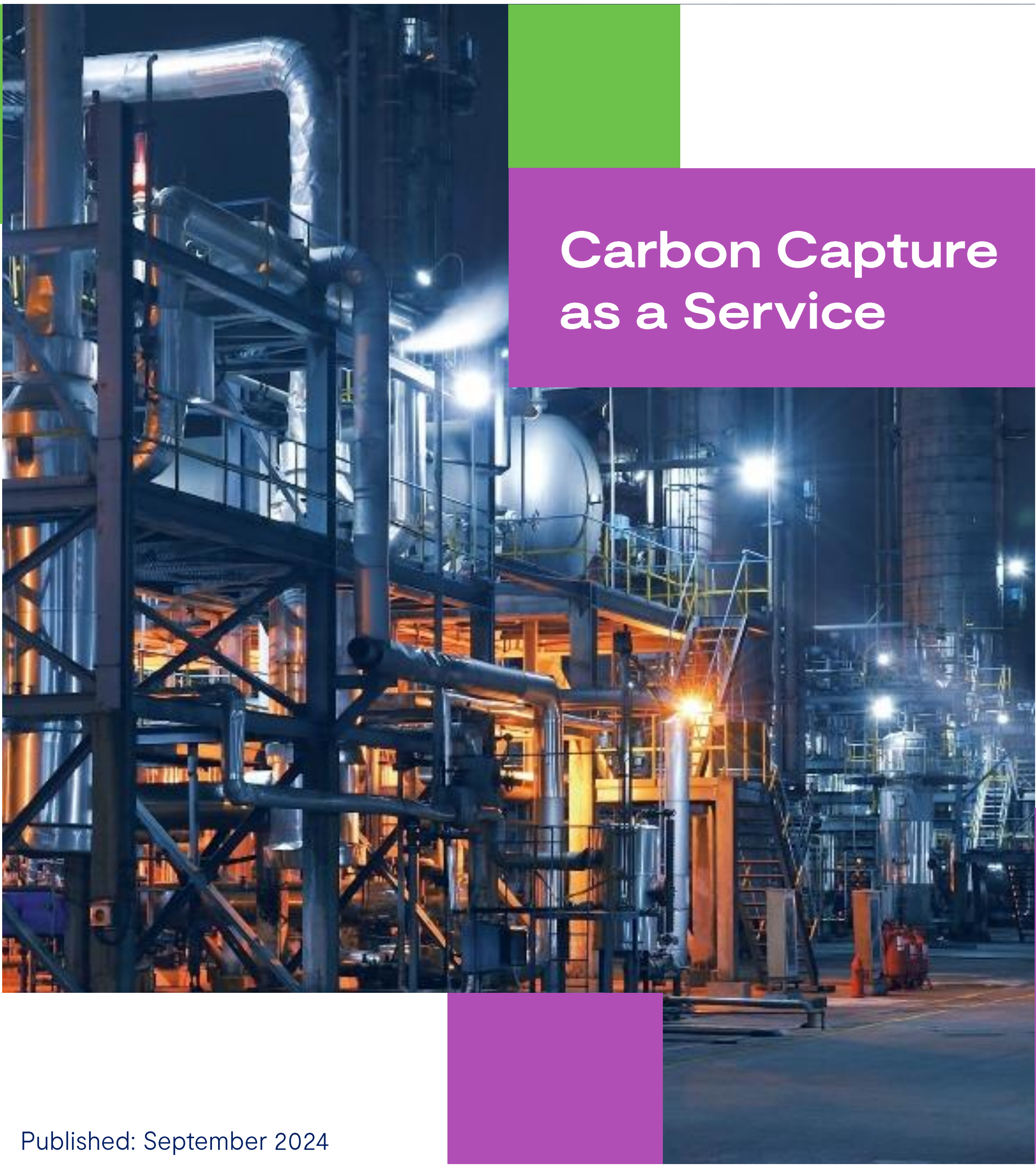
This report was commissioned by the Industrial Decarbonisation Challenge

Delivered by Innovate UK

Industrial Decarbonisation



Carbon Capture as a Service

Published: September 2024

DISCLAIMER

Executive Summary

As the UK advances towards its legal commitment to net zero CO_2 emissions by 2050, decarbonising industry - which accounts for 14% of total greenhouse gas emissions - is critical. With a clear strategic commitment to carbon capture, utilisation and storage (CCUS) from government, these technologies feature heavily in the decarbonisation strategy of the industrial clusters that will pioneer their adoption. However, there are industrial emitters within these clusters that need to capture carbon to achieve decarbonisation, but for whom there are significant barriers in adopting and operating these technologies.

Carbon capture as a service (CaaS) could offer a decarbonisation pathway for such emitters who either lack the scale for economically viable point source capture, or the expertise to implement and operate a plant. The CaaS market is still emerging and lacks clarity; necessitating a deeper understanding of the key challenges and feasible implementation pathways to support industrial arrangements and inform policy makers.

UKRI commissioned this study, as part of the Industrial Decarbonisation Challenge, to better understand the current CaaS landscape and explore the pathways for developing a thriving market. The study set out to:

- Gain an understanding of the feasible pathways for the deployment of CaaS for industrial emitters in the UK.
- Explore components of the business case for carbon capture service providers.
- Understand the type and scale of emitters suited to access the service.
- Clarify the roles and responsibilities of each party involved with carbon capture services.

Through review of existing studies and targeted engagement with industrial cluster representatives, the study has identified seven insights from which corresponding recommendations have been drawn:

1) Complex Cross Chain Integration Requires Direct Support:
The deployment context of each prospective CaaS system is unique and comes with distinct technical and commercial integration challenges that intensify with system complexity. Formalising support to enable cohesion across system interfaces can de-risk this process.

Recommendation 1:
Accommodation for an 'aggregator' in business model guidance is advised. Where possible, guidance should also support emitters in identifying a suitable aggregator or vice versa. The relevant CCUS guidance should also be adapted to consider this role.

2) Consistent Guidance Across the CCUS Value Chain:
CaaS relies on integration with a reliable wider system which has the awareness to accommodate it.

Recommendation 2:
Business model guidance for CaaS should closely align to existing established CCUS guidance. Successful implementation of CaaS will rely upon the wider CCUS system, therefore it is critical to ensure that any CaaS business model guidance conforms to, and doesn't contradict with, established CCUS guidance.

3) Emitter Location Impacts Ease of Participation:

The proximity of emitters to each other, as well as to shared infrastructure, significantly affects the complexity and cost of CaaS.

Recommendation 3:
Provide clear business model guidance which clarifies both how, and to what extent, the access gap between emitters via infrastructure developments and funding might be bridged.

4) Small Emitters Require Additional Incentives:

By reducing the operational costs associated with participating in carbon capture, CaaS can provide a pathway for smaller emitters to decarbonise. However, existing financial incentives and structures, primarily the UK Emissions Trading Scheme (ETS) market, do not adequately include these small emitters.

Recommendation 4:
Options to better accommodate small emitters could potentially include revisions to the UK ETS or the introduction of a separate scheme specifically designed to increase participation from this group. Additionally, support the development of micro-networks to further assist small emitters.

5) Interacting with the International CaaS Market:

The development of the international CaaS market will significantly influence the UK market, with ongoing competition for skills, resources and customers across the value chain.

Recommendation 5:
Business model guidance should focus on creating the conditions for a thriving UK CaaS market that embraces and integrates parallel international developments.

6) Risk Allocation Between Stakeholders:

A considered and well-balanced assignment of risk in a future CaaS system is important to satisfy the needs of all stakeholders and ensure their participation.

Recommendation 6:
Stipulation from Government of the boundaries of responsibility within the system and ensuring they are clearly signposted would support well-balanced assignment of risk.

7) Attracting Essential Investment for CaaS:

CaaS has many characteristics of a high-risk investment profile. To attract the necessary investment to realise CaaS, financers require support in understanding the business case before they commit.

Recommendation 7:
Develop credible and realistic guidance through collaboration with financial experts. Additionally, consider implementing a subsidy mechanism to offset high upfront costs and create a more attractive profile.

Contents

1 Introduction

This study, commissioned by UKRI as part of the Industrial Decarbonisation Challenge (IDC), investigates the potential for developing Carbon Capture as a Service (CaaS). Its primary objective is to examine how a future CaaS market could be leveraged to support industrial decarbonisation within the UK through identifying the critical development pathways.

1.1 Background context

UK Decarbonisation Context

The UK has committed to a legally binding target of achieving net zero CO_2 emissions by 2050. Industrial emissions currently contribute 14% of the UK's total greenhouse gas (GHG) emissions. To expedite industrial decarbonisation, the Industrial Decarbonisation Challenge has supported six industrial clusters (as shown in Figure 1), in establishing tailored decarbonisation strategies, outlined within the UK Government's Industrial decarbonisation strategy [2]. The October 2023 report, "Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation" by UKRI [3], outlines these strategies and underscores the vital role of carbon capture, usage, and storage (CCUS) in achieving decarbonisation goals.

UK Carbon Capture Development

In 2020, the (then) UK government published the Ten Point Plan for a Green Industrial Revolution [4], with a commitment to CCUS by investing up to £1 billion in areas such as the industrial clusters. The ambition is to capture 20-30Mt of carbon dioxide a year by 2030, with two clusters operating CCUS technologies by the mid-2020s [5]. Following this, the Cluster Sequencing Process was launched with "Track 1" cluster projects selected for initial funding [6]. This sequencing process has also been expanded to include the development of "Track 2" clusters, aiming to build up the momentum developed during Tack 1.

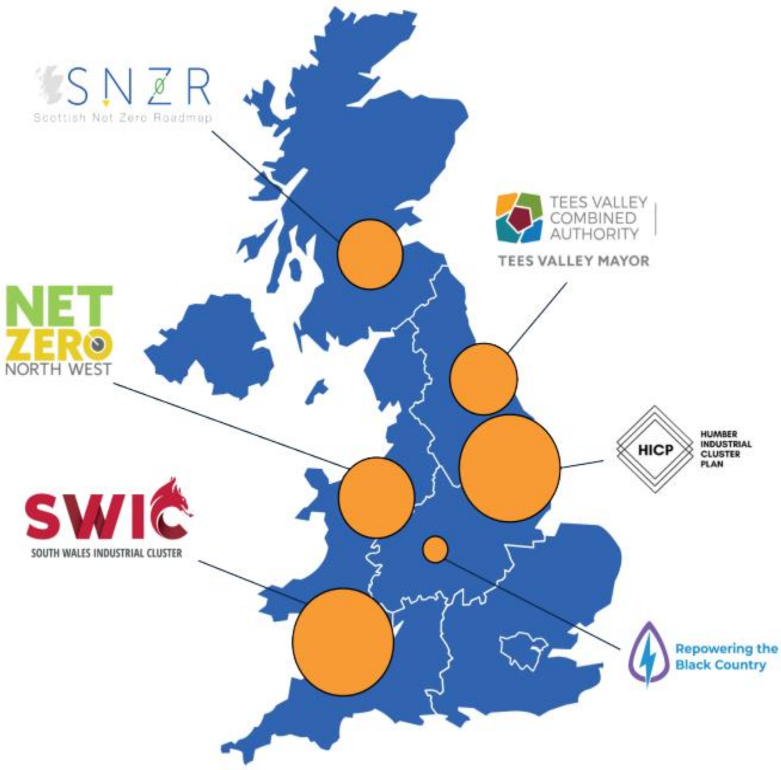


Figure 1: Overview of the Industrial Clusters and associated emissions as reported in decarbonisation plans.

1.2 Scope of study

The scope of this study is to consider the challenge of CaaS, exploring it as a concept, its barriers, drivers and its potential implementation in industry.

CaaS Within UK Decarbonisation

The Department of Energy Security and Net Zero (DESNZ) has released a number of updates [7] to the CCUS business models to provide guidance and support the Track 1 deployment projects within IDC funded industrial clusters, including updates specifically referencing transport and storage (T&S). Guidance on CaaS has not yet been issued.

Capture "As-a-Service"

The value proposition for CaaS is to enable the UK's CCUS decarbonisation plans through:

- Providing a decarbonisation mechanism for emitters who are perhaps not willing or able to take on the complexities of CCS for themselves, for reasons which might include technical capability, company size etc.
- Creating efficiencies based on aggregation and economy of scale.
- Introducing alternative options for decarbonising sites outside of the major clusters, where access to the main T&S connections from an individual site may be unviable.

The current understanding of CaaS and its implications remains limited. In order to fully grasp the potential of CaaS, and its integration within broader CCUS advancements, it is essential first to consider the wider context of traditional "as a service" models.

Developing "Capture as a Service" Models

"As a Service" models typically arise from companies extracting additional value from well-established products, assets or infrastructure. Examples of this include Rolls-Royce's "Power-by-the-Hour" [8], Airbnb or Amazon Web-Services (AWS). In these examples, companies create opportunities from their liabilities, by for example extracting value from necessary maintenance, idle assets or an abundance of resources.

CaaS differs from other "as-a-Service" models in that carbon capture is not a well-established technology or product. With CaaS, carbon capture has arisen from a specific regulatory need (i.e., to meet net-zero targets) rather than an ability to make profit within current markets.

Against a backdrop of carbon capture development, CaaS aims to provide certain emitters with the ability to decarbonise, such as those that:

- Can't afford the upfront capital expenditure (CapEx) required to invest in their own carbon capture plant;
- Don't have the in-house experience to operate their own carbon capture plant;
- Lack enthusiasm for venturing into the service for any other reason.

1.3 Purpose & Structure of this Report

This report seeks to advance current understanding of CaaS, and its potential to function within the UK decarbonisation market, and to:

- Gain an understanding of the range of feasible pathways for the deployment of CaaS for industrial emitters in the UK, and how these might support emitters to get involved.
- Explore components of the business case for carbon capture service providers.
- Understand the type and scale of emitters suited to access the service.
- Clarify the roles and responsibilities of each party involved with carbon capture services.

This approach begins by first defining a future CaaS system to serve as a frame of reference. It also focusses on identifying the necessary stakeholders to support the functions of a CaaS system, and the opportunities and barriers within the market.

Given the uncertainty surrounding possible CaaS deployment scenarios, flexible deployment pathways have been outlined to aid decision makers in understanding how to support the future roll-out of CaaS. From this, seven whole-landscape insights are drawn to help industry stakeholders understand interactions across the CaaS landscape.

This report was created through liaising with representatives from across the industrial clusters to help shape the insights and recommendations. It acts as a baseline for providing an initial view which will need to be consolidated by further, targeted studies to support the development of formal guidance. Specific engagement should be sought with capture plant providers, islanded emitters, financial regulators, safety specialists, storage providers and academia.

2 Exploring a future CaaS market

To understand the potential development of a future CaaS market, it is essential to first define the boundaries of what constitutes the system of interest, identify the stakeholders involved, and examine the broader infrastructure it relies on and interacts with.

In this section, we first define a baseline CaaS system that can be used as a point of reference for this report. A future CaaS value chain is outlined in Section 2.2, exploring how CaaS may interact within the wider carbon capture market, with functional descriptions of each stakeholder provided in Section 2.3. Key stages of the value chain are explored in Sections 2.4 through to 2.6, providing discussion on the emission system, transportation and finally CO_2 Sequestration. Section 2 concludes with some discussion on the future governance requirement and the role of Government in a future CaaS market.

2.1 Defining the CaaS System

Fundamentally, the objective of a carbon capture plant is to process emissions and remove the CO_2. This is achieved through specialist plant which is designed to meet the specific operational conditions of the emissions. In the case of a "traditional" CCUS value chain, large emitters[1] - such as owners of large-scale process plant – may possess the in-house capability to design and operate such plant. However, smaller emitters are likely to require additional support.

CaaS provides a route to decarbonisation for smaller emitters who lack the necessary capability in design, construction, operation and/or management of a bespoke carbon capture plant.

The function of the CaaS system is to provide the necessary competencies to facilitate CaaS. Currently, due to its nascent nature, the overall structure of this system – particularly the type of organisation fulfilling each role - is not yet defined and this report considers some of the options.

For the purposes of this report, CaaS has been defined as:
"The provision of Carbon Dioxide capture and removal on behalf of industrial emitter(s) for onward storage (or usage)."

Roles within a CaaS System

Within current CCUS development schemes, the owner of the plant (the emitter) takes on multiple roles which allow them to control the impact of capture plants on their upstream processes. An Engineer, Procure, Construct (EPC) contract may be placed to support this; the plant owner retains the ownership of the plant through construction and operation.

CaaS differs from conventional CCUS in that the following activities need to be undertaken, but they can be done by one or more third-parties:

[1] Emitting more than 25,000 tonnes CO_2 equivalent per year

- **Technology Provider** - Provides the carbon capture technology.
- **Financer** - Provides funding for the required investments.
- **Operator** - Operates, maintains and repairs the carbon capture technology whilst in operation.
- **EPC Company** - Designs and builds the carbon capture plant, including any necessary infrastructure.

In an emerging market, there is scope for entities to take on multiple roles.

For example, technology providers may seek to ensure they are also responsible for operation of the plant, (possibly to enable a more consistent stream of revenue). Close relationships may also be forged with engineering, procurement and construction (EPC) companies as these entities gain expertise in installing specific technologies.

The entities who may act as a financier(s) are likely to vary widely and by emitter. The investment risk associated with differing CaaS configurations is also variable (i.e., more complex configurations may have a higher financial risk).

System Dependencies

Within the system, there are a number of interdependencies for both upstream and downstream stakeholders. These dependencies present barriers such as:

- **Assurance of Supply:** The CaaS system is reliant on continued supply from emitters to optimise the operation of the plant. Based upon current T&S Network Code [9], there is a need to meet a relatively high mass flow continuous supply of CO_2.
- **Contract Lengths:** Current CCUS contract lengths leave little room for flexibility within an uncertain market. There are questions over how to guarantee certainty of ROI when emitters must guarantee continued business (and hence production of CO_2) over extended timeframes (e.g. 15 years).
- **Cross-Chain Risk:** Finally, there is scant understanding of the accountability of cross-chain risk. In particular, this relates to how consent limits – regulatory permits for combustion plants- are defined and capped across the CaaS system, and who takes accountability for faults.

Insight #1: The deployment context of each prospective CaaS system is unique and comes with distinct technical and commercial integration challenges that intensify with system complexity.

2.2 General Future CaaS System Arrangements

Figure 2 illustrates how a CaaS interfaces with the wider system of interest in a carbon capture market.

The green connections indicate the flow of carbon, with yellow indicating a fee and blue indicating the exchange of carbon credits. The figure includes the key stakeholders using symbols which are defined in Section 2.3 The primary function envisaged for an aggregator (see Section 2.3) at each stage (capture, transport, end-use) of the CaaS value chain is also detailed.
Note that the system presented in the schematic is intended to serve as a point of reference and actual systems could vary significantly in their arrangements and stakeholders.

Insight #2: CaaS relies on integration with a reliable wider system which has the awareness to accommodate it.

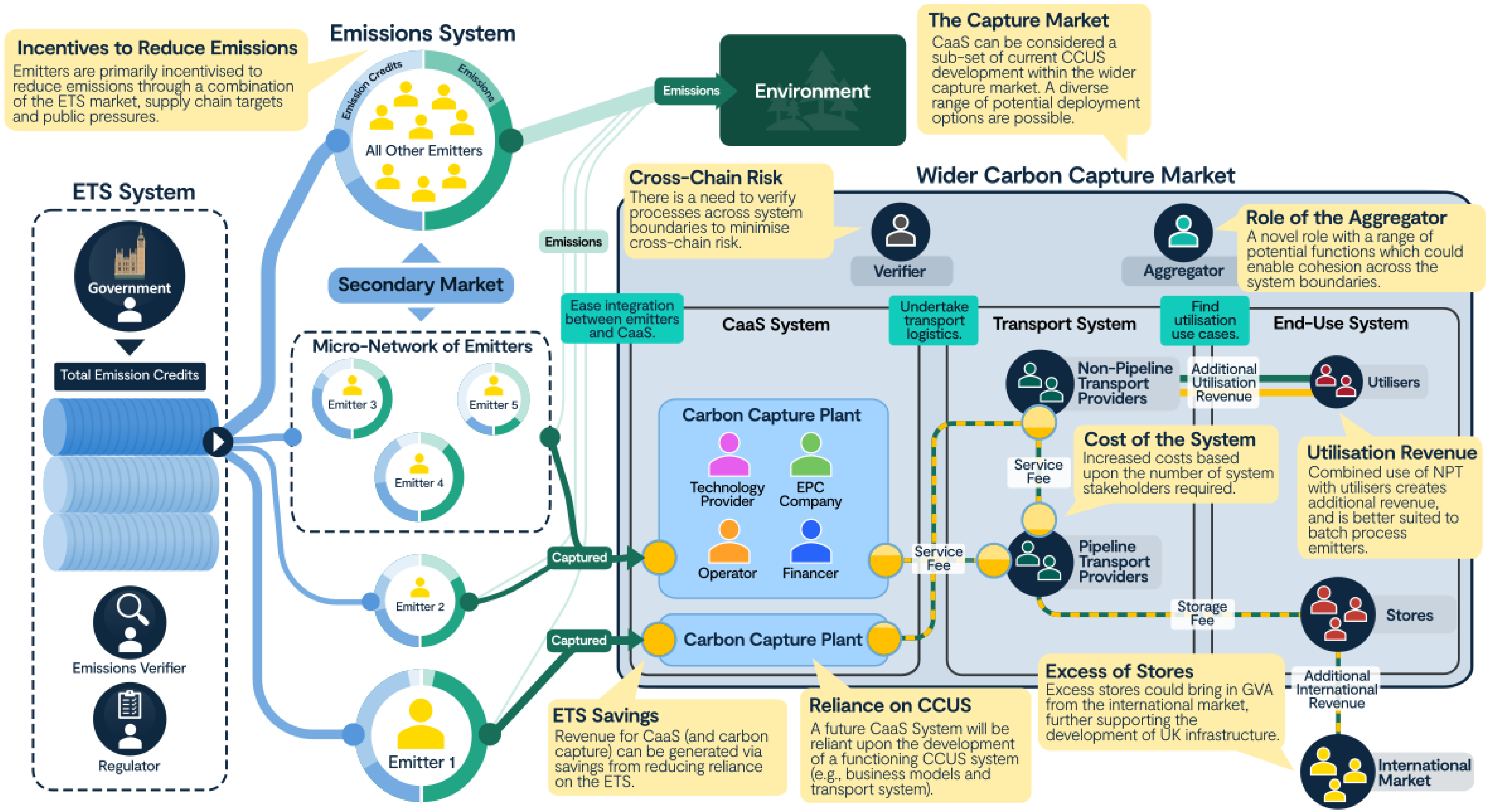


Figure 2: Arrangements for a Potential Future CaaS System

2.3 Key Stakeholders

Table 1 defines various stakeholder roles within the context of the CaaS system, as well as the component subsystems. These terms are used throughout the rest of the report with specific reference to the functional descriptions. Note that a real system may include additional stakeholders beyond these outlined functions.

Note: There is a need for wider engagement with the wider value chain to better inform the way ahead.

Table 1: Key CaaS System Stakeholders and Functional Definitions

System	Stakeholder	Functional Description
Emission	Emitter	Emits carbon dioxide which is required to be captured.
CaaS	Technology Provider	Provides the carbon capture technology.
	Financer	Provides funding for the required investments.
	Operator	Operates, maintains and repairs the carbon capture technology whilst in operation.
	EPC Company	Designs and builds the carbon capture plant, including any necessary infrastructure.
Transport	Transport Provider	Provides transport of capture carbon dioxide to its end-use.
	Aggregator	A novel role with a range of potential functions which could enable cohesion across the system boundaries[2].
End-Use System	Utiliser	Has a use case for emitted carbon dioxide beyond storage.
	Storage Provider	Owns and maintains the long-term storage site of the captured carbon.
Governance	Verifier	Verifies the processes across the system (e.g., levels of carbon dioxide emitted by emitters).
	Government	Provides governing systems which may enable CaaS (such as the ETS market).

[2] Note that the aggregator forms part of the 'transport' subsystem for the purpose of this report but has significant relevance across the whole value chain.

Role of Aggregators

Because of the operational dependencies which exist across the CaaS value chain, there is a potential role for an 'aggregator' to be involved in the activities needed to deliver CaaS on behalf of the various CO_2 emitters and transport& storage providers.

A current lack of understanding of the cross-chain risk and its impacts across the system is preventing overall system development. The aggregator role could reduce this risk, ensuring responsibility for the whole systems function.

An aggregator role could be taken by a stakeholder within a project or be an independent role. If independent, this adds an additional stakeholder and may increase costs, although this should be balanced against system benefits, which may be significant.

Table 2 presents the potential opportunity for aggregator support to address a need within each subsystem. The aggregator may also adopt a role in sequestration or utilisation, but this is outside the scope of this study.

Table 2: Dependencies, Barriers and Opportunities associated with Aggregators for each Subsystem

System	Dependency or Barrier	Opportunity for Aggregator Support
Emission System	▪ Lack of understanding of the wider CCUS market creates barriers to entry compared to other decarbonisation options.	▪ Aggregator brings local emitters together into Micro-Networks to increase technical and commercial feasibility.
CaaS System	▪ Variety of potential CaaS system arrangements and stakeholders' apprehension to enter market.	▪ Aggregator brings technical knowledge of CCUS & local industries to enable the technical co-ordination of CaaS projects.
Transport System	▪ Pipeline transport requires a high continuous supply of carbon dioxide. ▪ Nascent Non-Pipeline Transport (NPT) market, further discussed in Section 2.5, is likely to have large upfront logistical challenges understanding value for money and development pathways.	▪ Aggregator acts as a single source of liaison for pipeline transport, easing the technical and commercial interface associated with the delivery of a continuous supply of CO_2. ▪ Aggregator brings experience of local NPT developments to ensure value for money and reduces logistical burden on upstream stakeholders.

2.4 Emissions System

The main interest of emitters is to be able to continue to operate their plants and processes, whilst becoming compliant with Net Zero. Participation in CaaS should enable this by providing a decarbonisation route.

This section considers the attributes of emitters that can influence potential participation in CaaS. Three attributes are discussed:

- **Geographical Location** which relates to ease of access to T&S services.
- **Emitter size** which defines categorisation within the UK ETS market (e.g., small and ultra-small emitters) [10], and the relative volume of their emissions.
- **Emitter type** relates to the products and processes taking place at emitter locations and is used to define regulated activities within the scope of the ETS.

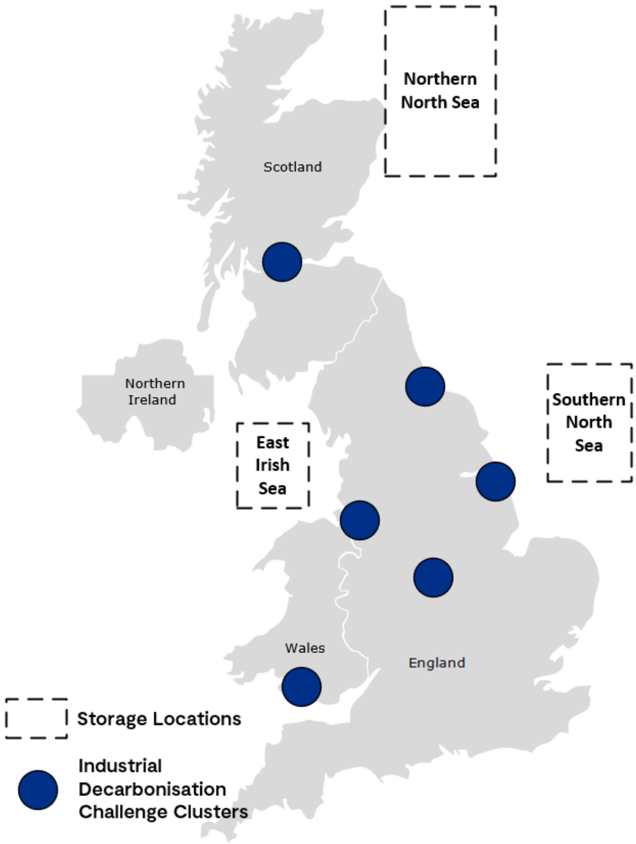


Figure 3: Location of Potential CO_2 Storage Facilities in reference to UK Industrial Clusters.

Geographical Location

The relative density of emitters within a cluster will influence potential CaaS configurations; some clusters such as Teesside are dense and radial whereas other clusters, such as South Wales, are more spread out. The proximity of emitters to suitable stores (initial storage sites being developed as part of the CCUS Cluster Sequencing Process [6] are highlighted in Figure 3) and proposed CCUS infrastructure, are also important to consider.

Insight #3: The proximity of emitters to each other, as well as to shared infrastructure, significantly affects the complexity and cost of CaaS.

Emitters which are not co-located with other emitters or nearby to planned CO_2 pipelines, face challenges to access transport options. In this regard, development of additional pipelines, or of non-pipeline transport (NPT), of CO_2 will be crucial for their entry within a CaaS market.

In general, emitters which are not located in the major industrial clusters may struggle to access onshore pipeline transport. Well-defined CaaS solutions which consider this could provide a decarbonisation route for these emitters.

Size of Emitters

Emitters which are categorised as small[3] or ultra-small[4], are not subject to emission tax (as defined by the ETS) and are motivated to decarbonise through other public and market pressures (including international regulations, such as in the EU [11]).

Appetite for participation and responsibility may vary by emitter site. Larger emitters may have a greater appetite for management (or ownership) of portions of the value chain.

> Insight #4: Through managing the costs associated with operating (and owning) carbon capture facilities, CaaS can enable smaller emitters to decarbonise. However, existing financial incentives and structures do not adequately include these small emitters.

Types of Emitters

Emitters vary by process category (batch or continuous) as well as by the composition of the flue gas they produce (notably the concentration of CO_2 within the flue as well as the presence of impurities). Capture plants typically require a continuous and steady supply of CO_2 to operate effectively and so emitters who operate batch may require configuration support. The CO_2 concentrations at the input of the capture plant impacts the efficiency of the capture process; with lower concentrations of CO_2 in flue gas leading to a less cost-effective process.

It is also important to acknowledge the interaction between capture and upstream processes, with some degree of expertise being required across both operations at the interface. For very specialised industries, the pool of resources with sufficient in-house knowledge could present a limitation to carbon capture adoption. One way in which some of these issues could be addresses is by developing a 'micro-network' of emitters, which refers to a collection of small emitters which come together and participate in the same CaaS system.

Further research into micro-networks or other novel configurations could present a potential solution through aggregation and motivate smaller emitters to participate in CaaS.

[3] Emits less than 25,000 tonnes CO_2 equivalent per year

[4] Emits less than 2,500 tonnes CO_2 equivalent per year

2.5 Transport System

The function of the transport system is to move the captured CO_2 from emitters to permanent storage offshore (with utilisation of the CO_2 being an option in some cases). Hence, the growth of this system will be dependent on both the location and types of emitters which utilise a future CaaS system.

Types of Transport

Methods of transport can be split into pipeline, or non-pipeline transport (NPT). Currently, the development of pipeline transport is at an advanced stage compared to NPT. Notably, pipeline transport is being developed in the Track 1 cluster projects. NPT is at an earlier stage of development, with the government recently launching a call for evidence on its development [12]. Both transport options come with their own opportunities and challenges regarding CaaS deployment.

Pipeline Transport

Limitations which may impact CaaS include:

- Transport providers generally only seek to liaise with a single point of contact when requesting permission to connect to a pipeline.
- There are technical compatibility requirements which may introduce constraints in managing pressure and concentration of carbon dioxide.

Pipeline transport presents opportunities owing to its relative maturity and accessibility for the largest and favourably positioned emitters. However, these opportunities are currently limited to emitters which can feasibly connect to these pipelines.

Non-Pipeline Transport

The government call for evidence is focused on progressing understanding of CO_2 transport via road, rail, barge and/or shipping. Key challenges to NPT include:

- The addition of "intermodal facilities" (such as intermittent compression and storage) before reaching final offshore storage sites;
- Ensuring that safety can be demonstrated in the context of planning and permitting;
- Increased complexity of the supply chain and required logistics to operate.

Despite this, NPT also provides a number of opportunities to enabling CaaS, such as:

- The potential for increased competition to reduce costs;
- Increased flexibility and diversity of transport options and routes;
- The potential to co-ordinate with a variety of emitters more easily.

These opportunities in combination present an opportunity for optimisation across the CaaS value chain e.g. the optimisation of variable CO_2 flows of multiple emitters.

The opportunities brought by NPT increase the ability for the CaaS system to target and enable the decarbonisation of smaller, dispersed emitters which don't have ease of access to the main pipelines. For this to function, advanced co-ordination at the interfaces is required.

2.6 CO_2 Sequestration

Sequestration can be achieved by permanent storage (offshore in depleted gas fields or saline aquifers) or, in a limited number of cases, can be utilised in the making of other products.

Although there are similarities in end-use systems, whether CaaS is present in the CCUS value chain or not, this aspect is important to consider as the promise of larger market opportunities is a key enabler for creating investable conditions for CaaS.

Storage

In the majority of cases, stores are the necessary final location of any captured carbon, ensuring released CO_2 can't reach the atmosphere and contribute to climate change. All other stakeholders across the value chain are dependent upon a storage location. Stores are highly geographically dependent, with 3 major storage regions across the UK:

- Southern North Sea;
- Central/ Northern North Sea; and,
- East Irish Sea.

With 70 billion tonnes of potential UK storage capacity, stores with excess capacity could also provide services to broader international markets, bringing Gross Value Added (GVA) to the UK economy. Early entry into a developing international business market could enable significant opportunities for the UK. Moreover, engagement with an internationally invested supply chain is a key enabler in a thriving future market.

Storage providers with excess capacity are well-placed (and should be encouraged) to interact with other stakeholders across the value chain. This allows for the development of close relationships between a storage and transport provider (or another stakeholder) which is conducive in increasing the rate of system development.

Utilisation

CO_2 utilisation can enable increased revenue streams across the value chain, and there is substantial innovation in this area. For example, Tata Chemical's CCU plant in Cheshire will create sodium bicarbonate from captured CO_2 [15].

Some CO_2 utilisation opportunities may provide an End-Use route for emitters which are categorised by their batch processes and which emit relatively small volumes of CO_2, although the current lack of utilisation use cases leading to permanent sequestration should be noted.

Insight #5: The development of the international CaaS market will significantly influence the UK market, with ongoing competition for skills, resources and customers across the value chain.

2.7 Governance System and Government

Any future CaaS market will require a clear and established governance framework that can provide the necessary processes and controls required for a market to develop. This governance should extend from early market definition, through to ongoing support across the value chain in the domestic market, as well as accommodating any international opportunities.

A key feature of this governance will be in the management of risk between individual stakeholders and functional subsystems. In the context of this report, and in the absence of alternative structures, **government** provisionally sits within the governance subsystem.

Assurance to Enter the CaaS Market

A successful CaaS system will rely on commitment from stakeholders across the value chain. A lack of commitment could be attributed to a number of factors, including:

- High up-front costs;
- Reliance on downstream infrastructure; and,
- A lack of certainty around carbon pricing and regulation.

A governance subsystem could support the early provision of straightforward and understandable regulation to promote stakeholder confidence. In particular, **government** could take decisive action around supporting infrastructure to send signals which would increase confidence around future market development, building momentum from the CCUS Sequencing Programme, through the issue of new guidance.

> Insight #6: A considered and well-balanced assignment of risk in a future CaaS system is important to satisfy the needs of all stakeholders and ensure their participation.

Ongoing Market Stimulation

Governance structures can act as levers to promote innovation and competition, whilst also maintaining control by considering the whole system (including elements like non-pipeline transport and utilisation). Novel contracting and financial levers - such as accelerated depreciation methodologies or aggregating incomes – may be considerations; specialist financial consultation is recommended.

Supporting International Interactions

The governance subsystem could embed the international context in policy forming to allow compatibility and competition. The UK Emissions Trading Scheme (described in Appendix A) is mandatory for certain businesses operating in the UK and constitutes a key market force. However, it should be noted that carbon credits are a commodity which can also be traded internationally. As such, any guarantees provided **by government** would have to defend against potentially superior profitability in a voluntary market.

Value Chain Assurance & Verification

Emitters which participate within the UK's ETS scheme must have their emissions verified by an accredited UK ETS verifier [10] (see Appendix A for further details). In future, this may need to be expanded to consider emissions across a wider value chain (i.e. cross-chain verification), with a clear need to define the allocation of risk at system boundary. Industry expressed an appetite for this to be led by government.

Verification, control and assurance of processes at the system boundaries would strengthen the robustness of the overall value chain. In general, activities that sit best with government are categorised by their cross-cutting nature, leading to uncertainty around who is responsible for mitigating them.

Insight #7: CaaS has many characteristics of a high-risk investment profile. To attract the necessary investment to realise CaaS, financers will require support in understanding the business case before they commit.

3 Discussion of Insights and Recommendations

3.1 Insight #1 Complex Cross Chain Integration Requires Direct Support

The deployment context of each prospective CaaS system is unique and comes with distinct technical and commercial integration challenges that intensify with system complexity. Formalising support to enable cohesion across system interfaces can de-risk this process.

Insight

The boundaries between capture plants and either emitters or T&S providers are technically challenging and impose system constraints. Were an emitter to connect directly to a capture facility, this could place requirements on their flue gas, including but not limited to: pressure; temperature; flow rate; batch or continuous processing; carbon dioxide concentration.

CaaS creates more complex interfaces than other operations which adopt an "as a service" model (like waste disposal) as there is a feedback impact on the process, and process efficiency, of the core emitter operations. There are similar requirements for carbon transferring from capture plant to T&S infrastructure. These challenges are likely to increase based upon the required complexity of the system.

Discussion

From a skills perspective, there is a substantial degree of technical knowledge required of both the capture process and the interfacing processes of the emitters. Emitters seek assurance that participation in CaaS will not overtly compromise core operations and income stream (when compared to other decarbonisation options). Additionally (as referenced in Insight 6) the inherent interconnectedness of the CCUS value chain presents a 'stranded asset risk' which may be of particular concern to emitters who seek clarity around income loss should CaaS be unavailable for some reason. Within this report, the responsibility of this role has been assigned to the "aggregator". However, in such a novel system, some or all of its responsibilities could be fulfilled by other stakeholders.

An aggregator could provide wider functionality across the value chain acting, for example, as a distribution point for the CO_2 to multiple users or stores. An international example of this concept being developed is Kairos@C (see Case Study 6). This would also create some buffer should the emitter, capture plant, user or store encounter unplanned technical challenges or outages.

Recommendation

Acknowledgement of the criticality of cross-chain risk and the necessary responsibilities to mitigate this risk within business model guidance is advised.

This could be achieved through consultation with wider industry to understand if a novel aggregator role is necessary. These responsibilities could be distributed between stakeholders across the value chain. For example, industry could investigate the flue gas properties of their processes and provide this data to academia and developers to support the development of bespoke integration solutions. NPT providers could investigate local area logistics to aid the uptake of CaaS in areas with more widely distributed emitters.

3.2 Insight #2 Consistent Guidance Across the CCUS Value Chain

CaaS relies on integration with a reliable wider carbon capture system which has the awareness to accommodate it.

Insight

As discussed in Section 2, a CaaS system will provide the interface between emission and T&S systems. Commercial and operational arrangements between these entities (and potentially an aggregator if this role is required) must be developed and can grow from viable CCUS arrangements. Conflicting or incomplete guidance across the value chain would likely amplify the challenge of adopting CaaS; therefore, the timely development, and reliable performance of interfacing systems are clear enablers for CaaS.

Discussion

Business model guidance for CCUS and, specifically, for the provision of transport and storage already exists, with the notable omission of detail regarding CaaS being a key driver to this study. However, engagement with stakeholders indicated that the concept of CaaS was itself challenging to explain to those in the wider value chain, even with good awareness of existing guidance. This highlights a need for better dissemination of the CaaS concept throughout the value chain to enable existing and emerging guidance to be developed with consideration towards CaaS. The challenge is that the requirements CaaS places on these interfacing systems is not yet known, a feature which is detailed further in Insight 6.

Although aspects of how best to develop CaaS may not be confirmed for some time, it is important that the value chain creates the conditions to allow CaaS to thrive. This should naturally manifest through activities across the value chain (e.g. training, regulatory frameworks) as well as by leveraging guidance.

Recommendation

Business model guidance for CaaS should closely align to existing established CCUS guidance. Successful implementation of CaaS will rely upon the wider CCUS system, therefore it is critical to ensure that any CaaS business model guidance conforms to, and doesn't contradict with, established CCUS guidance.

Care should be taken to ensure that CaaS business model guidance does not contradict or supersede any of the terminology or arrangements described in the CCUS guidance, which should be treated as the 'parent' document. Specifically, it is recommended that CaaS guidance be authored as an appendix to the CCUS business model guidance and that compatibility in the following areas be addressed with care:

- **Language:** both the system and its stakeholders should be described consistent with a taxonomy being used to support this.
- **System Boundary Definitions:** these should be described with reference to the transfer of responsibility at this boundary being contained within the parent CCUS document.
- **Sequencing of Guidance Documentation:** ensuring that updates to parent documentation are made in line with the release of any CaaS documentation.
- **Hierarchy and Cross-referencing in Guidance Documentation.**

3.3 Insight #3 Emitter Location Impacts Participation

The proximity of emitters to each other, as well as to shared infrastructure, significantly influences the complexity (and therefore cost) of CaaS.

Insight

A prominent theme emerging from stakeholder engagement was the relationship between geographic factors and the ease of participation in CaaS, including:

- Position relative to other emitters;
- Position relative to transportation infrastructure;
- Availability of space and utilities;
- Proximity to a storage site;
- Proximity to a potential utilisation entity.

Discussion

Concerns over a 'level playing field' were raised by projects during stakeholder engagement; particularly by highly dispersed sites that are reliant on more complex (and potentially costly) arrangements to allow them to participate in CaaS.

If the dominant CaaS business model is driven by IDC funded clusters which have a favourable geography - and guidance is designed to this effect - then there is a perceived risk of clusters which have more widespread sites losing out on an opportunity to decarbonise and participate in the emergent market. This will need to be considered within the context of a wider industrial decarbonisation landscape, as some sites which rely upon CCUS (and potentially CaaS) to decarbonise may require extra support to do so.

Non-pipeline transport has the potential to unlock a wider range of CaaS emitters (as explored in Case Study 5b). NPT is perceived as being more challenging to support via business model guidance due to the increased configurability when compared against a pipeline.

The appetite for utilisation to be included as part of a future CCUS system was also a key source of discussion throughout engagement. This was heightened among dispersed sites or emitters geographically far from storage sites; however, sequestration of CO_2 remains the priority of CCS business model guidance.

Recommendation

Provide clear business model guidance which clarifies both how, and to what extent, the access gap between emitters via infrastructure developments and funding might be bridged.. Guidance relating to NPT is also advised.

3.4 Insight #4 Small Emitters Require Additional Incentives

By reducing the operational costs associated with participating in carbon capture, CaaS can provide a pathway for smaller emitters to decarbonise. However, existing financial incentives and structures, primarily the ETS market, do not adequately include these small emitters.

Insight

During the stakeholder engagement process, the determination of risk and liabilities across the system were identified as key areas requiring attention and necessary to successfully developing a future CaaS system. Specifically, the CaaS system is:

- Highly interconnected in terms of both physical and commercial interfaces with the wider CCUS value chain;
- Not well established, with a number of variables that contribute to an uncertain future (e.g. technology efficiency improvements, infrastructure developments, operations, commercials, regulation).

These features contribute to a complex risk landscape which is challenging to control over time. This is especially pertinent at the physical system interfaces; allocation of responsibility requires clarification in these areas.

Discussion

The disconnect between the motivation for CaaS and applicability of existing financial incentives to participate was flagged in stakeholder engagement as a barrier to implementation. There was also some feedback received around the suitability of the ETS more generally to support a commercial CCUS system, but this is beyond the scope of this study. The governing condition for participation in a future system was identified as cost; where it is cheaper for an emitter to release rather than capture carbon, there is a requirement for external financial intervention or system shift. The ETS does not necessarily need to be the mechanism which provides this intervention. Other interventions which could help incentivize and support smaller emitters to participate in CaaS include:

- Strategically deploying CaaS projects alongside major CCS projects. These larger projects could act as "anchor sites" justifying larger infrastructure investments (such as required pipeline transport or onshore compression and storage sites) from which smaller emitters could also benefit.
- The development of 'micro-networks' (i.e., a collective of emitters) could support the development of CaaS systems through reducing overall system costs through the sharing of technologies or transport logistics.

Recommendation

Options to better accommodate small emitters could potentially include revisions to the UK ETS or the introduction of a separate scheme specifically designed to increase participation from this group. Additionally, support the development of micro-networks to further assist small emitters is recommended. Stakeholders indicated a desire for a coordination role to instigate and support the development of these networks among small emitters. Government, or existing industrial networks or regional authorities, could adopt this role to align the actions of small emitters with their strategic priorities. A detailed economic impact study which investigates the potential financial levers, and models potential responses, is recommended.

3.5 Insight #5 Interacting with the International Market

The development of the international CaaS market will significantly influence the UK market, with ongoing competition for skills, resources and customers across the value chain.

Insight

CCUS is rapidly becoming a growing part of the global approach to decarbonisation, with CaaS having the potential to form a key link in this value chain. This has implications on the evolving CaaS market in the UK, including:

- **The risk of delivery stakeholders preferring to do business elsewhere.** Increasing dependency on global material, technology and skills supply chains, in conjunction with an evolving regulatory landscape and carbon trading frameworks are all trends which shape this risk profile.
- **The opportunity to provide a service to the international community.** The UK is well positioned to provide a service through the availability of storage locations. Growing the UK's international carbon capture presence could help support the development of services in the UK and accelerate future CaaS systems.

Discussion

Factors like import costs and competition for skilled workers led stakeholders to express concern that the design of very rigid CaaS business model guidance could impact the commercial prospects of international business currently or considering locating in the UK.

Counter to this, the opportunities relating to expanding CaaS across borders is viewed as an exciting opportunity for the UK in utilising the proportionally high number of stores. Authoring successful CaaS business mode guidance and demonstrating successful operations could be a substantial enabler in accessing this market. Infrastructure investments throughout the wider CCUS supply chain are critical accompaniments to guidance to access this opportunity. In addition to the competition for skills and goods, there is also an international competition for carbon and carbon credits.

Recommendation

Business model guidance should consider how best to create the conditions for a thriving UK CaaS market which embraces the development of an international marketplace.

3.6 Insight #6 Risk Allocation Between Stakeholders

Considered and balanced assignment of risk in a future CaaS system is important in satisfying the needs of all stakeholders and ensuring their participation.

Insight

During the stakeholder engagement process, the determination of risk and liabilities across the system were identified as key areas requiring attention and necessary to successfully developing a future CaaS system. Specifically, the CaaS system is:

- Highly interconnected in terms of both physical and commercial interfaces with the wider CCUS value chain;
- Not well established, with a number of variables that contribute to an uncertain future (e.g. technology, infrastructure, operations, commercials, regulation).

These features contribute to a complex risk landscape which is challenging to control over time. This is especially pertinent at the physical system interfaces; allocation of responsibility requires clarification in these areas.

Discussion

The stakeholder consensus was that for CaaS to be successful, the allocation of risk (and access to reward) between system stakeholders (including government) should be 'fair'. A specific definition of 'fair' risk allocation would need to be decided (which could be reviewed and updated as the system developed). Stakeholders considered that government contribution to this activity via business model guidance was fundamental to the future success of CaaS to enable buy-in across the delivery stakeholder landscape. 'Reward' in this context is not limited to financial reward but also to other impacts such as job creation or carbon abatement that result from the acceptance of risk. Entities adopting a similar role in the CCUS value chain (whether CaaS is present or not) would expect compensation if required to take on additional risk.

Government is well-placed to make executive decisions and provide guarantees around risk (although this does not mean they are the only organisation that can). As an entity they have oversight of regulatory bodies and potential orchestrators of functional guidance which can create these desirable market conditions. Case study 5a provides a clear example of the role government and the public sector had in the development of roles and regulators.

Recommendation

Stipulation from Government of the boundaries of responsibility within the system and ensuring they are clearly signposted would support well-balanced assignment of risk. They could also provide a safeguard which may address concerns of potential participants who are perhaps more risk averse.

3.7 Insight #7 Attracting Essential Investment for CaaS

CaaS has many characteristics of a high-risk investment profile. In order to attract the necessary investment to realise CaaS, financers will need support to understand the business case.

Insight

At the point of commission, any entity providing financing requires a reasonable degree of assurance that a return on this initial (high) CapEx investment is likely, and so visibility of the future financing landscape is essential. Currently, CaaS is not yet operational, making demonstrating the opportunity for profit challenging; business model guidance could provide clarification of this mechanism.

Certain markets operating "as-a-service" such as waste collection or public transportation, are not necessarily inherently profitable, but are essential for broader societal wellbeing or environmental reasons. CaaS also likely requires external mechanisms like subsidies or penalties to create funding to deliver this service.

Discussion

There is a delta between the cost of carbon disposal and carbon pricing which could serve as the funding source. A key piece of stakeholder feedback concerned the viability of CaaS as a business strategy against a backdrop of the compulsory UK ETS pricing. More broadly, feedback reflected a concern around the return on investment and the generation of profit for an investor. Assurance of ETS pricing approaches spanning the plant operational life was highlighted as a key enabler for CaaS (alongside adapting the applicability of this scheme which is detailed in Insight 3). By arming prospective CaaS providers and market participants with, at a minimum, information about the future landscape and intent of government, this means businesses can respond suitably in accordance with government guidance.

It is worth noting that the total cost of CaaS will vary widely as a function of its arrangement (i.e., the specifics of how it is deployed and the number of associated stakeholders). To consider two contrasting examples, a micro-network utilising either NPT or a pipeline will have different commercial arrangements (and overall profitability) to that of a single emitter connecting to a pipeline. In particular, the T&S requirements for delivery will affect the overall commercial arrangements of the system; an insight which is detailed later in this report (Insight 3). In addition to business models being developed in the UK, Porthos, a project being developed in the Netherlands, provides an international example of how subsidies and grants are helping to overcome high infrastructure cost in CCUS compared to ETS prices, with further examples given in case studies 2, 3 and 4 on the following page.

Recommendation

Project financers are best placed to resolve 'who pays for what, when' and collaboration with financial experts will support the development of credible and realistic guidance. Implementing a subsidy mechanism to offset high upfront costs is recommended to provide prospective investors with financial assurance, with examples of this shown on the following page.

4 Deployment Pathways

4.1 Development Horizons

The CaaS market comprises a number of vectors of uncertainty as highlighted throughout this report. With so many unknowns yet to be resolved, and with limited opportunity for industry engagement to date, it is unrealistic to attempt to chart a rigid path.

To fully embrace the opportunity CaaS presents to progress industrial decarbonisation, a deployment plan should be flexible; focussing on key enablers that would allow market transformation. This report presents a readiness framework which considers three **"development horizons"** that is, distinct states of CaaS market readiness which represent threshold indicators of future progress. The status of each horizon is described in response to the four distinct **"development pathways"** which are advised to be matured at a similar pace.

4.2 Identified Development Pathways

Building on the insights and corresponding recommendations, four core themes have been identified. These form distinct activity streams terms here as "development pathways":

- **Broader Engagement (communication)**
  Relates to gathering opinions, disseminating understanding, establishing communication channels and developing a brand.
- **Mature wider value chain (activity)**
  Describes acquiring or developing technology, materials and resource to create a robust pipeline.
- **Create Market Forming Policies (policy)-** Relates to the creation or updating of policy which relates to or is impacted by CaaS in a UK context.
- **Refine Scheme for all (strategy)**
  Focuses on decision prioritisation which balances benefits in the context of finite time and cost.

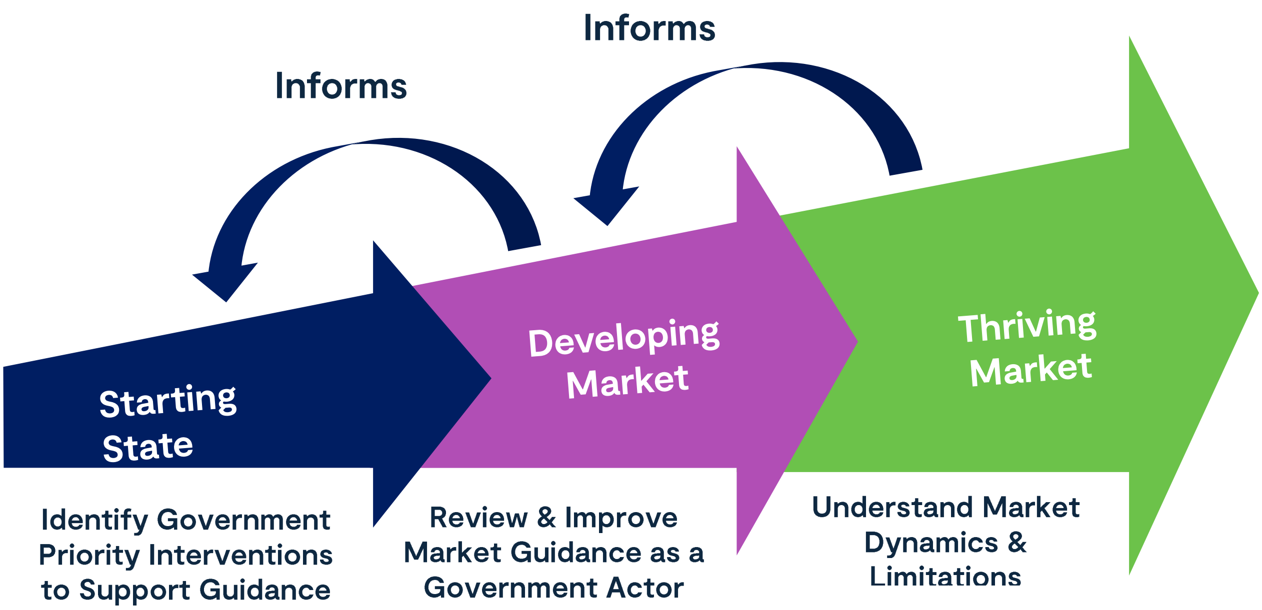


Figure 4: Development Horizons for CaaS used in the Readiness Framework. Each of the Deployment Pathways must step through these Horizons.

4.3 Broaden Engagement Pathway

Starting State

- CaaS is challenging to describe and conceptualise for many of the prospective delivery stakeholders.
- Views surrounding CaaS collated primarily from participants involved in industrial decarbonisation challenge projects.
- Messaging around CaaS from government has been provided only in reference to the existing CCUS guidance.
- Prospective CaaS delivery entities do not yet have well-established networks to allow communication.

Developing Market

- Key stakeholders gain a robust understanding of CaaS as a concept and are able to explain this in simple terms.
- A typical set of relationships between delivery entities becomes apparent, and they work together to present an industry view.
- Opinions have been proactively sought across the value chain and the supporting market infrastructure reflects these views.

Thriving Market

- There is awareness and some fluency from secondary stakeholders (such as the general public) around CaaS.
- There is a well-established route for feedback and knowledge sharing with engagement networks being a source of innovation.
- It is easy for any entity within a prospective CaaS delivery framework to instigate a relationship with others and interface in a manner tailored to both entities.

4.4 Mature Wider Value Chain Pathway

Starting State

- Capture technology is not widely deployed and is typically delivered in-house.
- An international supply chain is not well established despite there being growing interest in CaaS internationally.
- Operator training is not widely undertaken and the route to skill acquisition is not established.
- Technology developers and manufactures are seeking commitment before they invest.
- There is not a complete commitment to shared infrastructure.

Developing Market

- There are a number of case studies which demonstrate CaaS in action via common configurations.
- Major components establish a robust supply chain, and this is accompanied by an understanding of typical technology assurances.
- Skills pathways are established for operators and engineers. Local clusters become hotbeds for CaaS skills and job creation.
- The specific role of an aggregator is defined and acts as a key enabler within the value chain.

Thriving Market

- There are diverse examples of deployment in action with innovative examples of unusual configuration.
- The cost of less common and auxiliary components is brought down as an international supply chain find optimal manufacturing practices. A lean route to market is now available for several bespoke CaaS configurations.
- There is a well-developed understanding of skill requirements and pathways.
- The UK takes full advantage of our access to storage.

4.5 Create Market Forming Policies Pathway

Starting State

- The primary financial mechanism for incentivising CaaS is the ETS; however, it is generally incompatible with the investment case for smaller emitters. This is undesirable as smaller emitters, who are one of the groups that may utilise CaaS, are less motivated to decarbonise under the current ETS framework.
- The commercial vehicle for CaaS is not well understood and so entities do not know how to enter the market and instigate contractual relationships.
- There is a sense of 'policy pending' in the UK.

Developing Market

- There are a number of decisive policies in place which clarify CaaS participation for a majority of stakeholders.
- Policy relating to funding and financial penalty is clarified with a focus on 'who pays for what when' and a means of subsidising high up-front costs.
- Policy directly relating to CaaS is established and this has a high degree of compatibility and connectivity with existing guidance.

Thriving Market

- Policy takes full account of and embraces the international trade opportunity.
- There is accommodation and acknowledgement of less common CaaS configurations via more comprehensive policy, particularly those outside of a cluster.
- Policy referring to interfacing systems or frameworks accurately represents and does not stifle the deployment of CaaS.
- Innovation is actively encouraged

4.6 Refine Schemes for All Pathways

Starting State

- The ambition for CaaS to exist has been proposed but specificity around emitters that should engage does not yet exist.
- There is considerable discrepancy in access to CaaS between different emitters; geography plays a substantial role in perceived system complexity.
- An investable business case for both clustered and dispersed emitters does not exist.

Developing Market

- “Priority” emitters to participate in CaaS have been identified. These sites proceed through a well-defined pathway.
- “Quick wins” instigated in the marketplace for emitters that are not optimally positioned. These are enabled through the identification of “anchor sites” and the supported creation of “micro-networks”.
- Once CaaS becomes operational, the strategy for including diverse emitter sites can be better informed using evidence from the field.

Thriving Market

- Emitters for whom CaaS participation is more challenging are subject to business case assessment to support strategic decisions. Where there is a clear cost-benefit reason to participate, appropriate funding mechanisms are deployed.
- Specific schemes associated with alternate funding and policy are strategically deployed to ensure inclusivity for emitters. For example, sites which require non-pipeline transport may be included here.

5 Conclusion

Industrial decarbonisation is a challenge that must be addressed if the UK is to meet its legal commitment of net zero CO_2 emissions by 2050. The government has shown clear strategic commitment to CCUS, recognising the role it must play; however, the pioneering industrial emitters currently adopting this technology are not representative of the wider industrial emitters, which also need to decarbonise.

Some industrial emitters may lack the scale for economically viable point source capture or the expertise to implement and operate a plant, presenting significant barriers to adopting and operating carbon capture technologies. CaaS could offer a decarbonisation route for these emitters, but with so many unknowns yet to be resolved, it is not yet clear how the CaaS market will evolve and develop.

This study identifies seven insights into the development and evolution of the CaaS market, providing corresponding recommendations. Through these insights and recommendations, four distinct "development pathways" have been outlined within a framework of three "development horizons". This framework can be used evaluate the development of the CaaS market, from a current starting state through to a thriving CaaS market. The four development pathways are:

Broaden Engagement (Communication)
Each prospective CaaS system presents unique challenges from both a technical and commercial perspective, necessitating formalised support to ensure cohesion across system interfaces. Recognition of an 'aggregator' role will facilitate this process. A thriving UK CaaS market would embrace and integrate international advancements, both ensuring global competitiveness and learning from global examples.

Mature wider value chain (Activity)
The proximity of Emitters to shared infrastructure influences the complexity (and, as such, the cost) of CaaS. Clear guidance on how (and whether) government plans to bridge this gap in access to infrastructure through additional development and funding is crucial. Additionally, revising the UK Emissions Trading Scheme (ETS) and/or introducing a separate scheme tailored to small emitters will be vital in enabling their participation. The development of micro-networks or other novel configurations can further aid these smaller emitters.

Create Market Forming Policies (Policy)
Seamless integration with a reliable and accommodating wider system is fundamental for CaaS implementation. Guidance should build upon existing CCUS guidelines, ensuring they are robust, clear, and relevant. Well-considered and balanced risk allocation will be essential in meeting the needs of all stakeholders and ensuring their participation. This may include government taking on additional liability relative to the existing business models.

Refine Schemes for All (Strategy)
Attracting the necessary investment for CaaS requires credible and realistic guidance developed in collaboration with financial experts. Implementing a subsidy mechanism to offset high upfront costs can make the investment profile more attractive. The intricate nature of CaaS underscores the necessity for a multifaceted and adaptive approach, ensuring that all stakeholders are aligned and equipped to navigate the challenges and opportunities that lie ahead.

This high-level framework, and positioned recommendations, can be used to guide the deployment of CaaS in the UK. By addressing these key areas, a sustainable and effective CaaS strategy can be developed to further progress towards industrial decarbonisation.

6 References

1. **Department for Energy Security & Net Zero.** 2023 UK greenhouse gas emissions, provisional figures. [Online] 2024. https://assets.publishing.service.gov.uk/media/6604460f91a320001a82b0fd/uk-greenhouse-gas-emissions-provisional-figures-statistical-release-2023.pdf.
2. **HM Government.** Industrial Decarbonisation Strategy. [Online] 2024. https://assets.publishing.service.gov.uk/media/6051cd04e90e07527f645f1e/Industrial_Decarbonisation_Strategy_March_2021.pdf.
3. **UKRI.** Enabling Net Zero: A Plan for UK Industrial Cluster Decarbonisation. [Online] 2023. https://www.ukri.org/wp-content/uploads/2023/09/IUK-131023-UKRI_EnablingNetZero.pdf.
4. **HM Government.** The Ten Point Plan for a Green Industrial Revolution. [Online] 2020.https://assets.publishing.service.gov.uk/media/5fb5513de90e0720978b1a6f/10_POINT_PLAN_BOOKLET.pdf.
5. **Department for Energy Security & Net Zero.** Carbon Capture, Usage and Storage: A Vision to Establish a Competitive Market. [Online] 2024. https://www.gov.uk/government/publications/carbon-capture-usage-and-storage-a-vision-to-establish-a-competitive-market
6. **Department for Business, Energy & Industrial Strategy.** Cluster Sequencing for Carbon Capture Usage and Storage Deployment: Phase-1. [Online] 2021. https://assets.publishing.service.gov.uk/media/609c01db8fa8f56a353a1349/ccus-cluster-sequencing-phase-1-guidance-for-submissions.pdf.
7. **Department for Business, Energy & Industrial Strategy.** Carbon Capture, Usage and Storage: An update on the business model for Industrial Carbon Capture. [Online] 2021. https://assets.publishing.service.gov.uk/media/615b0ce3e90e07197f18fba1/icc-business-model-october-2021.pdf.
8. **Rolls Royce.** Rolls-Royce celebrates 50th anniversary of Power-by-the-Hour [Online] https://www.rolls-royce.com/media/press-releases-archive/yr-2012/121030-the-hour.aspx
9. **Department for Business, Energy & Industrial Strategy.** Carbon Capture, Usage and Storage: CCS Network Code – Indicative Heads of Terms. [Online] 2022. https://assets.publishing.service.gov.uk/media/62b9b12ae90e0721c781feba/ccs_network_code_draft_heads_of_terms_explanatory_note.pdf..
10. **Department for Energy Security & Net Zero.** Participating in the UK ETS. [Online] 2024. https://www.gov.uk/government/publications/participating-in-the-uk-ets/participating-in-the-uk-ets.
11. **EQS.** EU Supply Chain Act: Tough New Sustainability Standards That Could Impact UK Companies [Online]
12. **Department for Energy Security & Net Zero.** CCUS: non-pipeline transport and cross-border CO_2 networks - call for evidence. [Online] 2024. https://www.gov.uk/government/calls-for-evidence/carbon-capture-usage-and-storage-

ccus-non-pipeline-transport-and-cross-border-co2-networks/ccus-non-pipeline-transport-and-cross-border-co2-networks-call-for-evidence

13. **HM Government.** Aviation fuel plan supports growth of British aviation sector. [Online] 2024. https://www.gov.uk/government/news/aviation-fuel-plan-supports-growth-of-british-aviation-sector.
14. **Imperial College London.** Assessing the Potential of CO_2 Utilisation in the UK. [Online] 2017. https://assets.publishing.service.gov.uk/media/5cc9bd9c40f0b64c1e187664/SISUK17099AssessingCO₂_utilisationUK_ReportFinal_260517v2__1_.pdf.
15. **Tata Chemicals Europe.** Carbon Capture & Utilisation [Online] https://tatachemicalseurope.com/carbon-capture-and-utilisation/
16. **Porthos.** Will Porthos receive subsidy for this project? [Online] https://www.porthosco2.nl/en/faq/will-porthos-receive-subsidies-for-this-project/.
17. **The CCUS Hub.** Porthos. [Online] https://ccushub.ogci.com/focus_hubs/rotterdam-porthos/.
18. **European Union.** What is the Innovation Fund? [Online] https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/what-innovation-fund_en.
19. **European Union**. Innovation Fund Projects. [Online] https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/innovation-fund-projects_en.
20. **Qlik.** Innovation Fund - Portfolio of signed projects. [Online] https://dashboard.tech.ec.europa.eu/qs_digit_dashboard_mt/public/sense/app/6e4815c8-1f4c-4664-b9ca-8454f77d758d/sheet/bac47ac8-b5c7-4cd1-87ad-9f8d6d238eae/state/analysis.
21. **Office for the Parliamentary Budget Officer.** Investment Tax Credit for Carbon Capture, Utilization and Storage. [Online] 2024. https://www.pbo-dpb.ca/en/publications/LEG-2324-022-S--investment-tax-credit-carbon-capture-utilization-storage--credit-impot-investissement-captage-utilisation-stockage-carbone.
22. **Department of Finance Canada.** Budget 2024: Fairness For Every Generation. [Online] 2024. https://budget.canada.ca/2024/report-rapport/budget-2024.pdf.
23. **Global CCS Institute.** The US Section 45Q Tax Credit for Carbon Oxide Sequestration: An Update. [Online] 2020. https://www.globalccsinstitute.com/wp-content/uploads/2020/04/45Q_Brief_in_template_LLB.pdf.
24. **Carbon Capture Coalition.** Primer: 45Q Tax Credit for Carbon Capture Projects. [Online] 2023. https://carboncapturecoalition.org/wp-content/uploads/2023/11/45Q-primer-Carbon-Capture-Coalition.pdf.
25. **Longship (Langskip) Details.** [Online] https://www.geos.ed.ac.uk/sccs/project-info/2726
26. **European Commission.** Kairos@C: Building strong momentum for massive decarbonisation in the EU through a unique end-to-end CCS project. [Online] 2022.
27. **The CCUS Hub.** Antwerp@C. [Online] https://ccushub.ogci.com/focus_hubs/antwerpc-kairosc/
28. **Global CCS Institute.** Global Status of CCS 2023 Scaling Up Through 2030. [Online] 2023. https://res.cloudinary.com/dbtfcnfij/images/v1700717007/Global-Status-of-CCS-Report-Update-23-Nov/Global-Status-of-CCS-Report-Update-23-Nov.pdf?_i=AA.

29. **PETRONAS.** PETRONAS and JERA to Explore Feasibility of the Entire CCS Value Chain Between Japan and Malaysia [Online] https://www.petronas.com/media/media-releases/petronas-and-jera-explore-feasibility-entire-ccs-value-chain-between-japan-and

30. **Northern Lights.** About the Longship project. [Online] https://norlights.com/about-the-longship-project/.

31. **Northern Lights.** What it takes to ship CO_2. [Online] https://norlights.com/news/what-it-takes-to-ship-co2/.

7 Abbreviations / Glossary of Terms

Term	Definition
Batch process	A process that is carried out in discrete amounts rather than continuously.
CapEx	Capital Expenditure
Capture as a Service (CaaS)	The provision of carbon removal on behalf of industrial emitter(s) by for onwards use or storage.
CCfDs	Carbon Contracts for Difference
Carbon capture	The process of capturing CO_2 from industrial process and/or power generation.
Carbon Capture, and Storage (CCS)	The process of capturing CO_2 from industrial processes, power generation and other sources of CO_2. The captured CO_2 is then stored permanently in disused oil and gas fields or naturally occurring geological storage sites
Carbon Capture, Utilisation, and Storage (CCUS)	The process of capturing CO_2 from industrial processes, power generation, and other sources of CO_2. The captured CO_2 is then either used, for example in chemical processes, or stored permanently in disused oil and gas fields or naturally occurring geological storage sites
Continuous process	Constant flow of material through processing equipment to produce the product without interruption.
Cross chain risk	Risks associated with elements across a value chain which have dependent relationship with one another.
DESNZ	Department of Energy Security and Net Zero
Emissions Trading Scheme (ETS)	‘Cap-and-trade' approach scheme where the emissions of specified pollutants over a specific area are limited. Companies are able to trade emissions within a secondary market.
EPC	Engineering, Procurement and Construction
Flue gas	Mixture of gases produced within an industrial plant and/or power station.
Free allowance (FA)	Credits allocated to emitters which are driven by industry benchmarks alongside the application of an annual reduction rate.
Greenhouse Gas (GHG) Emissions	Emissions from natural or human activities that intensify the greenhouse effect and contribute to climate change.
Gross Value Added (GVA)	The value generated by the production of a good and/or service.

Industrial cluster	Location where hard-to-abate industries are located, often energy-intensive manufacturing processes.
IDC	Industrial Decarbonisation Challenge
Micro-Networks	Small collection of emitters, featuring potentially smaller emitters able to pool resources and share costs to enable increased participation within CaaS.
NPT	Non-Pipeline transport
SAF	Sustainable Aviation Fuel
T&S	Transport and Storage
UKRI	UK Research and Innovation

8 Annexes

Annex A - The Emissions Trading Scheme

Overview of the ETS

The UK's emission trading scheme (ETS) replaced participation in the EU ETS market at the beginning of 2021. The goal of this scheme is to increase the climate ambition of the UK carbon pricing policy whilst maintaining the competitiveness of UK business. In simple terms, it operates using a 'cap-and-trade' approach wherein an initial cap is set on the total amount of greenhouse gases (GHGs) which can be emitted by specified sectors covered by the scheme. This cap is then reduced each year. More details of the ETS and how it functions can be found on the following page.

Incentivising Decarbonisation

The aim of the ETS (as defined by the UK government) is to "promote cost-effective decarbonisation, allowing business to cut carbon emissions where it is cheapest to do so". Effectively, the scheme aims to create a market whereby emitters are rewarded for reducing their carbon emissions (in the form of reduced tax).

A key point to note is that emitters are financially incentivised to reduce carbon emissions irrespective of their means of decarbonisation. Currently, a suite of decarbonisation options exists, including the future use of hydrogen, electrification of processes, and increased energy and resource efficiencies (such as through use of the circular economy). Hence, carbon capture, and subsequently CaaS, represent a means of decarbonisation within a suite of options. Although it has been highlighted that many emitters will be reliant on carbon capture technologies to meet net zero targets, there is still a need for future business arrangements to fulfil the needs of emitters in overcoming their reliance on the ETS market.

The overall aim of CaaS, therefore, should be to lower the barrier to entry for emitters wishing to increase their rate of decarbonisation, within the context of the ETS market.

CaaS Within the ETS Market

An expanded view of the ETS market, with respect to emitters use of CaaS, can be found in Figure 6. This view aims to recontextualise many of the barriers and opportunities previously found within the additional context of market dynamics. This is expanded on in Figure 2, which shows various potential CaaS arrangements within this market.

Another pertinent consideration is the required level and application of funding necessary across the system. As found with the CCUS Track 1 & 2 Sequencing Process, targeted funding can be used to accelerate certain aspects of the value chain's development.

More generally, CaaS exists to support a range of diverse emitters, primarily defined by their position relative to each other. Hence, the development and required levels of support necessary to facilitate CaaS will need to be specific, targeted, and location dependent.

Overview of the Emission Trading Scheme

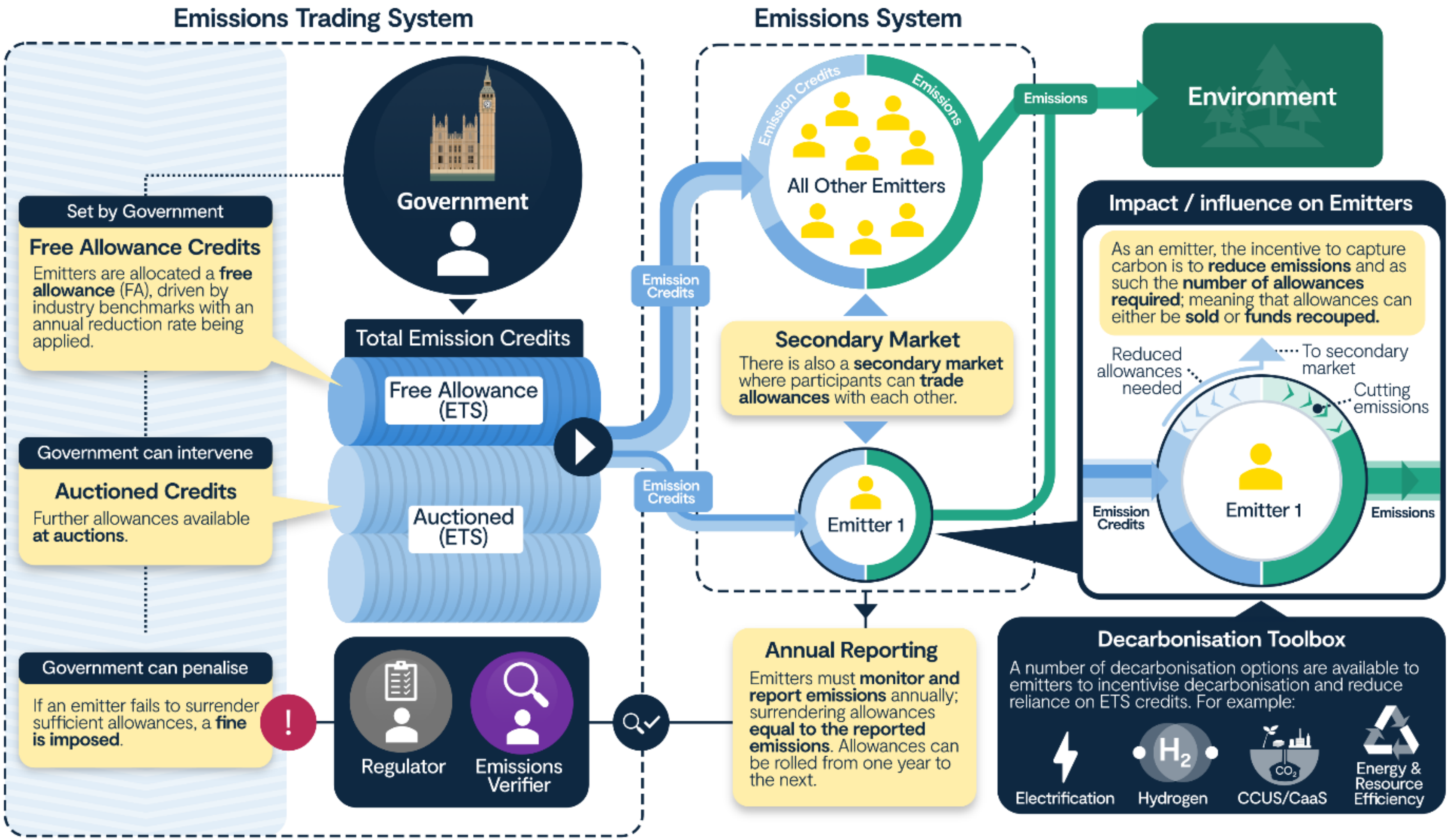
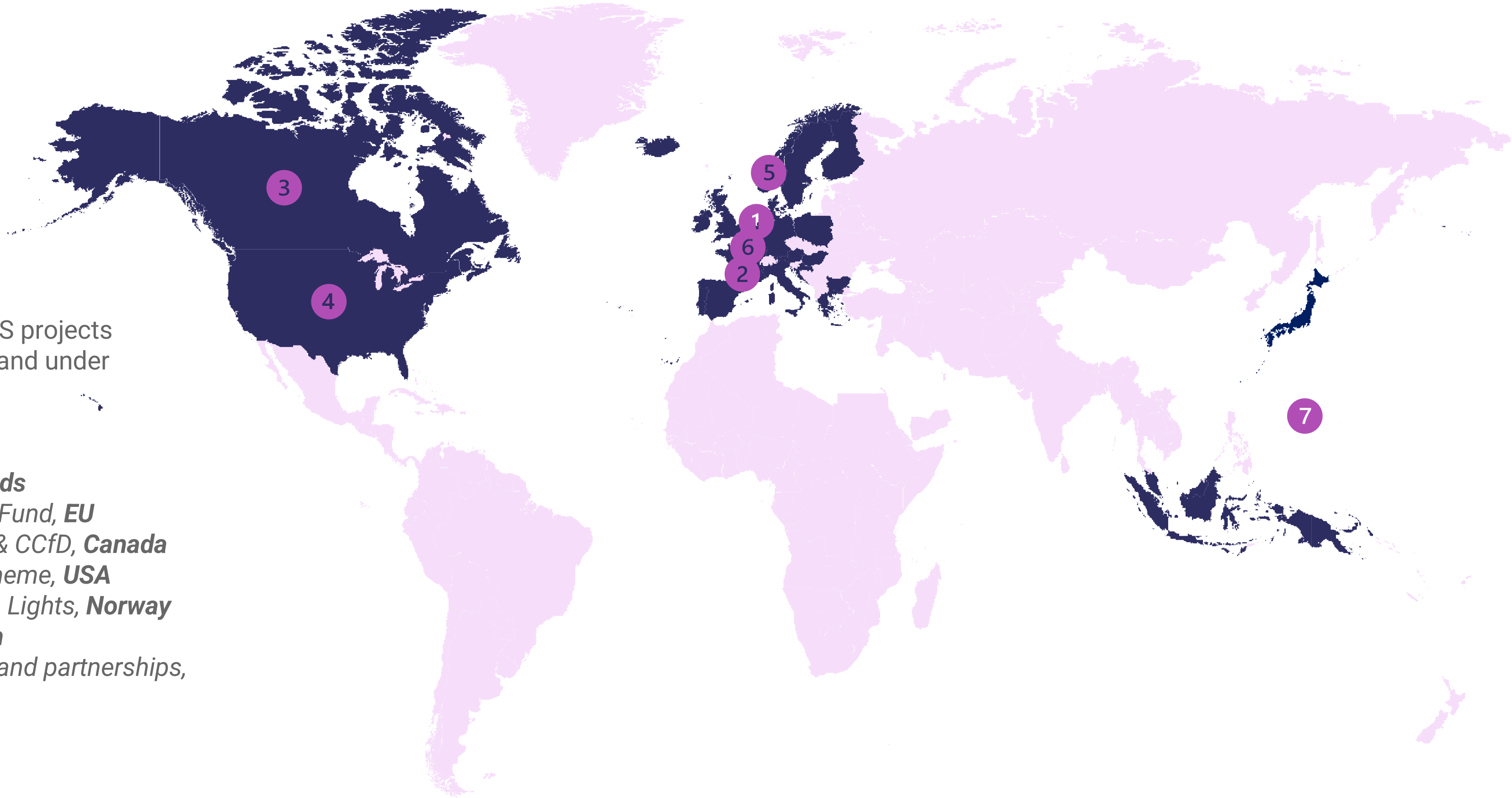


Figure 5: An Overview of the ETS market and how it may interface with incentivising emitter decarbonisation.

Annex B - International Outlook & CaaS Development

Currently, the number of specific CaaS projects within development is limited, with large levels of variety between countries on the progress of their CCUS projects. Case studies of CCUS projects which can help guide thinking and understanding of potential CaaS arrangements and support have been outlined in Figure 7 below and are referenced throughout the 'Insights and Recommendations' in particular in **Insight #5.**



Countries with CCUS projects (both initial stages and under development)

Case Studies

1. *Porthos, **Netherlands***
2. *Europe Innovation Fund, **EU***
3. *CCUS Tax Credits & CCfD, **Canada***
4. *45Q Tax Credit Scheme, **USA***
5. *Longship/Northern Lights, **Norway***
6. *Kairos@C, **Belgium***
7. *Feasibility studies and partnerships, **South-East Asia***

Figure 6: An overview of International CCUS developments.

Case Study 1 – Porthos, Netherlands

Open-access transport and storage service utility for hard to decarbonise industries. Open-access transport and storage service utility being developed for hard to decarbonise industries. Significant financial support has been provided to assist with the investment capital required for preparatory studies and the infrastructure. Subsidies/grants have been given from: European Commission - €6.5 million; RVO (A Netherlands Enterprise Agency) - €1.2 million; Brussels - €102 million [16]. Customers of Porthos have been awarded with SDE++ subsidies, which bridge the cost difference between EU ETS and cost of CCUS; enabling them to remain competitive whilst reducing GHG emissions [16,17].

Case Study 2 – Europe Innovation Fund, EU

The Europe Innovation Fund is focussed on highly innovative and flagship projects within Europe which will result in significant reductions in emissions [18]. The fund itself is generated via revenue obtained from EU ETS system [19]. Currently, 13 projects related to CCS (or contain CCS adjacent elements) are being funded, totalling €1,750 million. The largest value is Kairos@C, valued at €357 million (see Case Study 6) [20].

Case Study 3 – CCUS Tax Credits, Canada

In 2021, the Canadian government launched investment text credits from 2022 through to 2030, offering a refund on CCUS related equipment such as [21]:

- 60% on capture equipment using direct ambient air;
- 50% on other capture equipment; and,
- 37.5% on qualified carbon transportation, storage or usage equipment.

Moreover, the government has also re-affirmed to carbon contracts for difference (CCfDs), promising up to $7 billion to issue contracts for difference and offtake agreements [22].

Case Study 4 – 45Q, USA

45Q is a carbon oxide sequestration credit used within the USA (operating similarly to clean energy tax credits) which provides monetary credit for permanent storage of CO_2 (alongside carbon monoxide and carbon suboxide). Storage can occur via usage, geological formations or tertiary oil injection [23].

Different types of industrial facilities have annual carbon capture thresholds, which determines the facilities eligibility for tax credit. Private investment into sectors with higher carbon capture costs is strongly incentivised through this mechanism, as the cost and risk to private capital is reduced [24].

The allocated tax credit can be claimed by the taxpayer operating and owning the CCS equipment [23]. This party is able to transfer the credit to another taxpaying entity if desired. This provides flexibility and enables development of a significantly larger pool of carbon capture investors [24].The 45Q tax credit value is not affected by carbon market volatility or carbon trading mechanisms. This establishes a predictable and stable cost value for carbon, providing further encouragement.

Case Study 5a - Longship, Norway

Commercial and regulatory frameworks have been formed between various parties, including: EU and Norwegian legislation; international conventions; and state aid agreements between Government and industrial partners. [25] Project development has involved several Norwegian public sector bodies with established roles, which have proved integral to the project's success. Newly-developed roles include:

- *Project Integrator:* coordinates the development of individual subprojects to ensure the continued development whole CCS chain;
- State Aid Provider: establishes state aid agreements to reduce risks stemming from immature regulatory frameworks and/or commercial solutions.

Case Study 5b - Northern Lights Service Provision, Norway

The Northern Lights are responsible for the T&S components of the Longship project. Their current storage capacity exceeds the needs from Longship, establishing them as a T&S provider who can offer their service externally, enabling the development of T&S market [30]. Currently, excess capacity within the Northern Lights has been sold to a Danish power station and an ammonia production plant in the Netherlands [31].

Case Study 5c - Longship, Norway (NPT)

CO_2 is captured and liquified from cement and waste-to-energy facilities within the Longship Project [30]. This liquid CO_2 is shipped over 700 km from these industrial capture sites to the onshore Northern Lights receiving terminal facility prior to offshore storage. NPT proves integral to this project, as the cost and quantity of infrastructure required for pipeline transport across such a distance is not feasible.

Long-term charter contracts have been signed with Kawasaki Kisen Kaisha, Ltd. (a transportation company) for two 7500 m^3 shipping vessels [28]. Familiar ship designs have been adapted from transporting liquified petroleum gas, through the addition of a liquified CO_2 carriage system and insulation [31].

Case Study 6 - Kairos@C, Belgium

Kairos@C is located within the Port of Antwerp and forms the initial stage within a wider Antwerp@C project [26]. In initial project stages, CO_2 will be captured from 5 production plants, liquified, and then aggregated to an export terminal within the Port of Antwerp. From this aggregated terminal, CO_2 will then be transported by ship for permanent storage beneath the North Sea. Options for specific storage sites are currently being exploring in UK, Denmark, the Netherlands and Norway (potentially Northern Lights).

The number of emitters involved with capture and aggregation of CO_2 will increase overtime. The Kairos@C export infrastructure is to be operated on an open access basis, [26, 2727] establishing the terminal as a distribution point for CO_2 shipping for storage

Case Study 7 - Feasibility Studies within South-East Asia

Several investigations are currently exploring the feasibility of cross-border carbon capture projects within South East Asia, specifically Malaysia [28]. Two large multinational companies within the oil, gas and power industry (PETRONAS and JERA) have signed a joint study agreement to explore the feasibility of developing an entire CCS value chain between Japan and Malaysia [29].

South Korea have also announced a partnership with the proposed CCS hub in Sarawak, Malaysia [28]. These projects have the potential capacity to enable the development of a cross-country and cross-industry carbon capture service.