solutions may challenge more conventional or inflexible legal and regulatory regimes.

These examples illustrate how it is crucial that legal and regulatory regimes governing CCS, even in countries which have established detailed regulatory models, must remain dynamic and flexible to address various contingencies and practical challenges as they arise, as these may act as inadvertent roadblocks for projects.

2.5.5.3 European Union Member States

2.5.5.3.1 Transition from framework legislation to include greater detail, necessary for supporting projects throughout the project lifecycle.

Currently in the majority of the EU's member states, the EU CCS Directive has been transposed across various pieces of legislation in each jurisdiction. While the Directive acts as a framework for regulating CCS, it does not provide a comprehensive model addressing all aspects of a CCS project in the context of each jurisdiction. As such, it is necessary that these countries transition from framework legislation to include greater detail in their domestic legal and regulatory frameworks to achieve the 'comprehensiveness' required in regulating a CCS project throughout the CCS project lifecycle. The UK, Denmark, Croatia and the Netherlands afford examples of the EU CCS Directive being the underlying basis for their regulatory models which were then developed to include further and more specific regulatory requirements in line with the domestic regulatory context and objectives. Countries in the EU can draw upon the experience of these countries in expanding their own legal and regulatory frameworks to accommodate CCS-specific provisions.

2.5.5.3.2 Address gaps in regulatory frameworks and review national restrictions for CCS projects

Policymakers and regulators should examine those aspects of national regimes, which are currently incomplete or yet to be addressed. Currently, since several of EU member states have prohibited CO_2 storage within national legislation, the regulatory framework is silent in terms of key aspects of a CCS project, despite the EU CCS Directive being transposed in these jurisdictions. Others are yet to establish specific regulatory requirements addressing key aspects of a project, such as post-closure obligations and long-term liability provisions.

A failure to regulate the entirety or even discrete aspects of a process, presents a substantial barrier to investment and the deployment of projects. In light of wider commitments to net-zero and targets under the Paris Agreement, a review of the current national restrictions placed upon CCS deployment in countries such as Estonia, Austria and Slovenia, may be required. Where restrictions placed upon domestic storage are maintained, it may be necessary to consider authorising and regulating the export of CO_2 - captured within these territories - for CO_2 storage in neighbouring countries. Eliminating regulatory barriers and adopting a comprehensive and holistic approach to the design of legal and regulatory frameworks will be critical, particularly where there is an urgent need to deploy a wide range of emissions reduction technologies to achieve climate targets within proposed timeframes.

2.5.5.3.3 Incentives must be aligned with the need for CCS in key sectors

Currently, there is a mismatch between the region's need for CCS and the policies to support the technology's deployment. While refineries are covered under the EU ETS, the prevailing price has thus far not been sufficiently high to incentivise CCS investments at refineries. For CCS investments to become economically viable in such sectors, the price of ETS allowances must increase or be other mechanisms (such as the SDE++) will be needed to support investments.

Beyond the PORTHOS project, the EU region is lacking in initiatives to build or support investments in shared transport and storage networks. Individual countries must consider the business models and regulatory policies that will determine how shared T&S networks will function.

2.5.5.3.4 Further policy national policy developments may be necessary in many EU member states, to signal long-term commitments to the technology.

In addition to incentives, governments must take into account the need for financial de-risking of CCS projects. Due to constraints upon their balance sheets, some emitters will require significant debt financing to fund their CCS investments. During the early stages of CCS deployment, commercial banks are unlikely to meet emitters' debt needs. To this end, governments may need to extend the role of specialist financiers[18] to support CCS by partnering with project developers to secure commercial debt and to close funding gaps.

2.5.5.4 South Korea and China

2.5.5.4.1 Review legal and regulatory requirements necessary for supporting commercial-scale deployment of CCS

In both China and South Korea, achieving national policy ambitions for emissions reduction through CCS will require concerted and timely action. The failure to develop a comprehensive and supportive legal and regulatory framework, may ultimately lead to the frustration of national policy commitments and unnecessary project delays.

At this stage, both countries are yet to develop CCS specific legal and regulatory frameworks of the type developed in other jurisdictions around the world. It is imperative that both countries undertake a timely review of the legal and regulatory requirements necessary for supporting project-level deployment at a commercial scale.

2.5.5.4.2 Consider existing regulatory models and approaches to developing legislation

In developing legislation, China and South Korea can look towards existing regulatory models around the world, such as those established in the United Kingdom, Australia and the EU, which offer excellent examples for the design and implementation of CCS-specific legislation.

In all but one instance, one of two approaches has been adopted, with policymakers and regulators deciding to either enhance existing regulatory frameworks with CCS-specific provisions or enact stand-alone CCS-specific legal frameworks. For China and South Korea,

[18] Specialist financiers include development banks, multilaterals and export credit agencies.

the choice of approach in enacting CCS-specific legislation will depend to a large extent on the role and objectives underpinning legislation in each jurisdiction.

2.5.5.4.3 Urgency underpins the development of a legal and regulatory response

The legislative process in other jurisdictions also demonstrate the significance of factors such as political will, domestic political processes, stakeholder engagement and consultation processes and public attitudes towards CCS. In many instances, the management of these factors has led to delays and complex negotiations over the course of several years, prior to the establishment of final regulatory frameworks.

The lengthy timeframes involved in developing legislation demonstrate the need for policy makers and regulators in both South Korea and China to expedite the regulatory process to facilitate the deployment of CCS and ultimately realise national emissions reduction targets.

2.5.5.4.4 Establish CCS-specific policy mechanisms and targets to incentivise project deployment

Investments in CCS require the presence of business models that help to overcome the hard-to-reduce risks identified in Section 2.3. In the absence of business models, investments in CCS are unlikely to occur. This having been said, investments may still go ahead by way of non-market mechanisms, such as direct investment in CCS by governments, such as through state-owned enterprises. This approach, however, may not be scalable for most countries.

Governments can also provide strong signals to industry by setting CCS-specific targets such as clean hydrogen targets or emissions targets for hard-to-abate sectors. For refineries, targets can be complemented by a policy mechanism such as low carbon fuel standards, which can place an explicit or implicit value on the capture of CO_2.

3 Recommendations for capture of CO_2 at refineries

3.1 Summary

This section examines the financial support mechanisms, regulatory arrangements and prerequisites for successful CCS deployment in refineries. A CCS readiness indicator was developed to evaluate which refineries are best placed to deploy CCS in the EU. Lastly, recommendations for CO_2 capture at refineries were developed.

The availability of affordable finance for CCS is critical. Debt financing from commercial banks for CCS is currently difficult due to the immaturity of the CCS industry compared to other industries for which banks have a long history of lending. There are a range of green bonds, sustainable bonds/social bonds that are a potential financing option for CCS at refineries, subject to an assessment, on a case-by-case basis, as to whether the CCS project complies with eligibility requirements of the particular bond. National import export credit agencies can also provide debt finance, loans, lines of credit or bonds as well as insurance and guarantees to support CCS projects, in support of national companies seeking to export goods or services.

For finance of CCS projects the following key messages should be considered:

- There are many types of bond financing options that exist through capital markets, specifically loans from commercial banks, development banks, and other similar or associated lending institutions. Presently, sustainable bond financing definitions either do not explicitly include oil and gas projects or do not include oil and gas projects in combination with CCS under their definitions. This could limit CCS projects at refineries from receiving funding through these financing mechanisms.

- To avail of bond financing under the Green Bonds framework, the activities relating to CCS projects at refineries can potentially fit under the energy efficiency and pollution prevention and control categories (see 3.1.4.1.1 below). However, the project's eligibility will be determined by comparing it against the Green Bond Principle's core components, summarized in a matrix in Table 3. Repsol, the Spanish energy and petrochemical company has utilized the Green Bonds Principles at refineries, albeit without CCS (Repsol, 2017).

- The World Bank and the Asian Development Bank have CCS Trust Funds through which they support the development of CCS projects or supporting activities globally (Global CCS Institute, 2022b). The World Bank made a recent announcement that it would support the development of a domestic carbon market that could include CCS projects (International Finance Corporation (IFC) & World Bank Group (WBG), 2022i). In total, the World Bank has dedicated over USD 55 million in funding from its Trust Fund for CCS associated activities in Mexico and South Africa neither of which were associated with refineries (Global CCS Institute, 2022b; World Bank Group (WBG), 2017a, 2017b).

- CCS projects at refineries can potentially be supported under the following financing facilities. Details on each mechanism can be found in the relevant sub-sections.
    - Potentially with the direct lending facility through the UKEF in the United Kingdom – CCS projects are supported under the Clean Growth Strategy (HM Government, 2017).

- Potentially with project and structured finance through Export Finance Australia in Australia, since Export Finance Australia has supported financing for a refinery and for a CO2 reduction and capture project (Export Finance Australia, 2022d, 2022i).

- Potentially with direct loans through EXIM in the United States since EXIM has a CCS protocol in place and has supported financing for refineries (Export–(Export–Import Bank of the United States (EXIM), 2022d, 2022b).

- Potentially with buyer financing through Eksfin in Norway.

The suitability or readiness of a refinery to have CCS retrofitted to the plant depends on many factors. A Refinery Readiness Indicator was developed and applied to European refineries. It is a benchmarking tool that provides an indication of how close a refinery is to being "CCS Ready" compared to other refineries. The Refinery Readiness Indicator uses seven criteria, each with an appropriate weighting, to calculate the Refinery Readiness Indicator score for each refinery.

- Policy and Regulation
- CO_2 partial pressure and total CO_2 emissions
- Distance to geological storage resource and transport mode (ship and/or pipeline)
- Regulations for transport of CO_2, both domestic and transboundary
- Potential to form a CCS hub, considering other nearby CO_2 sources
- Location Cost Factor
- Presence of other active CCS projects in the host country

Overall, the highest-scoring refineries are large (>2Mtpa CO_2), adjacent to suitable storage and in a country with an enabling environment for CCS. The five highest scoring refineries in the EU were:

1. Shell Nederland, The Netherlands
2. BP Scholven, Germany
3. PCK Schwedt, Germany
4. PKN Orlen, Poland
5. ENI Taranto, Italy

The following high-level messages are clear from the results of the Refinery Readiness Indicator:

- Strong policy and regulatory frameworks create an enabling environment for CCS deployment
- The larger refineries (>2Mpta CO_2) are the highest-scoring, offering the lowest costs per tonne of CO_2
- Access to adjacent and viable storage formations promotes the highest score; however, longer distances to better storage also improve the overall result

Refineries are complex industrial plants with small, lesser complex plants still having many varied CO_2 emission sources. There are three major sources of CO_2 in refineries; process heaters and boilers, FCCs and power generation (utilities). Although hydrogen production only accounts for approximately 2% of refinery emissions, the flue gas that is produced has a significantly higher CO_2 concentration than other sources in a refinery (15 – 99%).

There is a range of technologies available to capture CO_2 from these sources including post-combustion carbon capture, pre-combustion carbon capture and oxy-fuel combustion. The selection of appropriate technologies for a given application should consider the typical partial pressure of CO_2 in a point source, the volume (tonnage) of CO_2 from that point source, and the relative availability and cost of energy sources (heat and electrical).

Within a refinery environment, it is essential that planning for staged deployment of capture projects is undertaken. Refineries have a range of point sources with varying costs and scales, and it is likely that these would be deployed in separate stages rather than as a single, integrated project.

Given the economics in most plants, it is likely that larger-scale capture projects would be deployed on the SMR and/or FCC units in stage one, then progressively working up the marginal abatement cost curve as resources are available.

3.2 Introduction

This section examines the financial support mechanisms, regulatory arrangements and prerequisites for successful CCS deployment in refineries. A CCS readiness indicator was developed to evaluate which refineries are best placed to deploy CCS in the EU. Lastly, recommendations for CO_2 Capture at refineries were developed.

Different funding streams for CCS projects at EU refineries and those for which business cases will be developed will be examined. This work will include a review of financial instruments that are currently available and their relevance to CCS at refineries. This will be done through a literature review and structured interviews with Financiers to examine:

- The role of sustainable bonds for funding CCS at refineries, and how these can be leveraged.
- The role of impact financing from multilaterals, development banks and other International Financial Institutions, and how they can support CCS at refineries.

- The role of Export Credit Agencies and how they can support CCS at refineries.
- How projects can be structured to best leverage applicable funding streams.

Building on the work done in prior tasks and using information available within the Global CCS Institute's CO2RE database, a Refinery Readiness Indicator rating will be developed for each EU refinery. The Refinery Readiness Indicator rating will consider:

- Policy: CCS policy development applicable to each refinery; drawing on previous work in this report
- Storage: Proximate storage sites will be assessed for each refinery.
- Legal and Regulatory: An assessment of the regulatory framework applicable to the deployment of CCS at each refinery.

A high-level overview of CCS technologies and strategy for deployment in a refinery setting will be provided. Focus will be given to retrofitting CCS at existing refineries as few new refineries are expected to be built. Post-combustion (amine absorption), pre-combustion (coupled with existing hydrogen production) and oxygen-rich combustion options will be included. Their nature and general considerations for application, including performance and cost, will be outlined. the approaches to capturing CO_2 from refinery CO_2 sources will be assessed.

Lastly, drawing on prior work in this section and report, general recommendations for CO_2 Capture at refineries will be developed, including:

- General application of the risk mitigation framework developed to refineries.
- Specific policy and regulation arrangements that would enable the capture of CO_2 at refineries.
- Considering Readiness ratings, identification of refineries best placed to deploy CCS and measures to increase ratings.
- Recommendations to enable the financing of Capture facilities at refineries.
- Capture technology and Deployment best practices/strategy.
- Prerequisites for successful CCS deployment in refineries will be outlined.

3.2.1 The role of sustainable bonds for funding CCS at refineries, and how these can be leveraged.

Debt financed through fixed-income securities is a crucial component of global capital markets. Under the international capital market umbrella, the total size of the global debt market in 2020 was USD 123.5 trillion (Securities Industry and Financial Markets Association (SIFMA), 2021). It is larger than the global equity market, valued at nearly USD 106 trillion in 2020. There are many organizations that classify debt capital. There are various international organizations that provide services to categorise, standardize, or classify debt capital (International Council of Securities Associations (ICSA), 2022). In some cases, these associations also assist with regulating securities markets.

The International Capital Market Association is a debt securities association that helps promote market resiliency (International Capital Market Association (ICMA), 2022a). ICMA has developed voluntary frameworks or principles for two broad categories of bonds that are underpinned by financial guidance to support the energy transition considering climate change (International Capital Market Association (ICMA), 2021). Namely, they are:

1. Sustainability bonds.
    a. Green bonds.
    b. Social bonds.
2. Sustainability-linked bonds.

The frameworks for these types of bonds are supported by multilateral development banks like the World Bank's International Finance Corporation (IFC) and the Asian Development Bank as well as by securities organizations like the Climate Bonds Initiative (Asian Development Bank (ADB), 2021a; Climate Bonds Initiative, 2022; International Finance Corporation (IFC) & World Bank Group, 2022).

Green bonds, social bonds, and sustainability bonds have four core components (International Capital Market Association (ICMA), 2021), which are namely:

1. Use of Proceeds.
2. Process for Project Evaluation and Selection.
3. Management of Proceeds.
4. Reporting.

This section will cover each type of bond and if CCS projects at refineries can potentially be financed through these securities.

3.2.1.1 ICMA Green Bonds

Green bonds, defined and described by the ICMA in its Green Bond Principles (GBP), are debt security instruments whose proceeds are used to either finance or re-finance Green Projects, summarized in section 3.1.4.1.1 below (International Capital Market Association

(ICMA), 2022b). There are several types of Green Bonds, summarized in section 3.1.4.1.2 below.

The activities relating to CCS projects at refineries can potentially fit under the 'Pollution prevention and control' category (see 3.1.4.1.1 below). However, the project's eligibility will be determined by comparing it against the GBP's core components, summarized in a matrix in Table 3.

3.2.1.1.1 ICMA Green Projects

Arranged alphabetically, Green Projects must fall under the following categories to be eligible. While this is a descriptive list, it is not exhaustive as Green Projects are not limited to this list alone.

1. Clean transportation.
2. Climate change adaptation.
3. Circular economy adapted products, production technologies and processes.
4. Energy efficiency.
5. Environmentally sustainable management of living natural resources and land use.
6. Green buildings.
7. Pollution prevention and control.
8. Renewable energy.
9. Sustainable water and wastewater management.
10. Terrestrial and aquatic biodiversity (conservation).

Table 3 GBP Core Components Matrix

Green Bonds	
Core component	**Summary**
Use of Proceeds	GBP eligible Green Projects contribute to supporting environmental objectives like climate change mitigation, climate change adaptation, natural resource conservation, biodiversity, conservation, and pollution prevention and control.
Project Evaluation & Selection Process	Bond issuer should communicate the project's environmental sustainability objectives, the process used to determine how the projects fits under the Green Projects category, and processes for identifying and managing social and environmental risks.
Proceeds Management	Net proceeds must be tracked with a high level of transparency through a sub-account or a sub-portfolio.
Reporting	Issuers should keep records for the accurate reporting with a list of projects for which bond proceeds are used.

3.2.1.1.2 ICMA Green Bond Types

There are four types of Green Bonds, all of which must be aligned with the GBP and the proceeds must be used for Green Projects (International Capital Market Association (ICMA), 2022b). They are listed below:

1. Standard Green Use of Proceeds Bond: this type of bond is an unsecured debt instrument/obligation with full recourse to the issuer only.

2. Green Revenue Bond: credit exposure is only to the bond's cash flows with no recourse to the issuer.

3. Green Project Bond: the investor has direct exposure to project risk with or without recourse to the issuer.

4. Secured Green Bond: secured bond where the proceeds are used to finance either Green Projects that secure the bond or other Green Projects.

3.2.1.2 ICMA Social Bonds

Social bonds, like Green Bonds are defined and described by the ICMA (International Capital Market Association (ICMA), 2022c). They are defined in the ICMA's Social Bond Principles (SBP) as debt security instruments whose proceeds are used to either finance or re-finance Social Projects, summarised in section 3.1.4.2.1 below . Like Green Bonds, there are several types of Social Bonds, summarized in section 3.1.4.2.2 below.

The activities relating to CCS projects at refineries are unlikely to fit under any of these categories. The eligibility of al projects will be determined by comparing it against the SBP's core components, summarized in a matrix in Table 3.

3.2.1.2.1 ICMA Social Projects

Arranged alphabetically, Social Projects must fall under the following categories to be eligible. Like with Green Projects, this is a descriptive list, not exhaustive since Social Projects are not limited to this list alone.

1. Affordable basic infrastructure.

2. Access to essential services.

3. Affordable housing.

4. Employment generation and alleviation of unemployment.

5. Food security and sustainable food systems.

6. Socioeconomic advancement and empowerment.

Table 4 SBP Core Components Matrix

Social Bonds	
Core component	**Summary**
Use of Proceeds	Bond proceeds must be used for Social Projects described in section 3.1.4.2.1 above. All projects must have clear social benefits that either mitigate social negatives or generative positive social outcomes.
Project Evaluation & Selection Process	Bond issuer should communicate the project's social objectives, the process used to determine how the projects fits under the Social Projects category, and processes for identifying and managing social and environmental risks.
Proceeds Management	Net proceeds must be tracked with a high level of transparency through a sub-account or a sub-portfolio.
Reporting	Issuers should keep records for the accurate reporting with a list of projects for which bond proceeds are used.

3.2.1.2.2 ICMA Social Bond Types

Similar in structure to Green Bonds, there are four types of Social Bonds, all of which must be aligned with the SBP, and the proceeds must be used for Social Projects (International Capital Market Association (ICMA), 2022c)(International Capital Market Association (ICMA), 2022c). They are listed below:

1. Standard Social Use of Proceeds Bond: this type of bond is an unsecured debt instrument/obligation with full recourse.

2. Social Revenue Bond: credit exposure is only to the bond's cash flows with no recourse.

3. Social Project Bond: the investor has direct exposure to project risk with or without recourse.

4. Secured Social Bond: secured bond where the proceeds are used to finance either Social Projects that secure the bond or other Social Projects.

3.2.1.3 ICMA Sustainability-linked Bonds

Sustainability-Linked Bonds (SLBs) are debt securities whereby issuers commit to achieving predefined Sustainability and/or ESG objectives within a predefined timeframe. They are defined and described in the ICMA's Sustainability-Linked Bond Principles (SLBPs) (International Capital Market Association (ICMA), 2020). This establishes the link for the Sustainability-Linked Bonds. The performance of these fixed-income instruments is measured through Key Performance Indicators (KPIs) against targets called Sustainability Performance Targets (SPTs).

The feature that distinguishes SLBs from Green and Social Bonds is that SLBs do not have a Use of Proceeds component. Hence, proceeds from SLBs need not be used exclusively for Green or Social Projects. They can also be used for general purposes. However, issuers may choose to use the GBP or SBP approach in conjunction with the SLBPs.

SLBs must comply with the SLBP's five core components which are summarized in a matrix in Table 4. SLBs have pre-issuance and post-issuance requirements. Additional details are included in the ICMA's SLBP (International Capital Market Association (ICMA), 2020). The activities relating to CCS projects at refineries can potentially fit under the SLBP. However, the project's eligibility will be determined by how the SLB is set up according to the core component requirements.

Table 5 SLB's Core Component Matrix

Sustainability-Linked Bonds	
Core component	**Summary**
KPI Selection	Must be relevant to the issuer's core business, measurable or quantifiable, verifiable externally, and possess the ability to be benchmarked.
SPT Calibration	SPTs must have certain characteristics: (1) represent material improvements for KPIs and go beyond "Business as Usual", (2) can be compared to external benchmarks or references, (3) possess alignment with the issuer's ESG or sustainability strategy, (4) have a predefined timeline.
Bond characteristics	The SLB's financial and structural characteristics must be able to respond to trigger events relating to the KPIs achieving or not achieving the SPTs.
Reporting	SLB issuers should publish and keep certain information up to date: (1) KPI performance, (2) an assurance report that verifies performance against the SPTs, (3) information that enables investors to judge the level of ambition against the SPTs.
Verification	Qualified external verifiers should be sought out by issuers who can judge performance of the KPIs against the SPTs. This information must be made publicly available.

3.2.2 World Bank Group (WBG)

In keeping with the WBG's missions to end extreme poverty and to promote a shared prosperity the WBG supports sustainable development by providing capital to governments and to the private sector (World Bank Group (WBG), 2022a). The WBG lends to governments through its constituent International Bank for Reconstruction and Development (IBRD) and to the private sector through the International Finance Corporation (IFC). Both institutions are members of the World Bank Group.

CCS projects at refineries can potentially be supported by the World Bank's Green Bonds and Sustainable Development Bonds administered by the IBRD under its Climate Change Mitigation Project category (see 3.1.5.1 below). CCS projects at refineries could also potentially qualify for the IFC's Green Bond's 'reducing impacts at the source' category (see 3.1.5.3 below). However, both the IBRD and the IFC have stringent requirements that must be met before funds are allocated. These requirements are summarized in sections 3.1.5.1 and 3.1.5.3 respectively. The World Bank does not finance new coal-fired power generation since 2010 and upstream oil and gas since 2019 (International Bank for Reconstruction and Development, 2021).

3.2.2.1 IBRD Green Bonds

The World Bank through the IBRD's Funding Program raises fixed-income funds from investors through its Green Bonds program. These bonds are used to find eligible projects in the IBRD's member countries (World Bank Group (WBG), 2022e, 2022c). The Green Bonds program was developed together with the Skandinaviska Enskilda Banken (SEB) to offer investors a triple-A rated fixed-income product that would meet the needs of financing projects that tackle climate change (Skandinaviska Enskilda Banken (SEB), 2022; World Bank Group (WBG), 2022c).

IBRD Green Bonds have specific criteria that need to be met so that funds can be allocated to eligible projects (World Bank Group (WBG), 2022c). They are summarized below:

1. **Project selection criteria**: projects are selected by environmental specialists through a process that has undergone independent verification by the Center for International Climate and Environmental Research at the University of Oslo (CICERO) (Center for International Climate and Environmental Research at the University of Oslo (CICERO), 2015).

2. **Use of Proceeds**: All eligible projects that are funded by the IBRD must be climate resilient and must promote the transition to a low-carbon economy. Some examples of eligible projects are:

    a. Mitigation projects:

        i. Solar and wind installations.

        ii. Funding new technologies that significantly reduce greenhouse gas (GHG) emissions.

        iii. Rehabilitating power plants and transmission facilities to reduce GHGs.

        iv. Transpiration efficiency including fuel switching and mass transport.

        v. Waste management (which includes methane emissions) and constructing energy-efficient buildings.

        vi. Reducing the carbon footprint through reforestation and by avoiding deforestation.

    b. Adaptation Projects:

        i. Flooding protection which includes reforestation and watershed management.

        ii. Improving food security and implementing stress-resilient agricultural systems that helps to reduce deforestation.

        iii. Sustainable forest management and avoiding deforestation.

3. **Review and approval**: after projects are deemed eligible by the Green Bonds' eligibility criteria, they must undergo a rigorous review and approval process and meet the member country's development needs. A screening phase will look for potential environmental and/or social risks.

4. **Allocating funds**: The proceeds from Green Bonds are allocated to a separate cash account through which funds are disbursed over the project's timeframe.

5. **Reporting and monitoring**: The member country's government and the World Bank monitors the progress of the project. It is also supervised and requires the compilation of several reports over the timeframe.

6. **Compliance**: Each project is assessed and reviewed by the Bank's experts and its outcomes are measured against the intended objectives.

3.2.2.2 IBRD Sustainable Development Bonds

The IBRD also maintains a Sustainable Development Bonds program (International Bank for Reconstruction and Development, 2021)(International Bank for Reconstruction and Development, 2021). These bonds are aligned with the Sustainability Bond Guidelines (SBG), covered in section 3.1.3 above. These bonds also have specific requirements, listed below.

1. **Use of Proceeds**: Funds must be used for Green or Social projects that are designed to improve social and environmental outcomes in member countries. Some examples of projects include:

    a. Social Projects that deliver improvements in:

        i. Health, nutrition, childhood development.

        ii. Access to education, school conditions, learning outcomes, teacher training.

        iii. Food security.

        iv. Long term security financial, social, and legal security.

        v. Access to affordable financial products that deliver credit, savings, insurance, transactions, and payments services.

        vi. Affordable housing by reforming regulations and policy and by better access to finance.

        vii. Quality of jobs, skill-building, and in eliminating barriers to jobs for disadvantaged people.

        viii. Effectiveness of formal training (vocational & technical), in developing short-term skills, and in access to apprenticeship programs.

        ix. Providing financial, technical, and advisory support to countries transitioning from coal to cleaner sources of energy.

    b. Green Projects that deliver improvements in:

        i. Agricultural infrastructure and support services while also increasing climate resiliency and market access for small farm holders, advancing climate-smart agriculture, and strengthening food value chains.

ii. Holistic water management and service delivery, while building resilience.

iii. Conserving biodiversity while addressing pollution and the degradation of natural resources.

iv. Market access for minerals and metals from resource-rich developing countries, while minimizing the climate and environmental footprint of mining operations.

v. Disaster risk legislation and national planning.

vi. Climate change mitigation through projects listed in section 3.1.5.1 above.

2. **Evaluation and selection process**: To support sustainable development, the World Bank follows its Environmental and Social Framework. The framework has ten environmental and social standards that must be met (mandatory requirements) by projects that win funding (World Bank Group (WBG), 2022b). Additionally, other mandatory requirements include compliance with the environmental and social policy for investment project financing (World Bank Group (WBG), 2019).

3. **Management of proceeds**: The IBRD follows an liquidity asset management investment policy to ensure that bond proceeds are disbursed when milestones are reached over the timeframe of the project.

4. **Reporting**: The World Bank publishes an annual impact report with details on projects financed over the previous financial year (World Bank Group (WBG), 2021).

3.2.2.3 IFC Green Bonds

While the IBRD lends to governments, the IFC lends to the private sector (International Finance Corporation (IFC) & World Bank Group (WBG), 2022a). The IFC's Green Bond Program is aligned with the ICMA's Green Bond Principles (GBP), see section 3.1.4.1 above for details (International Finance Corporation (IFC) & World Bank Group (WBG), 2022c). The IFC's Green Bond Program's process (International Finance Corporation (IFC) & World Bank Group (WBG), 2022e) is summarized below:

1. **Use of Proceeds & Project Evaluation**: the IFC maintains a climate-related loan portfolio from which eligible project are selected. All projects must comply with the IFC's Performance Standards and the IFC's Corporate Governance Framework (International Finance Corporation (IFC) & World Bank Group (WBG), 2022f, 2022b).

2. Green Bond project investments may include:

a. Cogeneration, reducing energy loss in transmission and distribution, waste heat recovery, and building insulation.

b. Geothermal, solar, hydro, and wind.

c. Reducing source impacts while enhancing conversion efficiency of energy, water, and raw materials to saleable outputs.

d. Components used in renewable energy, cleaner production, energy efficiency, solar photovoltaics, manufacture of turbines, and building insulation materials.

e. Sustainable forestry.

3. **Due Diligence**: All financed projects must go through a rigorous due diligence process, with responsibilities outlined in the IFC's Environmental and Social Performance Standards (International Finance Corporation (IFC) & World Bank Group (WBG), 2022d, 2022f).

4. **Management of Proceeds**: Bond proceeds are disbursed through a sub-portfolio over the course of the project's timeline.

5. **Reporting**: The IFC follows the principles set out in the ICMA's Green Bond Principles (International Capital Market Association (ICMA), 2022b).

6. **Monitoring**: The IFC supervises and monitors all projects/investments including those in the Green Bond program over the project's timeframe (International Finance Corporation (IFC) & World Bank Group (WBG), 2022g).

7. **Portfolio Management**: All projects are independently reviewed ad consider environmental and social impacts.

8. **Evaluation**: The World Bank Group through its Independent Evaluation Group (IEG) evaluates about 25% of the projects, while measuring them against their original objectives (World Bank Group (WBG), 2022d).

9. **Accountability**: Any investigations at the project level are conducted by the Office of the Compliance Advisor/Ombudsman (CAO). The intention is to enhance the project's outcomes; however, the CAO also addresses complaints.

3.2.3 Asian Development Bank (ADB)

The Asian Development Bank (ADB) also has a Green Bond program that is like the those run by the World Bank Group. In addition, the ADB also has a Blue Bond program. Both Green and Blue Bonds comply with the ICMA's Green Bond Principles (GBP), see section 3.1.4.1 above for details (Asian Development Bank (ADB), 2021b).

CCS projects at refineries could potentially fit under the Green Bonds program. However, while the ADB makes specific reference to sequestration of GHGs under its climate change mitigation category (see section 3.1.6.1 below), none of the categories refer to the integration of CCS. Also, the climate change adaption category rules out fossil-fuel related projects under the 'energy infrastructure resilience' category. Under the Blue Bonds program, a reference is made to the capture and storage of GHG emissions with marine-based technologies and solutions.

3.2.3.1 ADB Green Bonds

The ADB's Green Bonds are used for investments in projects that contribute to climate change mitigation and adaptation. The categories are summarised below:

1. **Climate change mitigation**: These projects target reductions in or the sequestration of GHGs from the atmosphere. GHG emission levels are measured against the business-as-usual case.
    a. Renewable energy.
    b. Energy efficiency.
    c. Sustainable transport.
2. **Climate change adaptation**: These projects target reductions in the vulnerability of human and/or natural systems to climate change while improving resiliency and adaptation.
    a. Energy infrastructure resilience.
    b. Water supply and other urban infrastructure and services.
    c. Sustainable transport.
    d. Agriculture.

3.2.3.1.1 ADB Blue Bonds

The ADB's Blue Bonds are used for projects that contribute to ocean health through ecosystem and natural resources management, pollution control, and marine development. The project's distance to the ocean is sued as a screening criterion.

1. Ecosystem and natural resources management:
    a. Ecosystem management and natural resources restoration.
    b. Sustainable fisheries management.
    c. Sustainable aquaculture.
2. Pollution control:
    a. Solid waste management.
    b. Resource efficiency and circular economy.
    c. Non-point source pollution.

d. Wastewater management.

3. Sustainable coastal and marine development:

   a. Ports and shipping.

   b. Marine renewable energy.

3.2.3.1.2 ADB Bond Framework

All projects that receive funding must comply with the Green and Blue Bond Framework. The areas of compliance are like the World Bank's offerings and are in alignment with the ICMA's Principles.

1. **Principles**: the ADB's Green and Blue bonds are in alignment with the ICMA's Green Bond Principles (Asian Development Bank (ADB), 2021b; International Capital Market Association (ICMA), 2022b).

2. **Project eligibility**: eligible project categories are listed in sections 3.1.6.1 and 3.1.6.1.1.

3. **Process for project evaluation and selection**: all projects are selected in alignment with the ADB's Safeguards Policy Statement (SPS) (Asian Development Bank (ADB), 2009). The SPS aims to achieve sustainable project outcomes.

4. **Allocation of proceeds**: bond proceeds are allocation to sub-portfolios from which they are disbursed to the project.

5. **Monitoring and reporting**: the ADB monitors all projects over their timeframes including measuring effectiveness against ESG aspects.

6. **Ensuring compliance**: borrowers must take corrective action if compliance issues arise during the project's timeframe.

7. **External review/second party opinion**: the ADB's Framework has been reviewed by CICERO, like the IBRD's offering (Asian Development Bank (ADB), 2021b; Center for International Climate and Environmental Research at the University of Oslo (CICERO), 2015).

3.2.4 The role of impact financing from multilaterals, development banks and other International Financial Institutions, and how they can support CCS at refineries.

This section will cover the role and impact of multilateral institutions like the World Bank Group (WBG), and development banks like the Asian Development Bank (ADB). These organizations are international financial institutions that are uniquely positioned to finance the energy transition. While the ICMA serves as a standard-setting organization, development banks issue bonds and utilize the bond's proceeds to finance eligible projects. In many cases, development banks utilize the ICMA frameworks to design their bond issues.

The World Bank and the ADB have CCS Trust Funds through which they support the development of CCS projects or supporting activities globally (Global CCS Institute, 2022b). The World Bank made a recent announcement that it would support the development of a domestic carbon market that could include CCS projects (International Finance Corporation (IFC) & World Bank Group (WBG), 2022i). In total, the World Bank has dedicated over USD 55 million in funding from its Trust Fund for CCS associated activities in Mexico and South Africa neither of which were associated with refineries (Global CCS Institute, 2022b; World Bank Group (WBG), 2017a, 2017b).

3.2.4.1 ADB's role in financing refinery projects

The ADB has financed a project at a refinery, the Surgil Natural Gas Chemicals Project operated by Uz-Kor Gas Chemical in Uzbekistan (Asian Development Bank (ADB), 2021c; Hankinson et al., 2021). The gas-to-chemicals project will utilize the gas as raw materials for chemical intermediates. The project does not have a CCS component.

The ADB has provided $ 400 million in two components, (1) a loan of up to $ 125 million, and (2) a 13-year guarantee of up to $ 275 million. The rest of the project's financing features inputs from export-import banks and export credit agencies in Korea and Europe. The ADB's project financing comes through its Private Sector Operations Department (or PSOD), which is the ADB's private sector investment division.

While the ADB is likely not to finance any CCS projects through its Green or Blue Bond program, the bank has looked at financing CCS projects at refineries (Hankinson et al., 2021). The ADB traditional financing mechanisms whereby it lends to governments are listed below:

1. LIBOR-based loans (LBL).
2. Local currency loans (LCL).
3. Concessional Ordinary Capital Resources (OCR) loans [COL]: offered at low interest rates with long maturities, these loans could benefit CCS projects by reducing through cost reductions (Asian Development Bank (ADB), 2022).
4. Debt management products for third party liabilities: includes currency and interest rate swaps, potentially useful for projects in developing member countries (DMCs) with inflation and/or foreign exchange risks.
5. Results based loans: like products offered by development banks, these instruments provide conditional funding subject to concrete results or policy, legal, governance, or regulatory achievements/changes.
6. Multi-tranche Financing Facilities (MFF): these products are typically used to finance medium to long term investments in DMCs and can include multiple funding streams delivered through guarantees, grants, and/or loans and could be co-financed in each tranche.

3.2.4.2 World Bank's role in financing refinery projects

The World Bank has financed three projects at refineries through the IFC which provides financing to the private sector (Hankinson et al., 2021). The projects are listed below with a brief description. None of the projects have a CCS component.

1. **Egyptian Refining Company**: The project involves converting fuel oil into lighter fuel products, upgrading another refinery for better environmental performance and energy efficiency. The IFC invested USD 120 million in equity.

2. **HPCL Mittal Energy**: This oil refinery expansion investment would have increased the throughput of the refinery, however information on the IFC investment amount is not available.

3. **Dangote Industries Limited**: An environmental and social review limited the investments to a fertilizer plant without any towards the oil refinery. The IFC invested USD 150 million through a loan.

4. **Campana Oil Refinery**: Through quality optimizations the project will lower emissions from petroleum-based products. The IFC invested USD 135 million through a loan and USD 50 million in co-lending through the IFC's Managed Co-lending Portfolio Program (MCPP) (International Finance Corporation (IFC) & World Bank Group (WBG), 2022h).

3.2.5 The role of Export Credit Agencies and how they can support CCS at refineries.

This section will cover the role that Export Credit Agencies – also known as export finance organizations – play in financing large industrial and infrastructure projects and how they relate to CCS projects at refineries. Four jurisdictions are covered in this section, all four of which have either sanctioned CCS projects, or have CCS policies/protocols policies in place, or have CCS-related policies under development.

In these four jurisdictions, CCS projects at refineries can be potentially supported through the following financing mechanisms. Details on each facility can be found in the relevant sub-sections.

1. Potentially with the direct lending facility through the UKEF in the United Kingdom – CCS projects are supported under the Clean Growth Strategy (HM Government, 2017)(HM Government, 2017).

2. Potentially with project and structured finance through Export Finance Australia in Australia, since Export Finance Australia has supported financing for a refinery and for a CO_2 reduction and capture project (Export Finance Australia, 2022d, 2022i).

3. Potentially with direct loans through EXIM in the United States since EXIM has a CCS protocol in place and has supported financing for refineries (Export–Import Bank of the United States (EXIM), 2022d, 2022b).

4. Potentially with buyer financing through Eksfin in Norway.

In addition, while the Export–Import Bank of Korea has financed a refinery project (without CCS), it has considered financing for a CCS project but has not yet made a commitment (Robertson et al, 2022; Hankinson et al., 2021) .

3.2.5.1 Export Finance Australia

Export Finance Australia offers a range of services to Australian businesses to support their international business goals (Export Finance Australia, 2022h)(Export Finance Australia, 2022h). Export Finance Australia also supports a wide range of overseas infrastructure projects including in energy and in critical minerals so long as the financed projects benefit Australia, have good governance, are commercially viable, meet environmental and social standards, and meet the requirements in the foreign country (Export Finance Australia, 2022f, 2022e). A short summary of the agency's solutions is listed below.

Export Finance Australia supported an Australian company through an Export Contract Loan to deliver on a CO_2 reduction and capture technology project (Export Finance Australia, 2022d). They also recently supported a critical minerals refinery through a loan (Export Finance Australia, 2022i).

1. **Small business export loan**: Designed for small businesses, these loan solutions do not require collateral and can be applied for online (Export Finance Australia, 2022b). Approvals are quick and the borrowing amount in between AUD 20k to AUD 350k.

2. **Loans**: Loans starting from AUD 350k and above must be used to transactions to export Australian goods and services, or to expand an Australian business in a foreign market, or to support future exports (Export Finance Australia, 2022g). The loan applications do require collateral and has a review and approval period before the loan is granted.

3. **Bonds**: Bonds of AUD 100k and above can be used as security for contracts and purchase orders to export Australian goods and services from Australia directly or as part of a supply chain (Export Finance Australia, 2022c). They have a review and approval period as well as collateral requirements. Four types of bonds are available, namely, (1) Advance payment bonds, (2) Performance bonds, (3) Warranty bonds, (4) US surety bonds.

4. **Guarantees**: Loan guarantees of AUD 250k and above help Australian businesses to get financing from the business' bank to enable the export transactions or to grow international revenue streams. They can also be used for transactions before and after shipment and can be used flexibly within the availability period. Guarantee repayments can be structured as payments from exports. Like loans, they also have a review and approval period.

5. **Project and structured finance**: Export Finance Australia has a better understanding of risk profiles in foreign markets, a longer-term risk time horizon, relationships with foreign governments and with their respective credit agencies than the individual businesses (Export Finance Australia, 2022a). They provide bonds, loans, or guarantees for project finance, buyer finance, supplier finance, sovereign finance, foreign direct investment, and insurance for political risk and export payments. These solutions are across full range of Australian industry sectors.

3.2.5.2 Export Finance Norway (Eksfin)

Norway's export finance agency (Eksfin) provides financing and financial products to help Norwegian businesses to export goods and services abroad. Eksfin provides financial products Export Finance Norway helps Norwegian exporters to succeed abroad. A summary of Eksfin's products and services are provided below:

1. **Loan guarantee for export-related investments in Norway**: For investments that lead to exports, Eksfin provides guarantees to banks, of up to 50% of their risk, that finance the Norwegian investments of companies (Export Finance Norway (Eksfin), 2022e). The investment must directly or indirectly lead to export. The bank approves the buyer's creditworthiness, and the maximum tenor is 8.5 years.

2. **Production loan guarantee**: Norwegian exporters who need their export related production costs financed apply for this guarantee. Eksfin provides the same terms as the Norwegian exporter's bank who applies to Eksfin to guarantee its loan to the exporter (Export Finance Norway (Eksfin), 2022g).

3. **Supplier Credit Guarantee**: Norwegian exporters who wish to ensure that they receive payment for foreign sales if the foreign buyer cannot pay, apply for Eksfin to guarantee 90% of the credit (Export Finance Norway (Eksfin), 2022h). Eksfin assesses and makes premium determinations based on the foreign buyer's creditworthiness. Factors that can affect this assessment include country political risk.

4. **Pre-shipment guarantee**: Norwegian exporters wishing to mitigate losses during a production period if a foreign buyer cannot fulfil an order apply for Eksfin to guarantee 90% of the Norwegian supplier's costs (Export Finance Norway (Eksfin), 2022f). Like the supplier credit guarantee, Eksfin assesses and makes premium determinations based on the foreign buyer's creditworthiness. Factors that can affect this assessment include country political risk.

5. **Investment guarantee**: Norwegian investors or lenders with equity or fixed-income investment holdings apply for this guarantee to mitigate against high political risk in certain countries (Export Finance Norway (Eksfin), 2022c). Eksfin assesses and makes premium determinations based on political risk indicators in the foreign country. After conducting a risk assessment, the guarantee can be up to 90% of the loan with coverage up to 20 years.

6. **Tender guarantee**: Administered by Eksfin and funded by Norfund, Norwegian companies that bid for aid-funded projects in developing countries can apply for this guarantee to get reimbursed for their expenses (Export Finance Norway (Eksfin), 2022i). Companies that have not received a tender guarantee in the preceding 12 months that do not win contracts can receive up to 50% of tender costs that are between NOK 80,000 – 250,000. The guarantee is subject to products that are do not conflict with export controls.

7. **Buyer financing**: Eksfin can provide long-term loans with long maturities to foreign buyers of Norwegian capital goods and services (Export Finance Norway (Eksfin), 2022a). This extends to Norwegian buyers of ships built abroad with Norwegian equipment or those built in Norway, and to foreign companies with Norwegian parentage. The loans are issued with a commercial bank, development bank, or

other financial institutions collaborating with Eksfin and have maturities of at least two years. Eksfin's financial products in this category include directs loans assuming the foreign buyer's credit, a guarantee of another's lenders loan, or a loan where a Norwegian bank or another financial institution guarantees the loan.

8. **Counter guarantee**: These guarantees, of up to 50% of the issuing bank's risk, are issued by Eksfin to Norwegian companies doing business with foreign companies that require a bank guarantee (Export Finance Norway (Eksfin), 2022b). This may be increased up to 70% for guarantees up to NOK 10 million.

9. **Letter of credit guarantee**: Eksfin guarantees the transfer of money between the foreign buyer's and the Norwegian exporter's respective banks of up to 50% of the bank's risk (Export Finance Norway (Eksfin), 2022d). Like the supplier credit and pre-shipment guarantees, Eksfin assesses and makes premium determinations based on the foreign buyer's creditworthiness. Factors that can affect this assessment include country political risk.

3.2.5.3 UK Export Finance (UKEF)

The stated mission of UK Export Finance (UKEF) – the export finance agency of the United Kingdom – is to enable UK exports even if they are unable to secure financing or insurance from commercial banks or other related financial institutions (United Kingdom Export Finance (UKEF), 2022k).

UKEF's products are summarized and listed below:

1. **Financing**: UKEF can help UK exporters sell their goods and services abroad by offering attractive financing to foreign buyers through several financing mechanisms. Each facility has terms and conditions and eligibility criteria.

   a. ***Buyer credit facility***: This is a guarantee on a loan to a foreign buyer to buy UK goods and services (United Kingdom Export Finance (UKEF), 2022c). While the UK exporter receives payment upfront, the foreign buyer has minimum period of two years to repay the loan. This facility is supported through export refinancing or local currency financing.

   b. ***Direct lending facility***: The UKEF can allocate up to GBP 200 million in individual loans to foreign buyers in assistance to purchase UK goods and services (United Kingdom Export Finance (UKEF), 2022e). Provided at a fixed rate of interest in up to 8 currencies, the total available funds are GBP 8 billion of which GBP 2 billion is to support clean growth projects. Clean growth projects are highlighted in the UK's Clean Growth Strategy in which CCUS projects are included (HM Government, 2017). The lending facility for clean growth will be aligned with the ICMA's Green Bond Principles (GBP) (International Capital Market Association (ICMA), 2022b; United Kingdom Export Finance (UKEF), 2022d).

   c. ***Lines of credit***: Foreign buyers can avail of a UKEF line of credit to buy UK goods and services (United Kingdom Export Finance (UKEF), 2022j). It functions like a loan but can be used for multiple contracts.

d. ***Standard buyer loan guarantee***: Typically used for contracts between GBP 1 million – 30 million, this mechanism guarantees a loan made to a foreign buyer to purchase goods and services from a UK exporter.(United Kingdom Export Finance (UKEF), 2022m)

e. ***Supplier credit financing facility:*** The UKEF guarantees payments to financial institutions from UK exporters due to them through promissory notes or bills of exchange obtained by UK exporters (United Kingdom Export Finance (UKEF), 2022n). The UK exporters receive payments for goods and services bought by foreign buyers.

2. **Guarantee schemes**: UKEF supports UK companies in winning export contracts through these schemes (United Kingdom Export Finance (UKEF), 2022k). Like with financing, each facility has terms and conditions and eligibility criteria.

    a. ***Bond support scheme***: UKEF can guarantee up to 80% of a contract bond's value to minimize pressure on a UK exporter's cash flows if a bank needs collateral (United Kingdom Export Finance (UKEF), 2022b).

    b. ***Export development guarantee***: This guarantee helps companies who wish to export from the UK with up to 80% of the lender's risk for up to 5 years. The period is increased to 10 years for clean growth projects, which also includes CCUS (HM Government, 2017; United Kingdom Export Finance (UKEF), 2022f). Typical projects that fall under this scheme require between GBP 100 – 500 million in financing. UKEF only considers transactions of a minimum of GBP 25 million.

    c. ***Export working capital scheme***: This guarantee covering 80% of the lender's risk is to complement a UK exporter's working capital when they win export contracts that stretch their order fulfilment capabilities (United Kingdom Export Finance (UKEF), 2022h). There are no minimum or maximum limitations.

    d. ***General export facility***: UK exporters can avail of this facility to get access to trade finance. They are partial guarantees for trade loans and letters of credit with a maximum repayment of up to 5 years (United Kingdom Export Finance (UKEF), 2022i).

    e. ***Supply chain discount guarantee***: Covering up to 80% of the lender's risk, this facility avail of supply chain finance through a commercial bank. An exporter's suppliers can discount invoices by drawing on it. The exporter gets the advantage of a longer payment term to pay the invoice at face value at maturity (United Kingdom Export Finance (UKEF), 2022o).

3. **Insurance**: This facility is used to manage risks to UK exporters when the private market cannot or is unwilling to offer insurance. Like with financing and guarantee schemes, each facility has terms and conditions and eligibility criteria.

    a. ***Bond insurance***: This scheme covers 100% of bonds issued by UK banks to foreign buyers to facilitate UK exports in the event of unfair practices or political risk (United Kingdom Export Finance (UKEF), 2022a).

b. ***Export insurance***: Covering up to 95% of the risk, this scheme protects against non-payment under the export contract's term or the inability to recover costs related to fulfilling the export contract's terms (United Kingdom Export Finance (UKEF), 2022g).

c. ***Overseas investment insurance***: UK investors can avail of this scheme to cover 90% of the risk when investing abroad (United Kingdom Export Finance (UKEF), 2022l). They can be used for long-terms projects with a limit of 15 years, annual renewal of the same terms is possible over this duration.

3.2.5.4 Export–Import Bank of the United States (EXIM)

EXIM, or the Export-Import Bank of the United States, fills the role of providing financing for American businesses when the private sector is not willing or is not able to provide financing. EXIM can assume the credit and country-related risks to enable these transactions because the bank is backed by the full faith and credit of the United States (Export–Import Bank of the United States (EXIM), 2022a).

EXIM supports US-made goods and services only. It provides export credit insurance, loans for small businesses, and loan guarantees to lenders. It also provides supporting letters of credit and supporting foreign buyer credits to lenders (Export–Import Bank of the United States (EXIM), 2022i). EXIM does not provide grants or personal loans.

EXIM has a CCS protocol in place and has supported financing for refineries (Export–Import Bank of the United States (EXIM), 2022d, 2022b).

A summary of the solutions that EXIM provides to facilitate foreign sales transactions are listed below:

1. **Working capital loan guarantee**: While financing is still provided by private lenders, EXIM serves as an intermediary to provide security for financing that is related to international sale (Export–Import Bank of the United States (EXIM), 2022j, 2022g)s. For qualified exporters, EXIM provides the lending institution with a loan guarantee. For a percentage of the loan, this guarantees repayment to the lender if the US exporter (borrower) is unable to pay and defaults on the loan. The loan from the lending institution can be used for any activities to facilitate sales, e.g., materials, equipment, and labor.

2. **Export Credit Insurance**: This facility serves as an insurance policy for the US exporter's foreign accounts receivable (Export–Import Bank of the United States (EXIM), 2022e). Since EXIM provides backing for foreign receivables if the foreign buyer does not pay, private lending institutions are willing to lend against these previously insecure assets.

3. **Limited recourse project finance**: With this facility, newly created project companies will receive lending from EXIM directly (Export–Import Bank of the United States (EXIM), 2022h). The project's future cash flows are valued and used as the repayment source for the debt instead of other financial institutions, foreign governments, or other established corporations. This financing mechanism is most suited to projects with long-term offtake contracts and those that earn hard currency abroad. EXIM can structure the financing over the project's timeframe.

4. **Structured finance**: Through this facility, existing companies (as opposed to newly created project companies) abroad are viewed as potential borrowers by EXIM (Export–Import Bank of the United States (EXIM), 2022h). Determinations are made based on the company's balance sheet, creditworthiness, loan security enhancements and other sources of collateral. Large infrastructure projects in the manufacturing, oil and gas, and telecommunications sectors have been financed through this mechanism. EXIM facilitates this financing mechanism support a US company's participation in export transactions and to support US jobs.

5. **Finance lease guarantee**: EXIM provides guarantee support for finance leases that transfer all ownership benefits and risks to the lessee (Export–Import Bank of the United States (EXIM), 2022f). A form of medium-term financing, this mechanism is supported by EXIM because lease financing is preferred by some foreign buyers of US goods and services. EXIM will transact with are creditworthy international lessees in both the public and private sectors to guarantee lease financing of US goods and services.

6. **Direct loans**: EXIM can provide direct loans to international buyers in both the private and public sectors (Export–Import Bank of the United States (EXIM), 2022c). The precondition that these loans are provided to creditworthy entities that buy US goods and services, thus helping US companies. The financing is fixed rate for 12-year terms and up to 18-year terms for renewable energy projects. The financing is fixed rate, up to 12 years in general and up to 18 years for renewable energy projects.

3.2.6 How projects can be structured to best leverage applicable funding streams.

There are many types of bond financing options that exist through capital markets, specifically loans from commercial banks, development banks, and other similar or associated lending institutions. Presently, sustainable bond financing definitions either do not explicitly include oil and gas projects or do not include oil and gas projects in combination with CCS under their definitions. This limits the ability of CCS projects at refineries to avail of these types of financing mechanisms.

If an attempt is made for CCS projects at refineries to avail of bond financing under the sustainable bond category, the following types of financing mechanisms may seem amenable:

1. Green Bonds under the *energy efficiency* or the *pollution prevention and control* categories. Repsol, the Spanish energy and petrochemical company has utilized the GBP at refineries, albeit without CCS (Repsol, 2017).

2. Export financing through the UKEF's direct lending facility in the United Kingdom (United Kingdom Export Finance (UKEF), 2022d, 2022e). CCS is included in the UK's Clean Growth Strategy (HM Government, 2017).

3. Export financing through EXIM in the United States. EXIM has a protocol in place to support CCS projects (Export–Import Bank of the United States (EXIM), 2022d). EXIM has also supported transactions at refineries (Export–Import Bank of the United States (EXIM), 2022b).

4. Export financing through Export Finance Australia. Export Finance Australia has recently issued a loan for a critical minerals refinery and has supported a company in a CO_2 reduction and capture project (Export Finance Australia, 2022d, 2022i).

3.3 CCS Readiness Indicators for EU Refineries

3.3.1 CCS Readiness Concept and the Refinery Indicator

Readiness indicators are widely accepted benchmarking tools for tracking a particular technology or an industry's development.

The Institute produced the CCS Readiness Index to track the development and deployment of CCS (Havercroft & Consoli, 2021). The premise of the Index is to understand the potential deployment of CCS in a country considering current technical and non-technical conditions. The Index results clearly show that those countries that create an enabling environment for CCS, with high scores in the Index, also have a higher success rate for CCS projects. The Index is used in global energy and climate indicators, such as The Circular Carbon Economy Index 2021 (Luomi et al., 2021). However, the CCS Readiness tracks a country's progress rather than an individual facility.

The Global CCS Institute built the CCS Facility Readiness Indicator to assess the viability of an emissions-intensive industrial plant to utilise CCS technologies to reduce its emissions. The Institute has adapted this tool for refineries of Europe, known as the Refinery Indicator.

The Facility Indicator is a criteria-based assessment that captures three pillars critical to the successful deployment of CCS: an enabling environment for deployment, commercial viability, and low technical complexity. These three pillars are present across all criteria.

A facility's readiness score is not a ranking exercise, with the highest scoring facility being the most likely to succeed. In addition, a high score does not result in deployment because too many factors are not accounted for when considering deployment.

However, a facilities readiness score is a benchmarking tool, with scores interpreted as an indication of how close it is to being "CCS Ready" compared to other facilities, highlighting its strengths and weaknesses across the technical and non-technical criteria.

3.3.2 Data, Methodology and Scoring System

3.3.2.1 Data

The datasets are detailed below.

3.3.2.1.1 Refinery

The refinery data is from the European Pollutant Release and Transfer Register (E-PRTR)(European Commission, 2022d), which is part of the public domain databases of pollutant releases - EPER (European Pollutant Emission Register). The E-PRTR requires yearly emissions reporting of key species (in this case, CO_2) where those emissions exceed a minimum threshold of 100,000. The category "Mineral oil and gas refineries" is used in this analysis. In addition, this dataset cross-references the McKinsey Refinery Capacity Database (McKinsey, 2020) and the EU ETS emissions reporting.

The production rates for the refineries utilise McKinsey Refinery Capacity Database (McKinsey, 2020) and other minor sources where required.

3.3.2.1.2 Storage

The Institute's Basin Suitability Assessment Tool also uses a criteria-based approach, utilising the Institute's data and expert knowledge on commercial deployment for storage and best practice manuals for basin and site selection.

At a high level, these criteria include:

- Basin geology: tectonic evolution, depositional history, geomechanics and fault characterisation
- Reservoir and seal characterisation
- Storage resource assessment maturity
- Data availability: the existence of wells, seismic, and monitoring data and access to that data
- Accessibility: regulations, environment, competition for water, oil, gas, or CO_2 resources, social impacts

Adding the individual storage criterion's scores creates a final score for each basin. The final score places basins into one of the following four categories:

1. Highly suitable basins have sufficient data to appraise individual storage sites for large-scale CO_2 storage immediately. A highly suitable basin meets the three criteria below:
    i. High confidence in storage resource estimates
    ii. Storage formation is viable for large-scale storage
    iii. A site(s) is identified for exploration or appraisal
2. Suitable basins have viable storage formations, but confidence in storage resources and maturity of assessment is lower than that of highly-suitable basins
3. Possible basins generally have immature characterisation and score poorly in data, accessibility, and regulation criteria but are likely to host viable reservoirs and seals for storage
4. Unlikely basins have limited potential to host viable reservoirs and seals for storage or the storage potential is unknown due to a lack of geological data and information.

Finally, the storage units of the European Commission European CO_2 Storage CO2StoP project (CO_2 Storage Potential in Europe) determined the optimal location within basins and storage resource potential.

The basin's suitability is detailed in Figure 14. The basin suitability, nearest CO2Stop site and associated refinery are in Appendix F – Refinery Indicator Results: Storage

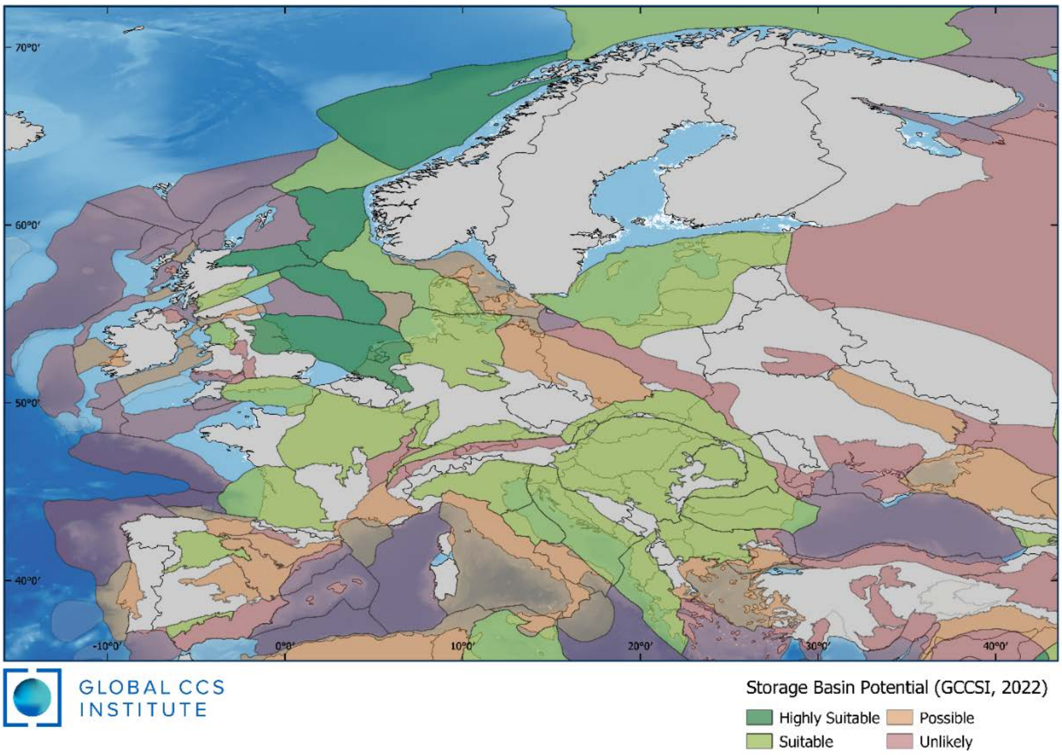


Figure 13. European Basin Suitability Map. Source: GCCSI (2022)

3.3.2.2 Criteria

The Refinery Indicator developed for each EU refinery has seven criteria (Table 6). Four criteria are technical factors of the refinery (capture rate, transport type and location, storage quality and quantity). The other three criteria are non-technical factors - domestic policy and regulatory frameworks, location cost-factor, and active CCS projects (Table 6).

Table 6. Criteria of the CCS Facility Readiness Indicator.

Criteria	Explanation	Rationale	Score	Weighting (%)
Criterion 1 - Policy and Regulation	Cumulative Score of the Policy and Regulatory Indicators. Values are derived from the CO2RE Database	A country with supportive policy and regulatory regimes builds an enabling environment for the deployment of CCS	Maximum score 100	30

Criteria	Explanation	Rationale	Score	Weighting (%)
Criterion 2 - Capture	The CO_2 partial pressure and total CO_2 emissions for the refinery	The partial pressure of CO_2 reflects the relative ease with which CO_2 can be captured from a gas mixture. Higher partial pressures are easier and cheaper to capture than lower pressures because less external energy is required to increase the CO_2's partial pressure to that in the final captured CO_2 stream. Capture costs will also decline, on a cost per tonne CO_2 basis, as the scale of the capture plant increases. For a complex refinery with multiple capture plants as the overall emissions increase the capture costs and costs for integration into the existing refinery should decline, on a cost per tonne CO_2 basis.	Score 100= >250 Score 70= 100-250 Score 50= 25-100	30
Criterion 3 - Transport and Storage	Distance and type of transport (onshore/offshore pipeline or shipping) to nearest suitable storage complex and its quality and resource potential	Access to a nearby highly-suitable storage site with sufficient resources is lower cost and technically less challenging	Scores: 15-100. See Table 11 and Table 12 for scores breakdown.	25
Criterion 4 - Regulations on the transportation of CO_2	Assesses the regulatory complexity of transporting CO_2 and offshore storage within jurisdictional borders, and international export and import of CO_2	Regulatory barriers may arise if a refinery needs to transport CO_2 with offshore storage. Complexities arise under maritime dumping laws, including the London Protocol (LP) and can apply to both transport and storage of CO_2 within jurisdictional borders and international import and export of CO_2.	Score 100 = -No export of CO_2 -Nation is Party to LP if offshore storage -Export CO_2, but all Parties have declared intent to export/import Score 50= -Only one Party has declared intent to	5

Criteria	Explanation	Rationale	Score	Weighting (%)
			export Score 0 = -Not Parties to the Protocol; this can include within domestic borders	
Criterion 5 - Hub Potential	Potential to form a CCS network by combining multiple sources of CO_2 within 100 km of the refinery	CCS networks can reduce overall costs and operational risks to a project	Score 100= >5Mtpa CO_2 Score 70= 2.5-5.0 Score 30= 0.01-2.5	5
Criterion 6 - Location Factor	Location cost factor using CDOL Richardson International Construction Factor	Location cost factors can impact the overall cost of the CCS project	Score 100= Below Average Score 70= Average Score 30= Above Average	5
Bonus Point - Active CCS Project	Active CCS Project in the same country	If a country has a CCS project, the technical, policy, and regulator aspects are in place in that country for CCS deployment	Score 10= Operation/Construction Score 5= Advanced Development	N/A

3.3.2.2.1 Criterion One: CCS regulation and policy

The objective of this criteria is to determine the domestic policy and regulatory frameworks for CCS for each refinery. A supportive policy environment with a clear, robust regulatory framework is critical to the successful deployment of CCS.

The CCS legal and regulatory indicators offer a detailed examination and assessment of a country's legal and regulatory frameworks. The Refinery Indicator focuses upon a broad spectrum of administrative and permitting arrangements across the project lifecycle, including issues related to environmental assessments, public consultation and long-term liability

The CCS policy indicator records an individual country's CCS policy development. The Refinery Indicator tracks an overall spectrum of policies ranging from direct support for CCS to broader implicit climate change and emission reduction policies. The resulting indicator score represents a comprehensive model for tracking progress and opportunities for developing policies to support CCS deployment.

The data and scores (out of 100) are derived from the Global CCS Institute's CO2RE database (Global CCS Institute, 2022a).

3.3.2.2.2 Criterion Two: CO_2 Capture

This criterion aims to surmise the cost of CO_2 capture from a particular refinery. The criteria include several sub-criteria.

Based on IEAGHG (2017c) Techno-economic evaluation of oil refineries, the analysis behind the criteria assessment summarises the costs and complexity of capture for each refinery through evaluating the refinery configuration, production rate and total emissions.

The assessment uses four case studies (Table 7). Through analysis of design capacity, fuel type, CO_2 partial pressure and total emissions of each unit within the four case studies, a pseudo techno-economic ranking can be derived.

Table 7. Capture case studies for Criteria 2.

Case	Case Description	Refinery Size (KBPSD) Kilo-barrels per stream day
Case 1	Skimming Refinery (simple refinery, lighter fuels)	100
Case 2	Medium Conversion Refinery (larger-scale, heavier fuels, eg. process fuel oil (FCC))	220
Case 3	High Conversion Refinery (dirty crude oils, intensive conversion units, more methane to clean up fuels)	220
Case 4	High Conversion Refinery	320

The case studies consider a refinery scale up to 320 kilo-barrels per stream day (KBPSD), however, there are mega-refineries at a capacity of >500 KBPSD. The criteria defined in this analysis will still be applicable for these larger-scale mega-refineries.

The partial pressure of CO_2 reflects the relative ease with which CO_2 can be captured from a gas mixture. Higher partial pressures are easier and cheaper to capture than lower pressures because less external energy is required to increase the CO_2's partial pressure to that in the final captured CO_2 stream.

For a typical refinery, the following process units and utilities have the following share of refinery CO_2 emissions and stream properties influencing the capture costs and complexity.

Table 8: Typical CO_2 sources, their share in total refinery CO_2 emissions and the corresponding CO_2 concentrations in them.[19]

Sources of CO_2 emissions	Share of refinery CO_2 emissions	Typical CO_2 concentration	Gas stream pressure (bar)[20,21]
Furnaces and boilers	65%	7 - 11%	1 – 3
Fluid catalytic cracking (FCC) Regenerators	16%	13%	2.4 – 3.8
Power generation (55% imported)	13%	3%	1
Steam methane reformers (SMRs)	2%	15 – 45%*	1 - 22

* An SMR has multiple CO_2 sources, and the concentration depends on the capture point.

As the configuration, and therefore specific sources of CO_2 for a refinery are often not shared for competitive reasons, this criterion takes the following assumptions based off the refinery capacity (KBPSD).

For smaller refineries, it is assumed that they are of reduced complexity with no Steam Methane Reformer (SMR) for hydrogen generation and no Fluid Catalytic Cracker (FCC), two typically large higher partial pressure process units. Based on the typical share of refinery emissions in Table 8, the following partial pressures for overall refinery CO_2 sources were assumed.

- For refineries less than 100 KBPSD a partial pressure of 0.09 Bar(a) was assumed
- For refineries greater than 100 KBPSD a partial pressure of 0.11 Bar(a) was assumed

A refineries capacity (KBPSD) is derived from McKinsey Refinery Capacity Database (McKinsey, 2020)

Capture costs will also decline, on a cost per tonne CO_2 basis, as the scale of the capture plant increases. For a complex refinery with multiple capture plants, as the overall emissions increase the capture costs and costs for integration into the existing refinery should decline on a cost per tonne CO_2 basis.

The refinery's annual emissions are derived from the European Pollutant Release and Transfer Register (E-PRTR) (European Commission, 2022d).

The final result is the overall cost per tonne of CO_2 avoided against the partial pressure in the flue gas multiplied by the overall refinery emissions that can be used as an indicator for overall

[19] International Energy Agency (IEA), (1999) The reduction of Greenhouse Gas Emission from the Oil refining and Petrochemical Industry. Report Number: PH3/8.

[20] Hsu et al., (2022) State-of-the-art review of fluid catalytic cracking (FCC) catalyst regeneration intensification technologies. Energies, 15, 2061.

[21] https://ieaghg.org/exco_docs/2017-TR3.pdf

capture costs. From here, each refinery, according to their case study can be categorised into three scores (Figure 15), detailed below:

- >250 points= 100
- 100-250 points = 70
- 25-100 points = 50

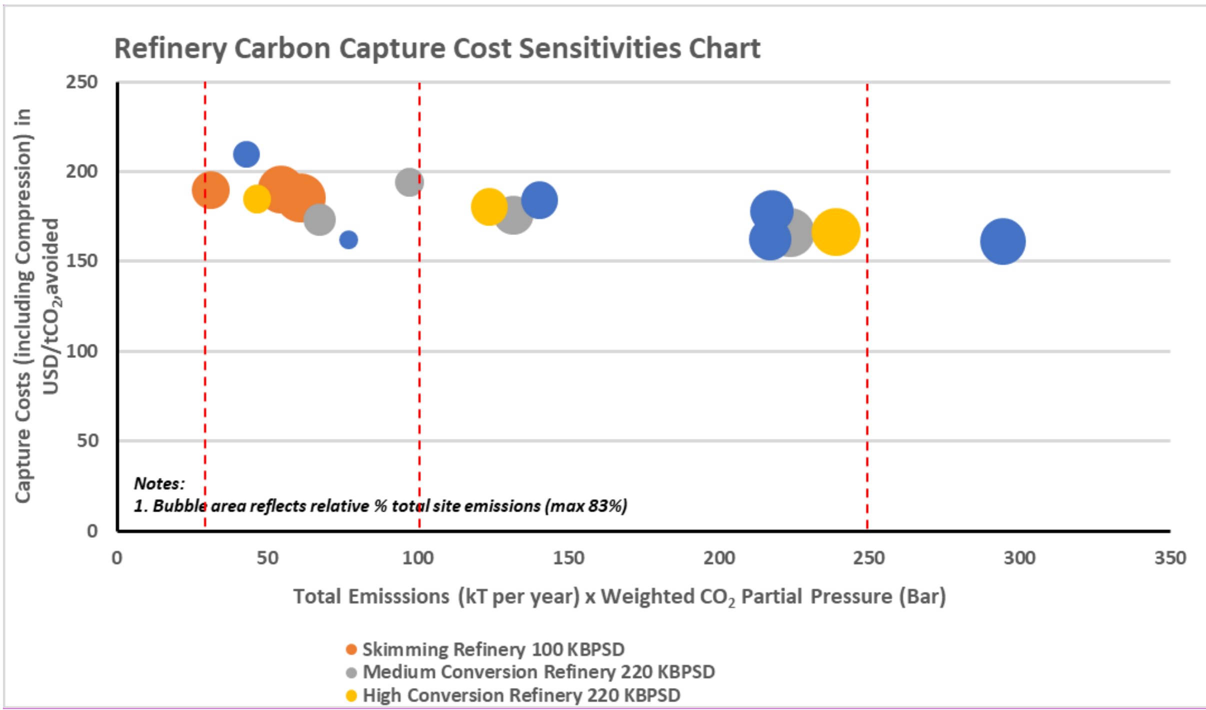


Figure 14.Refinery carbon capture cost sensitivity chart.

3.3.2.2.3 Criterion Three: Transport and Storage

This criterion aims to surmise the lowest cost and least complex option for transporting and storing CO_2 from a particular refinery. The criteria include several sub-criteria.

3.3.2.2.3.1 Storage

The first step is identifying the storage location, quality and resource potential nearest to each refinery. Selecting the closest storage unit with sufficient resources for each refinery, preferencing highly suitable and suitable basins. The final scores of resource quantity versus quality are presented in Table 9. Basin suitability is discussed in the Section: Data above. The area of interest selected within each basin is determined by the location of CO_2StoP's storage unit or daughter unit[22]. The resource quantity is determined from the CO2Stop Resource Calculation for a storage unit, as follows:

- Limited: theoretical storage resource is comparable to 30 years of injection rates for the refinery.
- Competition: multiple refineries are accessing a storage unit
- Sufficient: theoretical storage resource orders of magnitude larger than emissions from surrounding refineries.

Table 9. Storage quality and quantity scores

	Basin Suitability		
Resource	Possible	Suitable	Highly suitable
Limited	1	1	2
Competition	1	2	2
Sufficient	2	3	3

3.3.2.2.3.2 Transport

The transport analysis starts on the basis of annual CO_2 emissions versus distance to storage formation. The parameters of type, length, and capacity are defined by the IEAGHG (2021) in cost ranges and detailed in Table 10. These cost ranges are then translated into scores of one to three (Table 11). The flowrate is the annual emissions from the European Pollutant Release and Transfer Register (E-PRTR) refinery data used in Criteria Two. The nearest (direct-line) storage unit or daughter unit with sufficiently defined storage resources was used as the distance for transport. This analysis does not consider avoiding prohibited areas, geography, changes in elevation, shipping routes or pipeline easements. Collectively the transport and storage sub-criteria are used to score out of 100 (Table 12).

Table 10. Parameters for Transport Costs.

	Onshore pipeline		Offshore pipeline		Ship
	EUR 10	EUR 25	EUR 10	EUR 25	EUR 25
Distance (km)	Flowrate (Mtpa)	Flowrate (Mtpa)	Flowrate (Mtpa)	Flowrate (Mtpa)	Flowrate (Mtpa)
100	0.5		1	0.3	0.4
250	1.9	0.43	3	0.9	0.5
500	7.5	1.25		2.7	0.8
750		2.7		6.1	0.9
1000		4.4			1.35

[22] Definition Storage Unit: A storage unit is defined as a part of a reservoir formation that is at depths greater than 800 m and which is covered by an effective cap rock. Daughter units are defined as structural or stratigraphic traps which have the potential to immobilise CO_2 within them, e.g. domes or proven oil and gas fields.

Table 11. Parameters for Transport Scores

	Onshore pipeline		Offshore pipeline		Ship	
Distance (km)	Flowrate (Mtpa)	Points	Flowrate (Mtpa)	Points	Flowrate (Mtpa)	Points
100	>0.5	3	>1	3		
100	<0.5	2	0.3-1	2	>0.4	2
100			<0.3	1	<0.4	1
250	>1.9	3	>3	3		
250	0.43-1.9	2	0.9-3	2	>0.5	2
250	<0.43	1	<0.9	1	<0.5	1
500	>7.5	3				
500	1.25-7.5	2	>2.7	2	>0.8	2
500	<1.25	1	<2.7	1	<0.8	1
750	>2.7	2	<6.1	2	>0.9	2
750	<2.7	1	>6.1	1	<0.9	1
1000	>4.4	2			>1.35	2
1000	<4.4	1	all	1	<1.35	1

Table 12. Final scoring of the Transport and Storage Criteria

	Storage Quality		
Transport Score	**1**	**2**	**3**
1	15	35	50
2	35	50	75
3	50	75	100

3.3.2.3 Criterion Four: Regulations of the Transport of CO_2

Where it is anticipated that CO_2 will be exported and stored in offshore, subsurface geological formations, obligations arise under regulatory frameworks governing the disposal of waste in the marine environment, including the London Protocol (1996).

In 2009 Contracting Parties adopted a formal amendment to the Protocol, known as Article 6. The amendment previously had the effect of prohibiting transboundary CO_2 transport for offshore storage. Despite the amendment's adoption, an insufficient number of parties have ratified the amendment that requires two-thirds of the Protocol's Parties to enter into force for all Parties. At the time of writing, the following EU Contracting Parties had submitted acceptances of the amendment: Denmark, Estonia, Finland, Netherlands, Norway, and Sweden.

In 2019, Parties agreed to allow for the provisional application of the amendment to Article 6, allowing proponents to proceed with transboundary CO_2 transport and storage plans. Parties must declare a provisional application and notify the International Maritime Organisation (IMO) of any arrangements or agreements. Furthermore, Parties need to meet the standards prescribed by the Protocol. The governments of Norway, Denmark and the Netherlands have deposited declarations stating their intent to allow the provisional application of the 2009 amendment pending its entry into force.

The premise of this criterion captures the regulatory barriers that may arise if a refinery needs to transport CO_2 across international boundaries. For example, if a refinery resides in a jurisdiction that has not submitted acceptance for the Article 6 amendment, the movement of CO_2 may be more complex. This complexity also applies to the country accepting CO_2 for storage.

Scoring is commensurate with complexity. A score of 100 is awarded for refineries that meet either of the following three factors:

1. Onshore transport only
2. Transport and offshore storage within jurisdictional borders
3. All parties (countries hosting the refinery and the storage site) have deposited their declaration of intent to export or import CO_2

A refinery that requires the transboundary movement of CO_2, but one country has not deposited its declaration of intent to export or import CO_2 receive a score of 50. A score of zero is given to those refineries that are within a territory which are not a party to the Protocol or plan to export to a non-party country.

3.3.2.4 Criterion Five: Network Potential

Capture projects, including refineries, sharing CO_2 transport and storage infrastructure (pipelines, shipping, port facilities, and storage wells) are known as CCS networks. Networks enable smaller projects to benefit from economies of scale by transferring the costs across the entire technical chain. It also reduces operational risks and technical complexity by allowing each entity to focus on its core competencies. For example, an oil and gas company could build and operate the CO_2 transport and storage infrastructure, charging each plant a cost per tonne of CO_2 to transport and store their CO_2.

The emission sources surrounding each refinery are derived from European Pollutant Release and Transfer Register (E-PRTR) (European Commission, 2022d). Each source within 100 km (direct line) of the refinery and their emissions were added together to give a cumulative million tonnes per annum of CO_2. The economies of scale improve the larger the network, and the refineries were scored accordingly:

- >5 Mtpa CO2 = 100
- 2.5-5.0 Mtpa CO2 = 70
- 0.01-2.5 Mtpa CO2 = 30

3.3.2.5 Criterion Six: Location Cost Factor

The country the refinery operates in can impact the cost of the overall CCS Project and is known as the Location cost factor. The dataset used in this study is the CDOL Richardson International Construction Factor (Richardson, 2021).

Scoring is simple: those countries above the average scoring lower - 30 points; average – 70 points; and below-average scoring 100 points.

3.3.2.6 Criterion Seven: Active CCS Project

The basis of this last criterion is if a previous CCS project is in operation or under construction (scores 10 points) or in Advanced Development (scores 5 points), that country has all the required technical and non-technical factors for future projects to commence. It also infers that all barriers are overcome to enable deployment. This criterion uses the Global CCS Institute's CO2RE database (Global CCS Institute, 2022a)

3.3.2.7 Scoring

The Refinery Readiness Indicator scores a refinery based on the total of each of the seven criteria (700). The criteria are then weighted to emphasise the importance of each measure relative to the other (Table 6). The weightings are strongest for the factors directly impacting the refinery's commercial viability and technical complexity, with heavy weighting on criteria two and three. In addition, supportive policy and regulatory frameworks are also critical for a project's commercial viability and are weighted accordingly.

3.3.3 Results

This scope of work and report aims to create a criteria-based assessment method to identify the CCS Readiness for European Refineries. Hence, this section presents only a short review of the results and analysis of the Refinery Indicator to show its implementation. The full results are in Appendix D – Refinery Maps.

3.3.3.1 National emissions and refineries

The national emissions from refineries in Europe are declining due to energy, emissions and environmental policies. Also, declining domestic demand impacts overall emissions (Marschinski et al., 2020).

The highest emitting country based on cumulative emissions from their refineries is Germany (22 MtpaCO_2), followed by Italy (18 MtpaCO_2), with Spain and the Netherland at 11 MtpaCO_2 (Figure 16). This result is not surprising given that Germany has the most significant number of refineries at 16, with Italy (11) and France (7) and Spain (7) (Figure 17).

However, when reviewing the emission intensity (Figure 18), Poland and Austria have the highest emitting facilities. In contrast, Ireland, Czechia and Denmark have the lowest emissions intensity.

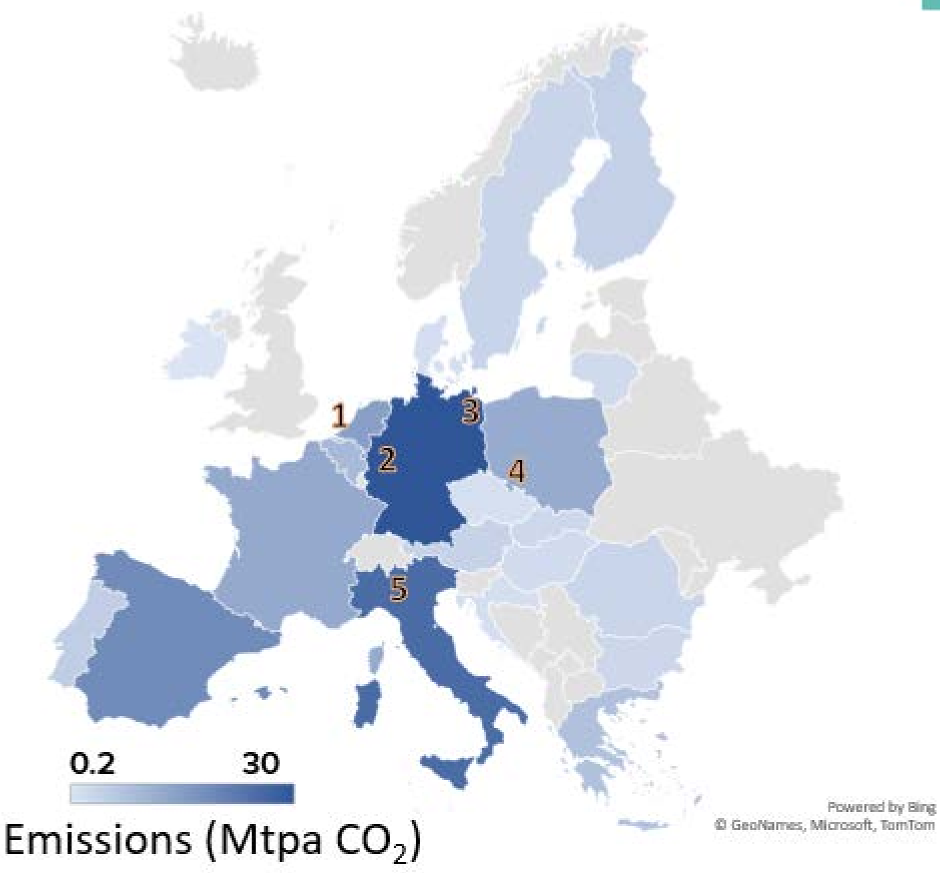


Figure 15. Net Refinery Emissions in Europe, including top-five refinery emitters.

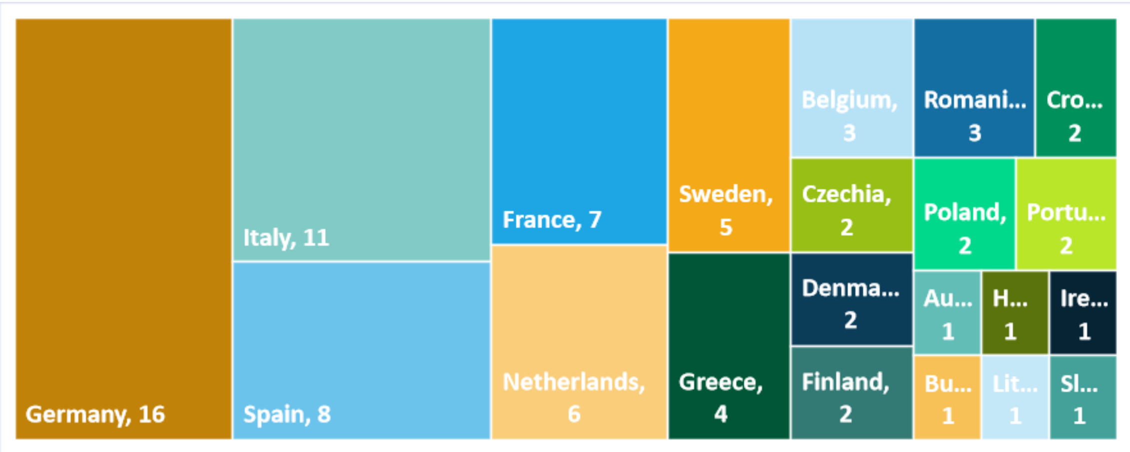


Figure 16. The number of refineries in each country.

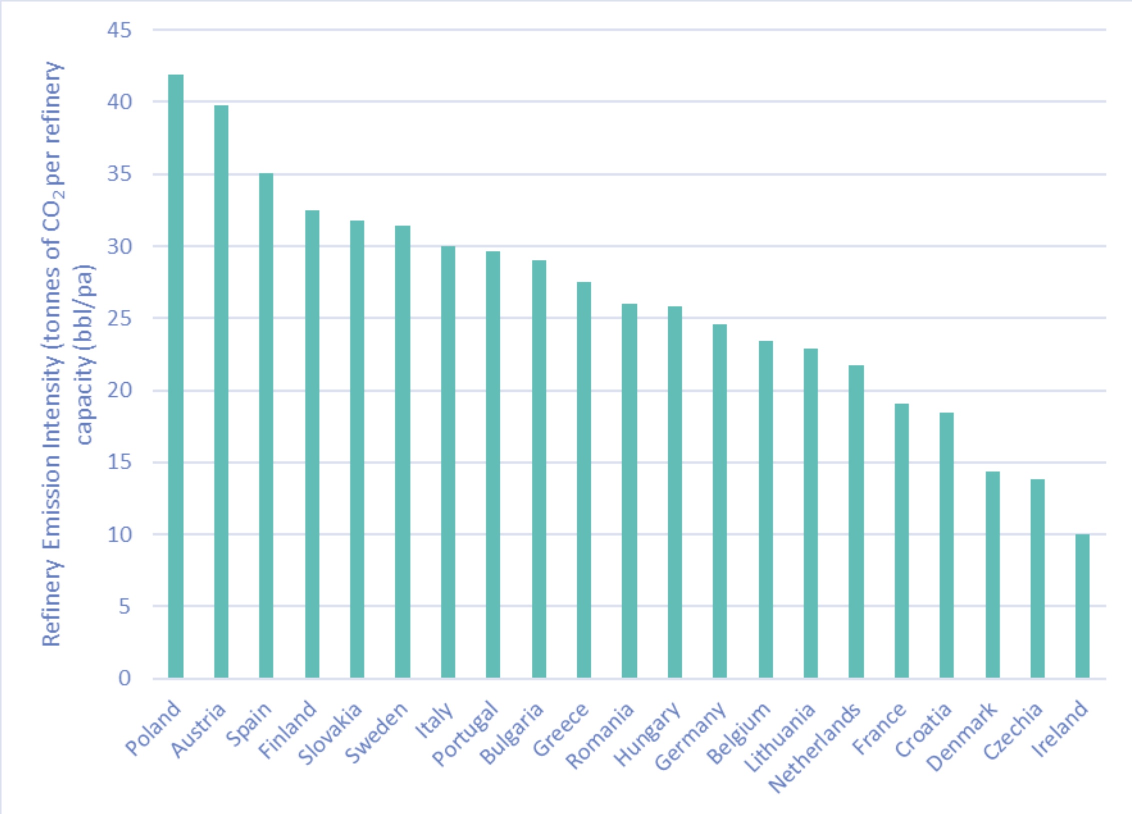


Figure 17. Refinery Emission Intensity

3.3.4 Refinery Scores

In reviewing the final results of the top 20 scoring refineries (Figure 19; Table 13), it is clear that those refineries score highest in the first three criteria – policy and regulation, capture, and transport-storage. The heavy influence of these criteria is by design. The criteria's weighting is high due to their importance to project viability.

Overall the highest-scoring refineries are large (>2MtpaCO2), adjacent to suitable storage and in a country with an enabling environment for CCS. However, not one criterion dominates all the high-scoring refineries. For example, Poland's PCK Orlen is a top-five refinery. However, the country of Poland scores low in criterion one.

Table 13. Top Scoring Nations of the Refinery Indicator.

Refinery	Country	Annual Emissions (MtCO$_2$)	Final Score (Weighted)
Shell Nederland	Netherlands	4.21	79
BP Scholven	Germany	3.32	77
PCK Schwedt	Germany	3.85	77
PKN Orlen	Poland	6.95	75
ENI Taranto	Italy	2.37	74
Total Antwerpen	Belgium	4.01	73
Total Normandie	France	2.37	73
S.A.R.P.O.M.	Italy	0.98	71
Orlen Lietuva	Lithuania	1.71	71
BP Rotterdam	Netherlands	2.25	70
ESSO Nederland	Netherlands	2.01	70
Repsol Cartagena	Spain	2.40	70
Mol Magyar	Hungary	1.55	70
ENI Livorno	Italy	1.11	69
Slovnaft (Mol)	Slovakia	2.00	68
MIRO	Germany	2.05	68
Shell Rheinland,Sud	Germany	2.18	66
Raffineria Milazzo	Italy	2.31	66
Equinor Denmark	Denmark	0.54	65
Refinaria De Sines	Portugal	2.60	65

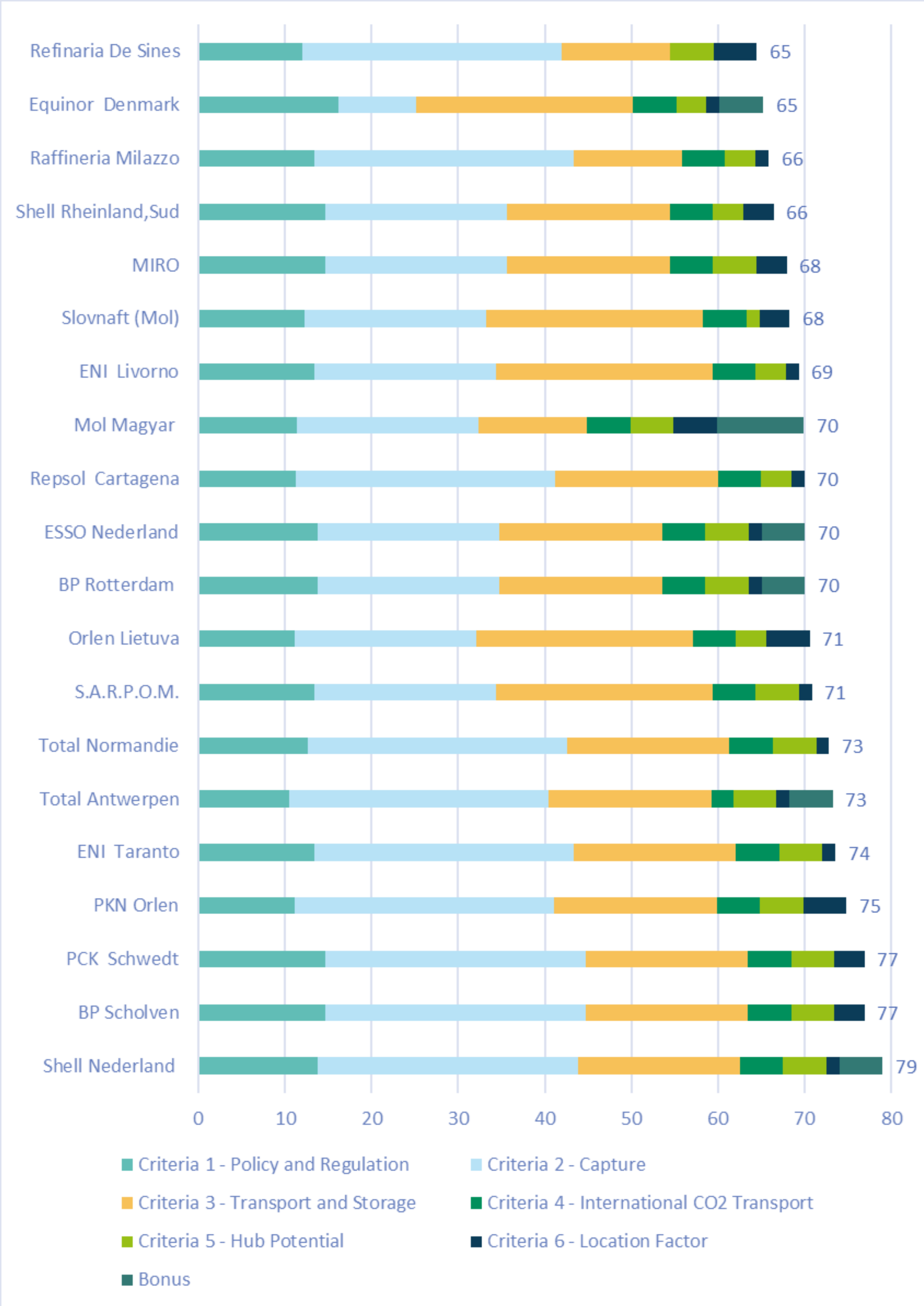


Figure 18. Refinery Indicator scores and proportional indicator contributions

For criterion one, those countries with supportive and robust regulatory and policy frameworks rank highly. Those refineries in the Netherlands, Germany and Italy all feature heavily in the top 20. Generally, the top 20 emitting refineries have annual emissions of over 2Mtpa CO_2 with few exceptions. This trend is evident in Figure 20.

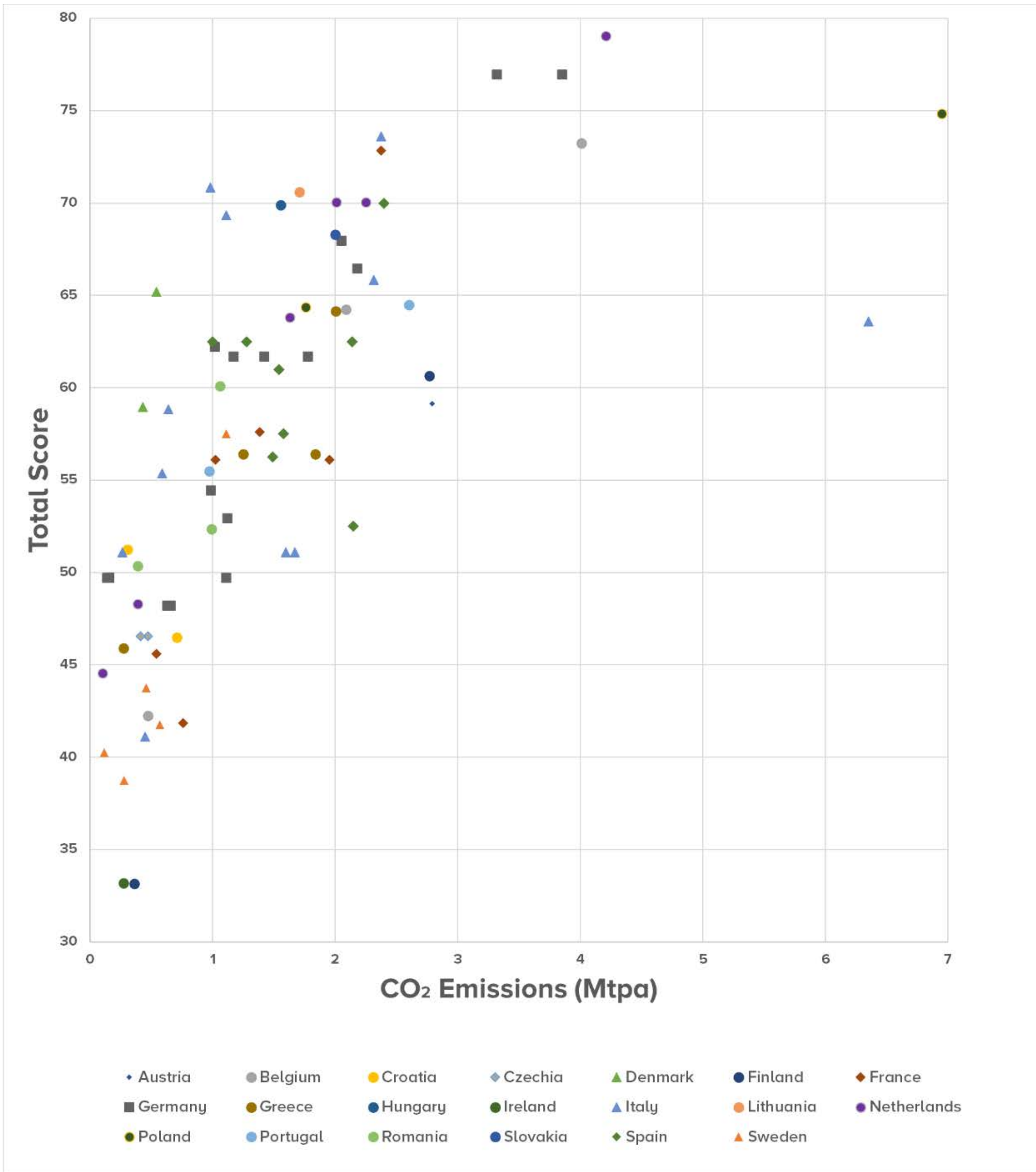


Figure 19.Refinery Indicator Score versus emissions.

The annual emissions impact criterion two foremost, as the greater the emissions (aligned with production rates), the lower the capture costs. Higher CO_2 capture rates also impact the transport costs analysed in criterion three. Hence higher emitting refineries reach higher scores. This overall conclusion generally applies to all CCS projects globally across most industries.

Finally, on criteria 3, each refinery has a mix of suitability for storage, distance and transport. The trends include:

- Onshore transport and storage networks rank highest
- Refineries targeting 'possible' basins must be adjacent or onshore
- Shipping CO_2 or pipeline distances greater than 100km (offshore), and 200km(onshore) reduces the overall score.

The Institute's analysis of successful and unsuccessful CCS projects over the past two decades shows that the viability of a project, from a technical aspect, is dependent on a balance of transport and storage. A higher injection rate and storage capacity can offset longer distances or technically complex transport (e.g. shipping).

Despite their low weight (5%), criteria 4-6 are critical to the deployment of CCS in European refineries. For example, being a non-Party to the London Convention can create significant regulatory burdens to deploy. Especially if two Parties are attempting the Export and import of CO_2. As a result, the Project may become unviable.

In addition, if a refinery can form a network where multiple capture plants use a shared transport and storage network this can significantly lower the cost of CCS. In addition, networks can reduce operational complexity for each component of the CCS chain. For criteria six, at its simplest, a CCS project could be cheaper in a lower-cost country.

Finally, the bonus criteria point – an active CCS project in the same country as the refinery- is a strong indicator that:

- There is an enabling environment for CCS
- Technical and regulatory complexities are addressed under local conditions
- CCS is commercially viable in that country
- Assumptions and shortfalls

First and foremost, the refinery indicator and the criteria used are among many measures to understand the potential viability of CCS. Also, the criteria and weightings may evolve in future indicator editions as new data becomes available and CCS matures as an industry.

In addition, despite the Refinery Indicator providing a final score and ranking of refineries, the numerical scores are not directly the highest to the lowest chance of success. The likelihood of success is not measured at this analysis level because too many factors not assessed could halt a project (e.g. social licence to operate). Alternatively, many other elements, such as a company’s mandate to net-zero emissions, can drive a project to success and are not recorded in this analysis.

The following sections describe the assumptions and shortfalls of the criteria.

Criterion one

The Policy and Regulatory indicators are only one method of understanding enabling frameworks for CCS in a country. The Institute's previous studies have found a strong link between high indicator scores and CCS deployment. However, there are cases where low-scoring countries have active CCS deployment, such as on the Gulf Coast. The primary reason is the indicators use over 50 individual criteria to reach a final score. However, one factor (e.g. carbon tax or regulations on a specific industry) can drive deployment stronger than many combined.

Criteria two

The primary assumptions for this criterion are the following:

- The refinery has the required physical space for the capture infrastructure
- Defined sources for a given refinery scale and source gas conditions
- Additional utilities infrastructure is installed, including internal power generation, to support the carbon capture and compress ion energy demand. In practice, this will be highly dependent on the existing infrastructure and utility balance.
- All carbon capture through post-combustion carbon capture, whereas this could be through multiple means such as pre-combustion carbon capture or oxy-combustion
- The emissions and production rates are the same over the life of the refinery

The criteria can be refined further if the configuration and overall source emissions are known. However the complexity of integrating the capture and compression systems can only be assessed through a detailed engineering design.

Criteria Three

Comparable to all high-level CCS analyses, the primary assumption is that the storage basin and region identified in this study can store CO_2. In reality, the storage injection rate and capacity are unknown until the completion of a comprehensive analysis and appraisal

The only future recommendation for this entire scope of work is to complete a more comprehensive storage analysis across Europe to identify the viable storage options for each refinery. This current study used the findings from CO2StoP (Poulsen et al., 2011). Using CO_2StoP as a single source of information enabled a proper comparison of storage formations and resources across Europe. However, subsequent studies may find those CO2Stop storage formations unsuitable or identify alternative better sites.

In addition, the transportation distance of this criteria uses a direct line between the refinery and storage basin. This analysis does not consider avoiding prohibited areas, geography, changes in elevation, shipping routes or pipeline easements. The main reason for this shortfall is that the storage formation selected was not accurate or conclusive (i.e. single viable injection site) to warrant such detailed transport mapping.

3.3.5 Conclusion

The Refinery Indicator examines trends, draws attention to issues, and sets technical and non-technical priorities for European refineries pursuing CCS. The Refinery Indicator also benchmarks refinery performance for CCS deployment against other refineries in Europe.

The design of this criteria analysis is to use publicly available information where possible. In addition, the criteria analysis is designed for use across other industries and emission-intensive plants. The criteria encompass three pillars critical to all CCS studies: creating an enabling environment for deployment, commercially viable, and lowest complexity. Therefore, these three pillars are present across all criteria.

Overall, the high-scoring refineries are large emitting refineries (greater than 2Mpta CO_2), adjacent to storage or with access to highly suitable storage, and located in a country with enabling policy and regulatory frameworks.

The Refinery Indicator is one method amongst many to understand the viability of CCS for an emissions-intensive industry. The Refinery Indicator provides a snapshot in time in a rapidly progressing sector and a climate-constrained world. Future reviews are critical and should evolve to reflect the current state of play for refineries in the EU.

3.4 Capture Technologies and Deployment Best practices

3.4.1 Refineries and their processes

Refineries are a critical part of our industrial and energy infrastructure. A refinery takes crude oil as a raw material and processes it into several higher value and useful products including liquid petroleum gas (LPG), gasoline, diesel, jet fuel, heating oil, heavy fuel oil, bitumen as well as specialty products including lubricants and petrochemical process raw materials. Refineries have a range of processes to produce these products, including distillation, reforming, cracking and hydrotreating as examples. All of these processes require large amounts of heat input, predominantly through fuel combustion. Besides the units used to produce these products directly there are many supporting utilities including steam boilers, power generators, flares that also utilise fuel combustion for the purpose of producing energy or managing unwanted by-products.

Figure 20 shows some of the key steps involved in a typical refinery and the example products coming out of it.

Refineries are often vast facilities, typically spread over *ca*. 5 - 10 km^2 area. The processes and their respective emissions sources are often not conveniently located near to each other, rather spread throughout the site. To add further complexity, the processes within the refinery are typically very complex and compact within the space they occupy (space constrained). This introduces a number of challenges with retrofitting for carbon capture that may drive a particular technology choice, limit the final overall capture rate and will add additional costs.

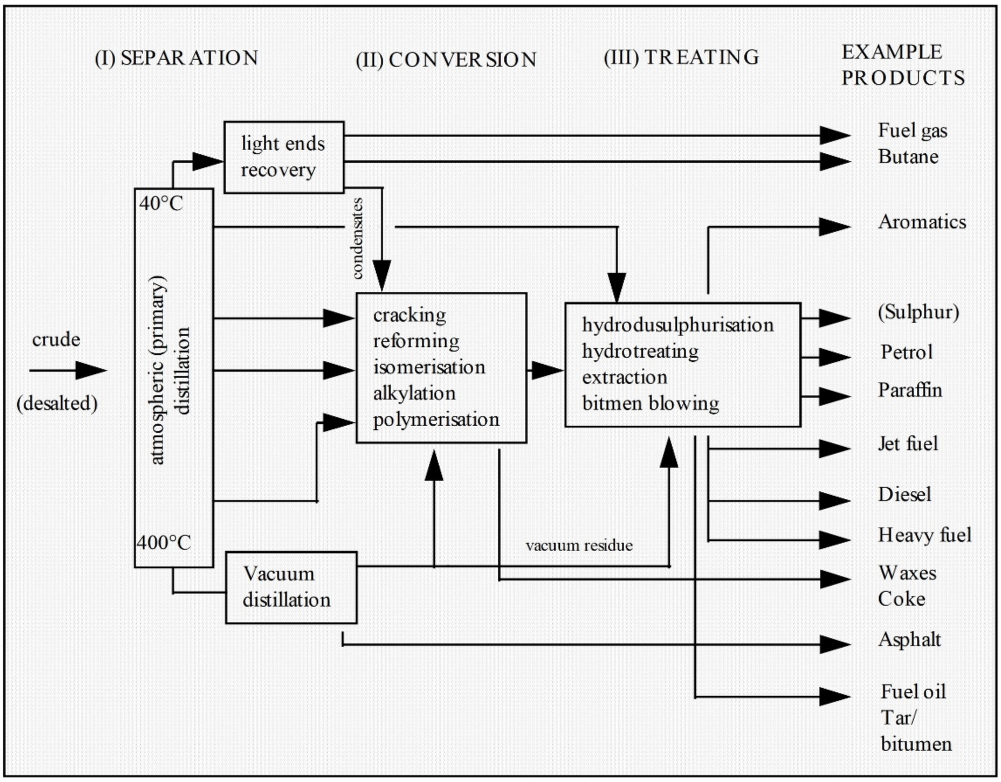


Figure 20: Key steps involved in a typical refinery and the example products coming out of it (IEAGHG 2000).

3.4.2 CO_2 emissions from refineries

Refineries are complex industrial plants with small, lesser complexity plants still having many varied CO2 emission sources.

Table 14 presents the major sources of emissions from a typical refinery, their respective shares in total CO_2 emissions from refineries, typical CO_2 concentrations and the corresponding stream pressures.

Table 14: Typical CO_2 sources, their share in total refinery CO_2 emissions and the corresponding CO_2 concentrations in them (van Straelen et al. 2009; Det Norske Veritas 2010; IEAGHG 2000, 2017a, 2017b; Güleç, Meredith & Snape 2020; de Mello et al. 2009; Chan et al. 2016).

Sources of CO_2 emissions	Typical share of refinery CO_2 emissions	Typical CO_2 concentration	Gas stream pressure (bar)
Process heaters	30-60%	7 - 13%	1 – 3
Fluid catalytic cracking (FCC)	20-50%	10-20%	2.4 – 3.8
Utilities	20-50%	3-13%	1
Hydrogen production	5-20%	20 – 99%†	1 - 22

† Depending on the capture source in the process. N/A: Data not available.

There are three major sources of CO_2 in refineries; process heaters and boilers, FCCs and power generation (utilities). Although hydrogen production only accounts for approximately 2% of refinery emissions, the flue gas that is produce has a significantly higher CO_2 concentration than other sources in a refinery (15 – 99%).

3.4.3 Overview of carbon capture technologies applicable to refineries

Carbon dioxide (CO_2) can be captured in a number of different ways in a refinery including post-combustion capture, pre-combustion capture and oxy-combustion capture.

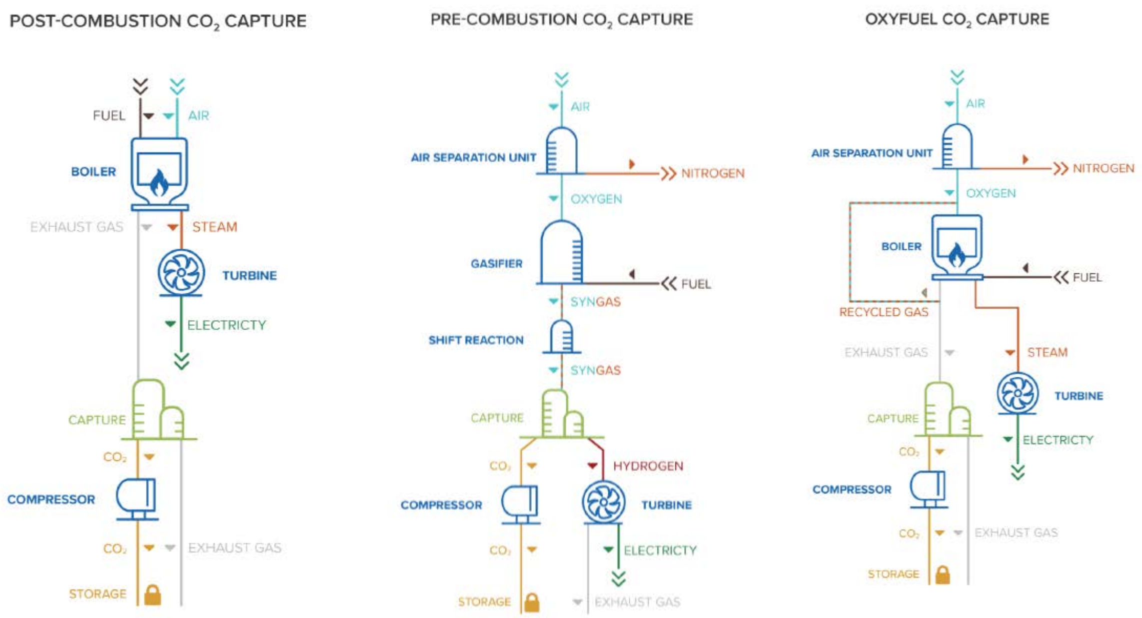


Figure 21: The three different methods for capturing CO_2 from industrial processes

In post-combustion capture, the hydrocarbon fuel is mixed with air for combustion to generate heat, power or both prior to the capture of CO_2 from the resultant combustion flue gas. Before the CO_2 can be separated from the flue gas, impurities must be reduced to tolerable levels for the capture plant, especially SO_x and particulates, resulting in additional cost and energy penalties.

Post combustion carbon capture covers a range of specific technologies that fall into the category's liquid solvents, solid adsorbents and membranes. Liquid solvents cover chemical solvents and physical solvents. Chemical solvent technologies (e.g., amines) are mature and can be applied to a range of CO_2 concentrations although is typically applied to lower concentrations as they have a higher absorption capacity, whereas physical solvents are more suited to higher CO_2 concentrations. Solid adsorbents work like physical solvents and are more suited to higher CO_2 concentrations with an advantage of lower energy for CO_2 recovery than liquid solvents and produce dry CO_2. Membranes focus on the permeability of one or more components in the flue gas stream passing (permeating) through a membrane to separate CO_2. Membranes are usually favourable for flue gas streams at higher pressures and can be an advantage where space for CO_2 capture technology is restricted.

Pre-combustion carbon capture refers to removing CO_2 from hydrocarbon fuels before combustion, typically through the generation of hydrogen as the fuel for combustion. Three processes - Steam Methane Reforming (SMR), Autothermal Reforming (ATR) and Partial Oxidation (PO) - are widely used commercially for the production of hydrogen and chemicals such as ammonia, methanol etc from natural gas. These processes can also be used with refinery produced fuel gas, propane, butanes or naphtha as the feed. All three processes produce a syngas containing hydrogen, carbon monoxide (CO), CO_2 and excess steam which is cooled and passed through a catalyst bed where the CO is reacted with steam to produce hydrogen and CO_2 (known as a shift reactor which produces shifted syngas) The CO_2 can then be removed from the shifted syngas by using currently commercially available post combustion carbon capture technology. The resultant pure hydrogen can then be used as a fuel in place of traditional hydrocarbon fuels.

Oxy-fuel combustion is the third method for carbon capture. The nitrogen that is approximately 80% of the air commonly used for combustion serves to dilute flue gas CO_2 content to less than about 15% for process heaters, boilers and other thermal heat recovery systems. Post-combustion capture processes are designed to separate the relatively dilute CO_2 from the bulk flue gas nitrogen. In oxy-combustion processes, the bulk nitrogen is removed from the air before combustion in an Air Separation Unit (ASU). The fuel is burned with a mixture of oxygen (from the ASU) and recycled flue gas to control the combustion temperature with the absence of nitrogen. The resulting combustion products will have CO_2 content to about 90% or greater. The raw, dehydrated flue gas may be stored directly without further purification depending on regulations and storage requirements. Otherwise, the flue gas impurities (predominantly O_2, N_2, and A_r) may be removed by reducing the flue gas (at moderate pressure) to a temperature at which the CO_2 condenses and the impurities do not.

3.4.4 Recommended CCS technologies for various CO_2 sources at refineries

3.4.4.1 Process heaters

Process heaters are often responsible for the highest proportion of CO_2 emissions from refineries (see Table 8). Generally, process heaters are scattered throughout the refinery posing a challenge for CO_2 from all flue gas streams. Studies have explored the capture of CO_2 from refineries for several different means including post combustion carbon capture, pre-combustion carbon capture and oxy-fuel combustion.

Process heaters in refineries can be of many various configurations including natural, forced, induced and balanced draft. Natural draft is where combustion air or flue gases due to the difference in density are naturally drawn through the process heater. There are few mechanical parts and often the process heaters are simple in design. Forced, induced and balanced draft furnaces are where the process heater operates above, below or near atmospheric pressure through the addition of fans on the combustion air piping, flue gas duct or both increasing their complexity when compared to natural draft process heaters.

Post-combustion carbon capture has been considered through several different configurations. Shell considered ducting the flue gas from all CO_2 sources, not just process heaters, to a central carbon capture plant (van Straelen et al. 2009). Many kilometres of large diameter ducting were required and the subsequent capital cost as well as the blower duty for transport resulted in a likely infeasible approach to capture CO_2 for a refinery. Finding space for large diameter ducting in a cramped refinery is also a challenge. (IEAGHG 2000) focused on a separate CO_2 absorber for each process heater transporting the CO_2 rich solvent to a central CO_2 recovery unit. This approach adds additional complexity with the need to have multiple CO_2 absorbers, however the piping for liquid solvent is considerably smaller in diameter than flue gas ducting allowing for less challenging integration in a cramped refinery.

Oxy-fuel combustion has no known applications to refinery process heaters, however this method could also be considered. Discussions with burner manufacturers and contractor process heater design experts by (IEAGHG 2000) determined there to be no fundamental barriers to oxy-fuel combustion. With no nitrogen in the combustion air to absorb combustion heat and assist with controlling combustion temperatures, a flue gas recycle is installed. Forced, induced or natural gas process heaters may offer opportunities for a simpler flue gas recycle retrofit.

Pre-combustion carbon capture could also be employed (IEAGHG 2000) and would be most practical if considering replacing existing hydrocarbon fuels by 100% hydrogen for process heaters. This would require the addition of new hydrogen production units converting existing refinery fuel gas and other hydrocarbon by-products with imported fuel such as natural gas. The CO_2 would then be recovered from the hydrogen production unit limiting the number of sources for CO_2 capture to a single or small number of sources. As with oxy-fuel combustion a review of the burner and process heater design would be required for operation on pure hydrogen. The existing fuel gas infrastructure would also need to be reviewed in detail to ensure it is capable of supplying the required hydrogen to the process heaters. Hydrogen has a lower energy density by volume than refinery produced fuel gas and natural gas and therefore higher volumes will be required. Complex retrofitting of existing process heaters or the need for process heater replacements to operate on pure hydrogen as well as the installation of new fuel gas distribution pipework would increase costs substantially.

Refinery process heaters can combust a number of different fuels from natural gas, LPG, refinery-produced fuel gas and heavy fuel oil. While some fuels such as natural gas, LPG and refinery produced fuel gas could have impurities such as SO_X, NO_X and particulates at levels acceptable that removal may not be required. Other fuels such as heavy oil will have levels of SOx, NO_X and particulates that need removal through additional infrastructure such as SO_X scrubbers. For process heaters with restricted space the addition of further infrastructure may increase the challenge for post combustion carbon capture and oxy-fuel combustion. This will be more prominent for the recovery of CO_2 from smaller process heaters in a refinery.

3.4.4.2 FCC

Not all refineries have FCCs, however when present they are considered the heart of the refinery and often be the largest single source of emissions. Unlike process heaters and power generation, emissions in an FCC are produced through the process rather than through traditional fuel combustion. During raw material conversion, carbon is deposited on the catalyst. The carbon is then burnt off the catalyst, both regenerating the catalyst and providing the necessary energy for raw material processing. Typical CO_2 concentrations in the flue gas from an FCC range from 10-20% (de Mello et al. 2009).

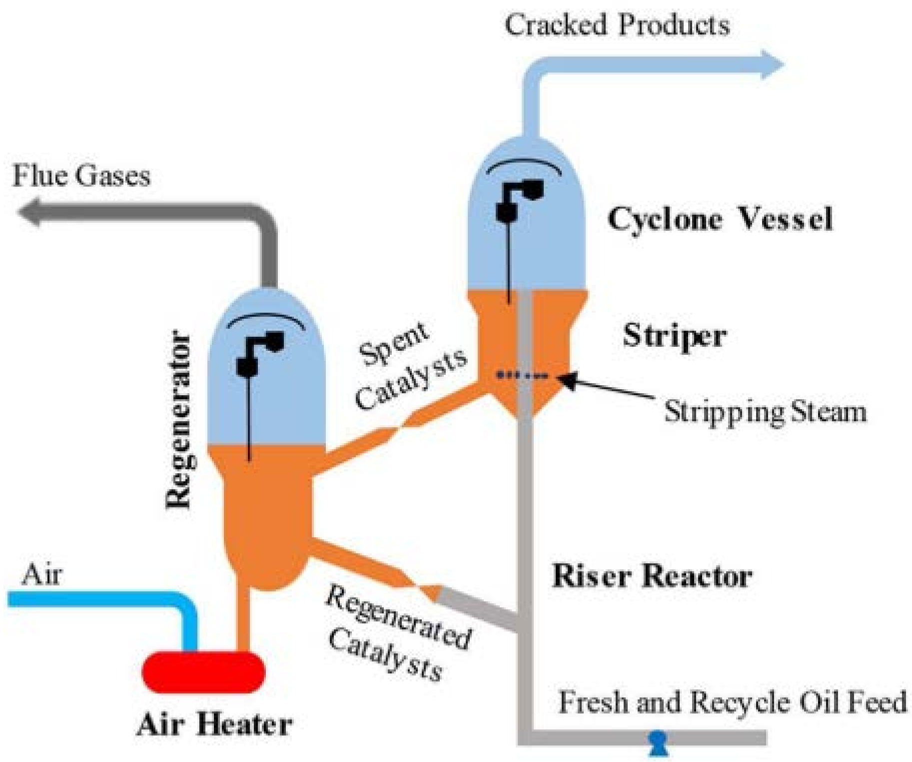


Figure 22: A typical FCC unit (Güleç, Meredith & Snape 2020)

There are two avenues for CO_2 capture from an FCC, post combustion carbon capture or oxy-fuel combustion.

Traditional post combustion carbon capture, using solvent-based capture technology, is the more mature technology. FCCs have high concentrations of SO_x that can result in significant degradation of amine-based solvents and therefore SO_x scrubbers are installed upstream of the capture plant to reduce SO_x to tolerable levels. The operating pressure of an FCC is one of the key operating parameters. The addition of new downstream flue gas equipment may result in limits on the operating pressure range and therefore a flue gas blower may need to be installed prior to the capture plant to off-set the additional pressure drop (Güleç, Meredith & Snape 2020).

Sinpoec in China commissioned the first commercial scale application of post-combustion carbon capture on an FCC at its oil refinery in the He'Nan Province recovering 100,000 tpa CO_2 for enhance oil recovery (EOR) in 2015. The project in this example recovers CO_2 through Sinopecs in-house amine based capture process followed by liquefaction of the CO_2 using an external ammonia refrigeration process for truck transport as a liquid to the oil fields for injection.

Figure 23: Photo of carbon capture plant at Zhongyuan Oilfield Refinery (Zhang et al. 2017)

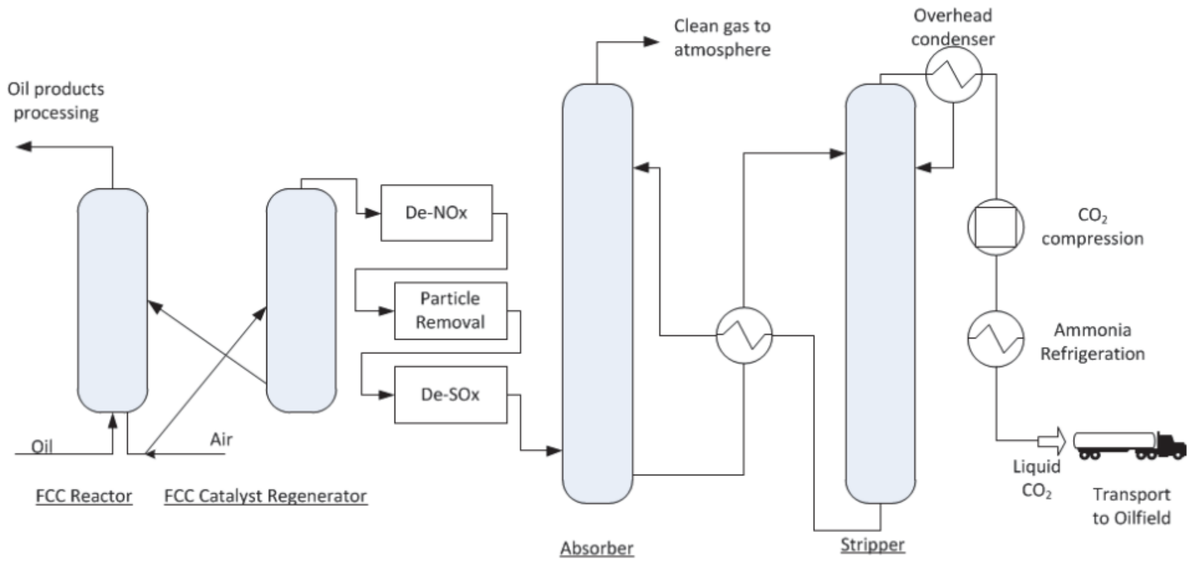


Figure 24: Flow chart for whole chain process (Zhang et al. 2017)

Oxy-fuel combustion is a less mature technology, however shows promise as a means for capturing CO_2 from FCCs (De Mello et al. 2013; Güleç et al 2020; Menon et al 1995; Olesen 2009; de Mello et al. 2009). Pure oxygen from an air separation unit is used to burn the carbon from the catalyst in place of air. A flue gas recycling system is required to manage combustion temperatures similar to process heaters. CO_2 concentrations in the flue gas with oxy-fuel combustion reach up to 99%. As with post combustion carbon capture a SO_x scrubber is installed to prevent the risk of corrosion in downstream transport equipment.

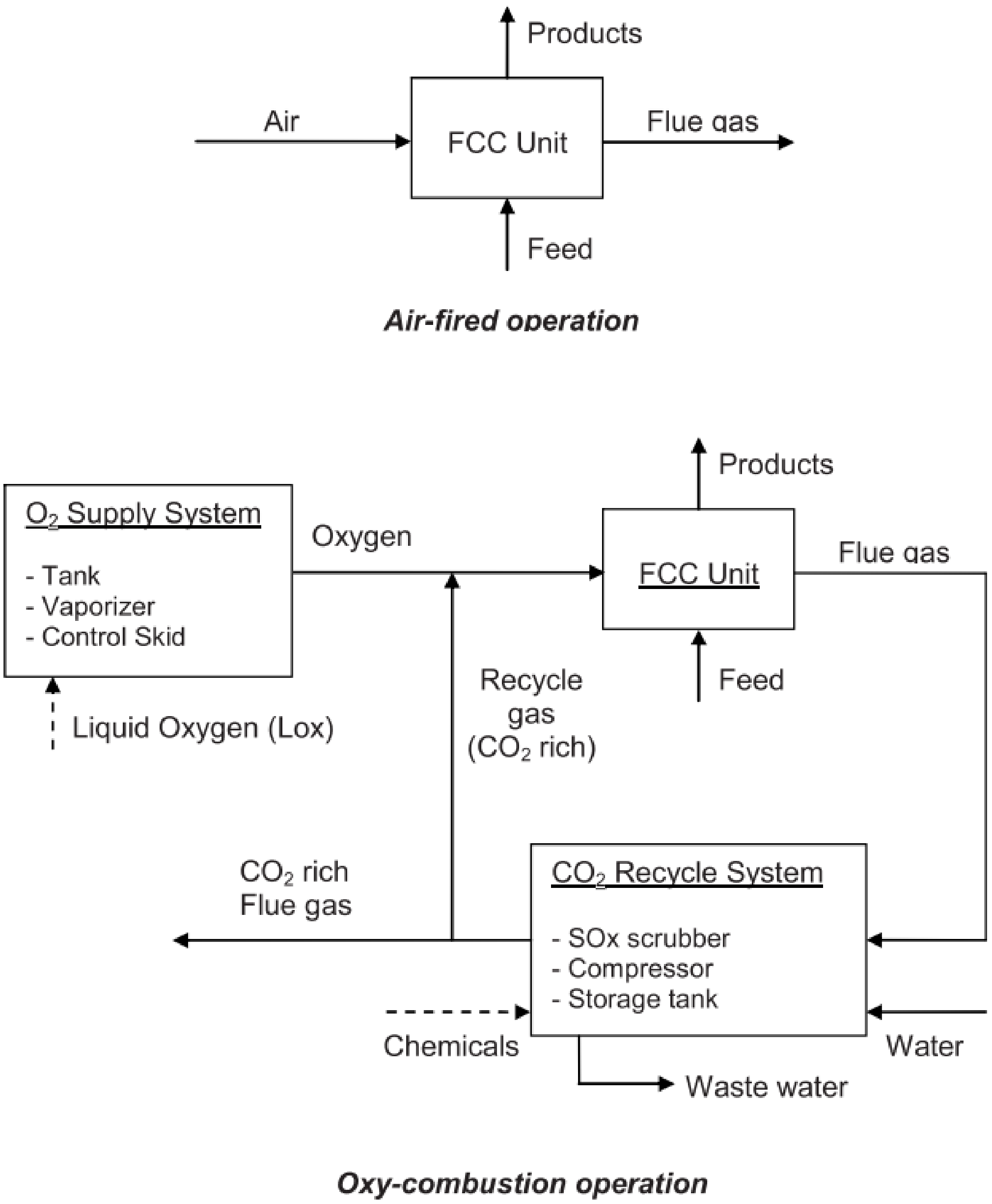


Figure 25: Process Schematic of traditional air-fired and proposed oxy- combustion operation of an FCC (De Mello et al. 2013)

(de Mello et al. 2009) reviewed the cost of the two approaches. Post combustion carbon capture was found to require a lower capital investment, however required higher operational costs, predominantly steam and electricity. The study came to the conclusion that oxy-fuel combustion was more favourable due to the lower operational costs, however this conclusion may differ depending on the source and costs of steam and power for other refineries.

3.4.4.3 Utilities

Utilities steam and power are required by many of the processes in a refinery. For all refinery configurations there is a much greater demand for steam than power.

Steam and Power may be imported, however when produced internally in the refinery it can be through a number of methods. Steam boilers are a common means of generating steam in a refinery. The approach to capturing CO_2 from a boiler is no different to the approach for a process heater defined previously. Power can be generated from the resulting steam from the steam boiler. Steam turbine power generators produce power from the boiler high-pressure steam as its pressure is reduced for distribution to the various steam users.

An alternative means of generating power in a refinery is through a gas turbine (GT) cogeneration plants designed to produce both power and steam. Cogeneration plants generate power through combustion of fuel in the GT. The hot exhaust gases are sent to a heat recovery steam generator (HRSG) to generate steam that can be used for heat or to generate further power through steam turbine power generators. The concentration of CO_2 in the exhaust gas from gas turbine cogeneration plants is very low, between 3-5% depending on the design of the GT. This low concentration is due to excess air required to control GT combustion and exhaust temperatures to within design metallurgical limits. Supplementary firing can be considered employed in the HRSG providing additional heat for steam generation by burning fuel in the presence of the excess air in the exhaust gas. This will result in the CO_2 concentration in the exhaust gas approaching that of process heaters and boilers. Post combustion carbon capture with solvent-based technologies is the likely near-term solution for refinery power generation, similar to the power industry.

Another possible option for reducing CO_2 emissions from utilities at a refinery could be to introduce the Allam-Fetvedt Cycle for power generation. The Allam-Fetvedt Cycle is an innovative natural gas (or syngas from gasification of coal) fired power generation technology. The technology produces pipeline-ready CO_2 without the need for add-on carbon capture equipment. It involves oxy-fuel combustion and the use of the produced CO_2 as the working fluid to drive a turbine which enables inherent CO_2 capture, compression, and dehydration as well as the elimination of SOx and NOx.

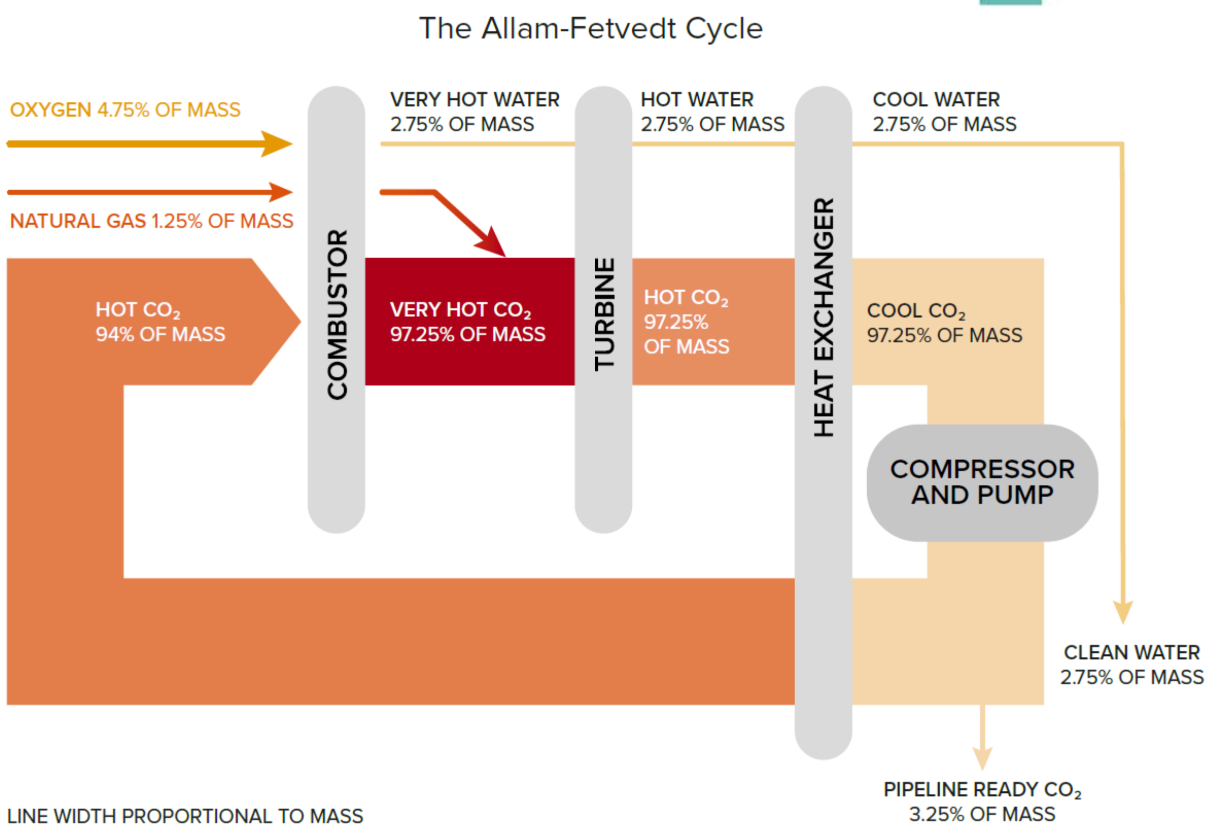


Figure 26: The Allam-Fetvedt Cycle process flow. Source: 8 Rivers Capital (supplied)

3.4.4.4 Hydrogen production

Hydrogen production will continue to grow as a contributor to overall refinery emissions for modern refineries as changes to fuel specifications increase the demand for hydrogen for fuel hydrotreating. Hydrogen is a by-product from some refinery processes, however in some refineries the demand for hydrogen is greater than by-product production and hydrogen must be generated by hydrogen production units. As highlighted in Section 3.3.3 hydrogen at a refinery can be produced through Steam Methane Reforming (SMR), Partial Oxidation (POX) and Autothermal Reforming (ATR).

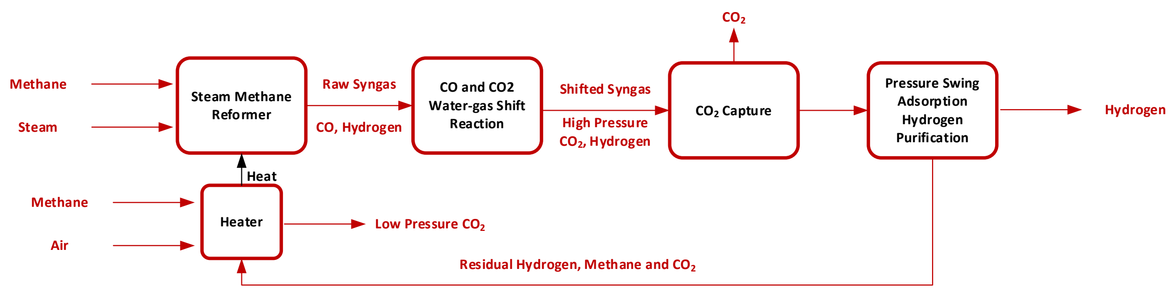


Figure 27: Steam methane reformer hydrogen production flow diagram

The SMR process involves the reaction of methane and steam in the reformer to produce a mixture of mostly CO and hydrogen called synthesis gas. The CO is converted to CO2 in the water gas shift reaction and then the CO2 is captured for storage using pressure swing adsorption and the hydrogen is available as the product.

Shifted Syngas contains approximately 60% of the total CO2 produced, is at high pressure ~23 bar and therefore relatively low cost to capture. Remaining 40% is produced by the combustion of methane to heat the reformer. This heater produces dilute CO_2 at low pressure and therefore has high capture costs. Typical capture projects targetting SMRs focus on capture of CO_2 from the shifted syngas but not from the heater because there is insufficient economic incentive. Current CO_2 capture rates are approximately 60%.

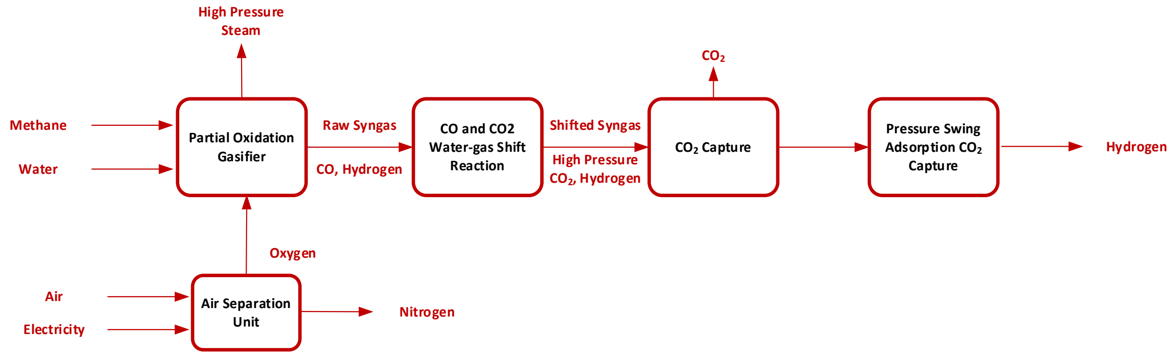


Figure 28: Partial oxidation hydorgen production flow diagram

The gas partial oxidation (POX) process involves the combustion of a sub stoichiometric fuel-air mixture in a gasified to create a hydrogen rich syngas. As a by-product

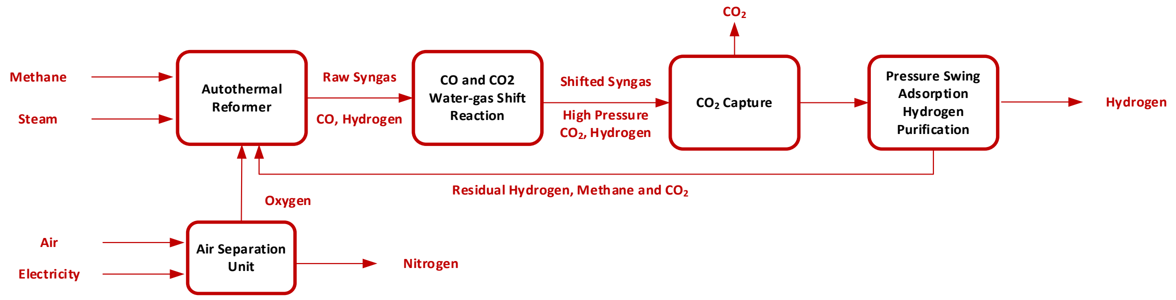


Figure 29: Autothermal reforming flow diagram

Autothermal reforming (ATR) is a combination of partial oxidation and steam methane reforming. ATR processes produce CO_2, unlike the SMR process the ATR process does not produce low concentration CO_2 that typically have insufficient economic incentive to capture. As a result, economical capture rates of 95% are achievable.

Post combustion carbon capture is the most suitable approach for capturing CO_2 from hydrogen production units. Gasification plants for POX hydrogen generation operate at pressures of 50-70 bar. At these operating pressures, physical absorption solvents or solid adsorbent is considered as they have higher loading and demand less energy than traditional chemical solvent technology. For gasification plants all emissions for conversion end up in the flue gas stream, a single source of capture allowing for a high capture rate over SMR which has multiple sources for capture.

For SMRs chemical absorption has been the typical route for capturing CO_2 from the syngas following the shift reaction. More recently solid absorbents have been considered to provide high purity hydrogen recovery from the shifted syngas. However, this results in lower concentration CO_2 streams with higher levels of impurities that need further separation is required to provide transport ready CO_2. The pure or higher concentration CO_2 streams such as hydrogen production using gasification and SMR with chemical absorption may be attractive unit processes for future CCS deployment in a refinery (Det Norske Veritas 2010).

It is worth noting that membranes for separating hydrogen from CO_2 are gaining increasing attention as a potential CO_2 capture option as the membrane-based plants can be modular and vertically-stacked, thus resulting in a smaller footprint. Companies such as Linde are offering membranes suitable to separate hydrogen from flue gas coming from synthesis plants. Another advantage of the Linde's membrane technology is that the separated hydrogen is collected on the permeate side without any significant pressure drop. Moreover, Eltron Research & Development Inc. is working on developing metallic hydrogen separating membranes, which can handle both the high-temperature and high-pressure conditions, making them suitable for application to SMRs. Similarly, MTR Inc. is offering membrane solutions to tweak the hydrogen-to-CO ratio in synthesis gas and separate hydrogen from it.

3.4.5 Deployment best practices

CO_2 capture technologies vary in type, cost and technology. The selection of appropriate technologies for a given application should take into account the typical partial pressure of CO_2 in a point source, the volume (tonnage) of CO_2 from that point source, and the relative availability and cost of energy sources (heat and electrical).

Within a refinery environment, it is essential that planning for staged deployment of capture projects is undertaken. Refineries have a range of point sources with varying costs and scales, and it is likely that these would be deployed in separate stages rather than as a single, integrated project.

Given the economics in most plants, it is likely that larger-scale capture projects would be deployed on the SMR and/or FCC units in stage 1, then progressively working up the marginal abatement cost curve as resources are available.

To facilitate this staged deployment, there are a number of considerations that need attention during the planning stages.

- Supporting infrastructure, especially utility capacity (steam, power, cooling)
- Available land for capture projects and available space in pipe racks
- Any planned changes to the future configuration of the refinery – for example, producing different projects as demand for liquid fuels changes

3.4.5.1 Refinery infrastructure and CCS deployment

CO_2 capture projects in refineries are typically brownfields projects, requiring careful consideration of the interactions and integration with an already-complex processing facility. Typically, shared refinery infrastructure includes key utilities such as cooling water, steam (at multiple pressures/temperatures), and electricity supply.

CO_2 capture plants can consume considerable additional utilities over and above those already in use in the refinery. Depending on the balance of existing supply and demand, it may be necessary to expand capacity (through upgrade projects) or reduce the spare capacity for each utility.

Supply of additional electricity is essential, but connecting it to the new capture system is also paramount. It may be necessary to upgrade substation equipment (transformers, switchgear, power electronics) to cope with additional power draw. New power cabling will also be required. For solvent-based capture plants, electrical demand is modest, reflecting the requirements of solvent pumping, blowers/fans and similar equipment items. In adsorption of membrane systems the power draw can be much more substantial, as these require substantial compression energy to drive the gas separation. In the design of substation upgrades and cabling, it is important to plan ahead for future stages of capture plant deployment. For example, if each stage required 4 MW of additional power, and three phases were planned, substation capacity should be built to prepare for at least 12 MW of capacity. This will be lower cost than building three separate substation upgrades.

If the capture system is solvent (absorption) based, it will require substantial additional heat input for solvent regeneration. This is usually in the form of low-moderate pressure saturated steam in the order of 3-5 barg, providing steam temperatures in the order of 130-150°C. It is important to liaise with the favoured capture plant technology provider to get guidance on capture unit steam specifications well in advance of the project being deployed. This will enable an assessment to be undertaken of required additional steam capacity.

If the refinery operates a combined heat and power (CHP) unit further consideration will need to be given to the relative additional amounts of electricity and steam needed, as these may not align with the typical ratios available from CHP systems. As many on-site steam or CHP systems are heavy users of refinery fuel gas (RFG) the impact of this additional draw on both RFG balance and refinery emissions should also be considered. Any emissions produced though power or steam generation which are not abated will reduce the net CO_2 avoided from the capture project. As such, efforts to acquire lower carbon power should be made, such as from renewable power projects on the refinery's grid. If a conventional fossil-fuel based power or CHP unit is selected, consideration should be given to whether CO_2 capture should be deployed at the outset.

Steam production from non-fossil fuel sources generally involves the use of biofuels which may be difficult to source reliably in some contexts. Alternatively, there have been efforts in recent times to develop high temperature heat pumps to enable substantial low-medium pressure steam from electricity with decent coefficient of performance (COP) – meaning multiple MW of steam can be made for each MW of electricity (de Boer et al., 2020). The key value of heat pumps for CO_2 capture projects is that they allow substantial production of industrial heat from low-carbon renewable electricity sources. This ensures that the capture performance is not offset by the emissions of CO_2 from steam generation. Industrial heat pumps are best suited for steam production in the 100-200°C range, which is ideal for solvent-based capture systems. The coefficient of performance (COP) of a heat pump is strongly dependent on the steam temperature chosen and should be the subject of careful optimization with the heat pump vendor and the capture plant vendor to minimize the overall system cost.

3.4.5.2 Available land for capture projects and available space in pipe racks

Physical space, both in terms of land and in terms of pipe rack availability, are crucial for all refinery upgrade projects, including CO_2 capture projects.

Land availability may be quite limited in refineries, particularly older refineries located in larger cities, where there is little or no opportunity to acquire adjacent land. As such, maximal use of limited land will commonly be required. This has several impacts on planning and design:

- CO_2 capture technologies with a smaller footprint will be favoured, even if they are not lowest cost.

- Consideration to flowsheets and layouts that enable a capture system to be vertically rather than horizontally stacked, maximising use of vertical space.

- If the land in question has been used before, a careful survey of the area to identify and remediate will be required. There may be historical foundations, buried pipelines or similar equipment which may impede construction works or undermine civil works if not identified and removed in advance on construction.

- CO_2 capture plant layout will need to take account of the dimensions of available land. Some capture plants are designed with a default layout which may not be able to be accommodated within the specific north-south or east-west dimensions of the construction site. It may require work with the capture vendor to ensure their offering works with existing boundaries.

In many refineries (particularly older ones) space in pipe racks is very limited or not available. Capture projects can require substantial piping connections for utilities (cooling water, steam) as well as other services such as inert gases for equipment purging.

It is recommended that refineries develop a constructability plan as part of their CO_2 capture strategy. This will provide guidelines for plant layout, space requirements, pipeline networks and racks, access routes for equipment, and fabrication methods (IEAGHG, 2017a)

3.4.5.3 Consideration of future refinery configuration and production

In Europe, there has been a rapid escalation in the proportion of electric cars registered in the EU, Iceland, Norway and the United Kingdom, from 0.01% of registrations in 2010 to 11.4% in 2020. (Europa.eu, 2021).

The proportion of the total car fleet lags behind new registrations, but clearly this trend is moving upwards with increasing speed into the future. This reflects a broader global trend towards vehicle electrification (both plug-in hybrid and full battery electric), as well as deep targets for CO_2 emissions cuts from cars and trucks in European countries.

As such, it is expected that the proportions of various refinery products will change considerably over time. Demand for gasoline and distillate will be expected to fall, but other refined products such as aviation fuel, maritime fuel and petrochemical feedstocks could remain high or even increase in some markets (Tan, 2021). By 2050, these changes have been predicted to cut demand for global refining capacity by 50% by 2050 compared to 2021 levels. Given the leading position of European countries in vehicle electrification, it’s likely that demand will decline even further for EU refiners.

These changes in both the scale and production of specific products mean that there is a high chance that the emissions profile for refineries in the future is going to be quite different to that of today, as a result of modifications to how refineries operate to target the new product requirements. Refineries should already be planning ahead to ensure their flowsheets are capable of adjusting to meet demand in coming decades.

Alongside the expected drops in overall demand, there is expected to be continued growth in demand for petrochemicals (ultimately producing plastics, synthetic rubber, fertiliser and detergents). These products have demand that rises broadly in line with global income. There has been some effort to reduce plastics pollution in the environment by substituting non-petrochemical materials, but these have not prevented substantial growth in petrochemicals demand, which has nearly doubled since 2000 (International Energy Agency, 2018).

These future refinery plans will be essential in developing CCS deployment plans. Some units within refineries, such as FCCs and alkylation units, will see adjustments to their CO_2 tonnages and partial pressures as gasoline demand falls – it is important that any capture equipment installed is able to work with current CO_2 streams as well as best estimates of what those streams are likely to be in the future. If new approaches are deployed to adapt to demand, such as high severity FCC or FCC to steam cracking, increased hydrocracking or maximising aromatics reforming (Fitzgibbon et al., 2022) these may benefit from a different capture technology or configuration than what is in the refinery today.

This is to say that CO_2 capture plans need to be suitably flexible to adapt to moving targets for the coming decades. Technologies and equipment should consider a range of future operational modes, including the potential to operate below full capacity for later stages of their operating life.

3.5 Recommendations for CO_2 capture at refineries

3.5.1 Application of the risk mitigation framework

As part of this engagement, the Institute undertook a process to identify and assess socio-political risks to CCS projects, using a risk mitigation framework. Out of this process, a number of recommendations emerged that help describe and strengthen the prospects of CCS projects gaining acceptance in communities and by political authorities. Management of stakeholders is a crucial component in a successful CCS project and should be considered an activity of primary importance.

It should be noted that most capture projects in refineries will be located within the refinery boundary limits, within an already-operating hydrocarbon processing environment. As such, much of the stakeholder interest will be less concerned with the capture unit itself, but in the interactions with surrounding areas, especially pipelines or shipping routes that will carry the captured CO_2 through neighbouring areas, and with storage projects that are near populated areas. Stakeholder engagement needs to consider these risks in conjunction with those of the capture unit on-site.

3.5.1.1 Treat socio-political issues in the same way as other risk elements

CCS projects are complex and require the management of a range of technical, safety, environmental, regulatory, operational and commercial risks. Typically, these are managed through the use of risk management systems, which are used to identify, assess and respond to risks throughout the project life cycle.

Socio-political risks should be incorporated into this same risk management process. Serious social or political risks can be showstoppers for CCS projects and therefore should be treated with the same importance as other potential project-ending risks.

Leading practice risk management systems use some form of rating and subsequent Risk Assessment Matrix (RAM) to allocate accountability for prioritising and managing individual socio-political risks.

3.5.1.2 Incorporate risk management into existing systems or processes

CCS project proponents and their contractors will already have risk management systems in place. Rather than building a new process, it is more effective to incorporate stakeholder engagement into these existing systems. Proponents who are not familiar with large capital projects can consider using their contractor's system, especially if that contractor is a large experienced EPCM firm.

3.5.1.3 Review best practices

Access key learnings from previous CCS projects. Typically, stakeholder engagement is part of those reviews. These reviews will provide valuable input into the stakeholder engagement process. CCS organisations and some

3.5.1.4 Communication

It is important to communicate the importance of stakeholder management to internal teams, and to commence engagement with external stakeholders.

3.5.1.5 Maintain an iterative process to manage socio-political risks

Risk management works best as an iterative process rather than as a once-through process. A circular analyse-diagnose-feedback-monitor cycle should be maintained throughout the project life cycle, responding to issues as they emerge and taking action to address risks in the earliest stages.

3.5.1.6 Social analysis should be undertaken at the project outset

Undertaking a baseline analysis of socio-political risks before the project goes too far will help proponents prevent blindsides and will improve ongoing monitoring of risks over the life cycle.

3.5.1.7 Broad engagement of stakeholders

One learning has been that stakeholders should not be considered too narrowly. Look beyond the obvious primary stakeholders (local community groups, regulators) and expand engagement to groups including the CCS operator (if different to the proponent), contractors, local government, CCS organisations, relevant NGOs and academic experts. This can yield unexpected insights into risks that can be managed, rather than waiting for them to emerge later.

3.5.1.8 Internalise key stakeholders if possible

Seek to incorporate key stakeholders into a supervisory board with genuine influence over the project direction. This will help facilitate buy-in and build stronger working relationships which may prove crucial at later stages of the project.

3.5.1.9 Describe and manage risks post-mitigation

Risk management doesn't always eliminate risks – sometimes residual levels of risk remain. Describing and actively tracking residual risks will help promote deeper understanding off issues, particular with social stakeholders.

3.5.1.10 Mitigation should be visible and concrete

It is important that stakeholders can observe real action in response to their concerns regarding CCS projects. This produces a narrative that encourages further consultation and ultimately more robust outcomes that further reduce socio-political risks.

3.5.1.11 Manage broader CCS value chain socio-political risks

In many CCS projects, there is a disaggregation of operators of different parts of the supply chain – capture, transport and storage may all be operated by separate parties. However, risks that affect one part of the value chain may imperil all other parts of the value chain. Socio-political risks around a pipeline, for example, should be managed effectively even if the capture project proponent is not directly responsible for the pipeline. CCS proponents and developers should consider an integrated approach to socio-political risk management, in cooperation with the other value chain proponents.

3.5.2 Policy and regulatory arrangements to enable refinery CCS

A supportive policy and regulatory environment is an essential element for CCS projects in general and capture projects in refineries in particular.

Key nations within the EU and its neighbours, in particular the UK, Netherlands, Denmark and Croatia, are leading the way with respect to their legal and regulatory responses in support of large-scale deployment of CCS.

A review of policies in EU countries as well as the UK, China and South Korea was undertaken. The following policy areas were identified as most beneficial in supporting CCS projects:

- A comprehensive legal and regulatory framework that addresses the CCS project cycle, including pipelines, shipping routes and geological storage.
- Specific policy measures to address barriers to investment and areas of market failure.
- Policy to provide a sufficiently high value on CO_2.
- Government support for CCS networks (CO_2 hubs in industrial clusters)
- Capital support for CCS project development.

The UK and the Netherlands were identified as having a high response to all five areas of policy and regulatory support for CCS, and are good models for any nation wanting to further develop CCS at its refineries. These two nations have seen multiple industrial CCS projects and CCS networks under development, highlighting the success of their multi-pronged approaches to policy and regulation.

More broadly, the EU has significant room for improvement in its policy and regulatory response to CCS. Although the EU ETS does provide a value on CO_2 across the region, this policy has not yet proven to be sufficient to drive CCS investments in EU refineries, suggesting that other areas of policy will be needed.

3.5.3 Identification of refineries best placed to deploy CCS and measures to increase readiness ratings

In this project, 81 refineries across the EU were assessed using a modified version of the CCS Facility Readiness Indicator developed by the Global CCS Institute. This indicator incorporated the following six quantitative and qualitative criteria into a single Indicator score:

Criterion 1 – Policy and Regulation (30% weighting)

Criterion 2 – Capture (30% weighting)

Criterion 3 – Transport and Storage (25% weighting)

Criterion 4 – Regulations on CO_2 transport (5% weighting)

Criterion 5 – Hub potential (5% weighting)

Criterion 6 – Location cost factor (5% weighting)

Bonus point – Active CCS project in same nation (no weighting – 5 or 10 bonus points).

Figure 31 (taken from Figure 19 in the Refinery Indicator section of this report) summarises the top 20 refineries in the EU assessed using the above criteria, and shows the breakdown of contribution of each criterion to the total score.

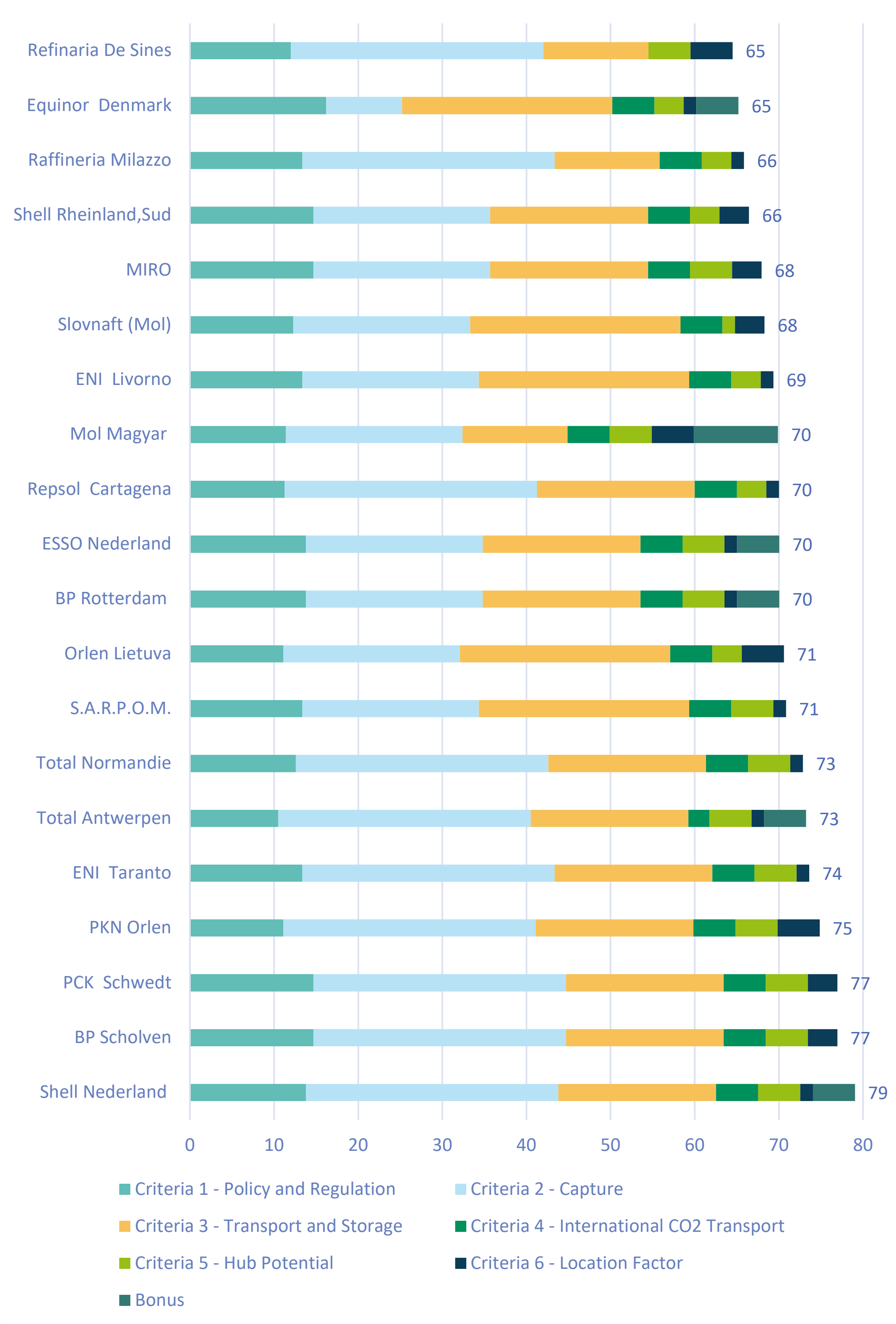


Figure 30 - Refinery Indicator scores and proportional indicator contributions

Key trends that were identified among the top 10 refineries were:

- Onshore transport and storage networks rank the highest
- Refineries targeting “possible” (not well characterised) basins need to be either adjacent to their basin or using an onshore basin
- For distances over 100 km (shipping or offshore pipeline) or 200 km (onshore) the scores are generally reduced.

Based on an assessment of 20 years of previous CCS projects, a balance of transport and storage factors drive the technical viability of CCS projects. This has proven true across industries and is not specific to the refinery sector.

3.5.3.1 Measures to increase readiness

Of the criteria included in the refinery indicator scores, the location factor (criterion 6), transport and storage (criterion 3) and capture (criterion 2) factors are mostly not amendable to change, as these are a function of the refinery scale and location.

The remaining factors are amenable to change and therefore could improve readiness. Policy and regulation are essential factors. As summarised in section 3.4.2, the Netherlands and the UK have well-developed policies and regulations for CCS, which is reflected in the highly ranked refineries in the refinery indicator scores. By following the example of these leading nations, other EU nations can also succeed in improving their refineries’ CCS readiness.

International CO_2 transport is another factor that can improve readiness. For facilities located near border regions or coastlines, the option for transport to storage sites in other countries depends upon having well-developed international law to facilitate transport, as well as the development of key infrastructure: international pipelines, ports, dedicated CO_2 carrier vessels etc.

Hub potential is the final measure amenable to improvement. This refers to the potential to form a CCS network by aggregating multiple CO_2 sources within a 100 km radius of the refinery. Although little can be done to change the distribution of CO_2 point sources in this radius, work to improve cooperation between multiple parties in the area, including joint ventures and agreements between the operators of industrial sites to coordinate their investments, can facilitate higher levels of hub potential.

3.5.4 Capture technology and deployment best practices

CO_2 capture technologies vary in type, cost and technology. The selection of appropriate technologies for a given application should take into account the typical partial pressure of CO_2 in a point source, the volume (tonnage) of CO_2 from that point source, and the relative availability and cost of energy sources (heat and electrical).

Within a refinery environment, it is essential that planning for staged deployment of capture projects is undertaken. Refineries have a range of point sources with varying costs and scales, and it is likely that these would be deployed in separate stages rather than as a single, integrated project.

Given the economics in most plants, it is likely that larger-scale capture projects would be deployed on the SMR and/or FCC units in stage 1, then progressively working up the marginal abatement cost curve as resources are available.

To facilitate this staged deployment, there are a number of considerations that need attention during the planning stages.

- Supporting infrastructure, especially utility capacity (steam, power, cooling)
- Available land for capture projects and available space in pipe racks
- Any planned changes to the future configuration of the refinery – for example, producing different projects as demand for liquid fuels changes

4 Review of wider transport and storage policy considerations

4.1 Summary

As part of the REALISE project, this section examines the wider transport and storage considerations as applicable to CCS at refineries and related policy.

CO_2 can be transported through a combination of four modes. Listed alphabetically, they are pipelines, rail, road, and waterways. Of these modes of transportation, pipelines are the most versatile, used extensively worldwide to distribute and transport oil and gas. Using roads or rail to transport CO_2 requires additional capacity planning and potential debottlenecking since these modes are also used to transport people, freight, and other types of cargo. The transport of CO_2 through waterways, especially international waterways, has unique requirements. Planning for staged deployment of capture projects at a refinery is essential, and transport design should be considered in unison to ensure the most suitable transport design and method selected. It is likely in Europe that a combination of transport methods will be applied for refinery, and other CO_2 sources, to transport CO_2 to a suitable storage location.

The provisions of the London Protocol could influence projects where transporting CO_2 through waterways is a requirement. Only eight countries (Contracting Parties) have ratified the agreement. However, a provisional application of the amendment to Article 6 of the London Protocol was agreed to in 2019 at the 14th Meeting of the Contracting Parties. Countries with plans to transport CO_2 internationally can proceed but have additional requirements to liaise with the International Maritime Organization (IMO).

There are several business models relevant to the transport and storage of CO_2. Government policy has a significant role in enabling the development of the necessary infrastructure, just as it did in other industries such as electricity and telecommunications, water distribution, renewable energy, road and rail. Examples of policies or business models applicable to CO_2 transport and storage include the following.

1. Regulated Asset Base (RAB): In this model while the asset is owned by the State, private companies manage and operate the infrastructure. However, investment decisions are managed by a regulatory body. The private company receives payments for services provided to customers while also receiving incentives (subsidies, tax benefits) from the government to ensure the continuity of operations.

2. Public Private Partnership (PPP) or Private Finance Initiative (PFI): The government invites tenders for infrastructure projects. A consortium between a public-sector entity and private companies is set up as a separate company. This company carries out all stages of the project, from initiation, selection, and design, to execution and operation. Through a contract, it receives revenues for services provided to customers or receives performance-based payments from the public-sector entity for managing the infrastructure.

3. Contract for Difference (CfD): Used in the power and utility sector, this structure is a financial contract awarded through an auction. The energy generator that wins the contract is guaranteed a revenue stream for the contract's duration by providing a difference payment and providing long-term revenue certainty (Low Carbon Contracts Company, 2022)(Low Carbon Contracts Company, 2022)(Low Carbon

Contracts Company, 2022). This guaranteed revenue stream can provide a basis for financing capital-intensive projects like CO_2 transport and storage.

4. Cost Plus: These financial contracts are used for capital-intensive projects. In this financial arrangement, project developers are paid for project expenses in addition to an additional payment for executing the contract (or a profit margin).

5. Waste sector type contract: These contracts are like other contracts common in the waste management sector. Project developers are paid for the units of CO_2 they can inject and store, or CO_2 sold for EOR.

6. Hybrid models/contracts: The models and contracts described above can be used in combination depending on the complexity of the project.

4.2 Introduction

As part of the REALISE project, this section examines the wider transport and storage considerations as applicable to CCS at refineries and related policy.

The first part of this report provides a review of existing policies, legal and regulatory frameworks to support the deployment of CCS at refineries across the EU, UK, China, and South Korea. This review includes a general overview of the different policies applicable to CCS, followed by an assessment of the different CCS-specific legal and regulatory frameworks for each jurisdiction.

To provide a high-level understanding of how CCS projects have been deployed globally, market failures and broader barriers to CCS investment are examined. Key recommendations to overcome CCS market failures are then outlined, serving as the basis upon which policies that have successfully supported the deployment of CCS are examined.

The report's concluding section comprises a gap analysis across legal, policy and regulatory environments for the deployment of CCS at refineries. This gap analysis categorises countries' level of response across several key categories, namely:

- Legal and regulatory framework that addresses the CCS project cycle
- CCS-specific policy framework addressing barriers to investment and market failures
- Policy instrument that places a sufficient value on CO_2
- Government support for hubs and clusters
- Capital support for CCS project development

Countries are grouped according to the gap analysis, with key policy and regulatory interventions subsequently recommended for each group of countries.

A key factor that should be noted from the outset is that the market failures, barriers to investment and policy, legal and regulatory frameworks identified in the report were found to be applicable in the context of all types of CCS projects located across the regions surveyed, including refineries. Thus, the conclusions and recommendations resulting from the review and gap analysis are not necessarily specific to one type of operation and will be applicable to all types of CCS operations, including those linked to refinery operations.

4.3 Transportation networks and methods

4.3.1 Modes of CO_2 transport

Transportation of CO_2 from emissions sources to storage sinks can be achieved with pipelines, rail, motor carriers, and ships. Each mode of transportation has different operational requirements and capacities which impact suitability for a given project (Table 15).

Table 15. Comparison of CO_2 transportation methods. (Al Baroudi et al., 2021)

Transport Method	Conditions	Phase	Current Capacity	Remarks
Pipelines	48-200 barg, 10 to 34°C	Vapour Dense phase	~100 $MtCO_2$/yr; 6500 km of pipeline transport in operation	• Higher capital costs, lower operating costs • Low-pressure pipeline system is 20% more expensive than dense phase transmission • Well-established for EOR use
Ships	7-45 barg, -52 to 10°C	Liquid	>70 $MtCO_2$/yr	• Higher operating costs, lower capital costs • Currently applied in food and brewery industry for smaller quantities and different conditions • Enhanced sink-source matching
Motor Carriers	17-20 barg, -30 to -20°C	Liquid	>1 $MtCO_2$/yr	• 2–30 tonnes per batch • Not economical for large-scale CCUS projects • Boil-off gas emitted 10% of the load
Rail	7-26 barg, -50 to -20°C	Liquid	>3 $MtCO_2$/yr	• No large-scale systems in place • Loading/unloading and storage infrastructure required • Only feasible with existing rail line • More advantageous over medium and long distances

While motor carriers and rail are viable means of transport, for large scale CO_2 transport applications required for commercial CCS projects pipeline and ship are the most suitable transport methods. While external factors may influence the choice of transport technology, the main driver for the choice of technology is economics.

4.3.2 Pipeline transport

There are two ways by which CO_2 may be transported by pipeline:

- Compression (source dependent) of CO_2 in gas phase (< 74 bar, or the CO_2 critical pressure)
- Compression of CO_2 to dense or supercritical phase (> 74 bar, or the CO_2 critical pressure)

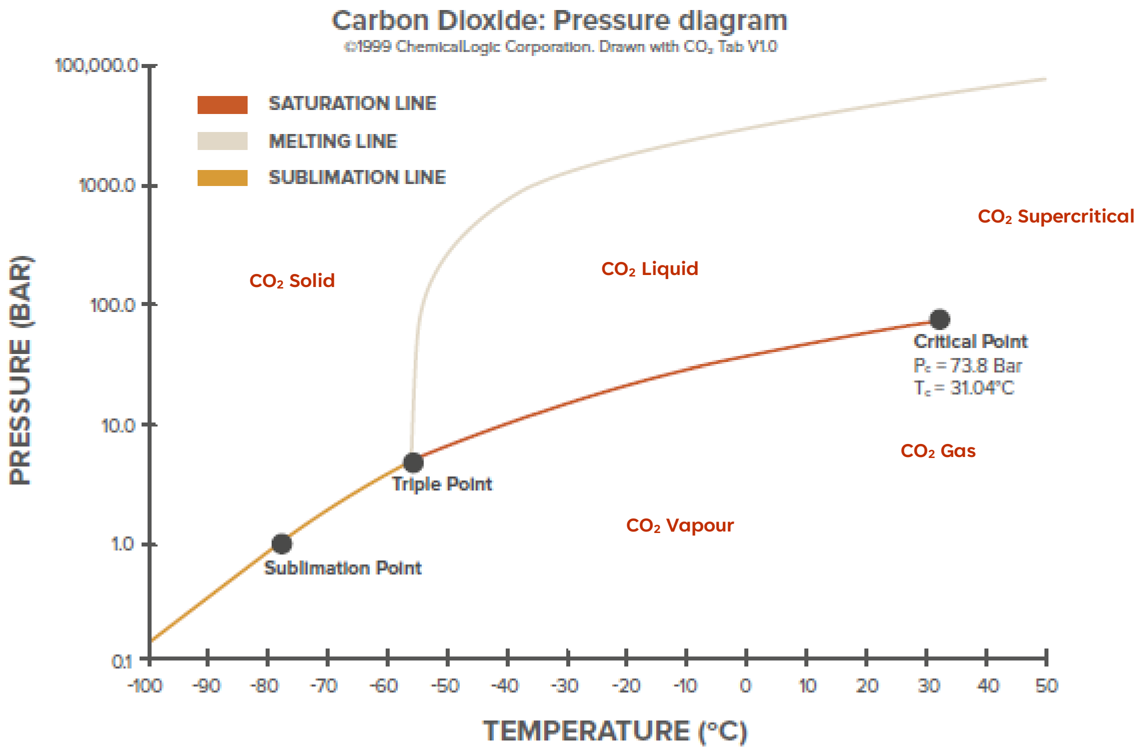


Figure 31 – Phase diagram for pure CO_2 (Serpa, Morbee & Tzimas 2011)

The following infrastructure is applicable to either gas phase or dense phase pipeline transport.

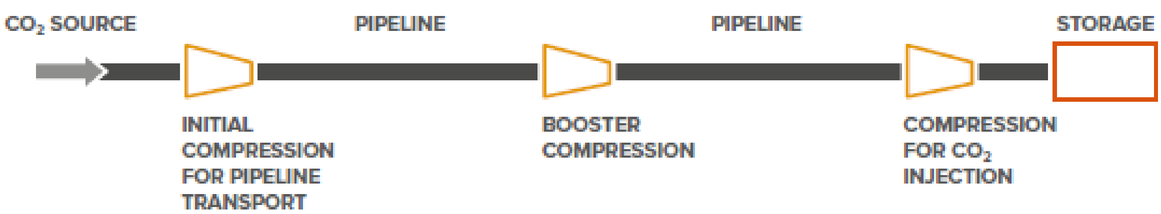


Figure 32 Typical CO_2 pipeline transport infrastructure

Typically, captured CO_2 first emerges from its capture plant at close to ambient pressure (~1 bar abs) and is compressed to the desired transport conditions.

If the CO_2 is compressed for dense phase transport, it will need to be compressed in a multi-stage compressor to the critical pressure (73.8 bar) and then be pumped to the final required pressure for transport. The upper limit will be set by economic concerns and pipeline flange ratings.

If the CO_2 is compressed for gas phase transport it is also compressed in a multi-stage compressor to the required pressure for transport. The upper limit will be set by economic concerns or ensuring the gas does not enter the supercritical state.

The minimum pressure for a CO_2 transport pipeline is a function of the differential pressure requirement for flow to occur and the need to avoid CO_2 phase changes (Peletiri, Rahmanian & Mujtaba 2018). If a pipeline reaches a minimum operating pressure, then booster compression is required to enable transport to continue. For gas-phase transport, this would require further gas-phase compression using a multi-phase compressor. For dense phase transport, it would require a dense phase pump.

Lastly, the storage conditions need to be considered. Gas phase pipelines will require multi-stage compression to the critical pressure followed by piping to the required injection pressure. Dense phase pipelines may already be at the injection pressure or require only pumping to the required injection pressure at a negligible cost.

4.3.3 Ship transport

Shipping is emerging as an essential means for CO_2 transport; often when CO_2 sources and storage sites are too far apart for pipelines. Ship-based transport requires the liquefaction of CO_2 making it denser and enabling ships to transport larger CO_2 mass for a given volume.

The shipping of CO_2 has been practised for over 30 years, but the size of the industry is small with only approximately 3 Mtpa of CO_2 being transported by ship in total (IEAGHG, 2009). The shipping experience to date is entirely connected with the food and beverage sector. Today, CO_2 is transported by small-scale ships of 800–1,800 m^3 from production sites to distribution terminals, and then distributed via train or truck to end-users.

Although experience with CO_2 shipping is limited, the gas industry has more than 80 years of commercial experience with the shipping of pressurised gases of different kinds. CO_2 transport by ships and the infrastructure required are very similar to those for Liquified Natural Gas (LNG) and Liquified Petroleum Gas (LPG). It is, therefore, reasonable to assume that the technical scale-up of CO_2 shipping to the scale required for CCS is achievable without major technical challenges as most of the technology and the expertise already exists. As an indication of scale, the IEAGHG estimated that the global CCS industry would need to grow to around the same size as the current gas industry to meet Paris Agreement targets (IEAGHG, 2017b).

4.3.3.1 CO_2 Ship Design

CO_2 is transported by ship in a liquid state at conditions near the triple point (Figure 34). Transporting near the triple point means the density of liquid CO_2 is much higher than when in a gaseous state and enables a larger amount of CO_2 to be transported per ship. Based on the density of CO_2, ships are categorised as low, medium and high pressure.

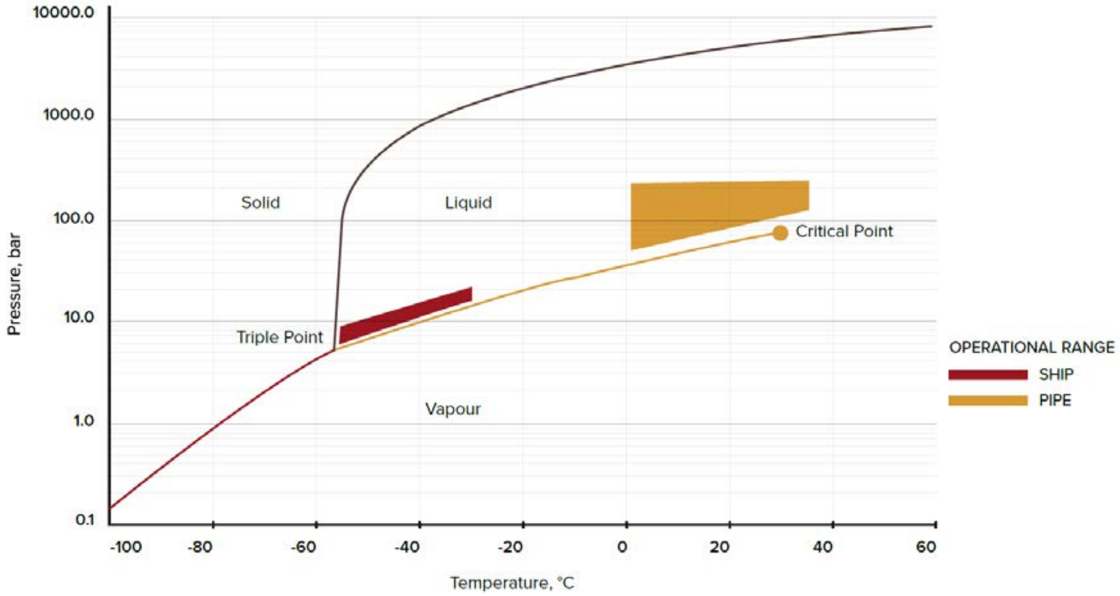


Figure 33. Pressure and temperature status diagram of CO_2. Note the small area for the transport of CO_2 near the CO_2 triple point.

Ships used today for food-grade CO_2 transport are referred to as medium pressure ships – they are designed to transport CO_2 as "refrigerated liquid", at conditions in the range of 15-20 bar abs and -20 to -30°C, which is similar to liquefied petroleum gas (LPG) carriers. The existing size and number of these ships are limited. To date, there are only a few operational vessels specifically designed for the transport of CO_2, with capacity in the range of 900-1,250 m^3 (Brownsort, 2015). Most of which were converted from LPG carriers. IM Skaugen specifically designed six LPG carriers of 10,000 m^3 capacity to be also capable of transporting CO_2. They have been operating since 2003, although not yet for CO_2 transport. The positive and negative factors of medium and low-pressure ships are presented in Table 16 and taken directly from (IEAGHG 2020a; IEAGHG, 2020).

Table 16 Positive and negative factors of medium and low-pressure ships. Taken directly from: IEAGHG (2020).

Factor	Medium Pressure	Low Pressure
CO_2 density	1 060 kg/m^3 × Less CO_2 is transported per tank for a fixed volume, and larger volume capacity is required for a fixed mass	1 153 kg/m^3 ✓ More CO_2 is transported per tank for a fixed volume, and smaller tanks are required for a fixed mass
Liquefaction	✓ Lower energy requirement for liquefaction (cooling and compression).	× Greater energy requirement for liquefaction (around 10% higher).
Transport and storage tank design	× Greater wall thickness is required, increasing weight and cost per volume stored and affecting workability. × Storage tanks must be smaller, requiring more tanks and therefore higher capital and operational costs. ✓ Less expensive materials such as carbon steel may be used (depending on impurity levels, see next section).	✓ Wall thickness can be lower, reducing weight and cost. ✓ Storage tanks can be larger, resulting in lower operational and investment cost. × Higher quality material may be required to handle the lower temperature (close to -50°C), increasing material costs, but not the installation cost.26
Ship design and operation	× Greater number of tanks increases required ship size, increasing cost. × Higher fuel consumption due to increased weight of tanks	✓ Lower number of tanks reduces required ship size, reducing cost. ✓ Lower operational and investment cost due to lower weight of tanks
Heel	× 4%, greater impact on transport capacity.	✓ 1.6%, lower impact on transport capacity.
Water content limit	× More strict requirements to avoid hydrate formation than Low P	✓ Less strict requirements – up to 100 ppmv.
Dry ice formation	✓ Little dry ice formation in the event of a pressure drop	× As the condition is close to the triple point, the margins for formation of dry ice are smaller with implications for required control systems and relief valve streams.

For large-scale CCS applications, larger ships would be required than those available today. The majority would require more than one tank. For larger ships, CO_2 conditions of 5-9 bara and lower temperature -55°C are proposed and are categorised as low-pressure. The lower pressure is advantageous to reduce the thickness of the tank's walls, which helps lower the weight of the ship and reduces transport costs. Ships for the transport of CO_2 at low pressure would have a comparable design to typical LPG ships, with large, cylindrical tanks. This concept, however, requires the most energy for the liquefaction (cooling) of the gas.

Because the market for bulk shipment of CO_2 is in its infancy, different CCS project scales and applications will require low-, medium-, and high-pressure solutions. Several different liquefied CO_2 ship designs are being developed by manufacturers. Table 17 summarizes announced liquid CO_2 ship design concepts.

Table 17. Announced design concepts for liquefied CO_2 carriers.

LCO_2 Ship Manufacturer or CCS Project	Volume	Dimensions	Transportation Conditions	Ship Fuel	Source/Notes
Ecolog	84,000 m^3	275 m x 48 m	8 barg, -55°C	Not reported	NH_3/CO_2/LPG cargo (Ecolog, 2022)
Hyundai Heavy Industries and Hyundai Glovis Co.	74,000 m^3	284 m x 42 m	High pressure, low temperature	LNG	AiP from ABS. (Chang-won, 2022)
Daewoo Shipbuilding & Marine Engineering	70,000 m^3	260 m x 44 m	Not reported	LNG	(Chang-won, 2022)
Stella Maris CCS	50,000 m^3	238 m x 38 m	6.5 barg, -47°C	LNG / Bio gas / NH_3	Dynamic positioning; Offshore offloading and direct injection capability. (Altera, 2022)
Mitsui O.S.K. Lines and Mitsubishi Heavy Industries	50,000 m^3	Not reported	Not reported	Not reported	NH_3/CO_2 carrier concept (MOL, 2022)
Hyundai Heavy Industries	40,000 m^3	239 m x 30 m	Not reported (IMO Type C cargo tanks)	LNG	(Lloyd's Register, 2022)
Daewoo Shipbuilding & Marine Engineering	40,000 m^3	Not reported	Not reported	Not reported	(Ovcina Mandra, 2022b)
Ecolog	20,000 m^3	167 m x 28 m	8 barg, -55°C	Not reported	NH_3/CO_2/LPG cargo (Ecolog, 2022)
Northern Lights	7,500 m^3	130 m length	15 bar, -28°C	LNG	Ships to be fitted with wind-assisted propulsion and air lubrication systems. (Northern Lights, 2021)
Mitsubishi Shipbuilding	1,450 m^3	72 m x 12.5 m	Not reported	Not reported	Demonstration test ship (Hakirevic Prevljak, 2022a)

4.3.3.2 CO_2 shipping infrastructure

The shipping supply chain for CCS consists of the following elements in Figure 35.

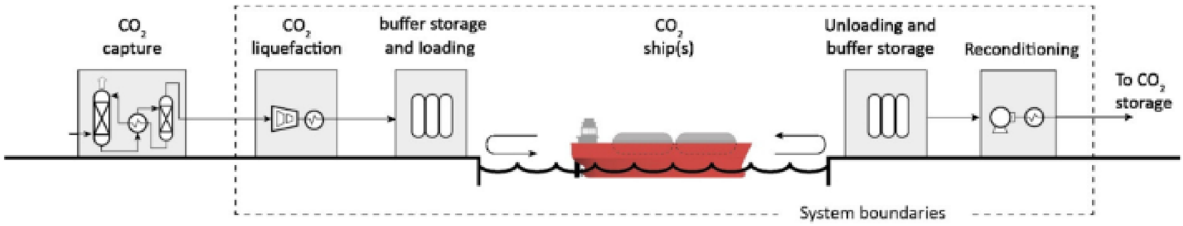


Figure 34 Main components for shipping logistics for CCS (Roussanaly et al. 2021).

Liquefaction

Liquefaction involves the compression and liquifying of CO_2 prior to storage and transport by ship.

Liquefaction processes are typically divided into two methods:

- Internal cooling system ("open" system) where CO_2 is compressed to near the critical pressure before being decompressed to the transport pressure.
- External refrigeration system ("closed" system) where the CO_2 is compressed to the transport pressure and then liquified using an external refrigeration system.

Open systems are simpler in configuration but are typically less efficient.

The choice of liquefaction method depends on a number of factors (IEAGHG, 2020b) :

- The state of the CO_2 before liquefaction (either pressurised, at 70-100 bar abs, or at no or low pressure, at 1-2 bar abs source pressure)
- The required transport condition
- The temperature of available cooling water
- Availability/desirability of an external refrigeration system (e.g. using ammonia)

The liquefaction process is often the most energy-intensive step in the ship transport value chain, requiring 11-14% more energy than the compression energy required for pipeline transport (IEAGHG, 2020b).

The removal of water is essential at the conditions for liquefying CO_2 to prevent ice formation. Dehydration can occur through the compression and condensation steps of the liquefaction process. Alternatively, the CO_2 can be dehydrated prior to liquefaction using glycol dehydration or molecular sieve technology. Non-condensables are typically removed through fractionation following liquefaction.

Buffer storage

The flow of CO_2 from their sources and subsequentially liquefaction of CO_2 is a continuous process. However, shipping operates discretely or in batches. To ensure that the flow of CO_2 remains continuous, buffer storage is required.

The capacity for buffer storage is important when designing shipping infrastructure. The capacity is based on factors including ship size and ship logistics. (BEIS 2018) cites several literature sources that choose capacities between 100-150% of the total ship capacity.

Typical buffer storage consists of pressure vessels that are horizontal, vertical or spherical in shape. The shape considered is dictated by the area available for storage and costs.

Loading and offloading facilities

Loading of CO_2 from the onshore buffer storage to the CO_2 carrier can be performed using conventional articulated loading arms that are commonly used for cryogenic liquids like LPG or LNG.

The offloading scheme in Figure 36 illustrates the three basic options for offloading CO_2 from a ship to an injection site.

- Option A where CO_2 is unloaded into an intermediate storage tank onshore from where it can be piped to the storage reservoir

- Option B where the CO_2 is unloaded to an intermediate floating vessel, platform or buoy mooring anchor for injection into the storage reservoir

- Option C where the CO_2 is injected directly from the ship into the storage reservoir

Regarding Options B and C, the IEAGHG Shipping study identified that offshore unloading, although present in the literature, is largely unknown when compared to onshore unloading (IEAGHG, 2020a). Also, the infrastructure and ship design vary significantly between Options B and C.

Depending on the storage injection option applied, the ship needs to be equipped for reconditioning the CO_2 to the temperature and pressure required for injection or offloading, which basically includes compressors and heat exchangers. This infrastructure can be located on the ship, on the platform or partially on both. Conditions vary from case to case depending on offloading system design, injection platform design, and storage reservoir conditions. Collectively, these variations are expected to lay in these indicative ranges:

- Pressure from 50 to 400 bar abs

- Temperature in the range of -15°C and 20°C

Studies carried out by Chiyoda (2011) and CATO (2016) considered the technical feasibility of direct CO_2 injection from the ship concluding that direct injection from a CO_2 carrier into a range of different injection wells is feasible. The equipment for compressing and heating of the CO_2 prior to injection can be installed on the ship (Chiyoda, 2011; CATO, 2016).

The CATO study also concluded that temporary near-well storage is the lowest-cost solution. When temporary, near-well storage is used, ship-offloading times are shorter, even for larger size ships. As a result, the shipping fleet is used more efficiently, and overall cost decreases, as opposed to direct injection from the ship into the well.

It is preferable to have intermediate storage because it allows a continuous and stable CO_2 flow from the tank into the reservoir. This contrasts with intermittent injection (as the ship unloads), which has significant challenges and detrimental effects on well and storage formation operation (Roussanaly, 2013).

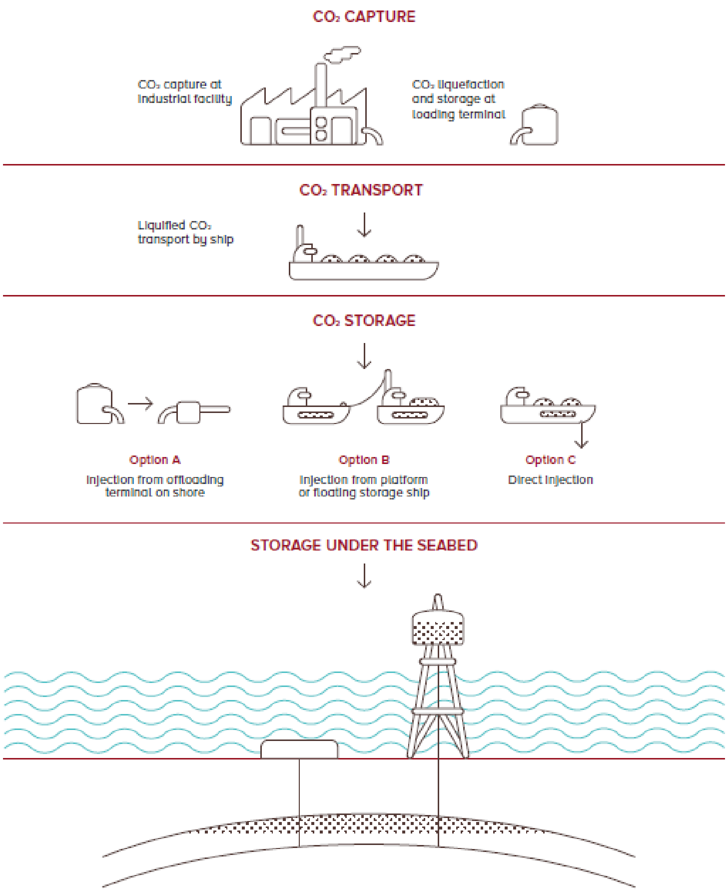


Figure 35 Offloading options from ship to reservoir.

Conditioning of the CO_2 corresponds to bringing the temperature and pressure of the liquified CO_2 to the desired conditions for further transport to the storage location. This process is fairly standard for cryogenic gases, with regasification of LNG a good example. Heating is simple through cryogenic heat exchangers using air or seawater with compression handled by dense phase pumps.

4.3.3.3 Shipping emissions

It is important to note that shipping adds emissions as a result of fuel combusted for transport. As the distance increases so will the tonnes of CO_2 produced from ship fuel combustion per tonne of CO_2 transported. This will be important if considering shipping of CO_2 as a transport method for CCS projects.

Avenues for decarbonising shipping are still in early development including on-board carbon capture and storage infrastructure, zero carbon fuels (hydrogen or ammonia), bio-fuels or batteries.

Commodities trader, Trafigura, and Yara International have signed a memorandum of understanding to develop ammonia as a clean fuel in shipping (Trafigura, 2021). The companies will explore research and development of both green and blue ammonia as marine fuel, as well as development of clean ammonia infrastructure for shipping.

Several corporations are now developing and testing ship-based carbon capture (SBCC) units to separate CO_2 from a ship's exhaust gases:

- A consortium of seven companies, led by the Global Centre for Maritime Decarbonization and the Oil and Gas Climate Initiative, have announced a two-year project to install a carbon capture system on-board one of Stena Bulk's medium range IMOIIMAXX tankers. The project aims to capture at least 30% of the tanker's CO_2 emissions while sailing and will sequester or reuse the captured gas. Notably, the project will employ non-proprietary equipment and processes such that results can be shared publicly to advance the capture science and technology. The project is named REMARCCABLE (Realising Maritime Carbon Capture to Demonstrate the Ability to Lower Emissions)(Carbon Capture Journal, 2022).

- Lloyd's Register, in September 2022, approved in principle Value Maritime's SBCC system – the Filtree System – which filters sulphur, 99% of particulate matter, and 40% of CO_2 emissions with potential to exceed 90% of CO_2 emissions in the future (Ovcina Mandra, 2022a). Installation of the system is planned for two Eastern Pacific Shipping (EPS, Singapore) MR tankers (M/T Pacific Cobalt by 2022 and M/T Pacific Gold in 2023), with the option to install the system on an additional three EPS vessels. Value Maritime installed its first CO_2 capture module on a Visser Shipping vessel in October 2021.

- Seabound (London) has designed prototype carbon capture equipment that uses a solid lime-based approach to capture 95% of ship's carbon emissions (Weber, 2022). Engine exhaust is routed through a container filled with calcium oxide pebbles, which bind with CO_2 to form calcium carbonate – a stable daughter product mineral. In contrast to solvent-based approaches, the processing of trapped CO_2 will take place on land rather than on-board vessels. This saves on-board space and energy requirements. On land, the calcium carbonate can be heated to release the trapped CO_2 or can be stored or sold as-is.

- Carbon Ridge (California) is developing modular SBCC solutions and has raised $6 million USD to help fund an on-board pilot project in 2023 (Hakirevic Prevljak, 2022c). Scorpio Tankers (Monaco) signed an MOU with Carbon Ridge in March 2022 to collaborate on the development of on-board carbon capture systems which do not require large structure modifications (Hakirevic Prevljak, 2022b). The agreement includes FEED studies, validation, and a small-scale test unit aboard on of Scorpio's tankers.

- In January 2022, Samsung Heavy Industries (SHI) gained approval in principle from the Korean Register of Shipping for its on-board CCS technology for ships fueled by LNG (Pekic, 2022). SHI developed the technology with its partner Panasia. The CCS system uses amine-based solvents to separate CO_2 from ship exhaust. The SHI CCS system for LNG fuelled ships is targeting 2024 for commercialization.

- Finland-based Langh Tech has begun testing its SBCC technology on one of Langh Ship's (its sister company) vessels (Hakirevic Prevljak, 2021; Langh Tech, 2021). The capture system is integrated into one of Langh Tech's existing closed loop SOx scrubbers. To capture CO_2, additional Alkali material is added to the scrubber's process water to stimulate a CO_2-capturing reaction. Initial tests showed a 5% increase in alkali dosing reduced CO_2 emissions by 3.3% for a main engine load of 85%. At a 40% main engine load, CO_2 reduction reached 7%.

- Cryogenic capture and Mitsubishi Shipbuilding have both developed onboard CO_2 capture units and both claim to capture 90-95% of a ship's CO_2 emissions (Morgan, 2020; PMW Technology, 2019). Mitsubishi Shipbuilding are currently undertaking the world's first voyage testing of their onboard CO_2 capture system on a coal carrier (MHI, 2021). In October 2021, Mitsubishi Shipbuilding and K Line announced they had successfully separated and captured CO_2 from the exhaust gas aboard coal carrier, Corona Utility – purported to be a world first (Bahtić, 2021). The captured CO_2 is reported to have had a purity of more than 99.9%.

- TECO 2030 and Chart Industries announced in June 2021 a 3-year agreement to jointly develop onboard carbon capture systems utilizing their Cryogenic Carbon Capture (CCC) technology, originally developed by Sustainable Energy Solutions and acquired by Chart in December of 2020 (Chart Industries, 2021). The CCC process produces high purity, liquid CO_2, which will be stored onboard in cryogenic storage tanks.

- Swedish company Alfa Laval has successfully tested a modified PureSOx scrubber onboard a new Japanese vessel, capturing CO_2 from auxiliary diesel engines while in port (Seatrade Maritime News, 2021).

- Windship Technology and Calix Limited have established a joint development agreement to integrate Calix's RECAST capture system, which not only captures CO_2 emissions, but also targets elimination of NO_x, SO_x, and particulate emissions from a ships' power systems (Windship Technology, 2021).

An advantage of these onboard systems is the captured CO_2 can be offloaded at port with bulk CO_2 shipment.

For long-term shipping of CO_2 this will be important to ensure that CO_2 produced from shipping fuel does not severely erode the CO_2 transported by ship for CCS.

4.3.4 Truck and rail transport

Truck and rail transport, while established methods for the transport of CO_2, are often not discussed as they are deemed only to suit small-scale CCS operations. While the discussion around large-scale transport methods is important when looking at the scale that CCS will be required to meet global decarbonisation targets, it does not mean that all modes of transport will not be required to support CCS projects.

CO_2 is transported by truck and rail in its liquefied form, similar to shipping. The infrastructure required prior to and following CO_2 transport is the same or very similar to that of shipping and that used for the truck and rail transport of other cryogenic liquids.

Truck-based transport of CO_2 uses tank trucks with trailers ranging in size from 2 to 30 tonnes. The CO_2 is typically at 17-20 barg and -30 to -20°C. Truck-based transport is similar to shipping on land with the ability to be a flexible, adaptable and reliable means for transporting CO_2 in smaller quantities. Like shipping, it offers the ability to scale up quickly, albeit on a smaller scale.

Rail-based transport uses special rail cars developed to transport CO_2 at conditions from 7-26 barg and -50 to -20°C. It can provide transport of larger quantities of CO_2, however only if existing infrastructure is available.

4.3.5 Transport cost drivers

Pipelines

The technologies involved in the transport of CO_2 are mature and it is not anticipated that costs will improve significantly with technological advancements. As an example, for compression technology there continue to be incremental improvements in efficiency and reliability, however these will not significantly reduce compression costs.

The key focus for reducing pipeline transport costs is through design optimisation and understanding the cost drivers for the different phases that CO_2 can be transported.

As highlighted previously gas-phase CO_2 transport is not a common mode of pipeline transport. The majority of CO_2 transported by pipeline is in dense or supercritical phases. This does not mean that all CO_2 should be transported in dense phase, under certain circumstances it may be favourable to consider gas phase transport.

Analysis undertaken by the GCCSI in (GCCSI 2021a) and (GCCSI 2021b) highlights that the cost of piping will always be greater for gas phase over dense phase transport. However, the cost trends also demonstrate that gas-phase CO_2 compression is lower cost than dense phase compression for the same flow capacity for compression from the source. Based on the analysis the following guidelines for gas phase versus dense phase transport were identified:

- All cost trends emphasise that economies of scale reduce costs for the infrastructure required for pipeline transport of CO_2.
- Pipeline routes carrying less than 0.5 – 1 Mtpa should be made as short as reasonably possible, with the objective of joining larger capacity pipeline routes before covering large distances
- Gas phase transport is cheaper, and therefore an advantage, for short transport distances and smaller flows using the following guidance:
    - If the flow is less than 0.3 Mtpa it should be transported in the gas phase to a shared compression system downstream for boosting to dense phase
    - If the flow is greater than 0.5 Mtpa full compression to dense phase at the source for transport should be done

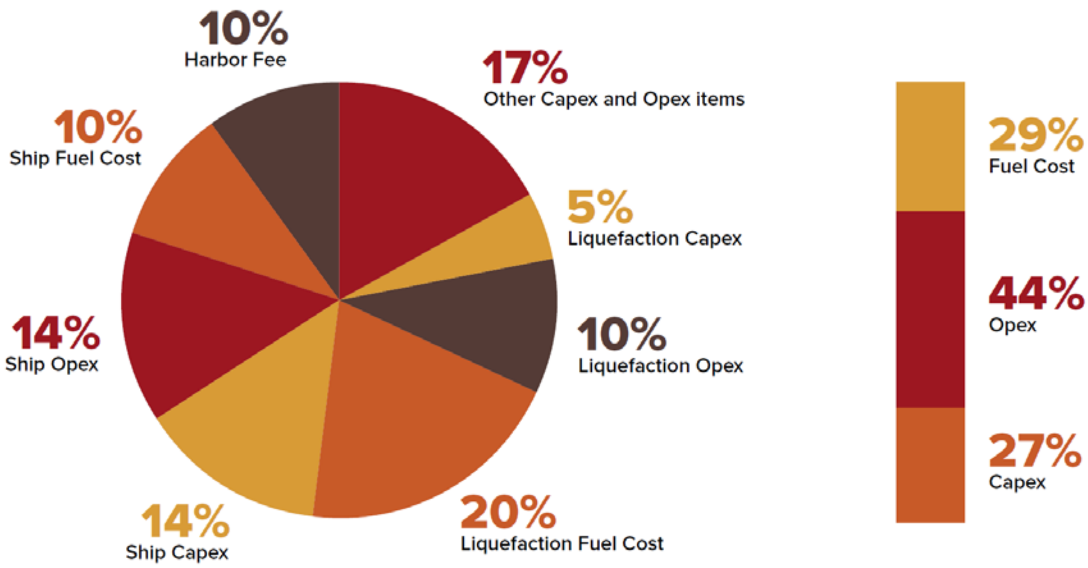
- o If the flow is between 0.3-0.5 Mtpa the transport phase should be chosen on a case by case basis.

Understanding the cost trends for the different approaches to pipeline transport is important when exploring which the application of pipeline transport to a refinery, or any indusrial facility. These will be discussed in more detail with exploring transport applications for refineries in the subseuqent sections.

Shipping

For shipping the main parameters influencing the cost are transport distance and volume, chain logistics, and vessel type (Figure 37).

Figure 36. Cost breakdown for CO_2 shipping in the UK (Source: Element Energy, 2018)



The largest capital expenditures in a shipping network are associated with the liquefaction plant and the ship(s). Operational costs (Opex) are mainly due to energy requirements (predominantly the liquefication) and operational crew (Skagestad et al., 2014). Opex represents the largest contribution to the overall shipping cost, accounting for about 60-80 percent of total cost per tonne of CO_2 over the lifetime of a project (Skagestad et al., 2014). The Opex costs of energy requirements is the driving reason low-pressure ships are found to be most cost-effective method for transporting CO_2 via ship (IEAGHG, 2020).

(Roussanaly et al., 2021) studied the optimal conditions for ship-based transport. Their models considered shipping volumes from 0.5 to 20 $MtCO_2$/yr, over transport distances from 100 to 2000 km, and shipping pressures of 8 bara (7 barg) and 16 bara (15 barg). For cases where shipping was more cost-efficient than pipeline transport, their results showed shipping at 8 bara was more cost-efficient than shipping at 16 bara, in all cases. Potential cost reductions when shipping at 8 bara ranged from 15 – 30% over 16 bara transport.

When considering shipping of CO_2, it is important to look at when it may be applicable to consider in place of pipelines as the only other large-scale means of transporting CO_2. Studies tend to agree on the following conclusions:

- For an individual project, the choice between piped or shipped CO_2 will be mainly defined by cost optimisation.
- Generally, pipelines have lower costs than ships for transporting large quantities of CO_2 over short distances, while ships have lower costs over long distances. See Figure 38.
- Pipeline costs are roughly proportional to distance, while shipping costs are only marginally influenced by distance.
- Costs of a pipeline generally consist for the most part of CAPEX (e.g. 75–95 percent), while the costs of ships consist for the most part of OPEX (e.g. 60–80 percent).
- A ship can be less costly than pipelines not only for single sources but also for CCS clusters during ramp up given the flexibility to adapt CO_2 shipping routes in contrast to pipelines.
- Due to the different CAPEX–OPEX structure, shipping might be used during the first-of-a-kind CCS deployment to limit investments upfront, reducing financial risk. Pipelines could be used in regions with well-established CCS infrastructure already available.

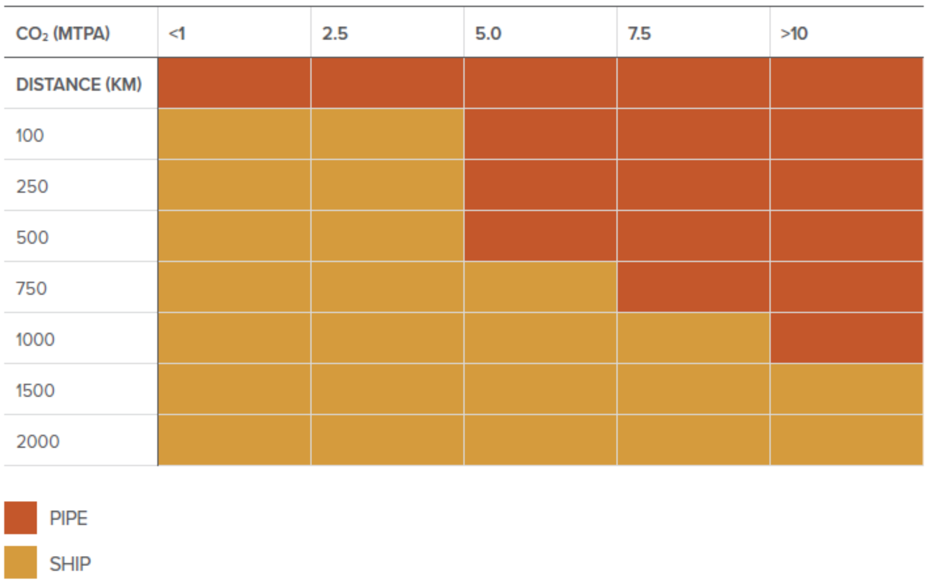


Figure 37 Preferred Transport Option based on Capacity (Mtpa CO_2) and Distance (km).

Besides costs, there are other factors that could influence the choice of transport method. CO_2 shipping can also offer a more flexible alternative to pipelines for offshore storage and during the overseas movement of CO_2, especially where there is variability in sources, demand and storage sites. There are four major advantages of shipping over pipelines:

- Shipping enables the scale of a project to be rapidly increased if the market demands. Whilst additional or larger ships can be added to increase CO_2 supply, the capacity of pipelines needs to be defined from the initiation of the project. This presents an issue of over-engineering a pipeline anticipating greater demand or limiting the demand to pipeline design.

- Shipping enables a single ship, or shuttle shipping to load from multiple CO_2 sources and offload to a single storage site. From a storage perspective, this increases the economics of multi-user offtake agreements. From a capture perspective, this enables various sized capture facilities, most likely industrial sources clustered in the same region to access transport and storage at a lower cost.

- Shipping routes can be changed, and new storage sites utilised if the original storage site becomes unusable. For example, if a storage site does not have the injection rates and total capacity as required for the corresponding capture rates, then the ship can be moved to another storage site. Re-routing a pipe and new pipelines would cost significantly more.

- On the closure of a CCS facility, a ship can be re-routed, sold or reused, whereas a pipeline needs to be removed at a cost.

Rail and Truck

As described previously the use of rail and trucks to transport CO_2 is not expected to be significant and there is limited data available to aid in cost comparisons with pipelines and shipping. The availability of existing infrastructure, project specific costs through initial technology evaluations or external factors may result in a project considering rail or truck transport.

4.3.6 Applicable transport strategies for refineries

Like CO_2 capture technologies, transport technologies vary in type, cost and technology. The selection of appropriate transport technologies should take into account the volume (tonnage) of CO_2, storage location, terrain to be travelled, among several other design factors.

As highlighted in 3.3.5 capture plant deployment best practices within a refinery environment, it is essential that planning for staged deployment of capture projects is undertaken. Refineries have a range of point sources with varying costs and scales, and it is likely that these would be deployed in separate stages rather than as a single, integrated project. The mode of transport and transport design must also consider this staged capture deployment and be planned accordingly.

For example, if a refinery is considering a pipeline to transport its CO_2 to the storage location and CO_2 sources were to be captured and stored in several stages; the pipeline should be designed to cater for the overall flow expected for all stages. This will often result in a lower cost and complexity overall for stage design. Existing pipelines are limited in their capacity to take additional flow and if the pipeline were sized for only the initial stage(s) and subsequent stages exceeded the available capacity, parallel pipelines would be required often at a greater cost and complexity. However, sizing for the overall flow can present a risk of over-engineering a pipeline if later phases of the project do not proceed.

Similarly, a refinery may choose to use ship-based CO_2 transport as it offers the ability to scale up quickly if required as well as offer the flexibility to not need to make an upfront decision on the size and scale of the infrastructure for transport that is required for pipeline transport.

Like capture plant deployment the development of transport infrastructure must also consider the following during the planning stages:

- Supporting infrastructure, especially utility capacity (power, cooling)
- Available land for transport preparation equipment and available space in pipe racks
- Any planned changes to the future configuration of the refinery – for example, producing different projects as demand for liquid fuels changes

However, transport strategies are not simply isolated to the refinery boundary and must also consider several other factors:

- Proximity to a suitable storage location and the terrain that must be traversed to reach this storage from the refinery location
- Access to existing infrastructure such as a port or rail network or existing pipelines
- Proximity to other industries that could support the development of networks, or hubs, facilitating the sharing of costs which can reduce the overall cost per tonne of CO_2

Designing both the CO_2 capture and transport infrastructure is a complex exercise and needs to be carefully managed in unison. Both capture and transport infrastructure are dependent on each other and risks identified in one can impact the other. Designing capture and transport infrastructure in unison is critical to ensure that risk or issues are identified early and can be considered and addressed.

4.3.6.1 Refinery infrastructure for transport systems

As already discussed with CO_2 capture plants, CO_2 capture projects at refineries are typically brownfield projects and require careful management of the interactions and integration with an already-complex processing facility.

Like CO_2 capture systems the compression of CO_2 for pipeline transport and liquefaction, storage and loading facilities for CO_2 for shipping, rail and truck transport will also consume considerable additional utilities. The additional utilities for both CO_2 capture and transport must be assessed with the balance of existing supply and demand to determine if expanded capacity (through upgrade projects) or reduced spare capacity for each utility is necessary.

Be it compression of CO_2 for pipeline transport or liquefaction, storage and loading facilities for CO_2 for shipping, rail and truck transport large amounts of power are required, above what is typically consumed in a refinery. Depending on the technology selected, CO_2 capture plants may also require either heat (steam) or power. If the refinery operates a combined heat and power (CHP) unit further consideration will need to be given to the relative additional amounts of electricity and steam needed. If conventional fossil-fuel based power or CHP unit is selected, consideration should be given to whether CO_2 capture should be deployed at the outset. Any emissions produced through power or steam generation which are not abated will reduce the net CO_2 avoided from the capture project. Alternatively, the use of renewable power on the refiner's grid should be sourced.

The additional infrastructure to connect the power supply to the transport infrastructure is also paramount as are any other utilities that may be required such as cooling water, instrument air and inert gases. As an example, for the supply of power to the transport infrastructure the substation equipment will likely need to be upgraded to manage the additional load and new power cables will be required. For other utilities, similar equipment upgrades may be required as well as new piping to transfer these utilities.

4.3.6.2 Available land for transport infrastructure

Physical space, both in terms of land and in terms of pipe rack availability, are crucial for all refinery upgrade projects.

Transport infrastructure may need to consider vertical rather than horizontal design for equipment, maximising the use of vertical space. As an example for shipping, this could be spherical or vertical buffer storage to limit space required or vertically designed liquefaction equipment (cold boxes).

In some refineries, available space may dictate the transport method that can be applied. As an example, if the footprint for liquefaction and buffer storage is greater than the available land for transport infrastructure this may drive the refinery to consider only pipeline transport where the footprint for compression may be more suitable.

As emphasised in deployment best practices for CO_2 capture, space in pipe racks may also be limited or not available in many refineries for the additional utilities required for CO_2 transport infrastructure.

A constructability plan should be developed as part of the CO_2 capture and transport strategy.

4.3.6.3 Consideration of future refinery configuration and production

Like CO_2 capture strategies, it will be necessary to deal with changes to refinery configuration as a result of the changes in refinery product demand over time and the need to be suitably flexible to adapt to moving targets for the coming decades. CO_2 transport must also offer suitable flexibility for adaption.

When planning for future refinery configurations several factors may influence the choice of transport technology, where this is an option to consider different technologies.

Shipping can provide greater flexibility with phased design as highlighted previously. A refinery may choose this transport method to aid in quick project ramp-up and the flexibility to review several potential configuration changes at a later date to ensure any early-stage emission targets are met.

Pipelines require greater attention during the planning stage as there is a risk of over-engineering a pipeline anticipating greater demand or limiting the demand to pipeline design.

However, a pipeline may be considered if planned changes to the refinery configuration result in a relatively consistent emissions profile over time.

Ultimately this comes back to planning for staged deployment of CO_2 capture projects and ensuring CO_2 transport is considered in unison.

4.3.6.4 Location of suitable storage

Ideally, CO_2 would be stored where it is captured. The reality is that capture and ideal storage sites rarely coexist, so the transport networks aim to fit between a range of capture and storage locations. In Europe, the majority of suitable CO_2 storage will be off-shore requiring either off-shore piping or shipping to off-shore injection required.

Many of the refineries in Europe are located along the coastline offering an opportunity to consider ship-based transport if they import feedstocks and export products in an adjacent terminal. For other refineries, it is likely that either a combination of on-shore and off-shore pipelines or on-shore pipelines and shipping to reach the storage location.

For pipelines, there are several factors that need to be considered:

- The geography and geology along the route linking CO_2 sources to the storage location;
- Rights of way (ROW) approvals and costs;
- The proximity of pipelines to population centres (including social preferences); and
- The ability to locate booster stations along the route.

The extent to which any sort of industrial infrastructure activity is located within close proximity to populated areas will have inevitable implications for local community acceptability of such proposed infrastructure – and this is equally true for CO_2 pipelines. Public scrutiny will likely focus on the safeguards needed to ensure that the design is safe for both above and/or below-ground installations; that there is provision of adequate and appropriate levels of signage; and that owners can appropriately provide for and/or protect the assets from intentional and/or unintentional third party activity. This will be a key challenge in Europe requiring careful community engagement to obtain community approval for pipeline infrastructure.

It is likely projects may consider combinations of transport methods, the Langskip project is a good example of this. The primary transport method for the Langskip project is by ship from ports near to the initial two sources of CO_2 to dedicated land-based import facilities prior to pipeline transport to the offshore CO_2 storage location.

4.3.6.5 Access to existing infrastructure

Existing industrial facilities, including refineries, may have active or dormant rail or truck infrastructure or existing pipeline or port infrastructure for importing feedstocks and exporting products.

If a refinery is located close to the coastline it is likely that it has existing port infrastructure that could be expanded or retrofitted for ship transport of CO_2 to the storage location.

For a refinery with existing rail infrastructure, this may result in rail transport of CO_2 being considered. Rail transport would only be part of the solution as it is unlikely that an existing rail system would end at suitable storage. It could, at least, assist in reducing the costs of overall CO_2 infrastructure.

Existing pipeline corridors that contain pipelines for refinery feedstocks or products with available space for a CO_2 pipeline can often reduce the costs involved, assuming the corridors are in the direction of suitable storage. Many feedstocks or product pipelines end at a port terminal enabling further transport by ship to the storage location.

Existing infrastructure could also offer reduced timeframes for the necessary permitting required for transport infrastructure which can take several years to navigate. Some of the requirements for permitting for CO_2 transport infrastructure may already have been covered through existing permits.

4.3.6.6 Proximity to other industries

Many studies have identified that costs for CCS infrastructure reduce on a per-unit basis with increasing scale. The development of shared transport and storage infrastructure through CCS networks or hubs has become a focus for project developers. Shared CCS infrastructure offers several benefits:

- Distributing investment and operational costs by sharing infrastructure
- Lowering the barriers for industries that may have lower CO_2 volumes and/or higher costs of capture
- Minimising the environmental and community impacts with transport infrastructure development
- Reducing the planning and regulatory approvals process for several industries
- Shared utilities for capture and transport equipment.

Refineries can often be located in larger industrial complexes with several other industrial facilities that may also be considering CCS deployment that could benefit from shared infrastructure. Exploring shared infrastructure will still be complex and industries that are considering this will need to commence engagement with adjacent industries during the initial scoping stages to explore commercial models and design of shared infrastructure and identify issues and risks early to assess whether shared infrastructure is the most suitable solution.

4.4 Barriers to transport and storage – Identification of barriers to transport and storage of CO_2 at refineries

4.4.1 Overview

This section will examine the barriers to the transport and storage of CO_2 in the European Union (EU) and their applicability to refineries. The EU adopted a CCS Directive in 2015 and the EU's Emissions Trading System (EU ETS) is the main driver for investments in CCS projects since 2015 (European Environmental Agency, 2015). The EU's legal framework states that the ETS considers captured CO_2 that has been geologically stored (or safely stored) to be "not emitted". Environmental Impact Assessments and storage permits are required, in addition to stringent requirements for site selection according to the CCS Directive (European Commission, 2022a; Directive of the European Parliament and of the Council on the Geological Storage of Carbon Dioxide, 2009). The Directive also requires verifying that the emission stream is mostly comprised of CO_2. Financial security of the operator is also needed before injection of CO_2 can commence (European Commission, 2022a).

The EU ETS is the world's first carbon market system. It is also the world's largest carbon market with jurisdiction over all 27 EU member states and Norway, Iceland, and Liechtenstein (European Commission, 2022b). The EU requires mandatory participation for companies that operate in energy intensive sectors and especially those that generate GHG emissions as part of their operations. The ETS cap and trade works by setting a cap on the total GHGs that can be emitted by all the entities under its jurisdiction. The cap is dynamically reduced over time to reduce annual emissions over time. Entities can trade allowances within the ETS that are allocated through auction sales or allocated for free. The free allocation of allowances is meant to address high risk sectors and those sectors that are deemed to be at risk for carbon leakage. Some examples of high-risk sectors include refining, mining, manufacturing, and petrochemicals to name a few (EUR-Lex Access to European Union law & Official Journal of the European Union, 2019). Free allocation of allowances is also used as a policy tool to incentivize the modernisation of the EU's energy sector through investments in clean technologies, diversifying energy sources, upgrading existing infrastructure, and modernising energy production and transmission (European Commission, 2021b).

4.4.2 Barriers – in general

There are several general barriers that prevent CCS projects from starting or in continuing operations. The EU lists twelve barriers, they are listed below for convenience and grouped by theme (European Commission & European Union, 2022). However, these are not unique to the EU since similar barriers exist in other jurisdictions

1. Technical:

   a. <u>Technical expertise</u>: there is a shortage of specific technical expertise since industries upstream and downstream of this technology have extensive supply and value chains that also require niche skills.

   b. <u>Technology performance</u>: while several CCS technologies are being developed and have been tested in pilot facilities, many have not been tested at scale. This leads to uncertainties about the technology's performance for large applications.

2. Economic:

   a. OPEX uncertainty: since operating expenditures rely on commodity prices, notably the price of oil, there is uncertainty about the reliability of cash flows after facilities start operating.

   b. CAPEX uncertainty: capital expenditures are related to site specificity and to distinct policy requirements in different jurisdictions. The resulting cost estimates are also unique to each facility. It is another source of uncertainty since it offers little replicability for future projects.

3. Commercial:

   a. Lack of revenue model: CO_2 prices are set through a patchwork of international compliance and voluntary markets each driven by their own jurisdictional policy, legislative, and regulatory requirements (The World Bank, 2022). The prices are low, and projects also require support through tax assistance (International Monetary Fund (IMF), 2021).

   b. Uncertainty in demand: Due to significant capital expenditure requirements, large industrial entities are usually the only viable project developers. Additionally, a seamless value chain for the utilization of CO_2 in most commercial and industrial products is lacking.

4. Operational:

   a. Resource usage at scale: if CCS is to be used at scale, it would require considerable supporting resources in addition to transportation networks. For example, scaling up CCS would also require scaling up electricity generation capacity (European Commission & European Union, 2022).

   b. Risk perception: the timelines for developing CCS projects are long and could take between seven to ten years for projects to come online after being initiated. The associated hurdle rates for CCS projects are higher because of the higher risk associated with future cash flows. Hence, CCS projects require a higher return on investment.

   c. Cross-chain integration: there are many entities involved with the CCS value chain, all of whom would need to be well integrated. Stakeholders include project developers, emitters, transportation networks, governments, regulatory authorities, and carbon markets, to name a few. CO_2 would need to be reliably transferred at every juncture to ensure that the project's viability is not compromised.

5. Socio-political:

    a. Public resistance: resistance to technologies is often driven because of the lack of useful information. The public would need to be made aware of the technology and its importance as a component of climate change mitigation. Public outreach at all stages of policy and project development is a crucial factor in project viability.

    b. Policy uncertainty: few jurisdictions around the world have policies, legislation, regulation, or protocols in place to support CCS project development. While they are expected to grow, there is scope to construct frameworks or mechanisms that support the integration of national or international policies where they do exist. Policy development is necessary to design reliable business models.

    c. Regulations and infrastructure: complying with regulations can be factor in bringing CCS projects online. The timeframes to design, construct, and operate these facilities are supported by regulations that will need to be developed and administered with the level of expertise. The factors listed above play a role in associated delays in rulemaking and the development of suitable regulations.

4.4.3 Barriers to transport

CO_2 can be transported through a combination of four modes. Listed alphabetically they are pipelines, rail, road, and waterways. Of these modes of transportation, pipelines are the most versatile, used extensively all over the world to distribute and transport oil and gas. Using roads or rail to transport CO_2 requires additional capacity planning and potential debottlenecking since these modes are also used to transport people, freight, and other types of cargo. The transport of CO_2 through waterways especially international waterways has unique requirements.

4.4.3.1 Lack of pipelines

The pipeline network in the European Union is large and is estimated to over 2 million km in total distribution length. Additionally, over 200,000 km of pipeline used for transmission (European Union Agency for the Cooperation of Energy Regulators (ACER), 2022). However, the planned CO_2 pipeline network is significantly smaller, in the range of hundreds of kilometres (European Commission, 2021a; International Association of Oil and Gas Producers, 2019). If developed, CO_2 pipelines would be limited to Belgium, the Netherlands, and Norway. This is a barrier to the safe and efficient transport of CO_2.

4.4.3.2 Transboundary requirements

The provisions of the London Protocol could influence projects where transporting CO_2 through waterways is a requirement (Havercroft et al., 2022). Projects with a transboundary component, notably international waterways, are influenced by the ratification of the London Protocol. Only eight countries (Contracting Parties) have ratified the agreement. However, a provisional application of the amendment to Article 6 of the London Protocol was agreed to in 2019 at the 14th Meeting of the Contracting Parties. Countries with plans to transport CO_2

internationally can proceed but have additional requirements to liaise with the International Maritime Organization (IMO).

More detail on this topic is provided in the section in this report, see the section on the review of transboundary transport considerations.

4.4.3.3 High costs

Transportation costs can be minimized or optimized by integrating CCS projects in hub developments near industrial clusters with high emissions (Global CCS Institute, 2016). In these types of developments, the high costs of expensive infrastructure like pipelines, transportation, and shipping facilities can be shared amongst project partners. A CCS project that can source CO_2 pooled from multiple industrial facilities could benefit from lower capital expenditures while taking advantage of economies of scale.

4.4.4 Barriers to storage

Policy considerations that could reduce barriers to storage are those that address risks to safety, health, the environment, security of transportation networks and storage locations (European Commission & European Union, 2022). Also, existing laws and regulations would need to be updated to accurately reflect advances in technology and the mitigative capability of CCS to address climate change. This section will highlight a few of these areas of interest.

4.4.4.1 Risks to health, safety, and the environment

In the EU, the CCS Directive passed in 2009 lays out the rules to ensure that CO_2 injected and stored does not leak to the environment (European Commission, 2022c; Regulation (EU) 2009/31/EC of the European Parliament and of the Council, 2009). While this is not a barrier in the EU, jurisdictions that do not have legislation, rules, or regulations face barriers to integrating CCS into industry value chains.

4.4.4.2 Risks to security of storage and transportation

The security of storage and transportation assets can be compromised due to deficiencies in how they are designed and operated or alternatively because of external risks. These are generally not barriers in the EU due to clear technical requirements and supportive property rights' laws.

4.4.4.3 Updating laws, rules, and regulations

This is an area where EU regulations can potentially be updated to facilitate CCS being deployed at refineries. Current EU laws, discussed further in section 4.4.1, only allow for CCS to be included with economic activities relating to electricity generation, cogeneration, and heat generation from fossil gaseous fuels (Regulation (EU) 2020/852 of the European Parliament and of the Council, 2020; Commission Delegated Regulation (EU) 2021/2139, 2021; Commission Delegated Regulation (EU) 2022/1214, 2022).

4.4.5 Transboundary transport considerations

The transportation of CO_2 across national boundaries will also be subject to a broad spectrum of regional and national laws governing shipping operations.

International marine legal agreements aimed at protecting the world's oceans and seas, have been central to the legality or otherwise of CCS operations. The 1972 London Convention and its 1996 Protocol, which seek to protect the marine environment from the unauthorised disposal of wastes, initially proved unwitting obstacles to CCS activities by precluding CO2 from the list of substances that may be 'dumped' at sea or stored in the seabed.

In 2006, during the first meeting of the Contracting Parties to the London Protocol, an amendment was adopted to include "*carbon dioxide streams from carbon dioxide capture process for sequestration*" within the Annex 1 categories of wastes which may be considered for dumping. The amendment, which ultimately entered into force in 2007, provides a legal basis for offshore storage operations and includes CCS activities within the licensing model set out in Article 4. The Scientific Group of the London Protocol also developed two sets of guidelines aimed at supporting the deployment of consistent regulatory frameworks and addressing the risks posed by CCS activities.

Contracting Parties' national authorities will be required to ensure that the Protocol's requirements and proposed methodologies are followed, when permitting and managing CCS projects in their territories.

4.5 Policy considerations – Identify and analyse business models for CO_2 transport

There are several examples of business models that have enabled technical demonstrations, trials, and commercial developments for CCS projects. Some examples of the variety of business models, incentivization schemes and regimes are presented below. Representing the level of involvement of the State in CCS projects, the business models range from active to passive State support. Passive State involvement is indicative of a more liberalized market. Jurisdictions in Europe have employed a combination of grants, loans, and participation in trading systems to spur innovation and the deployment of capital to CCS. These business models are effectively revenue streams, and they are often employed in concert to support project development. In addition, taxes have also been used by governments to motivate industry and to align policy and regulatory frameworks to meet the goals of the Paris Climate Agreement and the Glasgow Climate Pact.

Some examples of how these policies are integrated and applied to support business models in the European Union and in other countries in Europe are discussed in this section.

4.5.1 Business models – high level

At a high-level, business models for CCS projects and CO_2 transport by association can be described by the level of State support they receive (Zero Emissions Platform, 2014). CCS project developers fall into one or more of these categories:

1. <u>Contractors to the State</u>: with a view to ensuring that the infrastructure of the future is planned for in the present, the State not only reviews each project, but reviews and approves each stage of the project and its associated investment decisions. The State is vested in all stages and aspects of transportation and storage. This is typical

of early-stage markets where the private sector lacks the expertise or the incentive to develop projects. Small scale CCS demonstration projects can fall under this category.

2. Participants in an Enabled Market: a hybrid market of State support and a liberalized market. The difference in this scenario is that a regulatory authority or entity in the State has oversight of the project. Typically, it is a State-owned entity or a part of the government whose authority is supported by regulation. However, the regulatory authority is still influential enough to be a *market maker*. This is typical of new markets; a strong regulatory authority effectively serves as a gatekeeper of project development.

3. Participants in a Liberalized Market: little to no active involvement of the State in directing market participation. In this scenario, the regulatory authority still has oversight of the projects, but does not make the market. The market is robust enough to support itself. The State-entity or the State-owned regulatory authority ensures that projects comply with regulatory and statutory requirements.

As can be seen, in each of these scenarios, the role of the State or State entity is different. It gets progressively less involved in the day-to-day management of CCS projects in more liberalized market settings.

4.5.2 Business models for transporting and storing CO_2

This section covers financing and revenue models that are typically used by businesses with CCS projects to finance and derive revenue from the project. For CCS projects, capital investment can be a significant outlay. Projects can be financed through several financing mechanisms (Pale Blue Dot Energy, 2018). Some of them are briefly discussed here.

1. Regulated Asset Base (RAB): In this model while the asset is owned by the State, private companies manage and operate the infrastructure. However, investment decisions are managed by a regulatory body. The private company receives payments for services provided to customers while also receiving incentives (subsidies, tax benefits) from the government to ensure the continuity of operations.

2. Public Private Partnership (PPP) or Private Finance Initiative (PFI): The government invites tenders for infrastructure projects. A consortium between a public-sector entity and private companies is set up as a separate company. This company carries out all stages of the project from initiation, selection, and design, to execution and operation. Through a contract it receives revenues for services provided to customers or receives performance-based payments from the public-sector entity for managing the infrastructure.

3. Contract for Difference (CfD): Used in the power and utilities sector, this structure is a financial contract awarded through an auction. The energy generator that wins the contract is guaranteed a revenue stream for the contract's duration by providing a difference payment and providing long-term revenue certainty (Low Carbon

Contracts Company, 2022). This guaranteed revenue stream can provide a basis for financing capital intensive projects like CO_2 transport and storage.

4. Cost Plus: These financial contracts are used for capital intensive projects. In this financial arrangement, project developers are paid for project expenses in addition to an additional payment for executing the contract (or a profit margin).

5. Waste sector type contract: These contracts are like other contracts common in the waste management sector. Project developers are paid for the units of CO_2 they can inject and store, or CO_2 sold for EOR.

6. Hybrid models/contracts: The models and contracts described above can be used in combination depending on the complexity of the project.

4.5.3 Cap-and-trade systems (EU ETS)

The EU's ETS is the main driver for investments in CCS projects since 2015 (European Environmental Agency, 2015). The EU's legal framework states that the ETS considers captured CO_2 that has been geologically stored (or safely stored) to be "not emitted". Environmental Impact Assessments and storage permits are required, in addition to stringent requirements for site selection according to the CCS Directive (European Commission, 2022a; Directive of the European Parliament and of the Council on the Geological Storage of Carbon Dioxide, 2009). The Directive also requires verifying that the emission stream is mostly comprised of CO_2. Financial security of the operator is also needed before injection of CO_2 can commence (European Commission, 2022a).

Known as the European Union Emissions Trading System, the EU ETS is the world's first carbon market system. It is also the world's largest carbon market with jurisdiction over all 27 EU member states and Norway, Iceland, and Liechtenstein (European Commission, 2022b). The EU requires mandatory participation for companies that operate in energy intensive sectors and especially those that generate GHG emissions as part of their operations. The ETS cap and trade works by setting a cap on the total GHGs that can be emitted by all the entities under its jurisdiction. The cap is dynamically reduced over time to reduce annual emissions over time. Entities can trade allowances within the ETS that are allocated through auction sales or allocated for free. The free allocation of allowances is meant to address high risk sectors and those sectors that are deemed to be at risk for carbon leakage. Some examples of high-risk sectors include refining, mining, manufacturing, and petrochemicals to name a few (EUR-Lex Access to European Union law et al 2019). Free allocation of allowances is also used as a policy tool to incentivize the modernisation of the EU's energy sector through investments in clean technologies, diversifying energy sources, upgrading existing infrastructure, and modernising energy production and transmission (European Commission, 2021b).

4.5.4 Carbon taxes

The EU Emissions Trading System (ETS) and its CCS Directive applies in all EU countries as well as in Norway, Iceland, and Liechtenstein (European Commission, 2015, 2022b, 2022a). Norway, Iceland, and Liechtenstein are part of the European Free Trade Association (EFTA) in the European Economic Area (EEA).

While there are carbon taxes in EU and EFTA member states (Denmark, Finland, France, Iceland, Latvia, Liechtenstein, Luxembourg, Norway, Poland, Portugal, Slovenia, Spain, and

Sweden), these jurisdictions can also participate in the ETS while the European Commission works to implement the CCS Directive across the EU (European Commission, 2022c).

A summary listing of the carbon tax in each jurisdiction sorted by year is included in Table 18 (The World Bank, 2022).

Table 18 Carbon taxes in the EU and in the EFTA

Year	Country	Jurisdiction	Scope
1990	Finland	EU	Covers all fossil fuels except peat. Estimated 37% overlap of GHG emissions covered under EU ETS.
1990	Poland	EU	Covers all fossil fuels. Emissions covered under EU ETS are exempt.
1991	Norway	EEA EFTA	Covers liquid and gaseous fossil fuels. Estimated 43% overlap of GHG emissions covered under EU ETS. Emissions covered under EU ETS are exempt.
1991	Sweden	EU	Covers all fossil fuels. Emissions covered under EU ETS are exempt.
1992	Denmark	EU	Covers all fossil fuels. Due to lack of data, overlaps with the EU ETS are unavailable. Emissions covered under EU ETS are exempt.
1996	Slovenia	EU	Covers all fossil fuels. Emissions covered under EU ETS are exempt.
2004	Latvia	EU	Covers all fossil fuels and CO_2 emissions not covered by the EU ETS. Due to lack of data, overlaps with the EU ETS are unavailable. Emissions covered under EU ETS are exempt.
2008	Liechtenstein	EEA EFTA	Covers all fossil fuels and incorporated because of a bilateral treaty with Switzerland. Emissions covered under EU ETS are exempt.
2010	Iceland	EU	Covers all fossil fuels and is complimentary to the EU ETS. Emissions covered under EU ETS are exempt.
2014	France	EU	Covers all fossil fuels and is complimentary to the EU ETS. Emissions covered under EU ETS are exempt.
2014	Spain	EU	Applied to fluorinated GHG emissions only.
2015	Portugal	EU	Covers all fossil fuels. Emissions covered under EU ETS are exempt.
2021	Luxembourg	EU	Covers all fossil fuels and is complimentary to the EU ETS. Emissions covered under EU ETS are exempt.

4.5.5 Grants

4.5.5.1 Denmark

The Danish government made an announcement in December 2021 that it had reached an agreement with several political to provide EUR 2.2 billion to the development of carbon capture, utilisation, and storage (CCUS) projects (Global CCS Institute, 2022c). Earlier that month, the Government announced funding of US$ 41 million for two CCS projects in the Danish North Sea (Offshore Energy, Kulovic, 2021).

A US$ 30 million grant has been awarded to INEOS for the Greensand CCS project in the Danish North Sea. Greensand has the potential to store up to 8 million tonnes of CO_2 annually by 2030. The rest of the funding (DKK 75 million) is for a second smaller project called Bifrost led by TotalEnergie has the capacity to store 3 million tonnes of CO_2 annually by 2027 (Reuters, 2021).

4.5.5.2 Norway

The Norwegian Government subsidizes carbon capture and storage projects by supporting around 67% of the cost of projects like Langskip (Global CCS Institute et al., 2021; Norwegian Ministry of Petroleum and Energy, 2022). Langskip is a full-scale CCS project which includes the capture, transport, and storage of CO_2. Northern Lights is a component of Langskip (or Longship) that is open to third parties (Northern Lights, 2022).

The Norwegian Government has contributed NOK 10.4 billion (June 2, 2020, exchange rates) to Northern Lights. Together with Norcem and Fortum Oslo Varme, the Norwegian Government has contributed NOK 16.8 billion or US$ 1.69 billion (June 23, 2022, exchange rates) (Norwegian Ministry of Petroleum and Energy, 2020).

4.5.6 Regulations

While few jurisdictions around the world permit and regulate CCS projects, those that do have some similarities in their characteristics. The regulatory requirements that cover CCS projects typically govern the pre-site evaluation of the storage well, injection operations, testing and monitoring, and site closure. Pore space rights are also regulated but are generally part of a different regulatory regime. Some examples of regulatory regimes are provided below.

4.5.6.1 Norway

In Norway, storage of CO_2 is permitted on the continental shelf. Norway also has a comprehensive regulatory framework that covers site surveying, exploration licensing and permitting, licensing a subsea reservoir to inject and store CO_2, transporting, injecting, and storing the CO_2 (Norwegian Petroleum Directorate and Ministry of Petroleum and Energy 2014). There are additional requirements after CO_2 injection and storage has ceased with liabilities for any damages caused by pollution. There are also special provisions for safety overall and compensation to Norwegian fishermen.

The Norwegian regulations has detailed requirements for the collection of data, establishing a geological model, characterizing storage capabilities, and monitoring. The Langskip project in the Norwegian North Sea complies with this regulation (Norwegian Ministry of Petroleum and Energy 2022).

4.5.6.2 United Kingdom

Like Norway, the United Kingdom (UK) also allows for the storage of CO_2 offshore. Originally authorized by the Energy Act of 2008, the UK licensing authority for offshore CO_2 storage were transferred to the Oil and Gas Authority in 2016 (UK Government, 2022). Now known as the North Sea Transition, it is authorized by the Energy Act of 2016 to have jurisdiction over CO_2 storage. The regulation covers licensing of geological storage and the recent CO_2 appraisal and storage licensing round closed in May 2022. The awarding of licenses is based on technical capability, corporate governance, legal fitness, and financial fitness viability and capability (North Sea Transition Authority, 2022).

4.5.7 Tax credits (US 45Q)

The US Federal Internal Revenue Code (Federal tax code section 45Q) provides a specific federal tax credit for geologically sequestered CO_2 (Global CCS Institute et al, 2021; United States Congress et al, 2021). A summary of the key elements of the tax credit is included in Figure 39, excerpted from the analysis conducted by the Congressional Research Service (CRS).

Having been first introduced in 2008 as part of the Energy Improvement and Extension Act, the 45Q tax credit was expanded ten years later when the Bipartisan Budget Act of 2018 and the Taxpayer Certainty and Disaster Tax Relief Act of 2020 were enacted(United States Congress et al, 2021). Summarized here, they include:

a. Increased tax credits (up to $ 50 per metric ton of geologically sequestered CO_2 by 2026).

b. Allowing tax credits to be claimed for 12 years from the time the equipment begins service (previously claims would cease after 75 million tons of CO_2 were captured and stored).

c. Expanding tax credits to utilization of CO_2 (tax credit amount is different).

d. Allowing facilities that capture less than 500,000 tons annually to also avail of the tax credit.

e. Allowing owners of the capture equipment to claim the tax credits so long as they also ensure that the CO_2 is disposed, utilized, or used for injection.

f. A deadline to begin construction by January 1, 2026.

Table 1. Key Elements of the Section 45Q Credit

Equipment Placed in Service Before 2/9/2018	Equipment Placed in Service on 2/9/2018 or Later
Credit Amount (per Metric Ton of CO_2)*	
Geologically Sequestered CO_2	
\$23.82 in 2020. Inflation-adjusted annually.	\$31.77 in 2020. Increasing to \$50 by 2026, then inflation-adjusted.
Geologically Sequestered CO_2 with EOR	
\$11.91 in 2020. Inflation-adjusted annually.	\$20.22 in 2020. Increasing to \$35 by 2026, then inflation-adjusted.
Other Qualified Use of CO_2	
None.	\$20.22 in 2020. Increasing to \$35 by 2026, then inflation-adjusted.
Claim Period	
Available until 75 million tons of CO_2 have been captured and sequestered.	12-year period once facility is placed in service.
Qualifying Facilities	
Capture carbon after 10/3/2008.	Begin construction before 1/1/2026.
Annual Capture Requirements	
Capture at least 500,000 metric tons.	*Power plants:* capture at least 500,000 metric tons. *Facilities that emit no more than 500,000 metric tons per year:* capture at least 25,000 metric tons. *DAC and other capture facilities:* capture at least 100,000 metric tons.
Eligibility to Claim Credit	
Person who captures and physically or contractually ensures the disposal, utilization, or use as a tertiary injectant of the CO_2.	Person who owns the capture equipment and physically or contractually ensures the disposal, utilization, or use as a tertiary injectant of the CO_2.

Source: CRS analysis of IRC Section 45Q.

Figure 38 Key elements of IRS Section 45Q tax credit excerpted from the analysis by the CRS (United States Congress et al, 2021)

After the passage and enactment of the Inflation Reduction Act in August 2022, the carbon capture provisions that provide incentives for CCS projects were significantly enhanced (Clean Air Task Force, 2022; United States Department of Energy et al, 2022). The details are summarized below.

a. A significant change is that the new law now provides entities an option to receive the 45Q tax credit as a direct payment. This is like the entity receiving a tax credit for overpaid taxes. The durations are different depending on the type of entity.
    a. Five years for for-profit entities after initiation of the project.
    b. Twelve years for tax-exempt entities.
b. Further increases in tax credits for geological storage of CO_2:
    a. To $ 85/ton from power generation and industrial facilities.
    b. To $ 180/ton from direct air capture (DAC) facilities.
c. Further increases in tax credits for utilization of CO_2:
    a. To $ 60/ton from power generation and industrial facilities.
    b. To $ 130/ton from direct air capture (DAC) facilities.
d. More types of facilities can now qualify since the IRA reduces the annual CO_2 capture threshold to:
    a. 1,000 tons for DAC facilities.
    b. 12,500 tons for industrial facilities.
    c. 18,750 tons for power generation facilities (at least 75% of the CO_2 must be from a unit that generates electricity and has capture equipment installed).
e. Extends the deadline to begin construction by January 1, 2033.
f. Continue allowing tax credits to be claimed for twelve years from the time the equipment begins service.
g. The new law broadens the ability to transfer the 45Q tax credit. During the twelve-year period mentioned above, the entity that originally receives the 45Q tax credit can transfer the entire amount or any portion of it to another tax-paying entity in exchange for a cash payment. Furthermore, this cash payment will not be taxed.

4.6 Policy considerations – Value chain as applied to refineries

The previous sections explored how business models, financing, and revenue streams could be applied to CCS projects. In this section, deploying CCS to a refinery is examined against the backdrop of a refinery's value chain. The technology to deploy CCS exists with today's technology. However, policies that would incentivize the deployment of CCS are needed to ensure CCS can be effectively integrated.

4.6.1 Policy example – the EU Taxonomy

For example, in the European Union, the use of CCS is supported by Article 10 of an EU Regulation (2020/852) but is limited to economic activities which do not have low carbon alternatives (European Union and EUR-Lex 2020). Carbon capture is included with economic activities relating to electricity generation, cogeneration, and heat generation from fossil gaseous fuels. The transport and storage of CO_2 are listed as separate economic activities. There is scope for expanding the taxonomy to include CCS at refineries. Below is a summary of the EU regulations that support CCS.

1. The EU Taxonomy is discussed in Regulation (EU) 2022/1214 which amends Regulation (EU) 2021/2139.
2. Regulation 2022/1214 (European Union and EUR-Lex 2022):
    a. The amendment dated March 9, 2022.
    b. Includes carbon capture under three activities, but with the caveat of being transitional (European Union and EUR-Lex 2022); refers to regulation 2020/852.
    c. The amendment adds the use of fossil gaseous fuels for electricity generation, co-generation, and heating/cooling.
3. Regulation 2021/2139 (European Union and EUR-Lex 2021):
    a. This is the principal regulation, dated June 4, 2021.
    b. Includes carbon capture under four activities, again with the transitional caveat and referring to reg. 2020/852.

4.6.2 Refinery value chains

Refineries as part of the downstream segment of the energy industry have portions of their value chains in common with the upstream segment of the industry (Pelegry et al., 2018; Fernandez et al, 2019). For example, activities like corporate and investment planning, budget planning, and logistics are shared across integrated companies. However, the following activities are specific to the downstream segment:

1. Production:
    a. Planning.
    b. Accounting.
2. Operations:
    a. Scheduling.
    b. Optimization.
    c. Energy management.
    d. Performance management.
    e. Monitoring and control.
3. Feedstock management.
4. Distribution.
5. Retail and marketing.

Figure 39 and Figure 40 illustrate the value chain within the downstream sector and within the industry, respectively. The distribution arm of the sector has components with transportation and storage. As shown in Figure 42, raw materials and finished products are stored in bulk storage or in storage terminals and are transported by pipelines, tankers, and barges. The mechanisms used to transport has overlaps with CCS, the major difference being with the geologic storage of CO_2. However, refineries face cost pressures due to thin refining margins. Also, the cost of capture is higher for CO_2 of high purity. Additionally, transporting CO_2 will require building out CO_2 pipelines. The downstream and refining sectors have been looking at implementing CCS for several years.

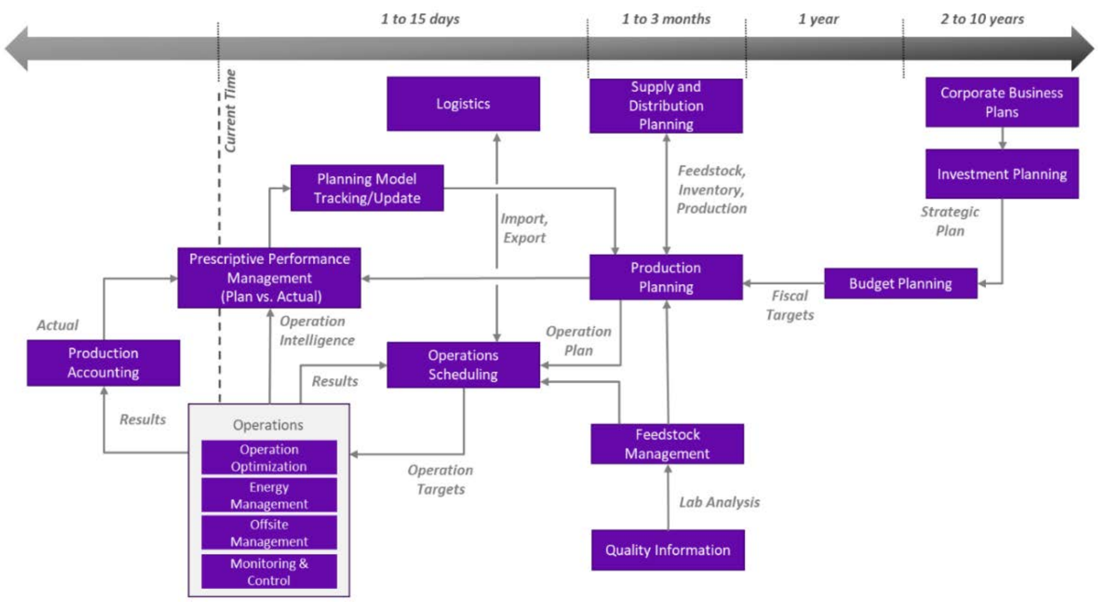


Figure 39 Downstream sector value chain (Fernandez et al, 2019)

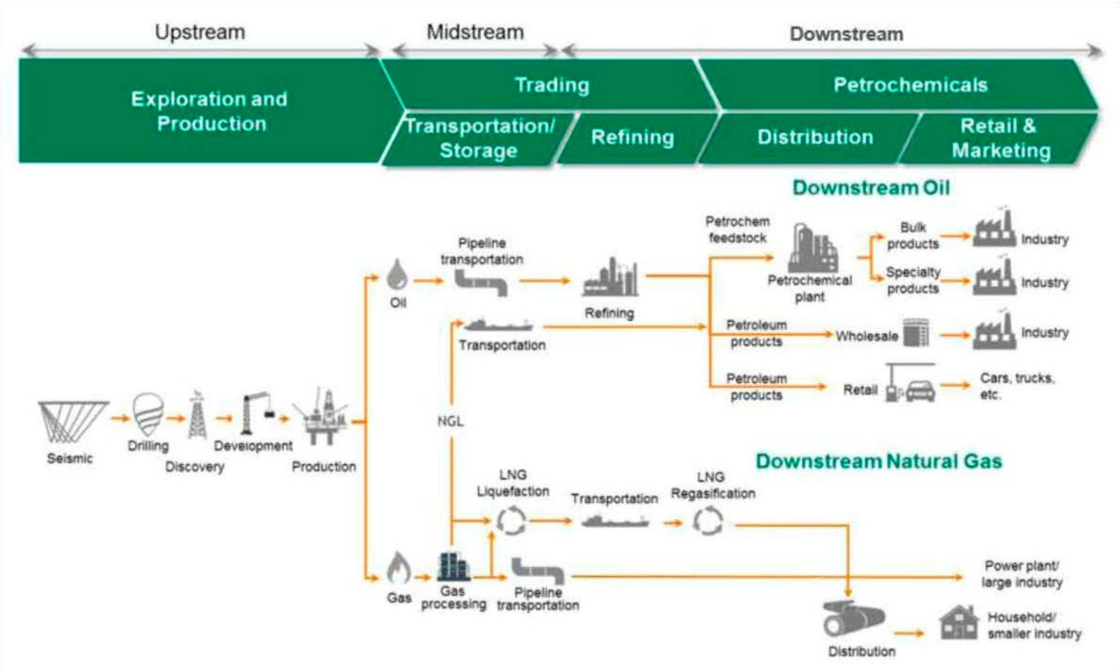


Figure 40 Oil and gas industry value chain (Pelegry et al., 2018)

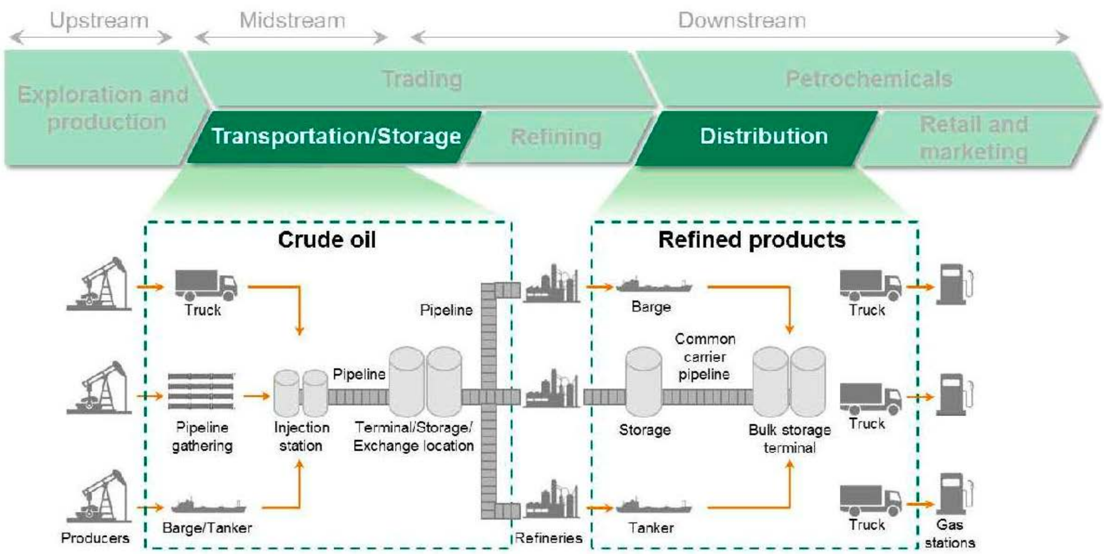


Figure 41 Transportation and storage in a downstream value chain (Pelegry et al., 2018)

4.7 Legal and regulatory considerations for CO_2 transport

The transport of CO_2, for the purposes of geological storage, will ultimately be subject to a wide variety of European and national laws and regulations that govern the conveyance of materials by pipeline, truck or ship. The European Commission recognised the substantial body of existing legislation that would be applicable to both the capture and transport aspects of the CCS process, when designing the EU CCS Directive. To this end, the final Directive uses these existing pathways when developing the regulatory framework and sought to ensure that operators were not subject to double regulation.

While it is not possible to provide an exhaustive analysis of all legislation, applicable across the various jurisdictions considered in this study, operators will need to consider how the transport of CO_2 will be regulated under national legislation that addresses, amongst other issues:

- Infrastructure planning.
- Environmental Impact Assessment.
- Pollution prevention and control.
- Environmental protection.
- Health and safety.
- Environmental liabilities.
- Regional and/or national emissions trading schemes.

4.5.1 Transportation of CO_2 in the offshore environment

Operations involving the transport of CO_2 via ship, for the purposes of offshore or onshore geological storage, will inevitably trigger a variety of obligations under international, regional and domestic legislation. The law of the sea and maritime health and safety legislation governing the transportation of substances, together with existing requirements regulating the shipping of certain particular substances, will all likely apply to the shipping of CO_2. These obligations are in addition to any applicable CCS-specific legal and regulatory obligations in the jurisdiction where the exported CO_2 is to be ultimately stored.

In instances where this exported CO_2 is stored in offshore storage locations, the recent CCS-specific amendments to the international marine agreements, which are aimed at protecting the marine environment and regulating the disposal of waste, will undoubtedly prove critical considerations. In addition, and irrespective of whether storage is anticipated to occur in either onshore or offshore formations, the export of CO_2 via ships will be the subject of a far broader body of international law including the law of the sea and maritime law.

4.7.1 Export of CO_2 under international marine legislation

Amendments to the 1996 London Protocol, agreed by the Parties in 2006, provide a formal basis for the regulation of CO_2 sequestration in offshore sub-seabed geological formations under the Protocol's mechanisms. Under the amendment, CO_2 streams that are to be sequestered are subject to permitting in accordance with the terms of Article 4 of the Protocol, which requires that:

"*Contracting Parties shall adopt administrative or legislative measures to ensure that the issuance of permits and permit conditions comply with the provisions of Annex 2. Particular attention shall be paid to opportunities to avoid dumping in favour of environmentally preferable alternatives*".

The effect of this licensing process means that, for a permit to be granted by a Contracting Party's government, an applicant shall be required to demonstrate compliance with the provisions of Annex 2.

Notwithstanding the 2006 amendment, however, a further issue was identified where CO_2 was to be exported for the purposes of geological storage. It became apparent to the Parties that Article 6 of the Protocol, which is principally aimed at preventing the export of wastes to non-Parties, has the effect of similarly prohibiting the transboundary transportation of CO_2 for the purposes of geological storage. The position was confirmed by a technical working group, who further recommended proposed text to amend the Protocol. This was a concern for Parties who were keen to export their CO_2 for storage, or host storage projects within their territory.

In October 2009, a formal amendment to Article 6 of the Protocol was adopted by the signatories to the London Protocol to allow for cross-border transport and export of CO_2 for geological storage. However, the amendment required ratification by two thirds of the Protocol's contracting parties to enter into force and thus far, only a slim number of countries have ratified this amendment. Consequently, the amendment did not enter into force and a sustained period of impasse prevailed until October 2019.

At the 2019 meeting of the Contracting Parties to the Protocol, agreement was finally reached to allow the provisional application of the 2009 amendment as an interim solution. The agreement will now allow those countries who wish to export their CO_2 for storage in another country's territorial waters, to implement the provisions of the 2009 amendment in advance of it entering into force. Adopting the resolution will not set a precedent and will only be binding upon those Parties that choose to be provisionally bound by the amendment. Parties still, however, will be required to meet the standards prescribed by the Protocol.

5 Conclusions

As part of the REALISE project, this report has reviewed and provided key insights in the following :

- the management of socio-political risks in carbon capture and storage (CCS) projects
- policy and regulatory frameworks that enable or incentivise investment in CCS
- financing options for CCS projects
- CO_2 capture technologies specifically relevant to refineries
- Barriers and policy considerations relevant to the transport and storage of CO_2.

The application of CCS to European refineries can reduce annual emissions of CO_2 by many millions of tonnes. The successful execution of a CCS project requires a robust and effective risk management process that includes socio-political risk. Some early CCS projects failed as a direct consequence of ineffective management of socio-political risk. Incorporating lessons learnt from previous experience coupled with robust risk management processes is critical to ensuring projects proceed successfully.

CCS is an immature industry that materially contributes to a significant public good - a stable climate. Government has a critical role in establishing the policies and regulations to create a business case for private sector investment in this critical technology. There are several examples of policies and regulations that have successfully supported CCS investments around the world that are applicable to European refineries

There are no fundamental technical barriers to the retrofit of CCS to refineries. A range of CO_2 capture technologies to suit the variety of gas streams created by refineries is commercially available. Large gas streams with higher concentrations of CO_2, such as from hydrogen production, are lower cost and should be the first to benefit from CCS.

The transboundary movement of CO_2 by ship must comply with the specific requirements of the London Protocol. Parties to the protocol wishing to import or export CO_2 must advise the International Maritime Organisation that they will comply with those requirements. CO_2 transport also requires infrastructure such as pipelines and port facilities. Government has a role in supporting the development of this infrastructure which is essential to meeting ambitious climate targets.

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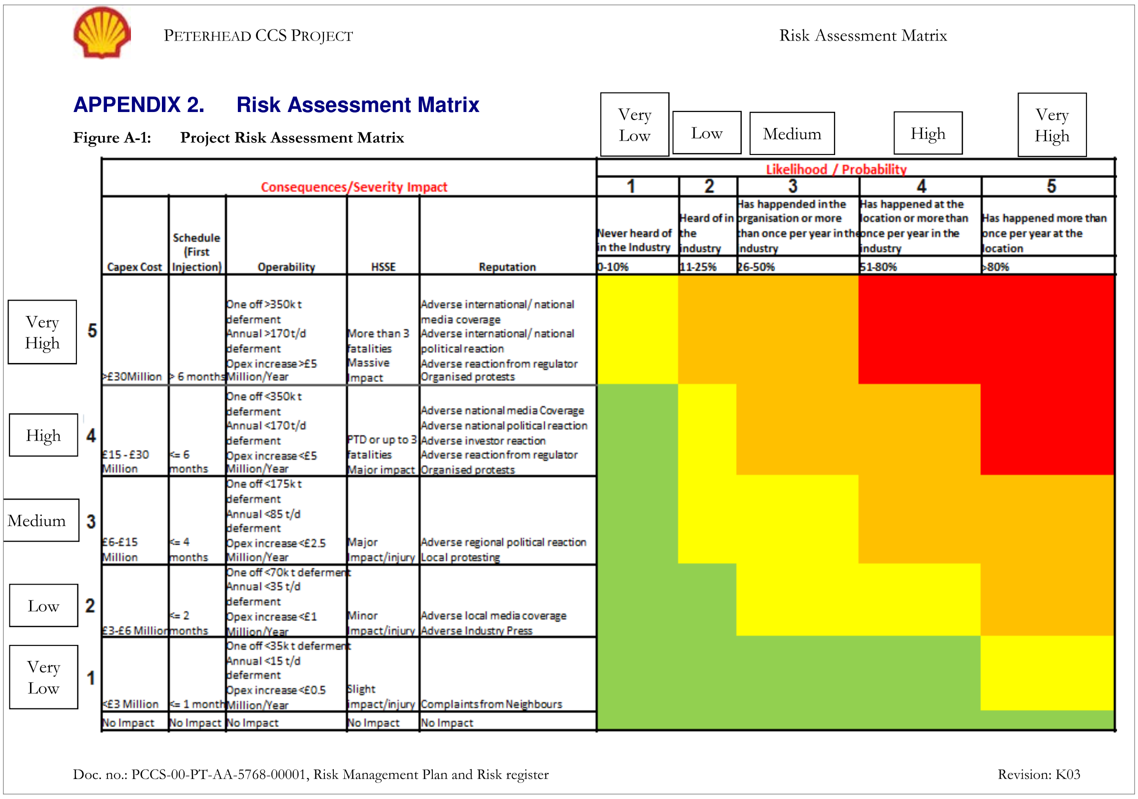
Appendix A - Risk Assessment Matrix (RAM) with mapping criteria from the Peterhead CCS project.



PETERHEAD CCS PROJECT

Risk Assessment Matrix

APPENDIX 2. Risk Assessment Matrix

Figure A-1: Project Risk Assessment Matrix

Consequences/Severity Impact

		Capex Cost	Schedule (First Injection)	Operability	HSSE	Reputation
Very High	5	>£30Million	> 6 months	One off >350k t deferment Annual >170t/d deferment Opex increase >£5 Million/Year	More than 3 fatalities Massive Impact	Adverse international/ national media coverage Adverse international/ national political reaction Adverse reaction from regulator Organised protests
High	4	£15 - £30 Million	<= 6 months	One off <350k t deferment Annual <170t/d deferment Opex increase <£5 Million/Year	PTD or up to 3 fatalities Major impact	Adverse national media Coverage Adverse national political reaction Adverse investor reaction Adverse reaction from regulator Organised protests
Medium	3	£6-£15 Million	<= 4 months	One off <175k t deferment Annual <85 t/d deferment Opex increase <£2.5 Million/Year	Major Impact/injury	Adverse regional political reaction Local protesting
Low	2	£3-£6 Million	<= 2 months	One off <70k t deferment Annual <35 t/d deferment Opex increase <£1 Million/Year	Minor Impact/injury	Adverse local media coverage Adverse Industry Press
Very Low	1	<£3 Million	<= 1 month	One off <35k t deferment Annual <15 t/d deferment Opex increase <£0.5 Million/Year	Slight impact/injury	Complaints from Neighbours
		No Impact	No Impact	No Impact	No Impact	No Impact

Likelihood / Probability

Very Low	Low	Medium	High	Very High
1	2	3	4	5
Never heard of in the Industry	Heard of in the industry	Has happended in the organisation or more than once per year in the industry	Has happened at the location or more than once per year in the industry	Has happened more than once per year at the location
0-10%	11-25%	26-50%	51-80%	>80%

Doc. no.: PCCS-00-PT-AA-5768-00001, Risk Management Plan and Risk register

Revision: K03

Figure 42. Risk Assessment Matrix (RAM) with mapping criteria from the Peterhead CCS project.

APPENDIX B

5.1 Overview of policies for incentivising the deployment of CCS in the European Union, the United Kingdom, China and South Korea

Country	Carbon tax	Tax credit/Emissions trading schemes	Grant Support	State owned enterprise	CCS-specific policies and actions	Net Zero commitments/ GHG policies
Austria		✔ EU ETS				✔ Policy commitment to achieve climate neutrality by 2050.
Belgium		✔ EU ETS				✔ Policy commitment to achieve climate neutrality by 2050 (NECP 2021-2030)
Bulgaria		✔ EU ETS				✔ Announced support to achieve the EU's goal of net zero emissions by 2050.
Croatia		✔ EU ETS				✔ Pledges to reduce greenhouse gas emissions are in line with broader EU commitments.

Country	Carbon tax	Tax credit/Emissions trading schemes	Grant Support	State owned enterprise	CCS-specific policies and actions	Net Zero commitments/ GHG policies
Cyprus		✓ EU ETS				✓ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states.
Czech Republic		✓ EU ETS				✓ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states.
Denmark	✓ (Implemented since 2002)	✓ EU ETS			✓ Participated in Nordic CCS Competence Centre, which issued the Nordic CCS Roadmap and Nordic CO_2 storage atlas. Denmark also hosted 2 CCS pilot plants.	✓ Legislated net zero by 2050 targets, with the establishment of a Danish Council on Climate Change and a Global Climate Action Strategy
Estonia	✓ (Implemented since 2000)	✓ EU ETS				✓ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction

Country	Carbon tax	Tax credit/Emissions trading schemes	Grant Support	State owned enterprise	CCS-specific policies and actions	Net Zero commitments/ GHG policies
						target of the EU and its member states.
Finland	✔ (Introduced in 1990)	✔ EU ETS			✔ Participated in Nordic CCS Competence Centre, which issued the Nordic CCS Roadmap and Nordic CO_2 storage atlas. Finland also ran a CCS research program to achieve technological and conceptual breakthroughs to incentivise commercialisation of CCS	✔ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states. In addition, Finland also has established individual emissions reductions targets and a commitment to climate neutrality by 2050.
France	✔ (Introduced in 2014)	✔ EU ETS		✔ 2 CCS test pilots were conducted in collaboration with the private sector, receiving funding through the New Technology Demonstration Fund and via governmental R&D support.		✔ Legislated target to achieve net zero emissions by 2050, as well as individual targets for greenhouse gas emissions not covered by the EU ETS.
Germany	✔	✔		✔		✔

Country	Carbon tax	Tax credit/Emissions trading schemes	Grant Support	State owned enterprise	CCS-specific policies and actions	Net Zero commitments/ GHG policies
	(Implemented in 2021)	EU ETS		CCS-specific RD&D funding		Commitment to net zero by 2045 in legislation, with interim target of 65% reduction by 2030.
Greece		✓ EU ETS		✓ RD&D funding for demonstration projects	✓ Research support for CCS is provided through the Centre for Research and Technology Hellas	✓ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states.
Hungary		✓ EU ETS				✓ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states.
Ireland		✓ EU ETS			✓ Feasibility studies into CCS technologies is currently underway by Irish state-owned utility company Ervia.	✓ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states.
Italy		✓ EU ETS			✓ Provides RD&D funding and support	✓

Country	Carbon tax	Tax credit/Emissions trading schemes	Grant Support	State owned enterprise	CCS-specific policies and actions	Net Zero commitments/ GHG policies
					to developing technologies, including pilot projects.	Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states.
Latvia	✓ (Implemented in 2010)	✓ EU ETS				✓ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states.
Lithuania		✓ EU ETS				✓ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states.
Luxembourg		✓ EU ETS				✓ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states.
Malta		✓				✓

Country	Carbon tax	Tax credit/Emissions trading schemes	Grant Support	State owned enterprise	CCS-specific policies and actions	Net Zero commitments/ GHG policies
		EU ETS				Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states.
Netherlands	✔ (Introduced in 2021 covering industrial emitters covered by the EU ETS)	✔ EU ETS, SDE++ subsidy to incentivise clean energy technologies including CCS	✔ Early stage support for the PORTHOS CCS hubs project, covering 50% of the costs for FEED studies. EU Commission also proposed EUR 102 million for capital construction costs.	✔ PORTHOS CCS project, joint venture agreement between 3 state owned enterprises.	✔ The Coalition Agreement of 2017 indicated CCS would contribute to 80% of emissions reductions annually to achieve 2030 targets	✔ Legislated interim and long-term targets to achieve a 95% reduction of emissions by 2050.
Poland		✔ EU ETS			✔ Historical RD&D funding and support for two CCS pilot plants	
Portugal	✔	✔ EU ETS				✔ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states. In addition, Portugal has developed a range of policies to achieve

Country	Carbon tax	Tax credit/Emissions trading schemes	Grant Support	State owned enterprise	CCS-specific policies and actions	Net Zero commitments/ GHG policies
						decarbonisation targets under the UNFCCC.
Romania	✔ (Implemented since 2015)	✔ EU ETS			✔ Conducted a technical assessment of CO_2 storage and developed a CCS Roadmap for Portugal to 2050.	✔ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states.
Slovakia		✔ EU ETS				✔ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states.
Slovenia	✔ (In place since 1996)	✔ EU ETS				✔ Pledges to reduce greenhouse gas emissions are in line with the joint economy-wide emissions reduction target of the EU and its member states.
Spain		✔ EU ETS			✔ Significant historical efforts to facilitate RD&D in CCS. CCS	✔ Legally binding interim and long-term emissions reduction target by 2030 and 2050.

Country	Carbon tax	Tax credit/Emissions trading schemes	Grant Support	State owned enterprise	CCS-specific policies and actions	Net Zero commitments/ GHG policies
					outlined as key technology to achieve emissions reductions in long term energy and climate strategy.	
Sweden	✓ (In place since 1996)	✓ EU ETS			✓ Significant commitments to RD&D efforts to advance CCS in the Nordic region, including support for 2 pilot and demonstration projects.	✓ Long term target of achieving net zero emissions by 2050. Sweden has also established a climate policy council to oversee implementation of climate targets.
South Korea		✓ Korea ETS (does not cover emissions reductions from CCS)			✓ Support for RD&D initiatives, including a nationwide master plan for CCS.	✓ Announced formal commitment to achieve net zero emissions by 2050.
China		✓ China national ETS (does not cover CCS)		✓ Sinopec Qilu CCS, Sinopec Zhongyuan CCUS, CNPC Jilin EOR, and Karamay Dunhua Oil Technology EOR	✓ Inclusion of support for large-scale CCUS demonstration projects within Five-Year Plan 2021-2025. Significant RD&D efforts to advance CCS, including support for pilot projects and a	✓ Announced formal commitment to achieve net zero emissions by 2060.

Country	Carbon tax	Tax credit/Emissions trading schemes	Grant Support	State owned enterprise	CCS-specific policies and actions	Net Zero commitments/ GHG policies
					roadmap for CCS deployment.	
United Kingdom		✓ UK ETS	✓ The UK CCS Infrastructure Fund will provide funding up to £1 billion for the deployment of CCS up to 2025 in the UK. Funding is also committed for facilitating CO_2 transport and storage networks.		✓ UK Industrial Decarbonisation Strategy commits funding amounting to £171 million to advance CCS projects.	✓ Legislated target of net zero emissions by 2050, with a Committee on Climate Change to oversee implementation of climate targets.

5.2 Overview of legal and regulatory regimes applicable to CCS activities in the European Union, the United Kingdom, China and South Korea

European Union

AUSTRIA

CCS LRI Band score	
CCS-specific legislation enacted	✓ (EU CCS Directive implemented, however, CCS activities are currently prohibited in Austria, except for limited research purposes)
Clarity and efficiency of the administrative process under the CCS legal	As CCS activities are currently prohibited in Austria, a review of the legal and regulatory framework has not been undertaken.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	
Stakeholder and public consultation	
Liability - closure, monitoring and accidental releases of stored CO_2	

BELGIUM

CCS LRI Band score	
CCS-specific legislation enacted	✓ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Allocates roles and responsibilities at the federal and regional level to various government agencies relating to authorising and overseeing CCS activities. • Belgium possesses an approvals process for CCS projects that is well regulated across most parts of the CCS project lifecycle, albeit the schemes vary across the different regions and at the federal level. • The roles of the project operator and regulator are not clearly defined according to the various stages of the CCS project lifecycle.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• Belgium's CCS framework is relatively integrated across most aspects of the CCS project lifecycle at the regional level. However, at the federal level there are minimal roles in respect of issuing permits for some projects. • Aspects such as subsurface ownership, surface access and reclamation activities, monitoring and verification obligations, storage and siting and closure of projects are regulated at the regional level. • Design standards for CCS projects vary across the federal and regional level, with federal regulations applicable to transport infrastructure for CCS projects and regional environmental regulations applicable for the construction of new CO2 plants.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• In general, CCS activities, including capture, transport and storage require EIAs under Belgian environmental legislation. • Project operators are responsible for complying with a wide range of mitigation and risk management obligations at the regional level.
Stakeholder and public consultation	• Public engagement is a feature of regional CCS frameworks, and there are some notification requirements in place across the regions in respect of CCS projects. • Federal and regional legislation also establish some dispute resolution mechanisms for CCS projects.
Liability - closure, monitoring and accidental releases of stored CO_2	• Closure of sites is strictly regulated at the regional level for CCS projects, with project operators required to comply with the conditions stipulated in the permit as a pre-requisite for obtaining government approval for site closure. • A transfer of responsibility for stored CO_2 is only possible where specific conditions are met, a minimum of 20 years has passed, financial security has been met and the storage facility is sealed.

BULGARIA

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Regulatory roles and responsibilities of various government agencies are well defined across the CCS project lifecycle. • Approvals for CCS projects are heavily regulated by the responsible Ministries, and a licensing scheme has been established to authorise different stages of a project. • The roles of project operator and regulator are clearly defined for most stages of the CCS project lifecycle.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• Bulgaria's legal and regulatory framework for CCS is fairly well regulated. o There are no specific regulations governing aspects such as the ownership of the subsurface geological area, the design and construction of CCS projects, the transport of CO_2, and CO_2 leakage; as such, general law is applicable to these aspects. o Project operators are required to ensure the suitability of underground geological formation for CO_2 storage and after site closure, conduct monitoring, reporting and corrective measures in the event of leakage, on the basis of a post-closure plan.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• All CCS infrastructure, including CO_2 capture facilities, transport pipelines and storage sites are subject to EIAs. • Operators have on going monitoring obligations with respect to the storage site and must fulfill conditions relating to mitigation and risk management as stipulated in the permit.
Stakeholder and public consultation	• Bulgarian legislation relating to public engagement on various aspects of CCS projects reflects EU legislation on public disclosure and access to information on environmental matters. • Bulgaria has not established dispute resolution mechanisms dedicated to CCS operations.
Liability - closure, monitoring and accidental releases of stored CO_2	• Site closure requirements in Bulgaria reflect the provisions of the EU CCS directive in holding the operator responsible for maintenance, monitoring, reporting and corrective measures pursuant to a post-closure plan approved by the relevant regulatory authority. • After site closure, the responsible minister assumes responsibility for all legal obligations relating to monitoring and corrective measures, the return of allowances in the event of leakage and all preventative and remedial actions.

CROATIA

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Allocates responsibilities to various government agencies established under petroleum and maritime legislation to regulate, authorise and oversee CCS operations. • Establishes a licensing scheme authorising the different stages of the CCS project lifecycle. • Clarifies the rights of project operators and their responsibilities towards regulators at each CCS project stage.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• The Croatian CCS legal framework essentially transposes the EU CCS Directive. Accordingly: o Legislation clarifies subsurface ownership issues, imposes monitoring and verification obligations, regulates transport of CO_2, provides for corrective measures in the event of CO_2 leakage and site closure requirements within relevant licenses.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• Establishes EIA requirements for CCS operations. • Project operators required to comply with environmental protection and health and safety obligations. • Project operators required to demonstrate technical and financial capability to operate CCS projects.
Stakeholder and public consultation	• EIA frameworks and safety legislation establish stakeholder consultation processes for CCS operations.
Liability - closure, monitoring and accidental releases of stored CO_2	• Provides for site closure requirements and the transfer of legal liability upon the passage of a minimum period determined by the responsible Ministry and the fulfillment of stipulated conditions by the project operator.

CYPRUS

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Government agencies have been allocated clear mandates covering CCS activities throughout the project lifecycle. • Establishes a highly regulated licensing and approvals regime authorising different aspects of the CCS project lifecycle. • The roles and responsibilities of Project operators and regulators have been clearly defined.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• Legislation comprehensively covers all aspects of the CCS project lifecycle including aspects such as: o Construction of CO_2 capture and transport facilities o Surface access and reclamation o CO_2 leakage o Monitoring and verification requirements o Closure of CO_2 storage sites. • Ownership regime for non-surface storage is not specifically regulated, largely due to the non-suitability of geological resources in Cyprus for CO2 storage.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• Not all CCS projects are required to undergo EIAs for capture and transport of CO_2, with only those projects categorised under domestic EIA legislation required to conduct EIA studies. • Characterisation and assessment of the potential storage complex is required to determine the suitability of the CO_2 storage site. • EIA legislation imposes various mitigation and risk management obligations on the project operator. • Technical information and technology development in respect of CCS is integral to the granting of permits for CCS.
Stakeholder and public consultation	• Public engagement is a key requirement for CCS projects requiring a permit under domestic environmental legislation. • The competent authority is required to create and maintain a dispute settlement mechanism in respect of CCS.
Liability - closure, monitoring and accidental releases of stored CO_2	• Closure of a storage site is subject to the fulfillment of conditions stipulated in the permit by the project operator; • A clear risk assessment framework is in place for post-closure of CCS projects. • After site closure, the competent authority is responsible for monitoring and corrective measures and for the surrender of emissions allowances in the event of leakage In accordance with national environmental legislation.

CZECH REPUBLIC

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Comprehensively allocates regulatory roles and responsibilities, including monitoring of the implementation of CCS legislation, across the CCS project lifecycle to various government agencies. • Establishes a permit scheme for the conduct of CCS activities across the project lifecycle. • Approvals for CCS projects are subject to review by the European Commission. • Project operator roles and responsibilities are clearly defined.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• The Czech Republic's legal and regulatory framework for CCS is well-integrated, essentially transposing the EU CCS Directive and addressing all aspects of CCS as per the Directive. Accordingly, it addresses:

CCS LRI Band score	
	o Monitoring and verification, transfer of legal liabilities, closure of a CO_2 storage sites, remedial measures in the event of CO_2 leakage and siting requirements for CO_2 storage sites. o Some aspects such as ownership of stored CO_2 and design standards for CCS projects are not specifically regulated. General legislation remains applicable to these aspects.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• Capture of CO_2 and transport of CO_2 via pipelines in the context of CCS projects is generally subject to mandatory EIAs under domestic EIA legislation. • CO_2 storage sites are subject mandatory EIA procedures • Provides for risk management as part of the ongoing EIA process, with project operators obligated to perform mandatory monitoring of injection facilities, storage sites and the surrounding environment.
Stakeholder and public consultation	• CCS-specific legislation provides for the participation of stakeholders throughout the CCS approvals process. • EIA processes also involve a range of legal entities committed to the protection of the environment or public health. • A heavily regulated dispute resolution regime whereby decisions can be appealed has also been established.
Liability - closure, monitoring and accidental releases of stored CO_2	• Establishes a heavily regulated CO_2 storage site closure regime, however, does not explicitly provide that ownership of CO_2 is transferred to the state. • Operator has continued monitoring and reporting obligations after closure; • Post closure transfer of liabilities is not explicitly provided for. • Operators incur liability under domestic environmental protection legislation for ecological harm caused by the operation of CO_2 storage sites. • Operator is liable to surrender emissions allowances as a consequence of CO_2 emissions released from the CO_2 storage site.

DENMARK

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Regulatory roles and responsibilities in respect of CCS activities are well defined. • A licence scheme has been established to authorise CCS activities at each stage of the CCS project lifecycle. • Legislation distinguishes between the role of the project operator and regulator for different aspects of the CCS project cycle.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• Legislation is fairly integrated in terms of dealing with all aspects of a CCS project; however, certain issues, such as liability relating to CO_2 leakages is yet to be comprehensively regulated.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• EIAs in respect of capture and transport is strongly featured in Danish legislation. • Environmental permits are required prior to construction and operation of CCS installations. • Siting for CCS projects and storage of CO_2 in the context of environmental legislation is strongly regulated. • The project proponent is responsible for various mitigation and risk management activities throughout the CCS project. • Technological information and developments are integral for the issuance of licenses for CCS activities in Denmark.
Stakeholder and public consultation	• Existing Danish law provides for comprehensive public engagement on CCS activities, that is built into the license regime. • Ordinary courts under Danish law are available in respect of CCS projects.

CCS LRI Band score	
Liability - closure, monitoring and accidental releases of stored CO_2	• There is a strong closure regime in place for CCS projects, with the operator remaining responsible for certain obligations and liabilities under the EU CCS Directive and ETS Directive. • Transfer of responsibility is conditional to satisfying the competent authority that all stored CO_2 is completely and permanently contained and the passage of a minimum period of 20 years since closure of the storage site. • A well-developed risk assessment framework is in place, with the operator required to provide financial security to the competent authority before the transfer of responsibility for the storage site. • Project operators are liable for loss or damage caused by CCS activities during the operational phase of the CCS project, although legislation does not address the issue of loss or damage in the event of CO_2 leakage.

ESTONIA

CCS LRI Band score	
CCS-specific legislation enacted	✔ EU CCS Directive transposed; CO_2 storage in Estonia is prohibited except for research and development purposes.
Clarity and efficiency of the administrative process under the CCS legal	• The regulatory roles and responsibilities of various government agencies are well defined in respect of CCS projects. • Environmental permits are required for a limited number of CCS projects authorised under domestic legislation. • The roles of the project operator and regulator are defined under different legislation.

Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• The regulatory framework for CCS projects is not well-integrated, and some aspects of the project cycle have not been addressed, including subsurface ownership, CO_2 leakage, monitoring and verification and site closure. In the absence of specific regulations, general environmental and construction legislation is likely to apply to these aspects. Notably:
	  o Strict limitations have been imposed on the construction and design of CCS facilities in Estonia, as CO_2 storage is prohibited.
	  o Transportation of CO_2 for storage is restricted under domestic legislation, with legal requirements for the construction of pipelines in place.

Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• The capture and transport of CO_2 is regulated, with requirements for the construction of pipelines as well as environmental impact assessments for pipelines of a prescribed length and diameter. • As storage is prohibited in Estonia, there is no provision for EIAs in respect of CO_2 storage sites. • Mitigation and risk management is governed under general environmental legislation in Estonia. • Technical information and technology development are well-regulated for CCS projects in Estonia.
Stakeholder and public consultation	• There is no provision for early and long term public engagement and communication in relation to CCS projects.
Liability - closure, monitoring and accidental releases of stored CO_2	• There is no closure regime for CCS projects in Estonia. • Environmental regulations are likely applicable to post closure liabilities.

FINLAND

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Well defined roles and responsibilities have been allocated to various government agencies in relation to regulating and overseeing CCS projects. • CCS projects are regulated through a general environmental licensing regime. • The roles of the project operator and regulator are well defined in respect of CCS projects.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• A range of different laws (not always specific to CCS) are applicable to CCS projects in Finland. Key aspects of a CCS project such as the ownership of subsurface geological structures and site closure, remain unaddressed or addressed limitedly. Notably: o General environmental provisions are applicable to leakages during the operational phase of a CCS project. o Transport of CO_2 is regulated in Finland, with safety of transport networks regulated through an EIA process and general environmental and building licensing procedures. o There is a storage and siting framework in place, including assessing the suitability of an area for CCS purposes and requirements for the construction of a CO_2 transmission network and storage facilities based on a land use plan.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• Capture and transport in respect of CCS activities are strongly regulated and subject to mandatory EIA processes. • The siting and storage of projects are also subject to a prescriptive EIA process. • Risk management and mitigation procedures feature within the approvals process for CCS projects. • Technical information for CCS projects are required as part of the licensing and permitting regime for CCS projects, although specific national standards are absent.
Stakeholder and public consultation	• There are no specific requirements for operators to communicate with stakeholders as part of a public engagement process on CCS projects. • In the event of conflict, stakeholders have access to the general courts system and various other dispute resolution mechanisms in Finland.
Liability - closure, monitoring and accidental releases of stored CO_2	• Conditions for closure are contained in issued licenses and approvals for CCS projects. • Post-closure liabilities remain with the operator until all post-closure obligations stipulated in the permit are complied with by the operator. However, all liabilities still remain primarily with the former operator after closure. • Finland does not provide a framework for risk assessment for closure of CCS projects.

FRANCE

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Designated competent authorities have been allocated responsibilities in the EU CCS Directive for overseeing CCS projects. • Has established a permit-based regime for approving CCS projects. • The roles of project operator and regulator are well defined.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• CCS projects are regulated under a reasonably well-integrated legislative framework in France. The legal framework covers issues such as ownership of subsurface storage formations, monitoring and verification requirements and provides for a strong storage and siting framework and closure regime.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• Capture and transport of CO_2 requires some form of environmental authorisation. • A regulated EIA process is in place in respect of storage and injection of CO_2 with EIAs and risk analysis required to be adapted to each site on a case-by-case basis. • Risk management and mitigation procedures are a feature of the approvals process for CCS projects. • Technical requirements for CCS projects are stipulated in environmental legislation.

CCS LRI Band score	
Stakeholder and public consultation	• Provides for some public engagement requirements for CCS projects in France. • Stakeholders have full access to the court system in France to resolve any conflicts that arise.
Liability - closure, monitoring and accidental releases of stored CO_2	• The operator is responsible for the site even after closure. • Liability can be transferred effectively 30 years after closure, or 10 years if operator proves that CO_2 will be completely and permanently contained and with the requisite approval from the responsible Minister.

GERMANY

CCS LRI Band score	
CCS-specific legislation enacted	✓ EU CCS Directive Implemented, however, several states have introduced bans on CO_2 storage)
Clarity and efficiency of the administrative process under the CCS legal	• Allocates roles and responsibilities to various government agencies in respect of authorising and overseeing CCS projects. • A permit scheme is in place to authorise CCS projects. • CCS legislation distinguishes between the role of the project operator and the regulator for different aspects of the CCS project lifecycle.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• Contains well-integrated CCS legislation, covering: o Ownership of the subsurface o Surface access and reclamation. o Obligations for project operators in the event of CO_2 leakage or significant irregularities during the operational phase of the project. o Transportation of CO_2 o Ongoing monitoring and verification activities. o Storage and siting o Closure regime dealing with post closure responsibilities and liabilities.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• Capture and transport of CO_2 attract EIAs under Germany's CCS legislation. • Siting and storage decisions are also based on an assessment of potential risks. • Germany does not issue permits for CO_2 storage unless for exploration, testing and demonstration of technologies, while several states have prohibited CO_2 storage. • The project proponent is responsible for various mitigation and risk management activities throughout the CCS project. • Responsible authorities are required to investigate the latest technical information and technology development in CCS projects during the approvals process, to ensure no risk is posed to public safety.
Stakeholder and public consultation	• German law provides for a comprehensive public engagement framework for CCS projects, with the public provided with a right to obtain detailed information about potential CO_2 storage sites and pipelines. • Rights of appeals are provided within CCS laws in Germany.
Liability - closure, monitoring and accidental releases of stored CO_2	• Operators are required to apply for a closure permit when the quantity of CO_2 stored reaches the amount specified in the CO_2 storage permit. • Operators retain responsibility for a CO_2 storage site for 40 years after closure, after which liability can be transferred to the state. • In the event of leakage, operator is required to take various corrective and preventative measures, in addition to notifying the competent authority.

GREECE

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Establishes a permit scheme for CCS operations, with detailed application requirements and overseen by the responsible Minister. • Defines rights and obligations of project operators including monitoring and reporting obligations and financial security prior to conducting CCS operations.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• Greece's CCS legal framework essentially reflects the provisions of the EU CCS Directive and regulates the range of issues arising under the CO_2 exploration and storage stages of a CCS project. However, some elements are not explicitly addressed under CCS legislation, including: o Ownership/interests within the pore space for CO_2 storage; as such, general petroleum legislation remains applicable. o CCS project design and construction, which is regulated under general planning and pollution control laws, as well as OH&S requirements. o CO_2 transport - general regulations relating to natural gas transport are applicable.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• The capture, transport and storage of CO_2 streams in storage formations must comply with domestic EIA requirements. • The project operator is required to comply with detailed monitoring obligations for the purpose of detecting irregularities, migration of CO_2, leakage and effects on the surrounding environment.
Stakeholder and public consultation	• Provides for public engagement at various stage of the CCS project lifecycle, with a dispute resolution body for expediting the settlement of disputes relating to access to transportation networks and storage areas.
Liability - closure, monitoring and accidental releases of stored CO_2	• Domestic provisions relating to site closure reflect the EU CCS Directive. • The operator remains liable for surrendering emissions allowances in case of leakage pursuant to the legal framework underpinning the EU ETS scheme. • The operator remains liable for violation of the terms of EIAs associated with the project and may incur civil and criminal liabilities in this context. • General environmental legislation on leakage also applies.

HUNGARY

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Various government agencies have been allocated roles and responsibilities corresponding to specific parts of the CCS project lifecycle. • A permit scheme has been stablished to authorise CCS activities. • The roles of the project operator and the regulator have been clearly defined.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• The CCS regulatory framework in Hungary reflects the EU CCS Directive in full, with the CCS-specific provisions incorporated within domestic mining legislation.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• EIAs for capture and transport of CO_2 is required where the government deems such operations will significantly impact the environment. • Mitigation and risk management frameworks are applicable generally under environmental legislation.
Stakeholder and public consultation	• There is a comprehensive public engagement framework under general environmental legislation, which is not specific to only CCS. • Although there are no dedicated dispute resolution mechanisms for CCS projects, existing mechanisms can be applied for different aspects of CCS projects.
Liability - closure, monitoring and accidental releases of stored CO_2	• Provides that a full transfer of responsibility for CO_2 stored can only be done subject to the fulfillment of conditions by the project operator for a period of at least 20 years from the closure of the storage site. •

CCS LRI Band score	
	• A risk assessment framework tailored to CCS projects is in place under domestic mining legislation.

IRELAND

CCS LRI Band score	
CCS-specific legislation enacted	✔ (Due to a prohibition on CCS projects over 100 kilotonnes, there is no CCS-specific regulatory framework in place in Ireland; however, the EU CCS Directive has been transposed within domestic legislation)
Clarity and efficiency of the administrative process under the CCS legal	• Although Ireland has transposed the EU CCS Directive, its domestic legal framework does not establish a clear role amongst government agencies in relation to authorising and overseeing CCS projects. • There is currently no specific approvals process for CCS projects, as only CCS projects for the storage of CO_2 under 100 kilotonnes is allowed. • The role of project operator and regulator is not clearly defined.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• Ireland does not possess an advanced legal and regulatory framework governing CCS activities, due to the prohibition of CCS projects over 100 kilotonnes. As such, key aspects remain unaddressed, including ownership of the subsurface, construction of CCS projects, surface access and reclamation, CO_2 leakage, monitoring and verification requirements and site closure.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• There is no dedicated EIA process applicable to the capture and transport of CO_2; however, an EIA is required to be conducted for certain CO_2 capture installations pursuant to the EU Directive and that is covered by Irish planning regulations. • EIA requirements are triggered where projects are carried out in accordance with Irish planning legislation. • There are no specific mitigation or risk management requirements for CCS projects in Ireland, although approvals under general planning legislation may still be required. • There are no specific technical requirements for CCS projects in Ireland.
Stakeholder and public consultation	• There is no public engagement framework in place specifically for CCS projects. • Stakeholders have full access to the court system in Ireland to resolve disputes.
Liability - closure, monitoring and accidental releases of stored CO_2	• There is no closure regime for CCS projects in Ireland, although general provisions in relation to industrial activities are still applicable.

ITALY

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Legislation provides for dedicated entities to oversee CCS projects at different stages of the project cycle. • Establishes a licensing scheme to authorise CCS projects. • The roles of the project operator and regulator are clearly defined.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• Italy's CCS legislation deals with all aspects of a CCS project in an integrated manner, with key aspects such as ownership of the subsurface, CO_2 leakage, monitoring and verification, storage and siting and site closure strongly regulated.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• Environmental legislation requires EIAs in respect of capture, transport, siting and storage of CO_2. • Under standard EIA requirements, project operators are required to comply with a range of mitigation and risk management responsibilities, including monitoring and reporting obligations. • There are no CCS-specific requirements relating to technology and technical information in Italy.

CCS LRI Band score	
Stakeholder and public consultation	• There are comprehensive provisions dealing with public engagement for CCS activities, in the context of the EIA process for CCS projects. • CCS projects are also subject to specific dispute resolution mechanisms.
Liability - closure, monitoring and accidental releases of stored CO_2	• After the closure of the site, the operator remains responsible for leakage and is required to comply with monitoring and reporting obligations until responsibility is transferred to the state. • After the closure of a storage site, all responsibilities are transferred to the state • A comprehensive risk assessment framework has been established for the closure phase of a CCS project, with project operators required to comply with obligations such as providing financial security and ensuring that CO_2 stored has been permanently sealed.

LATVIA

CCS LRI Band score	
CCS-specific legislation enacted	(EU CCS Directive implemented; however, storage of CO_2 prohibited)
Clarity and efficiency of the administrative process under the CCS legal	• Latvia regulates CCS under its general environmental and pollution legislation. As such, regulatory roles and responsibilities of various government agencies, the approvals process for CCS projects and roles of project operator and regulator are defined in terms of general environmental and pollution legislation.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• There is no integrated framework dealing with all aspects of the CCS project cycle in Latvia. Key aspects relating to CCS projects remain unaddressed since storage of CO_2 in the subsurface is banned. Int eh absence of CCS specific legislation, general laws are applicable if CCS activities were to take place.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• Capture and transport activities are subject to well regulated EIA processes in Latvia. • There is no EIA process for CO_2 storage and siting, as subsurface storage in Latvia is prohibited. • Latvia provides for a mitigation and risk management framework for capture and transport activities.
Stakeholder and public consultation	• Provisions on public engagement in respect of CCS activities is limited to the EIA process, during which public consultation can take place.
Liability - closure, monitoring and accidental releases of stored CO_2	• There is no specific closure regime or risk assessment framework applicable to CCS projects in Latvia. Risk is assessed through the EIA process, and the general liability regime is applicable to projects in the absence of CCS-specific legal regimes. • The operator is liable for damage to the environment resulting from CCS activities.

LITHUANIA

CCS LRI Band score	
CCS-specific legislation enacted	(EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Well-defined regulatory framework allocating responsibilities to various government agencies to authorise and oversee CCS activities. • Establishes a permit scheme for authorising various stages of the CCS project lifecycle. • The project operator and regulator have distinct obligations throughout the CCS project lifecycle.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• Lithuania's CCS framework deals with all aspects of a CCS project in an integrated manner, and clarifies the obligations of project operators of issues such as: o Subsurface ownership issues o CO_2 leakage o Siting and storage o Site closure o Monitoring and verification activities

CCS LRI Band score	
	• However, requirements under environmental, planning, pollution control, OH&S and building legislation also remain applicable to activities.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• There is a detailed EIA process in place for constructing infrastructure and facilities for CCS projects, through the capture and transport stages to siting and storage. • Mitigation and remediation activities are also required to be characterised and evaluated within EIA procedures. • There are some requirements for demonstrating technical competence and developments relating to CCS projects.
Stakeholder and public consultation	• Provision has been made for public engagement requirements throughout the CCS project cycle, albeit these are not comprehensive. • There is general recourse to dispute resolution mechanisms for CCS projects.
Liability - closure, monitoring and accidental releases of stored CO_2	• A detailed closure regime is in place, with the operator required to comply with permit conditions and demonstrate permanent storage of CO_2 to obtain site closure. • Liabilities are transferred to the state after the operator has demonstrated permanent storage of CO_2, a minimum period of 20 years (generally) has lapsed and the required financial security has been lodged.

LUXEMBOURG

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Well-defined regulatory framework allocating responsibilities to various government agencies to deal with the major aspects of the CCS project cycle. • Establishes a permit scheme for authorising various stages of the CCS project lifecycle. • The roles of the project operator and regulator are well defined.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• CCS legislation in Luxembourg is well-integrated and deals with all aspects of the CCS project lifecycle, such as design standards for projects, transport of CO_2, site closure, monitoring and verification and siting and storage. • However, there is no ownership regime for subsurface storage under Luxembourg's laws.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• Capture and transport of CO_2 is subject to ongoing risk assessment and monitoring obligations by the operator, as well as a specific EIA process. • An EIA procedure is in place for siting and storage laws. • Mitigation and risk management is a key feature of the EIA processes applicable to CCS activities. • Technical information and technology development standards for CCS projects are well-regulated and subject to detailed standards.
Stakeholder and public consultation	• Provision has been made for public engagement requirements for CCS projects. • There is general recourse to dispute resolution mechanisms for CCS projects.
Liability - closure, monitoring and accidental releases of stored CO_2	• A detailed closure regime is in place, with the operator required to comply with certain conditions for site closure and following closure, the operator responsible for monitoring, reporting and corrective measures until responsibility is transferred to the state. • Liabilities are transferred to the state after the operator has fulfilled their obligations under a post-closure plan approved by the relevant regulatory authority.

MALTA

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Establishes well-defined roles in respect of CCS projects to various government agencies. • A permit scheme has been established for approving CCS operations. • The roles of the project operator and regulator are clearly defined.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• CCS legislation deals with all aspects of the CCS project lifecycle in an integrated manner, including surface access and reclamation, obligations in the event of CO_2 leakage and the transport of CO_2. However, some issues are not addressed, for example, o There is no clarification of subsurface ownership issues in Malta's CCS legislation. o Design standards for CCS are limited to the characterisation and assessment of potential CO_2 storage sites.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• An EIA is required for CO_2 capture installations, however, no specific EIAs are required for CO_2 transport. • EIAs are mandatory for CO_2 storage sites. • EIA legislation also provide for mitigation and risk management steps to be taken by the operator. • The operator is also required to demonstrate that the project is up to date with technology developments with all such technology and developments requiring approval by regulators.
Stakeholder and public consultation	• There is no specific requirement to communicate with stakeholders throughout the project lifecycle. • Malta's ordinary courts and tribunals can be accessed for disputes in the context of CCS projects.
Liability - closure, monitoring and accidental releases of stored CO_2	• A prescriptive closure regime has been established, with closure only possible upon satisfaction of relevant conditions stipulated in the permit and the operator responsible for monitoring, reporting and corrective measures until responsibility for the storage site is transferred to the state. • Transfer of responsibility to the state after a passage of a minimum period of 20 years upon the operator satisfying regulators of the fulfillment of stipulated conditions. • A risk assessment framework has also been established, with liabilities and post-closure responsibilities clearly defined.

NETHERLANDS

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Allocates roles and responsibilities to various government agencies to authorise and oversee the implementation of regulatory requirements for CCS projects. • A license scheme has been established to authorise CCS operations. • The project operator's responsibilities and interactions with relevant authorities have been defined.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• Dutch legislation regulates CCS activities in an integrated manner by transposing the EU CCS Directive within domestic mining legislation. As such, key aspects such as subsurface ownership issues, the design and construction of CCS projects, surface access and reclamation, CO_2 leakage, the transport of CO_2, monitoring and site closure are all addressed in the Netherlands' legislation.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• EIA processes under general Dutch law are applicable to CCS projects. • Provides for risk mitigation and remediation activities to address the environmental impacts of CCS projects. • Projects are required to comply with technology standards.
Stakeholder and public consultation	• Public participation is required in the context of EIAs for the construction and setting up of CO_2 transport pipelines and storage facilities.

CCS LRI Band score	
	• Provides for a specific avenue to resolve disputes for CCS projects.
Liability - closure, monitoring and accidental releases of stored CO_2	• Responsibility for the CO_2 storage site is transferred to the state upon fulfillment of all obligations. • A risk assessment framework is in place addressing issues such as monitoring, measurement and verification.

PORTUGAL

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• The regulatory roles and responsibilities of various government agencies are well defined for CCS projects. • A permit scheme has been established to authorise various stages of the CCS project cycle. • The roles of project operator and regulator are defined in great detail in relation to various aspects of the CCS project cycle.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• Portugal's CCS legislation does not deal with CCS activities in an integrated manner. However, within its legal framework, key aspects of CCS have been regulated, including subsurface ownership issues, surface access and reclamation, CO_2 leakage and monitoring and reporting obligations, storage and siting and site closure. In addition, o General planning, pollution control laws and OH&S requirements are applicable to the design and construction of CCS projects. o Specific legislation governing transport of CO_2 is yet to be introduced.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• The capture, transport and storage of CO_2 under CCS projects are subject to EIAs under Portuguese law, due to its potential to cause significant impact on the environment. • Risk mitigation and remediation obligations arise for the project operator through the authorisation to conduct CCS activities. • There are no specific technology standards imposed on CCS projects in Portugal.
Stakeholder and public consultation	• Public engagement processes in relation to CCS projects are restricted to the responsible government authority and not imposed on project operators. • Dispute resolution mechanisms for CCS projects involve arbitration.
Liability - closure, monitoring and accidental releases of stored CO_2	• For a storage site to be closed, the project operator is required to comply with conditions stipulated in the permit and obtain the approval of the relevant authority. • The operator remains responsible for monitoring, reporting and corrective measures, until liability is transferred to the state.

POLAND

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Regulatory roles and responsibilities of various government agencies in relation to CCS projects are well defined. • A license scheme is in place for authorising CCS projects. • The roles of the project operator and regulator are well defined.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• CCS legislation in Poland reflects the EU CCS Directive and as such, is well-integrated. Key aspects such design standards for CCS projects, CO_2 leakage, monitoring and reporting, transport of CO_2, storage and siting and site closure are well-regulated. However, o Ownership of the subsurface is not clearly defined. o There are no specific provisions addressing surface access and reclamation activities.

CCS LRI Band score	
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• EIAs are required in relation to the capture, transport, siting and storage of CO_2; this occurs as part of the permitting process for these activities. • Project operators are required to comply with risk management and mitigation responsibilities throughout all stages of a CCS project cycle. • The permit process for CCS activities requires details relating to technical information and developments for CCS projects.
Stakeholder and public consultation	• Public engagement for CCS projects in Poland is limited to the first stage of the permitting process for CCS projects. • There are limited avenues for dispute resolution in the context of CCS projects.
Liability - closure, monitoring and accidental releases of stored CO_2	• Upon closure, Poland requires project oeprators to fulfill a range of conditions prior to approval being granted for closure. • Approval for closure results in the transfer of liability for the CO_2 storage site to the state. • A detailed risk assessment framework is in place in respect of the closure of a CCS site. • The operator is required to provide financial security for the monitoring and remediation purposes, for 30 years after the closure of the site and the transfer of responsibility to the state.

ROMANIA

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• Well-defined regulatory framework which allocates responsibilities to oversee and authorise activities across the CCS project lifecycle to various government agencies. • A permit scheme which corresponds to and authorises various stages of a CCS project has been established. • The project operator's responsibilities during the operational and closure/post closure phases have been clearly outlined.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• Romania's legal framework does not deal with all aspects of a CCS project in an integrated manner. Limited provision has been made in respect of key aspects such as ownership of the subsurface and surface access and reclamation. • However, the leakage of CO_2, CO_2 transport monitoring and verification obligations, storage and siting framework and site closure requirements have been established.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• General EIA frameworks require environmental permits when applying for a storage permit, despite this regulation not being specific to CCS projects. • Risk management and mitigation procedures are a feature of Romania's CCS framework, with rules on measures to be taken in the event of CO_2 leakage. • Some technical requirements for CCS projects are in place.
Stakeholder and public consultation	• There are no specific public engagement requirements that apply directly to CCS projects in Romania; however, regulatory authorities are required to publish information on the geological storage of CO_2. • There is access to dispute resolution mechanisms in the event of conflicts relating to CCS projects.
Liability - closure, monitoring and accidental releases of stored CO_2	• There is a highly regulated closure regime in Romania, with operators required to fulfill several conditions stipulated by the regulatory authority for closure to be given approval. • The operator has post-closure responsibilities relating to monitoring and corrective measures, until responsibility is transferred to the state. • The transfer of liability is conditional on the passage of at least 20 years since site closure, evidence that the CO_2 is permanently stored and the provision of financial security to cover costs to the state following transfer of liability.

SLOVAKIA

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• The regulatory roles and responsibilities of the government and agencies are well defined in relation to CCS projects. • A permit scheme has been established to authorise CCS activities. • The roles of the project operator and regulator are clearly defined.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• The legal framework regulates CCS projects in an integrated manner. Limited provision has been made in respect of issues such as ownership of the subsurface, surface access and reclamation activities, design standards for CCS, the transport of CO_2 and monitoring and verification requirements, with general legislation applicable in this regard. • However, specific provisions have been made for mitigation and accounting in the event of leakage of CO_2, assessing the suitability of storage sites and site closure.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• A detailed environmental assessment regime for the capture and transport of CO_2. • Permanent storage of CO_2 is subject to a compulsory EIA process. • Appropriate mitigation and remediation measures are in place to address environmental impacts at all stages of a CCS project. • Operators are required to demonstrate technical competence when applying for storage permits.
Stakeholder and public consultation	• There is a comprehensive framework for early and long-term public consultation with stakeholders through the EIA process for CCS projects. • There is no dedicated CCS dispute resolution mechanism – there is recourse to the general legal system.
Liability - closure, monitoring and accidental releases of stored CO_2	• Provides for the closure of a storage site and relevant corresponding measures and responsibilities. • Provision has been made for the transfer of long-term liability to the state. • There is a risk assessment framework dealing with closure issues, including an MMV process for CCS projects upon closure.

SLOVENIA

CCS LRI Band score	
CCS-specific legislation enacted	✔ EU CCS Directive transposed; however, the injection and storage of CO_2 in Slovenia is currently prohibited; the capture and transport of CO_2 is authorised in limited circumstances.
Clarity and efficiency of the administrative process under the CCS legal	• The regulatory roles and responsibilities of various government agencies relating to CCS projects are well defined. • The approvals process for CCS projects is highly limited and restricted due to the injection and storage of CO_2 in Slovenia being limited. • The terms and conditions for the authorising CO_2 storage are imposed by regulation. • The roles of the project operator and regulator are not defined at each stage of the CCS process.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• CCS legislation in Slovenia is not integrated. No specific provision has been made to address subsurface ownership issues, design and construction of CCS projects, surface access and reclamation, CO_2 leakage, siting and storage and site closure. This may be due to the current prohibition on CO_2 storage onshore in Slovenia.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• There are no specific EIA requirements catering to CCS projects, although general EIA provisions may be applicable. • There are no specific requirements for EIAs in respect of siting and storage, as CO2 storage is prohibited. • There are no specific risk mitigation and remediation requirements for CCS projects, however, general EIA rule apply.

CCS LRI Band score	
	• There are no special requirements to comply with specific technology standards to conduct CCS projects. However, general environmental regulations may still be applicable.
Stakeholder and public consultation	• There are no CCS specific public engagement requirements; only general EIA provisions requiring public involvement during the EIA process may apply.
Liability - closure, monitoring and accidental releases of stored CO_2	• There is no CCS specific closure regime; general provisions maybe applicable to permitted CCS processes. • There are no specific provisions regarding liabilities and post-closure responsibilities for CCS projects. In its absence, general environmental provisions apply. • Environmental legislation is likely to apply in the context of liabilities for CCS operations.

SPAIN

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• The regulatory roles and responsibilities for CCS projects amongst various government agencies have been strongly defined. • There is a permit scheme in place to authorise CCS activities in Spain. • The role of the project operator and regulator are well defined at each stage of the CCS project cycle.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• CCS legislation deals with the various aspects of a project in an integrated manner. The CCS framework deals with ownership of the subsurface (vested in the state), CO_2 leakage, monitoring and verification obligations, storage and siting and site closure. • However, provision in relation to aspects such as design standards for CCS projects and transport of CO_2 is not comprehensive and remains limited.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• There are no specific EIA requirements that are additional to the permitting regime for capture, transport, storage and siting. • Mitigation and risk management measures are ongoing responsibilities for CCS project operators. • There are no provisions on technical information and technology development in Spanish CCS legislation.
Stakeholder and public consultation	• Public engagement is a key feature of the CCS legal framework. • There is also general recourse to Spanish courts in case of CCS project-related disputes.
Liability - closure, monitoring and accidental releases of stored CO_2	• There is a strongly regulated closure regime for the closure of CCS projects, where responsibility is transferred to the state by resolution and upon the regulatory authority's assessment of the stored CO_2. • A detailed risk assessment framework is in place, requiring the project operator to take corrective and preventative measures in line with the requirements of the regulatory authority. • The transfer of responsibility is to take place after the passage of a minimum period of 20 years. • Requires project operator to fulfill several post-closure obligations prior to the transfer of responsibility to the state.

SWEDEN

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• The regulatory roles and responsibilities of various government agencies have been defined for different aspects of CCS in Sweden. • A permit scheme has been established to authorise CCS activities, with applicants required to submit security to ensure compliance with obligations under emissions trading legislation.

CCS LRI Band score	
	• The legislation allocates responsibilities to both the project operator and regulator in respect of CCS projects.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• The regulatory framework does not address all aspect of a CCS project; however, capture, transport and storage have been addressed. Aspects such as CO_2 leakage, monitoring obligations and site closure (including transfer of responsibility) have been regulated. • However, there is limited provision in terms of clarifying subsurface ownership issues, design standards for CCS projects and CO_2 transport.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• EIAs are required for environmentally hazardous activities which include CCS. • Obligations are imposed on the project operator to take measures to develop corrective measures in the event of CO_2 leakage. • Project operators are required to utilise the best available technology to prevent harm to human health and the environment as a consequence of CCS operations.
Stakeholder and public consultation	• There are no specific provisions for public engagement in the context of CCS projects. General environmental legislation may apply in this regard. • Disputes arising out of CCS projects can be adjudicated by supervising authorities.
Liability - closure, monitoring and accidental releases of stored CO_2	• There is no closure regime in place specifically for CCS projects, although general environmental and energy closure provisions may still be applicable; • Post-closure liability has been addressed, through placing liability upon the operator until transfer of responsibility to the state, which is usually after the passage of a period of 20 years. • There is no provision for CCS-specific risk assessment measures. However, general environmental provisions apply.

UNITED KINGDOM

CCS LRI Band score	
CCS-specific legislation enacted	✔ (EU CCS Directive implemented)
Clarity and efficiency of the administrative process under the CCS legal	• The regulatory roles and responsibilities of various government agencies in relation to CCS activities are very well-defined. • A comprehensive licensing and leasing scheme is in place in to undertake CCS activities in the UK. • The roles of the project operator and regulator are clearly defined for all stages of the CCS project cycle.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• The UK's legal framework for CCS deals with all activities under the project cycle in an integrated manner. Thus the UK's CCS legal framework comprehensively covers subsurface ownership issues, CO_2 leakage, transport of CO_2, monitoring and verification obligations, site closure and the transfer of long-term liabilities.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• A strong EIA assessment regime is in place for CCS capture and transport which is incorporated in existing environmental and planning legislation. • Siting and storage is subject to the same EIA processes as capture and transport of CO_2. • The standard EIA requirements for CCS activities stipulate mitigation and risk management responsibilities to the project operator. • The UK legislative regime prescribes technical and financial competency as a pre-requisite for obtaining authorisation to conduct CCS activities.
Stakeholder and public consultation	• A comprehensive public engagement framework has been established for CCS activities, with regulatory authorities required to publish a register of all awarded licenses to conduct CCS activities, among other requirements. • CCS activities do not possess their own dispute resolution mechanisms in the UK; however, there is general recourse to the UK court system or existing mechanisms applicable to oil and gas activities.
Liability - closure, monitoring and accidental releases of stored CO_2	• Specific regulations have been enacted dealing with closure of a storage site and post-closure requirements for project operators.

CCS LRI Band score	
	• Closure is subject to prescribed circumstances and with the consent of the regulatory authority. • Liability is transferred to the state upon termination of a storage license, including after the post-closure monitoring period (which is generally less than 20 years. • The risk assessment framework during the closure phase of a CCS project is detailed and clearly allocates liabilities for closure issues relating to CCS projects. • Project operators are required to lodge financial security to mitigate risks to the regulatory authority upon transfer of responsibility. • After closure, the project operator is still liable for leakages and is obliged to undertake monitoring and reporting until responsibility is transferred to the state. • The project operator is liable for any damage stemming from CO_2 leakage under general environmental legislation.

CHINA

CCS LRI Band score	
CCS-specific legislation enacted	✗ There is no dedicated CCS legislation in China
Clarity and efficiency of the administrative process under the CCS legal	• There is no specific government agency that oversees CCS projects. Project operators will need to apply for permits as for any other major project. • The absence of a centralised approvals process for CCS means that authorisation for CCS activities will overlap various government agencies in respect of each aspect of the CCS project. • The project operator will be required to comply with any number of conditions stipulated in any license that is granted to conduct CCS activities.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• As there is no specific CCS legislation in China, any proposed CCS activity will be governed by a range of different environmental, oil and gas and land use regulations.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• China's general environmental regime and EIA frameworks are likely to apply to CCS projects. • Although specific regulations relating to mitigation and risk management have not been established, project operators will likely be required to submit plans detailing such measures to the responsible authority. • There are no statutory requirements to demonstrate technical capability to conduct CCS projects in China.
Stakeholder and public consultation	• EIA approvals require public participation when reviewing plans and projects. • There is no dispute resolution mechanisms to address disputes arising from CCS projects.
Liability - closure, monitoring and accidental releases of stored CO_2	• There is no closure regime for CCS projects in China. • In the absence of a CCS specific regime, domestic mining legislation and closure provisions for mines may be applicable to CCS projects. • There are no detailed rules regarding risk assessment frameworks for CCS projects, although obligations under general environmental legislation may arise. • A project operator is likely to be liable for any damage from CO_2 leakage, although there are no specific provisions in this regard.

SOUTH KOREA

CCS LRI Band score	
CCS-specific legislation enacted	❌ There is no dedicated CCS legislation in South Korea
Clarity and efficiency of the administrative process under the CCS legal	• South Korea's CCS National Master Plan divides government roles for various aspects of CCS projects, including infrastructure and safety. • A dedicated CCS approvals process has not been established. • In the absence of a dedicated CCS legal framework, the project operator is likely responsible for all stages of the CCS process.
Comprehensiveness of the legal framework in providing for all aspects of a CCS project	• There is no integrated framework for CCS projects in South Korea. In the absence of a dedicated CCS legal framework, general mining, environmental and safety regulations may be applicable to any proposed CCS activity.
Legislation addresses appropriate siting of projects and adequate Environmental Impact Assessment (EIA) processes	• There is no comprehensive law that addresses CCS projects in respect of activities such as capture, transport and storage of CO_2. • South Korea's general environmental impact assessment frameworks are likely to be applicable to CCS activities. • There are no requirements around demonstrating technological capability for CCS projects.
Stakeholder and public consultation	• There are no specific provision or frameworks for public engagement in relation to CCS projects.
Liability - closure, monitoring and accidental releases of stored CO_2	• There is no closure regime in place and the legal framework is silent with regard to post closure responsibilities and risk assessment obligations.

GLOBAL CCS INSTITUTE

Figure 43. Central European Refineries evaluated in this study.

Figure 44. Eastern European Refineries evaluated in this study.

Figure 45. Northern European Refineries evaluated in this study.

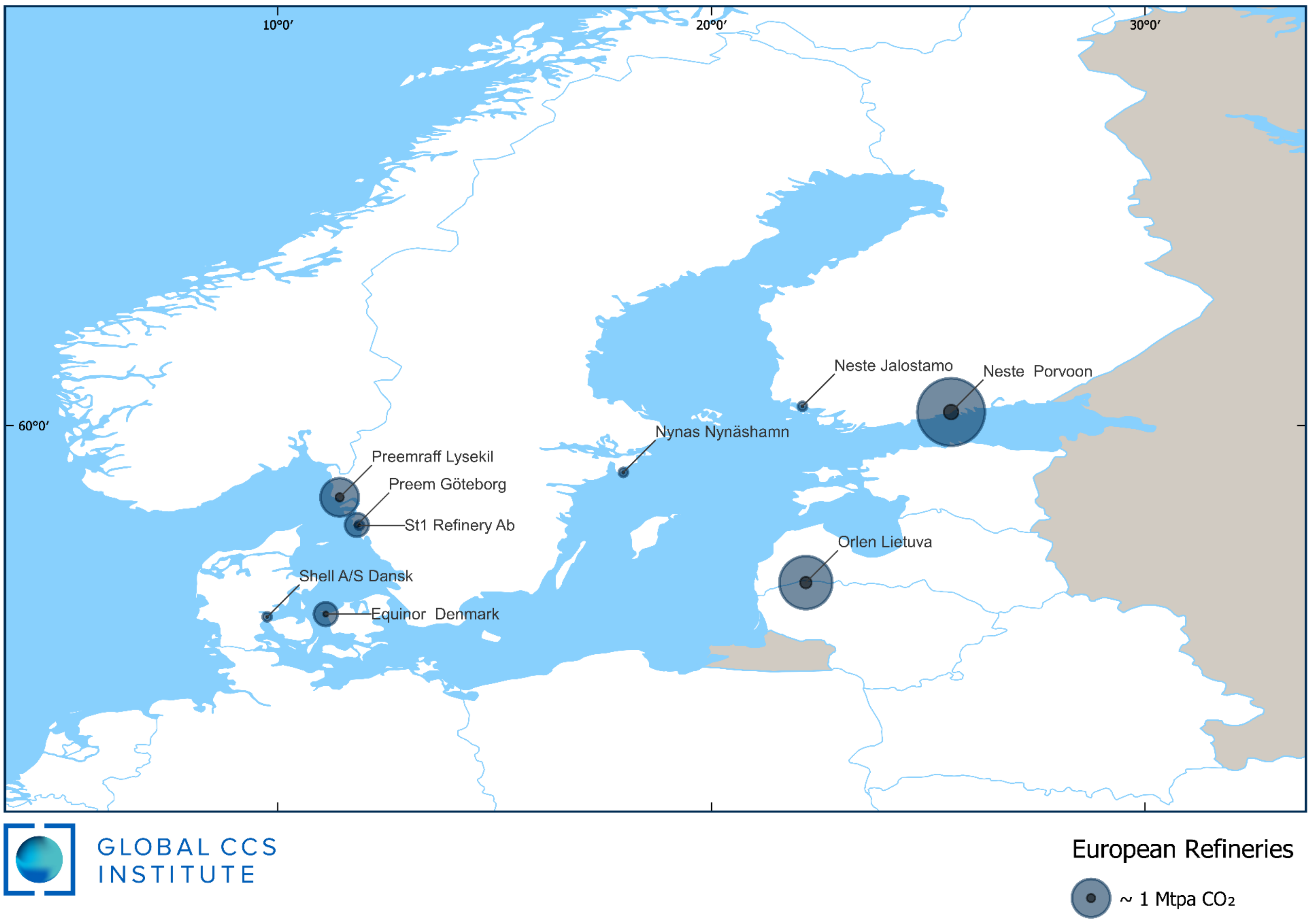
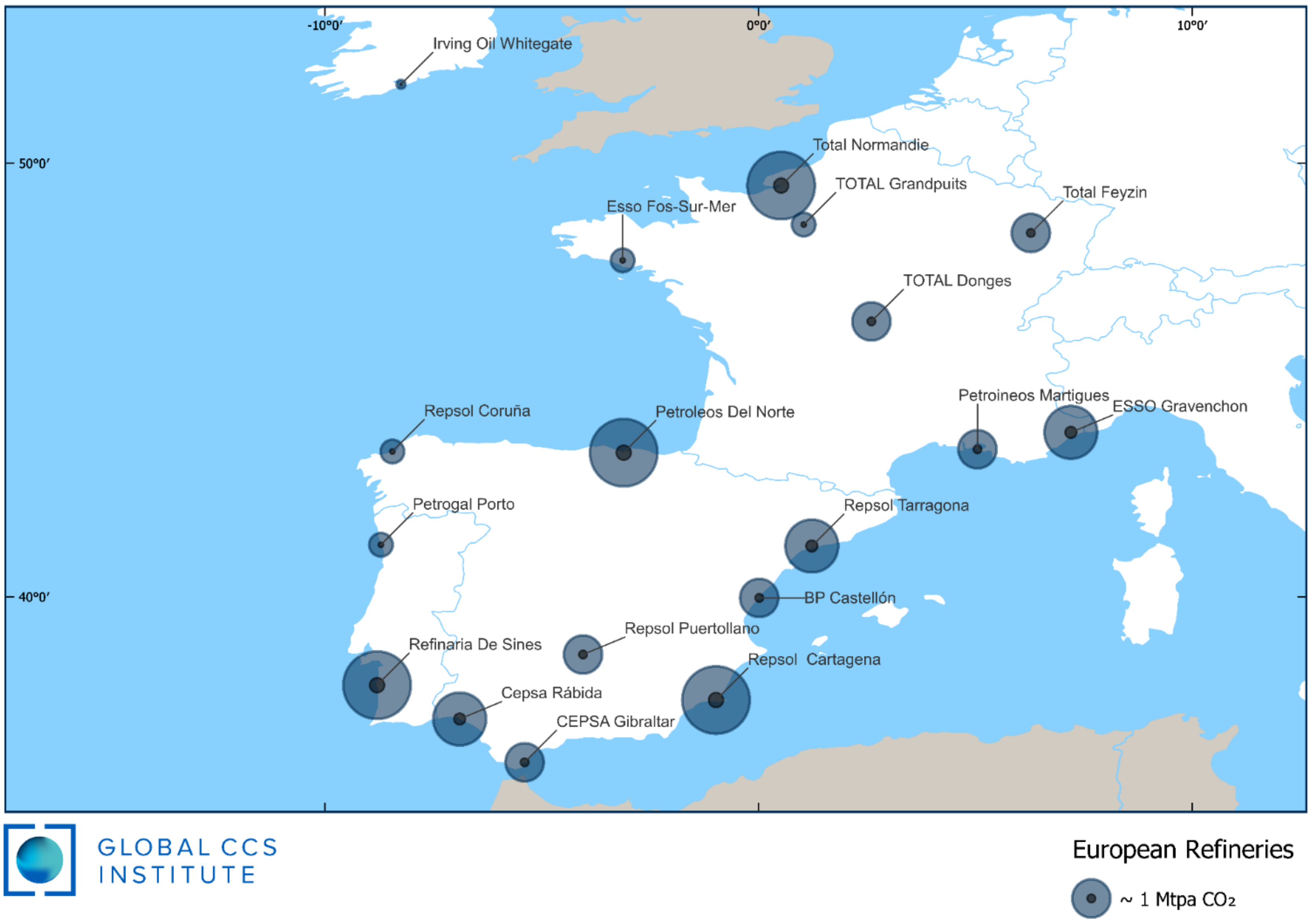


Figure 46. Eastern European Refineries evaluated in this study.



Appendix E – Refinery Indicator: Refinery Details

Short Name	Country	Annual CO_2 Emissions (Million Tonnes). Source:	Refinery Capacity (Kbbl/Day) Sources: Mckinsey (2020). Check footnote for comments.
Polski Koncern Naftowy Orlen S.A.	Poland	6.95	360
Sarlux SRL	Italy	6.35	315
Shell Nederland Raffinaderij BV	Netherlands	4.21	440
Total Raffinaderij Antwerpen	Belgium	4.01	350
PCK Raffinerie GMBHSchwedt	Germany	3.85	239
Ruhr Oel Gmbh Werk Scholven	Germany	3.32	132
OMV Downstream Gmbh[23]	Austria	2.79	192
Neste Oyj, Porvoon Jalostamo	Finland	2.77	206
CI - Refinaria De Sines	Portugal	2.60	220
Repsol Petróleo, S.A. - C.I. Cartagena	Spain	2.40	220
ENI S.P.A. Taranto	Italy	2.37	120
Raffinerie De Normandie	France	2.37	260
Raffineria Di Milazzo S.C.P.A.	Italy	2.31	248
BP Rotterdam Refinery	Netherlands	2.25	377
Shell Deutschland Oil Gmbh, Rheinland Raffinerie, Werk Sud	Germany	2.18	175
Petroleos Del Norte, Petronor, S.A. (Petronor)	Spain	2.15	240
Repsol Refineria Tarragona	Spain	2.14	190
Exxonmobil Petroleum & Chemical - Esso Raffinaderij	Belgium	2.09	307
Lukoil Neftohim Burgas AD[21]	Bulgaria	2.06	194
Miro-Mineralölraffinerie Oberrhein Gmbh & Co.KG	Germany	2.05	322
Esso Nederland Bv (Raffinaderij Rotterdam)	Netherlands	2.01	195
Motor Oil (Hellas) - Corinthos Refineries S.A.	Greece	2.00	185
Slovnaft (Mol)	Slovakia	2.00	124
Raffinerie De Port-Jérôme / Gravenchon	France	1.96	243
Hellenic Petroleum S.A. –South Refineries Complex – Elefsis Industrial Facilities	Greece	1.84	100
Total Raffinerie Mitteldeutschland GMBH (Raffinerie, BB01)	Germany	1.78	227
Grupa Lotos S.A.	Poland	1.76	210
AB Orlen Lietuva	Lithuania	1.71	205
ESSSO Italiana S.R.L.	Italy	1.67	198
Zeeland Refinery N.V.	Netherlands	1.63	149
Raffineria ISABImpianti Sud	Italy	1.60	110
Refinería La Rábida	Spain	1.58	213
Mol Magyar Olaj- És Gázipari Nyrt.	Hungary	1.56	165
Repsol Petroleo S.A.	Spain	1.54	150
Refinería Gibraltar	Spain	1.49	252
Shell Deutschland Oil GMBH Rheinland Raffinerie Werk Nord	Germany	1.42	175
Petroineos Manufacturing France SAS	France	1.38	210
BP Oil España S.A.U. Refineria De Castellón	Spain	1.28	110
Hellenic Petroleum S.A. - Industrial Division Of Aspropyrgos	Greece	1.25	150
Bayernoil Raffineriegesellschaft Mbh, Betriebsteil Neustadt	Germany	1.17	217
Ruhr Oel GMBH Werk Horst	Germany	1.12	132
ENI S.P.A. Livorno	Italy	1.11	106
Preemraff, Lysekil	Sweden	1.11	230
Omv Deutschland GMBH, Werk Burghausen	Germany	1.11	76
Omv Petrom Sa - Petrobrazi[21]	Romania	1.06	90
Plateforme De Donges	France	1.03	230
BP Europa Se BP Lingen	Germany	1.02	97
Raffinerie De Feyzin	France	1.01	117
Repsol YPF Complejo Industrial A Coruña	Spain	1.00	125
SC Rompetrol Rafinare Sa - Punct De Lucru Rompetrol Rafinare - Navodari[21]	Romania	0.99	100
Raffinerie Heide GMBH	Germany	0.99	93
S.A.R.P.O.M.	Italy	0.98	121
CI- Petrogal-Refinaria Do Porto	Portugal	0.97	110
Raffinerie Esso	France	0.76	133
Rafinerija Nafte Rijeka	Croatia	0.71	90
Bayernoil Raffineriegesellschaft Mbh, Betriebsteil Vohburg	Germany	0.66	217
ENI S.P.A. Sannazzaro	Italy	0.64	223
Gunvor Raffinerie Ingolstadt GMBH	Germany	0.63	110
Api Raffineria Di Ancona S.P.A.	Italy	0.59	83
Preem AB Preemraff Göteborg	Sweden	0.57	115
Raffinerie De Grandpuits	France	0.54	105
Equinor Refining Denmark A/S	Denmark	0.54	118
Rafinérie Kralupy Nad Vltavou	Czechia	0.47	66
Gunvor Petroleum Antwerpen[21]	Belgium	0.47	110
ST1 Refinery Ab	Sweden	0.46	80
Isab S.R.L	Italy	0.45	110
A/S Dansk Shell	Denmark	0.43	68
Rafinérie Litvínov	Czechia	0.41	109
SC Petrotel Lukoil Sa	Romania	0.39	68
Gunvor Petroleum Europoort B.V.	Netherlands	0.39	90
Neste Oyj, Naantalin Jalostamo	Finland	0.36	58
Rafinerija Nafte Sisak[21]	Croatia	0.31	61
Nynas Ab	Sweden	0.28	13
Irving Oil Whitegate Refinery Limited	Ireland	0.27	75
Hellenic Petroleum S.A. - Thessaloniki Industrial Complex	Greece	0.27	100
Iplom S.P.A	Italy	0.26	40
Holborn Europa Raffinerie GMBH	Germany	0.16	105
Nynas GMBH & Co. Kg Raffinerie Harburg	Germany	0.16	20
Wrg - Wilhelmshavener Raffinerie- Gesellschaft Mbh	Germany	0.14	87
Nynas AB, Oljeraffinaderiet I Nynäshamn	Sweden	0.12	30
VPREnergy B.V.	Netherlands	0.10	84

[23] http://abarrelfull.wikidot.com/

Appendix F – Refinery Indicator Results: Storage

Refinery	Country	Basin	Basin Quality	CO2Stop Region
PKN Orlen	Poland	Central European	Possible	Onshore Central Poland
Sarlux Srl	Italy	Pelagian	Suitable	Western Sicily
Shell Nederland	Netherlands	Southern North Sea - Anglo-Dutch	Highly Suitable	Nearshore North Sea (Netherlands)
Total Antwerpen	Belgium	Southern North Sea - Anglo-Dutch	Highly Suitable	Nearshore North Sea (Netherlands)
PCK Schwedt	Germany	Central European	Possible	Onshore Western Germany
BP Scholven	Germany	Northwest German	Suitable	Onshore/ Nearshore Northern Germany
Omv Schwechat	Austria	Vienna	Suitable	Central Vienna Basin (Vienna)
Neste Porvoon	Finland	Baltic	Suitable	Western Latvia
Refinaria De Sines	Portugal	Lusitanian	Possible	Offshore Portugal
Repsol Cartagena	Spain	Betic Cordillera	Possible	Southern Spain
ENI Taranto	Italy	Southern Appennines	Possible	Southern Italy
Total Normandie	France	Paris	Suitable	Central France
Raffineria Milazzo	Italy	Pelagian	Suitable	Western Sicily
BP Rotterdam	Netherlands	Southern North Sea - Anglo-Dutch	Highly Suitable	Nearshore North Sea (Netherlands)
Shell Rheinland,Sud	Germany	Northwest German	Suitable	Onshore/ Nearshore Northern Germany
Petroleos Del Norte	Spain	Duero	Suitable	Central Spain
Repsol Tarragona	Spain	Ebro	Possible	Eastern Spain
Esso Raffinaderij	Belgium	Southern North Sea - Anglo-Dutch	Highly Suitable	Nearshore North Sea (Netherlands)
Lukoil Burgas	Bulgaria	Burgas	Possible	Onshore Burgas, Eastern Bulgaria
MIRO	Germany	Paris	Suitable	Central France
ESSO Nederland	Netherlands	Southern North Sea - Anglo-Dutch	Highly Suitable	Nearshore North Sea (Netherlands)
Motor Oil Corinthos	Greece	Iberian Range	Possible	Onshore/Nearshore Thessaloniki region
Slovnaft (Mol)	Slovakia	Vienna	Suitable	Central Vienna Basin (Vienna)
ESSO Gravenchon	France	Paris	Suitable	Central France
Hellenic Elefsis	Greece	Northern Aegean	Possible	Onshore/Nearshore Thessaloniki region
Total Mitteldeutschland	Germany	Northwest German	Suitable	Onshore/ Nearshore Northern Germany
Grupa Lotos	Poland	Mid-Polish Trough	Possible	Onshore Central Poland
Orlen Lietuva	Lithuania	Baltic	Suitable	Onshore western Latvia
ESSO Augusta	Italy	Pelagian	Suitable	Western Sicily
Zeeland	Netherlands	Southern North Sea - Anglo-Dutch	Highly Suitable	Nearshore North Sea (Netherlands)
ISAB Impianti	Italy	Pelagian	Suitable	Western Sicily
Cepsa Rábida	Spain	Gulf of Cadiz	Unlikely	Offshore Southwestern Spain
Mol Magyar	Hungary	Pannonian	Suitable	Western Hungary
Repsol Puertollano	Spain	Guadalquivir	Possible	Southern Spain
CEPSA Gibraltar	Spain	Guadalquivir	Possible	Southern Spain
Shell Rheinland,Nord	Germany	Northwest German	Suitable	Onshore/ Nearshore Northern Germany
Petroineos Martigues	France	Paris	Suitable	Central France
BP Castellón	Spain	Iberian Range	Possible	Eastern Spain
Hellenic Aspropyrgos	Greece	Northern Aegean	Possible	Onshore/Nearshore Thessaloniki region
Bayernoil Neustadt	Germany	Northwest German	Suitable	Central Germany
BP Ruhr Oel	Germany	Northwest German	Suitable	Onshore/ Nearshore Northern Germany
ENI Livorno	Italy	Po	Suitable	Northern Italy
Preemraff Lysekil	Sweden	Skagerrak - Kattegat	Possible	Onshore / Nearshore Northern Denmark
OMV Burghausen	Germany	Vienna	Suitable	Central Vienna Basin (Vienna)
Omv Petrom Petrobrazi	Romania	Southern Carpathians	Highly Suitable	Central Romania
TOTAL Donges	France	Paris	Suitable	Central France
BPLingen	Germany	Northwest German	Suitable	Onshore/ Nearshore Northern Germany
Total Feyzin	France	Paris	Suitable	Central France
Repsol Coruña	Spain	Duero	Suitable	Central Spain
Rompetrol Navodari	Romania	Southern Carpathians	Highly Suitable	Central Romania
Raffinerie Heide	Germany	Northwest German	Suitable	Onshore/ Nearshore Northern Germany
S.A.R.P.O.M.	Italy	Po	Suitable	Northern Italy
Petrogal Porto	Portugal	Lusitanian	Possible	Offshore Portugal
Esso Fos-Sur-Mer	France	Paris	Suitable	Central France
Nafte Rijeka	Croatia	Adriatic - Dinaric	Possible	Onshore Central Croatia
Bayernoil Vohburg	Germany	Northwest German	Suitable	Central Germany
ENI Sannazzaro	Italy	Po	Suitable	Northern Italy
Gunvor Ingolstadt	Germany	Northwest German	Suitable	Central Germany
Api Raffineria Ancona	Italy	Northern Apennines	Suitable	Central Italu
Preem Göteborg	Sweden	Skagerrak - Kattegat	Possible	Onshore / Nearshore Northern Denmark
TOTAL Grandpuits	France	Paris	Suitable	Central France
Equinor Denmark	Denmark	Norwegian-Danish	Highly Suitable	Onshore / Nearshore Northern Denmark
Kralupy Vltavou	Czechia	Mseno-Roudnice Basin	Possible	Onshore north-central Czechia

Gunvor Antwerpen	Belgium	Southern North Sea - Anglo-Dutch	Highly Suitable	Nearshore North Sea (Netherlands)
St1 Refinery Ab	Sweden	Skagerrak - Kattegat	Possible	Onshore / Nearshore Northern Denmark
Isab Priolo Gargallo	Italy	Pelagian	Suitable	Western Sicily
Shell A/S Dansk	Denmark	Norwegian-Danish	Highly Suitable	Onshore / Nearshore Northern Denmark
Unipetrol Litvínov	Czechia	Kladno-Rakovnik Basin	Possible	Onshore north-central Czechia
Petrotel Lukoil	Romania	Southern Carpathians	Highly Suitable	Central Romania
Gunvor Europoort	Netherlands	Southern North Sea - Anglo-Dutch	Highly Suitable	Nearshore North Sea (Netherlands)
Neste Jalostamo	Finland	Baltic	Suitable	Western Latvia
Nafte Sisak	Croatia	Pannonian	Highly Suitable	Eastern Croatia
Nynas Goteborg	Sweden	Skagerrak - Kattegat	Possible	Onshore / Nearshore Northern Denmark
Irving Oil Whitegate	Ireland	North Celtic Sea	Possible	Nearshore Celtic Sea
Hellenic Thessaloniki	Greece	Northern Aegean	Possible	Onshore/Nearshore Thessaloniki region
IPLOM	Italy	Po	Suitable	Northern Italy
Holborn Europa	Germany	Northwest German	Suitable	Onshore/ Nearshore Northern Germany
Nynas Harburg	Germany	Northwest German	Suitable	Onshore/ Nearshore Northern Germany
WRG Gesellschaft	Germany	Northwest German	Suitable	Onshore/ Nearshore Northern Germany
Nynas Nynäshamn	Sweden	Skagerrak - Kattegat	Possible	Onshore / Nearshore Northern Denmark
VPR Energy	Netherlands	Southern North Sea - Anglo-Dutch	Highly Suitable	Onshore Burgas

Appendix G – Refinery Indicator Results

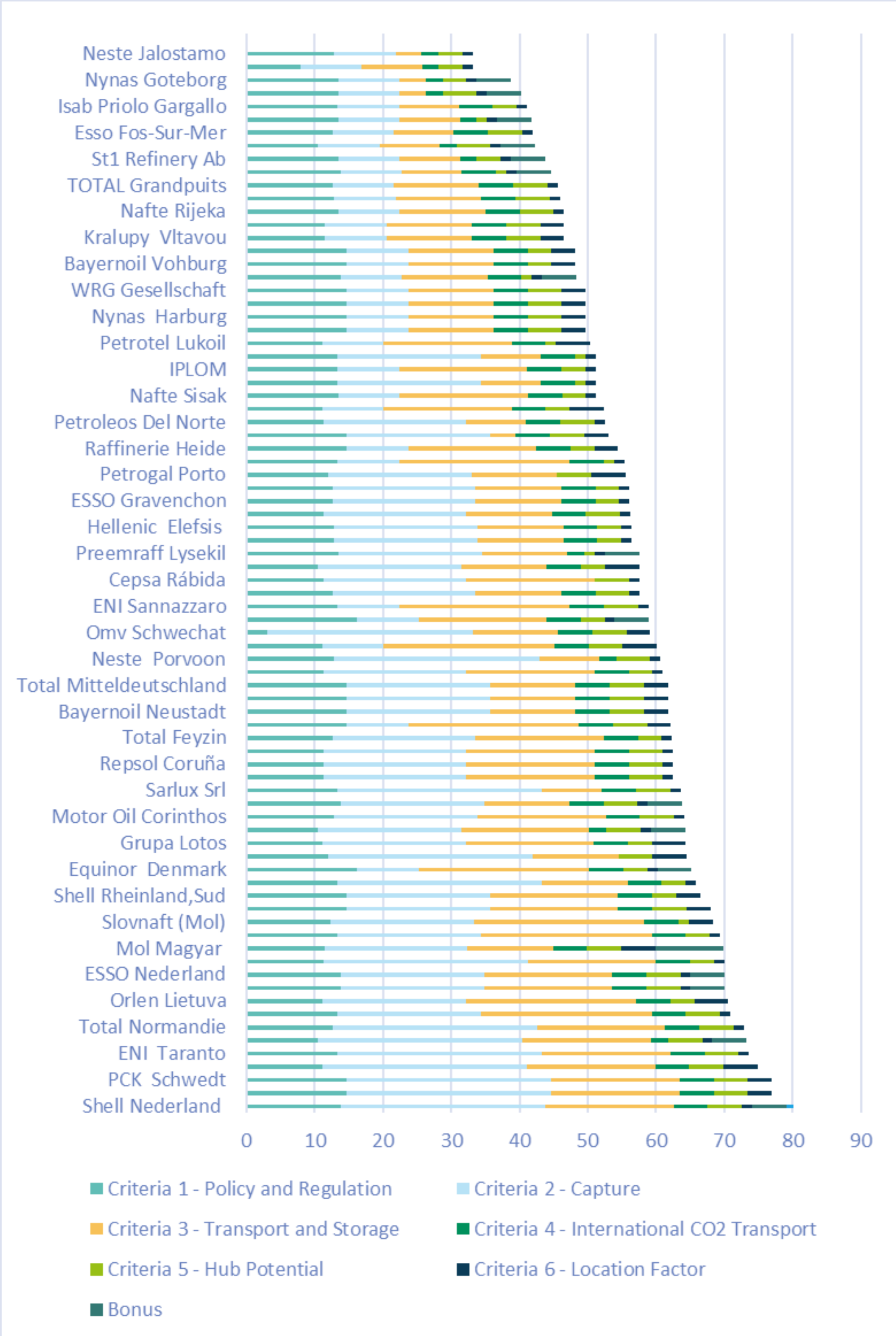


Figure 47 Full results of Refinery Indicator by criteria