Advanced Carbon Capture for steel industries integrated in CCUS Clusters

Innovation Action

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No 884418.

Feedback and policy recommendations from the C4U Project, to inform "EU strategy to create a single market for CO2 transport and storage services by 2030"

Contributors:
Porter, Richard (University College London); Martynov, Sergey (University College London); De Coninck, Eric (ArcelorMittal); Kustova, Irina (Centre for European Policy Studies); Elkerbout, Milan (Centre for European Policy Studies); de Gooyert, Vincent (Radboud University); Covarrubias Perez, Moises (Radboud University); Mitchell, Amelia (Element Energy Limited); Jiménez Rodríguez, Inés Holanda (Climate Strategies); Chavarría Flores, Adriana (Climate Strategies)

Table of Contents

Disclaimer

This report includes a summary of findings and contributions from the research conducted by C4U work packages "WP4: Integration of CO2 capture in industrial CCUS clusters", "WP5: Societal readiness and public policy" and "WP6: Long term business mode ls". C4U is a European Union's Horizon 2020-funded project aiming to advance emerging CO2 capture technologies for the decarbonisation of iron and steel production and their effective integration into industrial clusters. The statements herein do not directly represent the views of individual authors, members, or consortium partners of the C4U project, or the views of the European Union.

For more information on C4U or the evidence presented herein, please contact: chemeng.C4U@ucl.ac.uk, or visit: https://c4u-project.eu/

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No **884418***

1. Executive Summary

C[4]U is a holistic, interdisciplinary project aimed at addressing all the essential elements required for the optimal integration of CO2 capture in the iron and steel industry, as part of the CCUS chain. In this report, C[4]U project findings have been synthetised to inform the European Commission's Call for Evidence on its industrial carbon management strategy. These are the report's key recommendations:

- **Regulations for a CO2 transport infrastructure should ensure the resilient and timely deployment of CCUS infrastructure,** ensuring that it is optimal for the foreseen time horizons and re-scalable to accommodate future changes in demand for CO2 transport.
- **The EU/Europe may benefit from a regulated pan-EU/European CO2 infrastructure**, to remove cross-border issues and make available/fair solutions. Two options for CO2 quality standards may be considered:
    - To impose a single standard along with a set of policies to provide subsidies for cleaning/ purifying CO2 (thus assisting industries who cannot meet said standards)
    - To develop different CO2 stream specifications or separate standards for processing different quality CO2 streams
- **There are several technological developments relevant for the long-term infrastructure planning of CCS**. These developments will require policy support to ensure their best implementation.
- **CO2 storage directly on the sea floor is not recommended.**
- **A combination of a Joint Venture and Transport CCUS Business Models is shown to have the most adoption potential for CCUS by industrial firms**.
- **To support business strategies and the transition to industrial decarbonisation, a number of policy recommendations have also been identified.**
- **To support positive interaction among stakeholders, the following policy recommendations are suggested:**
    - Early and consistent engagement with the public.
    - Early engagement with society's perception of risks related to decarbonisation technologies.
    - The leading predictor for social acceptance is the perceived risk of unequal distribution of burdens – versus the benefits of a just transition.
    - To ensure a just distribution of burdens and benefits, one must ensure timely public participation, understandable and transparent information, and fair participation.

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No **884418***

2. The C4U Project

C[4]U is a holistic, interdisciplinary research and innovation project aimed at addressing all the essential elements required for the optimal integration of CO2 capture in the iron and steel industry, as part of the CCUS chain. It is a first-of-its-kind project, as it considers technology development alongside societal, environmental, business, and policy considerations for a real industrial cluster.

C[4]U aims to advance two emerging CO2 capture technologies, known as DISPLACE and CASOH. These are two highly energy-efficient, high-temperature, solid-sorbent CO2 capture technologies with the potential to tackle up to 94% of the CO2 sources in a steel mill. The project employs a whole-system approach which balances the different requirements of capture, pipeline transportation, and storage - as well as society. We account for the impact of the captured CO2's quality on the safety and operation of the CO2 pipeline transportation and storage infrastructure, whilst exploring utilisation opportunities and long-term business models based on its integration into the North Sea Port CCUS industrial cluster.

By undertaking integrated and solution-focused societal readiness research, C[4]U capitalises on diverse stakeholder knowledge and identifies public policy options that address the needs and concerns of stakeholders and end-users, in line with an engaging narrative for CCUS.

3. Introduction

In response to the European Commission's Call for Evidence on its industrial carbon management strategy, C[4]U project findings have been synthetised to inform the Communication's proposal of an EU strategy to create a single market for CO2 transport and storage services by 2030.

Section 4 delineates the regulatory needs for the development of a CO2 transport and storage infrastructure. It proposes possible avenues for the development of CO2 quality standards and identifies a series of technological developments relevant for long-term CCS infrastructure planning. **Section 5** evaluates key elements of the Business Model Innovation framework to facilitate the deployment of industrial CCUS infrastructure in an emerging market. Drawing from stakeholder feedback, it evaluates the business models with the most adoption potential for CCUS by industrial firms. **Section 6** then presents a series of policy recommendations designed to support business strategies and the transition to industrial decarbonisation. Lastly, **Section 7** explores current practices of social acceptance and policy instrumentation to incentivize CCUS in a socially acceptable manner. It presents policy recommendations to support positive stakeholder interaction for CCUS implementation.

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No **884418***

4. Regulatory needs for emerging CO_2 transport and storage infrastructure

- **The major challenge in planning the CO_2 transport infrastructure is associated with the long-term optimisation of CCS infrastructure, given the large uncertainties in the evolution of demand from energy and industrial sectors and the decarbonisation pathways** adopted by industries and set by governments. It is important that the regulations are set to bolster the resilient and timely deployment of the CCUS infrastructure, to ensure that the infrastructure is optimal for the foreseen time horizons and can be re-scaled in the future to accommodate for changes in the demand for CO_2 transport.

  Finding optimal solutions for CO_2 transport may require **balancing economic factors against other criteria** to meet the safety, societal benefits, and environmental impact requirements for the technologies, set by national and EU policies.

- **The EU/Europe can perhaps benefit from the regulated pan-EU/European CO_2 infrastructure**, similar to the EU power or natural gas ones, so that the standards and regulations will remove cross-border issues (e.g., for transporting industrial CO_2 streams) and make the solutions (e.g., CO_2 storage) available/fair for the different countries.

  However, **a pan-EU regulated infrastructure does not exclude CCS clusters, some of which are also cross-border, as the latter are likely to naturally evolve around large industrial clusters.** A European CO_2 infrastructure may and most likely will evolve organically through clusters connecting with one another. **Building CCS clusters and hubs may bring economic benefits, but would require subsidies** and policies to ensure their timely and fair implementation.

- **There has been little progress in finding a solution on whether a single CO_2 quality standard is needed, or separate standards would be better to suit specific industries / modes of transport / utilisation and storage requirements.**

  On the one hand, introducing **a unified standard based on a single set of CO_2 specifications can bring clear benefits to certain industries** by opening the market to them, removing cross-border issues and enabling their access to the relevant infrastructure.

  On the other hand, **purifying CO_2 to meet one-for-all standard set of specifications would create a barrier** to CCS deployment, because:

  (a) purifying CO_2 streams from (e.g.) steel and waste-to-energy power plants can be very expensive and the industries are not willing to start investing in CCS before they have certainty regarding CO_2 transport/storage solutions,

  (b) the transport and storage operators will require non-standard solutions to transport CO_2 streams containing impurities that are hazardous or may increase the risks of pipeline corrosion or fracture.

  To move things forward, two options are available:

  (1) One option would be **to impose a single standard along with a set of policies to provide subsidies for cleaning/ purifying CO_2** from industries who cannot meet this standard (so that

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No **884418***

these industries stay in the EU/ European market). Estimating the costs of CO_2 purification to meet the standard will require techno-economic evaluation on case-by-case basis.

(2) Alternatively**, different CO_2 stream specifications or separate standards could be developed for processing different quality CO_2 streams** captured from different types of emitters and targeting different modes of CO_2 transport / parts of CCUS chain. This would help collecting larger amounts of the same quality CO_2 at reduced costs, guaranteeing the interoperability of the CO_2 grid and the open access to large and small emitters. The extra funds made avaialble by avoiding the unnecessary purification step [e.g., saving of 1 €/t CO_2 by allowing Triethylene Glycol (a solvent used for CO_2 capture) in CO_2 stream captured at 100 Mt/year over the course of 10 years translates in ca 1 billion €] could be used on research and implementation of the required CO_2 processing/ infrastructure solutions.

- Based on the C4U studies, **several technological developments relevant to the "long-term infrastructure planning" for CCS have been identified**. These will require policy support to ensure they are implemented in the best way across EU/Europe and in a timely manner:

(1) **Using mobile/non-pipeline CO_2 transport (e.g., ships, barges and road trucks).** This solution may (a) become vital for decarbonising small and remote emitters not connected directly to a large CO_2 pipeline infrastructure, and (2) can bring economic benefits during the early stage of deployment of CCS by small industries, who under pressing emission regulations cannot afford to take risks such as investing into pipeline transport or have plans for switching to renewable electricity in the future.

(2) **Introducing CO_2 utilisation as alternative to CO_2 transport and storage in remote sites.** Although CO_2 utilisation is not as efficient as CCS in terms of emissions reductions, combining CCU and CCS can still be more cost-effective than CCS for scenarios where long-distance CO_2 transport has significant impact on costs and the environmental footprint of CCS. Also, it is important to do an LCA on the emission reduction potential of utilisation processes, as well as to acknowledge fundamental differences in terms of emission reduction between temporary and permanent CO_2 removal during CO_2 utilisation. CCU with permanent removal might be considered as always more attractive than storing CO_2.

(3) **Optimal scheduling of the deployment of CO_2 pipeline infrastructure for CCUS along with the infrastructure for hydrogen transport**, as required for the 'hydrogen economy' supported by the European Hydrogen Backbone initiative. Combining CCS with other decarbonisation strategies will be beneficial for economies.

(4) **Reusing the pipeline infrastructure for transportation of various gases at different times**, e.g., reusing the hydrocarbon/natural gas pipelines infrastructure for transport of CO_2 and later on for hydrogen. This scheme may present economic advantages by speeding up the CCS and the 'hydrogen energy' deployment.

Retrofitting is always done on a case-by-case basis. How easily natural gas pipelines can be retrofitted depends on many factors, including age of the pipeline, design specs, schedule, location, access for inspection, as well as expected CO_2 stream specs and operating conditions. Safety of CO_2 transport is the major criterion here. However, the EU gas industry may **re-use the majority of their natural gas pipeline infrastructure for transport of hydrogen**, and therefore **CO_2 transportation will require building new dedicated pipelines.**

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No **884418***

- Regarding CO_2 storage, **CO_2 storage directly on the sea floor should not be pursued**. This is due to the impact it would have on deep sea ecosystems, the risk of CO_2 coming out of sequestration due to ocean currents, and negative public perception of this storage option.

5. Business models for an emerging CCUS market

- The C[4]U Project has elaborated on the key elements of the **Business Model Innovation framework** that facilitates the deployment of industrial carbon capture and transport and storage infrastructure. Figure 1 presents a visualisation of the research conducted.

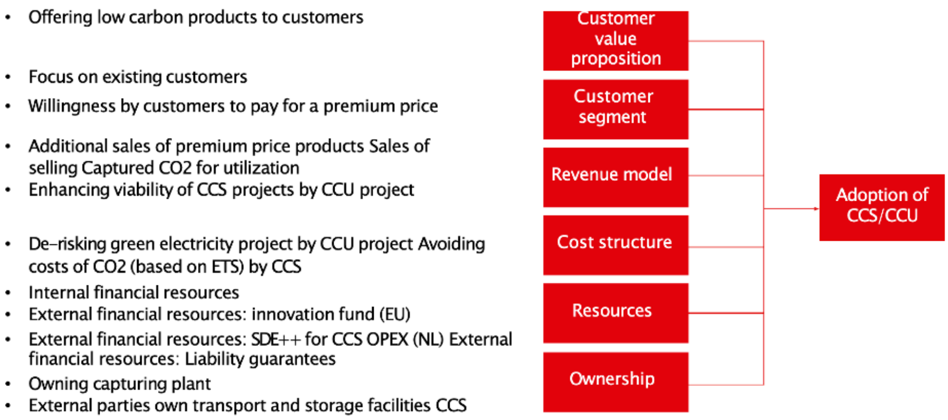

Figure 1: Business Model elements supporting the adoption of CCS/CCU

- Table 1 provides **the ranking of these elements,** summarising the feedback from the stakeholder participants of the Delphi session[1] workshop in January 2023 on the following question: ***Are the current business model framework elements relevant, or are some of these elements redundant/missing?***

- 'Customer Value Proposition' and 'Ownership' received the lowest ranking (2.5/5), while 'Resources' and 'Revenue Model' was ranked the highest (4.5/5). When validating the Business Model Innovation framework, stakeholders paid special attention to 'Revenue Model', 'Resources', and 'Ownership', as further elaborated below.

[1] [1] D6.4 employed a Delphi method. The report obtained, anonymously, individual answers from a group of experts throughout a set of two repeated interventions. The first round aimed to provide the researcher with the main trends derived from the respondents' answers and perceptions. This served as the background for a second round in which respondents, anonymously, were presented with the results of the main trends as found during the first round of intervention. Participants to the two rounds included CCUS adopters (industries), technology and infrastructure developers, policy makers & regional authorities, and research institutes.

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No **884418***

Table 1: Business Model Innovation framework elements ranking

Elements	Ranking	Observations from the focus group discussion
Customer value proposition	2.5	• Temporal dimension is important when considering relevance: importance of issues can change in later phases, e.g., green commodities might benefit from a premium price at present time but not in the future when green commodities become mainstream. • Note that some elements of the Business Model that depend on public policy or subsidies may be completely feasible/acceptable in the short term. However, in the long-term such incentives might lose their acceptance by industrial firms. • Willingness to pay a premium for CCU depends on what CCU replaces. • Industries need to observe both aims of global competitiveness and local European competitiveness while complying with European regulation. • Competition between CCS/CCU in the short vs long term: In the short term, CCS and CCU could compete for resources or prioritization due to finite resources (including funding). CCS could create a stable supply of CO2 for CCU in the future. CCS is an enhancer of CCU. • 'Grey' or 'green' CO2 captured may make a difference (e.g., green is for example waste converter). Distinguishing between 'grey' and 'green' CO2 captured is important. 'Grey' CO2 comes from industrial emissions, while 'green' CO2 is sourced from renewable or sustainable processes. This differentiation impacts the environmental impact and sustainability of CCU applications. • Intrinsically linked to the revenue model. There is a low value placed on this element from the industry – a solid revenue model irrespective of customer value is far more significant.
Customer segment	4	• Focus of industry is on the existing customer segments. • From a CCUS perspective – this element is of low importance. • Some niche cases are where customers are willing to absorb costs in a premium product. In general, complete reliance is not placed on this segment in the business models.
Revenue Model	4.5	• There is no project without a concrete revenue model and cost structure. The Resources and Customer Value Proposition are both linked to the Revenue Model in practice. • Participants highlighted differences between revenues from product sales through premium price part and funding from government (Resources) and distinction with cost structures. • Considering the risk of high costs from ETS (volatility of ETS price), Revenue Model is relevant for a CCUS business case. • In general, stakeholders perceive it as necessary to first enhance the viability of CCS projects, to then set up market conditions to develop CCU projects as a second step. • De-risking green electricity projects by CCU projects and avoiding costs of CO2 by CCS (based on the EU ETS) are the main strategies to define a cost structure that helps emitters to adopt CCUS. • A CCU project is perceived to lower the risk of green electricity projects due to the sharing costs potential and providing an alternative to the lack of agreements on green electricity projects. • From a market-oriented approach, additional sales of low-carbon commodities are a source of income for firms. However, they are foreseen to diminish their present premium value over time. In other words, low-

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No ***884418***

		carbon commodities might become mainstream in the future. Therefore, sales of low-carbon commodities in the future might have marginal returns (as additional income, thus CCS or CCU costs might be passed on to consumers). • Another source is the sales of captured CO_2 for utilisation purposes. However, this is an option perceived as primarily beneficial for chemical industries.
Cost structure	3.5	• Avoiding CO_2 costs is more important than avoiding energy costs. • For the steel industry, the cost of energy is likely to be the most significant driver in Europe.
Resources	4.5	• Financial managers are concerned with the temporality of finance support. One-off CAPEX and short-term OPEX support are likely not to be enough to completely absorb the costs of decarbonisation. • Internal financial resources are limited, particularly in the steel industry where profit margins are low and investment requirements are high.
Ownership	2.5	• Important for the industry to keep ownership of CO_2-capturing technologies on-site. Having control on the assets is preferred as it provides more control over uncertainty and liabilities. Proprietary innovations and learnings may be restricted. • However, the participants highlighted that the importance of owning CCUS-related infrastructure varies from one firm to another. Some firms may wish to have more control over industrial processes and related technologies adopted. In this sense, taking ownership of a CO_2 capture installation might be influenced by the specific operations of an industrial firm. • Emitters do not foresee anything on CO_2 accounting for CCU. For CCU to produce a product from CO_2, there is need to compare it to a reference product. Challenging to understand the benefits of CCU. • Both T&S providers and emitting firms prefer that the T&S parties keep the ownership of the transport and storage technologies, and related infrastructures and facilities. Issues related to third-party access to transport infrastructure are crucial. • Emitters' responsibility should stop 'at the gate'. Emitters do not foresee they will have storage liability. • Storage and transport require a long-term commitment; however, there is little appetite/responsibility for them. Even if economic incentives are high enough, the commitment to do CO_2 storage and having this long-term vision can be a barrier to engaging in CO_2 storage – upfront risk + need to operate the field for 10-20 years + legal requirement to look after it for another 10-20 years. This kind of setup is only interesting to major oil and gas players, but not even to smaller oil and gas players. However, many of the economic incentives are already there. There are other factors at play that act as a barrier to investment.
Ranking: 1 = not important; 2= low importance; 3 = medium; 4 = important; 5 = very important		

- **CCUS Business Models options.** Stakeholders participating in the workshop also ranked five Business Models for CCUS options based on answers to the question: ***Which of the CCUS business model options reflects best the participants' preference?*** (Table 2). **'Joint Venture' and 'Transport' CCUS Business Models received the highest preference.**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No ***884418***

Table 2: CCUS Business Model options: ranking stakeholder's preferences

CCUS Business Models	Preference	Observations by the stakeholders
Joint venture – Transport combination	Preferred Option	• A combination of the Joint Venture and Transport models is preferred. It is based on a partnership between an industrial firm(s) and external transport and storage provider firm(s). • A clear distinction between the Ownership of Capture and Transport/Storage is preferred (each provided by different parties). • The industrial firm is responsible for capturing CO2, and its related equipment and O&M costs. The industrial firm expects to generate revenues from CO2 sales and trading exceeding carbon permits in the market. This Business Model allows addressing one of the main concerns of industrial firms: it guarantees that captured CO2 is collected from industrial sites and transported to permanent storage. • A clear distinction of liabilities from capture, transport, and storage. The industrial company is liable for the operations of capturing CO2. Once CO2 is captured at industrial sites and placed 'at the gate', transport and storage firms come into the joint venture, as third parties. • Transport and storage firms cover costs of transport and storage equipment and their O&M. They charge a fixed fee for CO2 transport and storage to industrial firms. Transport and storage firms are responsible and liable for the transportation and/or storage part of the CCUS chain. • Regarding CO2 utilisation, CO2 users cover CO2 purchasing and utilisation costs, including O&M. • Stakeholders referred to the **Dutch model, which is a hybrid of JV and Transport**; the Aramis project is a JV example. • Industrial firms in the Netherlands are eligible for the SDE++ scheme, a Dutch Carbon Contract for Difference. SDE++ is one of the main public funding sources in the Netherlands to adopt inter alia CCUS. This instrument has a markup for covering transport and storage costs. Yet, transport and storage firms are currently not eligible for this instrument. There are expectations that in the future, transport and storage firms become eligible for the SDE++ scheme.
Joint Venture (JV)	Best Option	• A clear distinction between the Capture and Transport of CO2 (each provided by different parties). • Subsidies go to industrial firms (not to transport and storage) currently but tailoring them to transport and storage would be possible. • The Dutch SDE++ has a markup for transport and storage costs.
Transport	Second Best Option	• Stakeholders prefer a clear distinction between Capture and Transport of CO2 (each part of the value chain provided by different parties). • For example, in the Netherlands, industrial firms are eligible for the Dutch SDE++. Although this instrument has a markup for covering transport and storage costs, transport and storage firms are currently not eligible for this instrument. It might be that in the future, transport and storage firms become eligible for the SDE++.

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No **884418***

Operator	Least preferred option	• Stakeholders prefer a clear distinction between the Capture and Transport of CO2 parts in business models. Stakeholders prefer having process of the CCUS value chain provided by different parties.
Vertically Integrated	Least preferred option	• Creates a monopoly and leaves little room for negotiation from emitters. • Questions on whether the vertically integrated model works for European countries, an example is based on China.

- The participants suggested **a combination of a Joint Venture and Transport CCUS Business Models as having the most adoption potential for CCUS by industrial firms** (see models in Figures 2 and 3).
- The 'Operator' and 'Vertically Integrated' CCUS Business Models received the lowest preference of stakeholders.

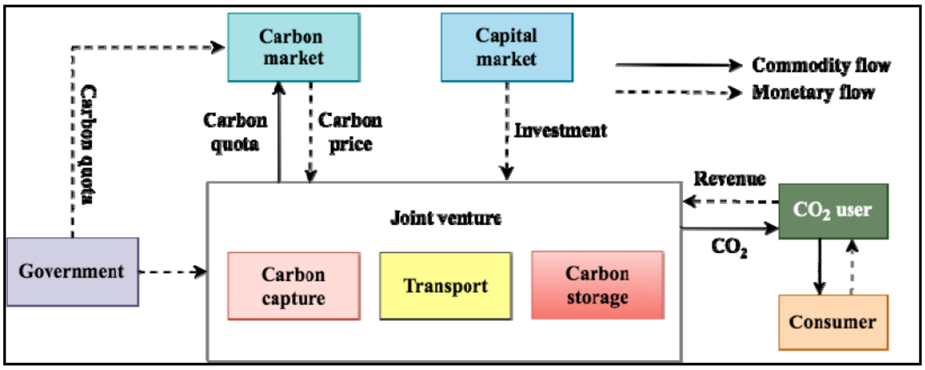

Figure 2: Joint Venture CCUS Business Model (Muslemani et al., 2020, p. 14).[2]

As shown in Figure 2, the Joint Venture CCUS Business Model is established through a collaboration between the industrial/power company and external consultants specializing in CO2 storage. This approach involves shared responsibilities. While the industrial company might bear the expenses and operation associated with CO2 capture, the tasks of transport and storage would be handled collaboratively. This would lead to a fairer allocation of both risks and returns.[3]

[2] Muslemani H.; Liang X.; Kaesehage K. and Wilson J. (2020) Business Models for Carbon Capture, Utilization and Storage Technologies in the Steel Sector: A Qualitative Multi-Method Study. Processes, 8, 576. https://doi.org/10.3390/pr8050576.

[3] Ibid.

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No **884418***

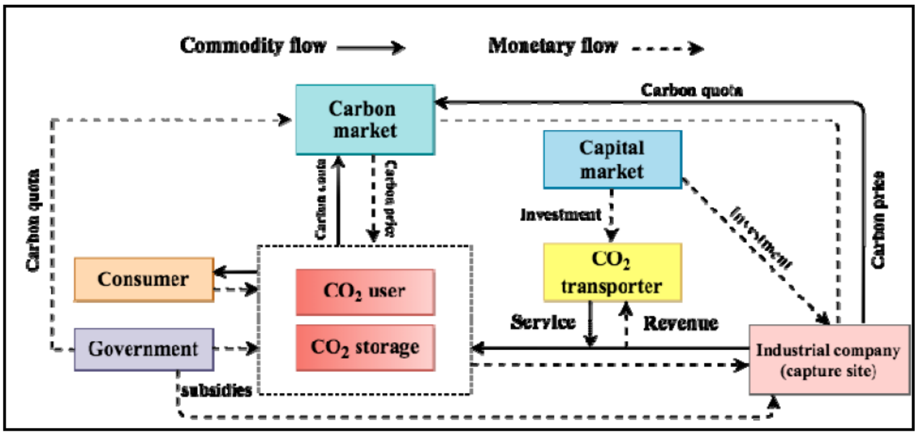

Figure 3: Transporter CCUS Business Model (Muslemani et al., 2020, p. 15).[4]

As illustrated in Figure 3, the Transporter CCUS Business Model entails that the transportation segment of the CCUS chain is solely overseen by a third party. Meanwhile, the task of capturing CO2, which encompasses the provision for capture equipment expenses and operational maintenance, falls under the jurisdiction of the industrial/power company. This entity not only generates revenue through the sale of CO2 and the trade of carbon credits, but also bears the responsibility for these operations. The transport company, on the other hand, is accountable for the costs related to transport equipment and its upkeep. For the CO2 transport service, a predetermined fee is charged, a value agreed upon in advance by all stakeholders. Lastly, the CO2 user assumes the costs associated with procuring CO2, as well as expenses tied to the utilization or storage equipment and their maintenance.[5]

[4] Ibid.
[5] Ibid.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No ***884418***

6. Public policies to support the CCUS business case

Without a level playing field and a business case, the industry will not invest in CCUS. Companies need to be provided with public support and equipped with policy incentives and policy certainty. Policy and decision-makers need to assess the extent to which policy instruments and incentives are necessary to ensure a successful takeoff of the CCUS value chain and its industrial clusters in the beginning.

To support business strategies and the transition to industrial decarbonisation, the following policy recommendations have been identified.

Table 3: Policy options along Elements of Business Models Innovation Framework

Business Model elements		**Policy options**
Customer value proposition	*Industrial firms offer low-carbon products to customers*	• Industrial firms could benefit from a **tax incentive** for providing low-carbon commodities or captured CO2 for utilisation (with an obligation, a 'stick policy effect'). • Moreover, a **demand-side management** approach could offer **tax incentives to customers** to purchase low-carbon commodities and captured CO2 for utilisation (with an obligation, 'a stick policy effect').
Customer segment	*Focus on existing customers*	• **Regulation, quotas or standards for minimum use** of low-carbon materials per specific industry might be an option (e.g., the building sector having a quota to utilize low-carbon materials).
	The willingness of customers to pay for a premium price	• **Public procurement** (helping to create new markets and premium prices by e.g., new buildings or new fleets by public entities and firms). • Industrial firms could benefit from a **tax incentive** for providing low-carbon commodities or captured CO2 for utilisation (with an obligation, 'a stick policy effect'). • **Tax incentives to customers** to purchase low-carbon commodities and captured CO2 for utilisation (with an obligation, 'a stick policy effect').
Revenue Model	*Additional sales of premium-price products*	• After the premium revenue from low-carbon commodities or captured CO2 for utilisation becomes marginal, industrial firms could be granted a **tax benefit** (VAT reduction or 0%).
	There is a need for a market for captured CO2 for utilisation.	• **Tax benefit** (VAT reduction or 0%).
	CCS projects need to enhance the viability of CCU projects	• CCS has benefitted from public incentives while CCU has been left to the market. CCU projects also need a stimulus (e.g., an **obligation quota** for sourcing production inputs by other industries from CO2 utilisation).
Cost structure	*To make green electricity projects more certain and to de-risk CCU projects.*	• After a market for methanol and other fuels for CO2 utilisation is established, an **obligation quota** for sourcing production inputs by industries from CO2 utilisation should be placed.
	Industrial firms have reduced emissions and	• If CCS is to be implemented as scheduled in the EU, guarantees for the energy-intensive industries need to be granted. Guarantees need to match obligations to

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No ***884418***

	therefore avoided some costs of CO2 (based on ETS) through implementing CCS.	capture CO2 with obligations to guarantee CO2 T&S provisioning. Having guarantees in place might help having CCUS technologies deployed, and CO2 emissions captured and reduced.
Resources	*Internal financial resources*	• Sales of low-carbon commodities and sales of CO2 for utilisation (**VAT reduction** or **VAT 0%**, and an **obligation quota** for sourcing production inputs by other industries from CO2 utilisation).
	External financial resources: innovation fund (EU) or State Aid.	• To fund additional costs to CCUS, including related supporting technologies (e.g., Green H2), **State Aid** is likely to continue being an option to further support CCUS and H2. • The **EU Innovation Fund** needs to become more accessible to the energy-intensive industries. Facilitation of procedures and assistance to obtain the Fund are desired.
	External financial resources (e.g., SDE++ for CCS OPEX in NL).	• To fund additional costs to CCUS adoption (e.g. additional funding to CAPEX) and related supporting technologies. For example, the SDE++ already supports CCUS and Green H2 as a supporting technology. • A clarification is missing on the possibility to use the SDE++ abroad (to address the cross-border nature of some clusters). For instance, the option to use the SDE++ for storage abroad (e.g., from Rotterdam to Northern lights in Norway or between the Netherlands and Belgium).
	External financial resources: Liability guarantees	• Each process provider should be **liable for its own process within the CCUS chain.**
Ownership	*Industrial firms own capturing plants*	• **Having access to available** (on time and specific qualities) and **affordable capture technologies** for industrial firms is necessary.
	External parties such as Transport and Storage firms own transport and storage facilities for CCS	• This premise needs to become clear in the **Joint Venture/Transport** contract which states obligations, rights, and liability of each specific party involved in the chain of CCUS.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No ***884418***

7. Public awareness and societal acceptance of CCUS

From a holistic perspective, trust between industry, government, and society is deemed a prerequisite for a carbon management market. However, the ways to incentivise CCUS in Europe from a business, policy, and societally acceptable approach are often overlooked. The C⁴U Project explores current practices of social acceptance and levels of policy instrumentation to incentivise CCUS in a societally acceptable manner[6]. Figure 1 visualises our conceptual model on interaction between stakeholders with regard to the implementation of CCUS.

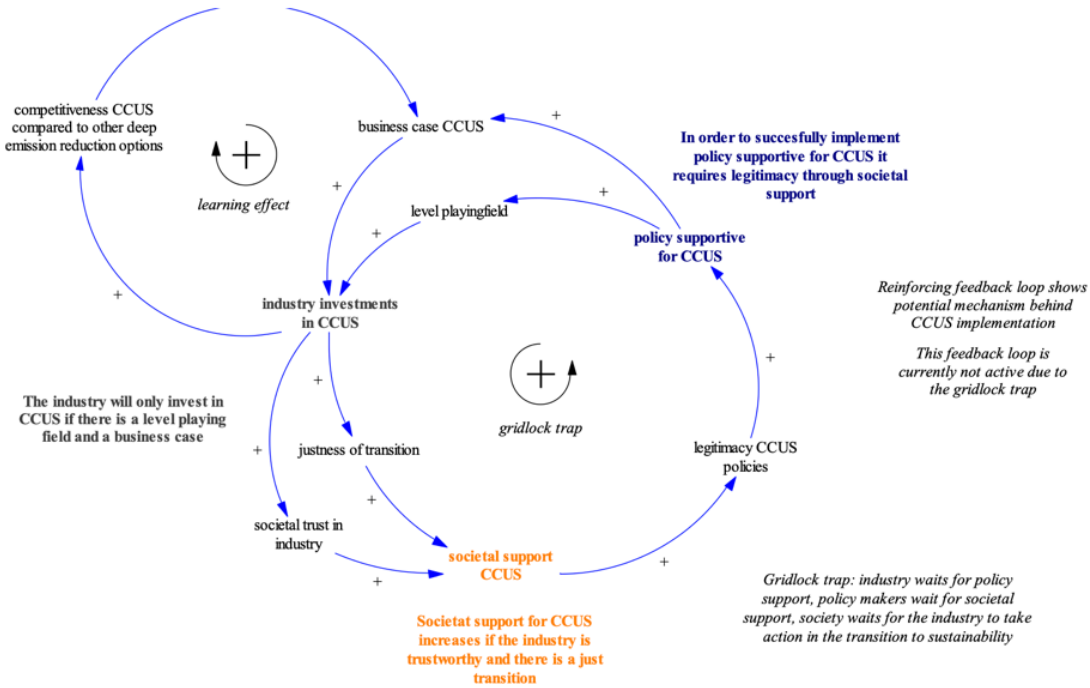

Figure 41: Conceptual model on interaction between stakeholders with regard to the implementation of CCUS

The holistic perspective shows how business, policy, and societal aspects cannot be addressed in isolation because they are inherently intertwined. Without a level playing field and a business case, the industry will not invest in CCUS. The level playing field and business case can only be achieved with effective policies, and these policies can only be implemented if they have enough support. This support depends on the perceived fairness and trustworthiness of industry. Only if citizens have enough trust in industry and government will they support the policies that are necessary for bringing about an effective carbon management market.

To support positive interaction among stakeholders as shown in Figure 1, the following policy recommendations are suggested.

[6] As a case study, the C⁴U Project embarks on options to incentivise societal acceptance of CCUS in industrial clusters, particularly in the North Sea Port (NSP), which aims to take off as a CCUS hub in 2026.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No ***884418***

- **An early engagement with the public is key. Rather than addressing societal aspects after the finalisation of technological development or demonstration projects, CCUS requires early stakeholder engagement in order to foster societal support.**

  Foremost, stakeholder engagement should start at the project's outset and involve a two-way dialogue – as opposed to a one-sided channel, where stakeholders are informed after key project decisions have been made. Information should be communicated in an understandable and transparent manner (taking into consideration the varying level of awareness and knowledge gaps) and be made accessible by engaging both locally and nationally through various channels: education, media, science, and government. Trusted parties and community leaders (NGOs, scientists, respected locals) should be included, and their participation should be accessible and meaningful. Ultimately, CCUS requires a genuine and continuous process of stakeholder engagement.

- **Early engagement with (society's) risk perception is key for a successful just transition of energy intensive industries.** Literature reviewing CCS projects across the world and the EU has underlined that social acceptance and support of decarbonisation technologies mainly relate to the **perceptions of risks (justice or environmental)**[7] by local communities (inter alia).

- **Our research has showed that the leading predictor for social acceptance is the perceived risk of unequal distribution of burdens - versus the benefits of a just transition of energy-intensive industries for local communities.**

  The main **benefits** associated with the implementation of CCS are its contributions to climate change mitigation, job creation and investment in the local economy. In the North Sea Port industrial cluster, the relationship between industry and other parties appears constructive as there is collaboration between industry, NGOs, and governmental stakeholders in regard to the future of the region. Overall, **regions with previous experience with fossil fuel-based industry may result in less opposition to subsurface activities associated with CCS**.

  Our research also observed that environmental risk associated with the subsurface, such as **leakage of stored CO2,** was viewed as the most important burden. **Low public awareness and knowledge** negatively impact the perception of CCS projects. Overall, research has shown that people are mostly unfamiliar with CCS and its potential role in a sustainability transition. There is also a gap between the experts and the general public in terms of how CCUS risk is perceived.

  How these burdens and benefits are perceived (and shared) also depends on the local context. Economic contributions to the local economy may be seen as more or less relevant and dependent on diversification of the cluster. If there are positive ties with industry, benefits may be highlighted. Conversely, if there are perceived grievances, the burdens may be magnified.

- **Ensuring a just distribution of burdens and benefits is important. Our studies showed that a) Public participation needs to be timely; b) Information needs to be understandable and transparent; and c) Participation needs to be fair.**

  As part of a just distribution, polluting industries needs to take responsibility for emissions, including footing (part) of the bill. Benefits should be made visible and understandable: i.e., by communicating about emission reductions and job creation. Additionally, citizens should be

[7] Alongside with the characteristics of the project; the engagement process; actions of the stakeholders; characteristics of the community; and the socio-political context.

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No **884418***

empowered to have a fair share in benefits: for instance, benefits should be reflected in work conditions (e.g., good salaries and environmental conditions) and economic benefits should also flow back into general society (e.g., through community compensation).

CCS is also strongly associated with the fossil fuel-based industry, whose social license to operate is under pressure. As there are concerns about CCS being an end-of-pipe solution, rather than a fundamental decarbonisation technology, **it is key to make CCS part of a complete plan for the sustainability transition and to demonstrate that CCS applied to industries does not create carbon lock-in.** In that regard, **CCS should be considered as having value to maintain specific industries beyond 2050, as well as having potential future purposes such as negative emissions.** These benefits should be communicated to the public early and in a transparent manner. It is also crucial to be clear on alternatives to decarbonise hard-to-abate sectors, which in some cases may become more competitive.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No ***884418***

8. Publications list

As part of the C⁴U Project, the following studies have been published, among others:

de Kleijne K., Hanssen S.V., van Dinteren L., Huijbregts M.A.J., van Zelm R., and de Coninck H. (2022) Limits to Paris compatibility of CO2 capture and utilization. One Earth, 5 (2), pp. 168 – 185. https://doi.org/10.1016/j.oneear.2022.01.006

Ejeh, J. Yousef, A., Bugryniec, P. , Wilkes, M., Porter, R.T.J. Martynov, S., Mahgerefteh, H. and Brown, S. (2022) Perspectives on Future CCUS Infrastructure Design (November 8, 2022). Proceedings of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16) 23-24 Oct 2022, Available at SSRN: https://ssrn.com/abstract=4271511 or http://dx.doi.org/10.2139/ssrn.4271511

Fantini, M., P. Fleming, A. Shogenova, S. Martynov and M. Elkerbout (2021) Webinar: Reducing Industrial Carbon Emissions. Carbon capture, utilisation, and storage technologies. 24 Nov 2021. https://doi.org/10.5281/zenodo.5752574

Fantini, M., R. Porter, E. Catalanotti, S. Baltac; L. Lochner, P. Fleming, I. Mann (2021) Better Carbon Capture for Industrial Emissions - Enhancing CCUS in Europe in support of the Paris Agreement. 22 Nov 2021 https://zenodo.org/record/5718833#.YZyoLboo9EZ

Janipour, Z. et al. (forthcoming). Business model framework to adoption of CCUS in energy intensive industrial clusters

Janipour, Z., Swennenhuis, F., Gooyert, V. de, & Coninck, H. de. (2021). Understanding contrasting narratives on carbon dioxide capture and storage for Dutch industry using system dynamics. International Journal of Greenhouse Gas Control, 105, 103235, https://doi.org/10.1016/j.ijggc.2020.103235

Swennenhuis, F., de Gooyert, V. (forthcoming 2023). Societal dynamics of carbon dioxide capture and storage in an industrial cluster.

Swennenhuis, F., de Gooyert, V., & de Coninck, H. (2022). Towards a CO2-neutral steel industry: Justice aspects of CO2 capture and storage, biomass- and green hydrogen-based emission reductions. Energy Research & Social Science, 88, 102598, https://doi.org/10.1016/j.erss.2022.102598

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No ***884418***