DELIVERABLE D2.1 REPORT

Methodologies for cluster development and best practices for data collection in the promising regions

Part 1

Industrial CCUS Clusters and CO_2 transport systems: methodologies for characterisation and definition

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Author: Dr Peter A Brownsort,
Scottish Carbon Capture & Storage, University of Edinburgh

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This document requires the following approvals:

AUTHORISATION	Name	Signature	Date
WP Leader	Júlio Carneiro		DD/MM/YY
Project Leader	Fernanda de Mesquita Lobo Veloso		DD/MM/YY

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Executive summary

The aim of the STRATEGY CCUS Project is to enable the short- to mid-term development of carbon capture, utilisation and storage (CCUS) through strategic planning of industrial carbon capture and storage (ICCS) clusters in Southern and Eastern Europe, within the overarching context of emissions reduction for climate change mitigation. Carbon capture and storage (CCS) is one of the main means of reducing carbon dioxide (CO_2) emissions from industry, along with improvements in materials efficiency, energy efficiency and fuel switching to low-carbon energy sources.

This report has been prepared to help local teams in the STRATEGY CCUS Project define options and scope for potential ICCS clusters in their regions, including the CO_2 collection and trunk transport systems needed to connect to a storage site. The report draws on experience from existing CCS cluster projects in Northern Europe and proposes a basic methodological approach for the definition of new ICCS clusters. A parallel report, forming part of the same project deliverable, covers assessment of suitable storage sites.

A review has been carried out of seven industrial areas in Northern Europe where ICCS cluster development is progressing, in order to understand what has led to their relative advancement. Recognising the considerable differences between these areas, each has been assessed against a common list of characteristics or factors, developed for this study, that describe an area in the context of its potential for forming an ICCS cluster.

Important technical characteristics include clear means of access to a well-defined CO_2 storage site and factors that can reduce initial investments and unit costs of CO_2 capture and transport, such as high-concentration CO_2 emissions or infrastructure that may be reused for CO_2 duty.

However, non-technical factors appear to have the greatest influence on advancement of ICCS cluster projects in the areas reviewed. Clear leadership and vision from an empowered public authority for the area, or from a credible industry leader or group, appear to be key, together with effective engagement of all stakeholders.

A basic methodology for definition of new industrial CCS clusters is proposed, intended to be adaptable to widely differing industrial areas. This is framed in three questions: what CO_2 will be captured; how will this be captured, collected and transported; and where will it be stored? Data and information needed for definition of ICCS cluster composition and CO_2 transport options are listed, and a database system for their collection has been developed by project partners.

The concept of ICCS clusters is based on the efficiencies that may arise from shared use of infrastructure, expertise and resources when a number of CO_2 capture facilities are linked within an industrial area, leading to lower costs for the reduction of emissions. When making decisions about CCS cluster composition or CO_2 transport integration, the primary objective of avoiding release of climate-damaging CO_2 to the atmosphere must always be clear.

However, an industrial cluster represents more than just the companies and industrial facilities present in an area. Benefits to the area of establishing an ICCS cluster are wider than just lower costs and include maintaining the presence of industry while achieving emission reduction targets, encouraging investment in new low-carbon industry, maintaining the value of industry to economy and to society through employment, and improving local air quality.

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Industrial CCUS Clusters and CO_2 transport systems: methodologies for characterisation and definition

1 Introduction

Industrial clusters have been around as long as industry itself. From the earliest manufacturing sites for stone-age tools in areas where the best flints were found, through siting of watermills along rivers, to the industrial revolution, where factories were often sited in coalfield areas, it has often been location of raw material or energy resources that has defined industrial geography. Natural transport potential, such as valleys, waterways and seaports, has also influenced clustering of industry, both for accessing raw materials and to allow trading of products. The recognition by economists of the advantages that clusters bring to industry and the dynamics of how they operate is more recent, being documented in the 1990s (Botham and Downes, 1999). An industrial cluster has been defined as "*a group of inter-related industries whose linkages mutually reinforce and enhance their competitive advantage*" (Porter, 1990).

Against this historical context, industrial carbon capture, utilisation and storage clusters are a relatively new concept. The term is not used in the Intergovernmental Panel on Climate Change Special Report on Carbon Capture and Storage (IPCC, 2005), but was clearly in use soon after in early proposals for carbon capture and storage (CCS) clusters in the UK (Yorkshire Forward, 2008; E.ON UK, 2009). The concept of industrial CCS (ICCS) clusters is closely related to Porter's definition of industrial clusters quoted above. It is based on the efficiencies that may arise from shared use of infrastructure, expertise and resources when a number of carbon dioxide (CO_2) capture facilities are linked within an industrial area. From the economist's viewpoint, the main advantage to companies participating in an ICCS cluster is anticipated to come from lower costs for the reduction of CO_2 emissions.

However, an industrial cluster represents more than just the companies present in an area. Benefits to the area of establishing an ICCS cluster are wider than just lower costs, including maintaining the presence of industry while achieving emission reduction targets, encouraging investment in new low-carbon industry, maintaining the value of industry to economy and to society through employment and improving local air quality. While all these wider benefits may add great support to justifying investment in CCS, the primary aim of avoiding CO_2 release to the atmosphere to mitigate against climate change must always be clear as the main basis of member selection and decision making for an ICCS cluster.

For the purposes of this review it is assumed that the need for reduction of CO_2 emissions from industry, or "industrial decarbonisation", is understood. Along with materials efficiency, energy efficiency and switching to low-carbon energy sources, CCS is one of the main means of reducing CO_2 emissions from industry. A number of important industrial processes produce CO_2 unavoidably from the chemistry involved and CCS is the only practical method of avoiding such process emissions being released to the atmosphere. For other industrial processes continued use of hydrocarbon fuels, coupled with CCS to avoid CO_2 emission, may be more practical and more economic than other decarbonisation approaches. In this review electricity generation, as well as combined heat and power (CHP) or co-generation, are included in the general meaning of “industry” whether such facilities are dedicated to particular industrial sites or supplying to grid distribution.

The role of carbon capture and utilisation (CCU) in industrial decarbonisation is less clear. Some utilisation processes lead to permanent removal of CO_2 from the atmosphere through its incorporation in stable products, while with other processes the CO_2 utilised is re-released in periods ranging from days to a few years. In general, this review will focus on the intention to reduce industrial emissions through the capture, transport and permanent geological storage of CO_2; that is, it will focus on CCS rather than CCU. It is suggested that factors related to CCS are the principle factors determining the suitability of areas as these clusters, and the term “industrial CCS clusters”, or “ICCS clusters”, will be taken to include CCU. It is acknowledged, however, that in some cases, such as capture and utilisation of CO_2 from steelworks gases or a local demand from enhanced oil recovery (EOR), the utilisation process may be an important determining factor.

1.1 Clusters, hubs and networks – terminology

The term “cluster”, in the CCS context, has often been used alongside the term “hub”; however, these terms describe distinct entities. A cluster, or in this sense more properly a “capture cluster”, is a geographical grouping of CO_2 emitters with potential or realised capture facilities. The main anticipated benefit of clustering comes from use of shared infrastructure to collect, transport and store the captured CO_2. This implies a shared collection network that would bring CO_2 to a consolidation point, a “collection hub”, for onward transport to storage by a trunk transport system. The collection network is sometimes assumed to be limited to a pipeline system. This may be appropriate for a cluster of large-capacity capture facilities, but a modular transport collection system may be appropriate in some cases, particularly for more spread-out clusters or where individual capture facilities are of smaller scale. Modular transport systems established for CO_2 include road tanker, rail tank-car and shipping; barge transport on inland waterways has also been proposed (Doctor, 2005; Vermulen, 2011; Brownsort, 2018).

Figure 1-1, Figure 1-2 and Figure 1-3 below show schematic outlines of example industrial CCS cluster configurations using different CO_2 transport options. Figure 1-1 shows an industrial cluster where some emitters have formed a capture cluster, with a pipeline network collecting CO_2 for transport to offshore storage. In this case the collection hub is minimal, just a pipeline junction; a compressor (booster) is shown at the coast, to deliver pressure needed at the storage site for well injection.

In Figure 1-2 a system is shown using different modular transport methods for liquefied CO_2 from capture facilities at all major emitters in a cluster. A collection hub with buffer storage at a port delivers CO_2 to ships for trunk transport by ship and offshore offloading to a storage site. Figure 1-3 shows a hybrid system with a pipeline collection network and onshore pipeline to a centralised liquefaction facility, transport overseas by ship to a receiving terminal, and onward transport by offshore pipeline to a storage site. Clearly different combinations of transport mode are possible.

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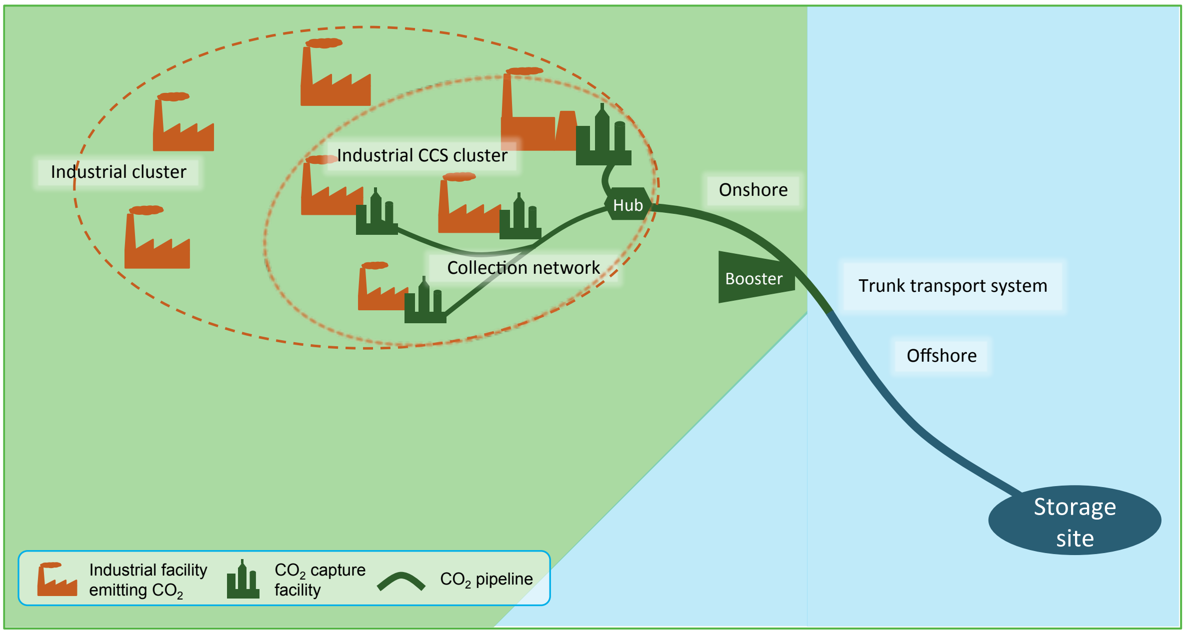
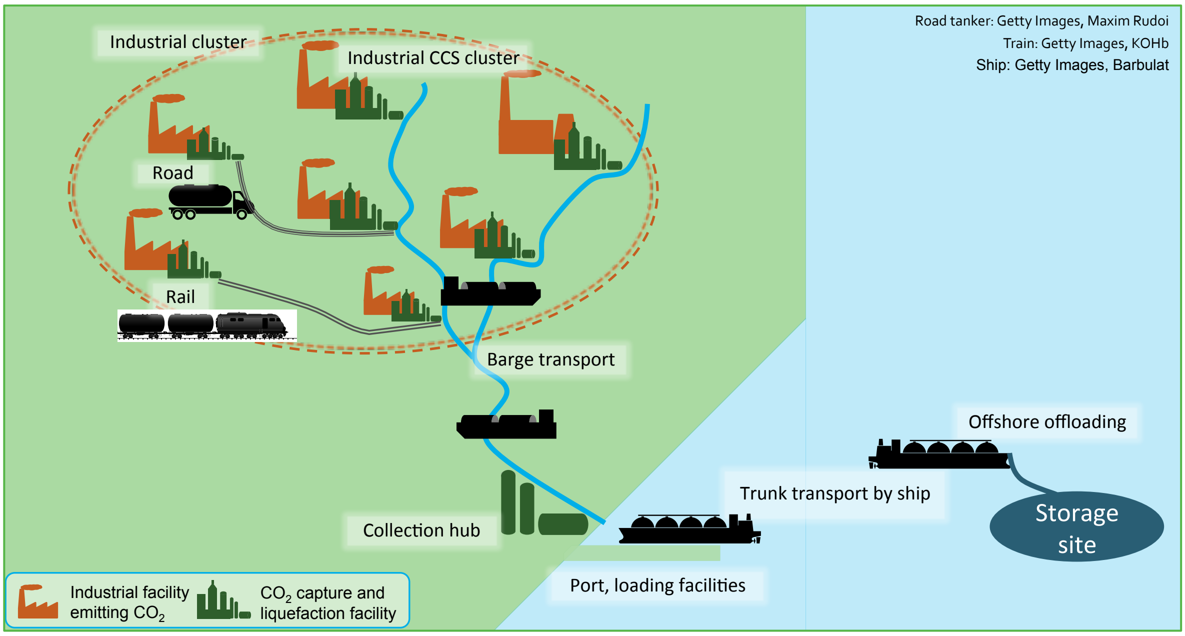


Figure 1-1 Schematic of ICCS cluster using pipelines for transport.



Road tanker: Getty Images, Maxim Rudoi
Train: Getty Images, KOHb
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Figure 1-2 Schematic of ICCS cluster using modular transport options for transport of liquefied CO_2.

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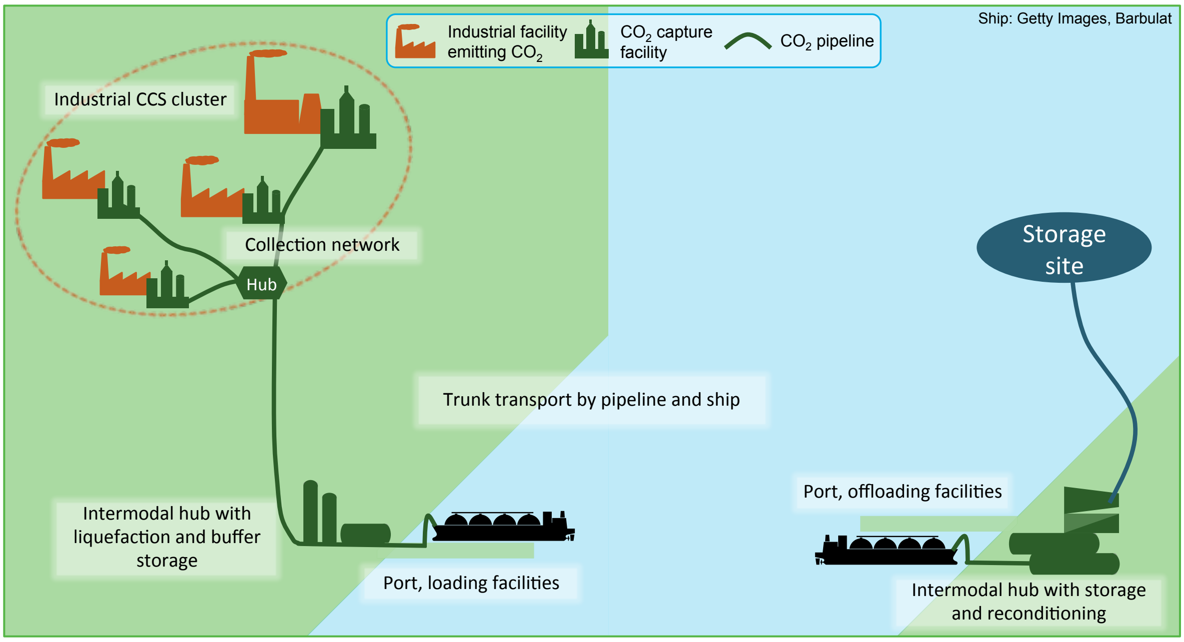

Figure 1-3 Schematic of ICCS cluster using a hybrid transport system with both pipelines and shipping.

The term “cluster” can also be applied to a geographical grouping of individual storage sites, a “storage cluster”, this situation might occur for operational robustness with a back-up store, or when a first store is nearing the limit of its capacity. In this case there might be a “distribution hub” at the downstream end of the trunk transport system. The trunk transport system linking from collection hub to distribution hub, or to an individual storage site, is also not limited to a pipeline system and may include shipping for all or part of its route, depending on geography and economic factors (Doctor, 2005; Brownsort, 2015).

Some authors (e.g. Purvis and Court in GCCSI, 2015) have written of “hub and cluster networks” to describe developed, full-chain CCS systems with multiple capture facilities, but this term has not been universally adopted.

1.2 Objectives and structure of this report

This report forms an early stage in the STRATEGY CCUS Project, aiming to provide some guidance to later stages as different teams define and progress potential ICCS clusters to help achieve industrial decarbonisation in their regions. The present report is prepared in parallel to a report, with similar objectives, covering CO_2 storage: *Storage Resource Assessment Methodologies* (Cavanagh, 2019).

A limited selection of relevant literature is presented in Section 2. Firstly, a number of recent reviews are summarised covering ICCS clusters from various points of view. Secondly, some reports are described that give detail of the methodologies they have used for (in most cases) individual cluster studies.

One objective of this report, covered in Section 3, is to review a number of ICCS cluster projects that have shown promise or are actively developing in the North Sea Basin region of Europe, in order to understand the factors and features that have led to their relative advancement – but note that no ICCS clusters have yet moved into a deployment phase in Europe. Understanding these factors, it is hoped, will help other promising regions elsewhere in Europe to form robust plans for their own ICCS clusters, and for the transport links that will be required to access CO_2 storage sites.

A further objective of this report is to consider the steps by which cluster projects have developed, the information gathered, the studies, considerations and engagements made, and from this to suggest a “best practice” for methodology to identify and define future cluster projects. This forms Section 4 of the report.

There is clearly a strong link between these two objectives in that the factors that characterise an ICCS cluster are based on information and data that would be needed to develop a cluster project. However, it should be recognised that all clusters are different, each has different strengths and weakness, and there is not one solution that will work for every cluster. So this aspired “best-practice” is not definitive, but aims to show examples of where strengths can be made use of and how some challenges may be tackled.

Equally, forming an ICCS cluster is not just a matter of technical definition. Section 5 considers some groups that may be involved and areas of engagement that are likely to be required. Within the STRATEGY CCUS Project, Work Packages 3 and 6 focus specifically on stakeholder engagement and on strategic communication respectively, so in this present report only brief consideration is given to these important areas.

Finally, Section 6 provides a summary and conclusions for this report, with reflections on how its ideas may be used in the wider STRATEGY CCUS Project and beyond.

2 Some relevant literature

2.1 Previous reviews of ICCS clusters

There are a number of previous reviews covering ICCS clusters to different extents. Some recent ones are summarised briefly below; this is by no means a comprehensive list of all such works.

A major review by the International Energy Agency Greenhouse Gas Research and Development Programme (IEAGHG) aimed to identify all documented CCS clusters globally, to gather key technical information on each and to consider development of business plans (Haines, 2015). The study covered both capture clusters and clusters of CO_2 sinks, being the major CO_2-EOR clusters in the USA. Twelve well-defined clusters were reviewed in depth, located in Europe (6), North America (4), China and Australia with maturity ranging from early concept studies to operating systems. The literature review carried out also identified a larger number of studies of potential clusters and of projects on clustering in a CCS context in general, including a number of previous European Framework projects.

Also in 2015, the Global CCS Institute published a Special Report (GCCSI, 2015) exploring the role that capture clusters and the networking of CO_2 transport into a “hub and cluster network” could play in the deployment of CCS in Europe. The report used a Q&A format to highlight the advantages of clustering and gave a number of case studies from projects developing at that time.

In 2016, the Zero Emissions Platform (ZEP) published a limited report on how the deployment of CCS hubs and clusters could contribute to achieving a “Net Zero economy” in Europe (ZEP, 2016). The work found limited data was available for some of the regions where CCS clusters were thought likely to be advantaged. It considered the policy and organisational needs to address this in order to progress regional development.

An interesting comparison of seven potential UK ICCS clusters was made in 2017 by ECOFYS for the UK Government (Stork and Schenkel, 2017). The study used a combination of literature and stakeholder interviews to compile a numerical (but fairly subjective) assessment of readiness for each cluster in terms of seven “dimensions”.

A study by Element Energy for IEAGHG used a modelling approach to investigate economic and business related issues with the formation of ICCS clusters in four global areas of focus (North America, Europe, China, Australia) (Element Energy, 2018b). It addressed the current lack of commercial maturity of ICCS and identified four key factors that may enable private investments. It proposed four different business models for ICCS clusters suggesting at least one was suitable for each global region.

The Carbon Sequestration Leadership Forum (CSLF) has recently published a report by its task force on CCS clusters, hubs and infrastructure. This gives up-to-date coverage of currently active CCS clusters (not just industrial CCS clusters), current projects proposing CCS clusters, and summarises recent reports and studies (some listed here above) (CSLF, 2019). It gives specific high-level recommendations, aimed at governments and industry, to accelerate progress on deployment of CCS clusters.

2.2 Previous work on ICCS cluster methodologies

Although there are quite a number of reports from studies on ICCS clusters, not so many detail the methodology they have used, focusing more on the benefits and the commercial aspects of bringing a cluster project into being. In Table 2-1 a brief list is given of some publications that include descriptions of at least some methodology. Some of these will be used in later discussion and development of a "best practice" methodology. Again, this list is not comprehensive and clearly other projects will have followed a methodology, but may not have explicitly described this.

The first entry in Table 2-1, by Haines (2015), gives a useful template for collecting information to describe ICCS clusters, but does not really consider how that information is used to develop a cluster project.

The final table entry, on the Liverpool-Manchester Hydrogen Cluster, has only limited relevance to CCS cluster methodology (Progressive Energy, 2017). It is included as a reminder that there are other options for industrial decarbonisation, still relying on CCS, that have different characteristics from the clusters of CO_2 capture facilities generally thought of as ICCS clusters

The other three entries all share parts of a similar methodology, most clearly laid out as a "workflow" by the COCATE Project (COCATE, 2013). This can be simply outlined based on three questions, defining:

- WHAT CO_2 will be captured?
- HOW will this CO_2 be captured, collected, transported?
- WHERE will this CO_2 be stored?

This outline will be developed in Section 4.

Also worthy of note, although not solely related to ICCS clusters, is a recent paper on approaches taken by the Acorn CCS Project in north east Scotland to two key challenges faced by early stage CCS projects: reduction of costs and lack of stakeholder support (Alcalde et al, 2019). The work (under the ACT Acorn Project funding) identifies seven key elements of the project development process that have helped address these challenges and make the project more attractive for investors. The key elements identified were:

- identifying infrastructure for reuse with cost savings;
- producing a detailed storage development plan to boost storage confidence;
- defining stepped expansion phases as "low-carbon build-out options" based on the initial development;
- having a development plan covering the full CCS chain – capture, transport and storage;
- developing the messaging required to gain policy support;
- setting CCS within the context of a "just transition" to gain public support;
- knowledge exchange at all levels of engagement.

The study concludes that addressing these elements makes a project more likely to progress, more sustainable, and so more likely to attract investment. It suggests this learning can be transferred to other projects seeking to develop CCS.

Table 2-1 Existing ICCS cluster study methodologies

Publication	Summary of relevant methodology
Carbon Capture and Storage Cluster Projects: Review and Future Opportunities. (Haines, 2015)	Used an extensive template to collect technical and business information. Flexible approach, template developed in line with information available.
The East Irish Sea CCS Cluster: A Conceptual Design - Technical Report. (Coulthurst, Taylor and Baddeley, 2011)	Assessment of available storage capacity. Analysis of existing and future CO_2 emissions, location, source, quantity, profile. Consideration of technical opportunities and constraints for sharing infrastructure, capture, purification, conditioning, transport (collection and trunk, on- and offshore), health and safety, infrastructure reuse, flow measurement, offshore facilities, storage monitoring, system integration.
COCATE: Large-scale CCS Transportation infrastructure in Europe, (Public Summary). (COCATE, 2013)	Workflow outline recommended for future projects includes 5 (+1) blocks, each with defined activities. Blocks are (1) emissions analysis, (2) capture pooling and clustering option definition (these to be done in parallel with storage capacity assessment), then (3) identification of CO_2 hubs and collecting networks, (4) export systems, (5) project deployment strategy (including financial and risk analysis).
Reducing costs of carbon capture and storage by shared reuse of existing pipeline—Case study of a CO_2 capture cluster for industry and power in Scotland. (Brownsort, Scott and Haszeldine, 2016)	Analysis of emissions, quantity, location, distance to potential shared transport infrastructure, screening to identify promising capture sites. Estimation of capture rate, and of capital cost for capture. Identification of connection pipeline network, estimation of capital cost. Analysis integrated with capacity information for existing trunk pipeline, cost comparison with new pipeline estimate.
The Liverpool-Manchester Hydrogen Cluster: A low cost, deliverable project. Technical report. (Progressive Energy, 2017)	Project clearly focussed on decarbonisation of industry cluster through replacement of natural gas usage by hydrogen (H_2), so methodology specific to that, to determine the H_2 supply system requirement. This simplifies the CO_2 management system leaving only centralised CO_2 “emission” at new and existing (for ammonia production) steam methane reformers, considers only pipeline and storage capacities.

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3 Characterisation of ICCS clusters

All industrial clusters, and so all potential ICCS clusters, are different, but they may be characterised by considering a number of factors and features. This section develops a list of such features then makes brief case studies of a selection of promising ICCS clusters from around the North Sea Basin and assesses how these may be described using the identified features.

3.1 Features that characterise a potential cluster

Many different features can be used to describe potential ICCS clusters and to compare one potential cluster to another. A list of features has been developed for this review based on general knowledge of existing and proposed ICCS clusters. These features are listed and explained in Sections 3.1.1 to 3.1.6 below. The list is not exhaustive, or definitive, but is proposed as a structure for considering the strengths and weaknesses of different clusters, to reflect on their relative positions. ECOFYS used a similar approach (Stork and Schenkel, 2017), but focused more on organisational capability in a cluster to judge its readiness to deploy.

This approach describes potential ICCS clusters in terms of six groups of features: emissions, the area, the industries, relationships, infrastructure and CO_2 storage. The last is rather the odd one out, as it does not describe the ICCS cluster itself, but is necessary to consider the potential of the area as an ICCS cluster.

3.1.1 Characterisation of emissions

- Emission location distribution – how closely “clustered” is the area, are there few or many vents at facilities?
- Emission volume distribution – are there “anchor” emitters, several large emitters, many small emitters?
- Emission volume profile – are facilities at risk/closing, or is investment occurring, is there seasonal variation?
- Emissions type and quality – are there significant process emissions, are there high-concentration emissions, are there problematic contaminants?

3.1.2 Characterisation of the area

- Industrial area character – is it urban or remote, large or small, spread out or dense?
- Importance of industry – is the area predominantly industrial, is industry main employer in area?
- Cluster recognition – is there an existing cluster mentality, history of cluster focus, existing study results?

3.1.3 Characterisation of the industries

- Integration of industry – is there a common culture, cross-industry bodies, service interdependence, sharable resources etc?

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- Decarbonisation alternatives – what scope/feasibility for energy efficiency, electrification or biomass, hydrogen?
- CCU – what potential for CCU, is it "defining" e.g. EOR demand or syngas availability?
- Motivation for decarbonisation – will industry prioritise decarbonisation?
- Motivation for CCS – can industry gain from CCS?

3.1.4 Characterisation of relationships

- Stakeholders – are key stakeholders recognised, engaged, supportive?
- Policy position – is local and/or national policy supportive?
- Public position – is local population engaged with industry, positively or negatively, e.g. employment or air quality issues?

3.1.5 Characterisation of infrastructure

- CO_2 collection options – are there existing pipeline corridors, rail links, liquid-CO_2 (L-CO_2) terminals, are there geographic or other constraints on routes for collection?
- CO_2 consolidation options – are sites for consolidation hubs available, e.g. for buffer storage, central processing, compression or liquefaction?
- Existing CO_2 infrastructure – are there any existing capture, transport or utilisation operations or experience?
- Infrastructure reuse options – are there relevant existing pipelines, ports, terminals?

3.1.6 Characterisation of storage

- Storage accessibility – is area close to known potential CO_2 storage sites?
- Storage capacity – is accessible storage of suitable capacity, injectivity, security?
- Storage flexibility – are there alternatives to primary storage site?
- Storage development integration – is there an organisation interested/capable of developing storage?

The relative importance of these characteristics is discussed in Section 3.3, following the case studies.

3.2 Case studies to characterise potential ICCS clusters

In the UK, six areas have been identified with potential ICCS clusters in recent policy developments (BEIS, 2018): Humberside, Teesside, Merseyside (Liverpool-Manchester), South Wales, Grangemouth and St Fergus, with the last two often considered together as the "Scottish cluster". These areas, plus two others around the North Sea Basin, Grenland in Norway and Rotterdam in the Netherlands, are shown in Figure 3-1 and described and considered using the framework of features identified above, presented as Tables 3.1 to 3.7, with supporting discussion, in the following Sections.

At the time of writing, several of the cluster areas in the UK are forming more focused, or refocusing existing, regional cluster projects to take advantage of changes in UK Government policy, with potential funding, to support ICCS clusters. The reviews of these areas presented here may, therefore, become out-dated fairly quickly as these developments proceed.

These case studies are mostly based on publicly available information plus the knowledge and opinions of the author who, while having been involved in the field of industrial CCS and CO_2 transport for a number of years in an academic role, has had no specific part in any of the projects with the exception of some studies of the Scottish Cluster, including for the ACT Acorn Project.

The studies do not cover all features in detail, but aim to highlight distinctive and significant features that help explain a cluster's position. While intended to be objective, the case studies will necessarily be coloured by the author's opinions and degree of knowledge. For the sake of space, the example questions listed in Sections 3.1.1 to 3.1.6 above are not repeated in the tables.

Figure 3-1 Locations of industrial clusters (red), storage sites (green) and associated facilities described in case studies. Base map from Google MyMaps - Map data ©2019GeoBasics-DE/BKG (©2009), Google.

3.2.1 Humberside

Humberside has been considered for a CCS cluster for at least ten years (Yorkshire Forward, 2008) and has benefitted from strong interest and leadership from Drax, initially as an anchor project for a cluster based on large coal-burning power stations (as the White Rose project) and more recently to enable large negative emissions through capture from Drax's ongoing biomass combustion operations. Other strengths include large and well-characterised storage sites, relatively close offshore in the Southern North Sea, potentially with pipeline infrastructure that might be reused; there are also good port facilities. There is active engagement on industry decarbonisation between the local enterprise partnership and an industry group, although not clear that CCS is a main focus, except for Drax.

Development of plans for CCS in the area exemplifies the need to take account of changes in the industrial landscape through scenario planning and considering phased development. The earlier plan to develop a cluster based on coal-burning power stations has become out-dated with closure, or planned closure, of these emitters. While Drax has converted to biomass combustion and remains a very large-scale emitter, it is unlikely that the trunk CO_2 transport route previously planned is optimal to include other large emitters along the South Humber axis. Current questions over the future of the Scunthorpe steelworks also leave uncertainties for overall cluster composition. This all suggests the need to retain flexibility in planning for industrial CCS, as it is likely that Humberside will remain an important industrial area.

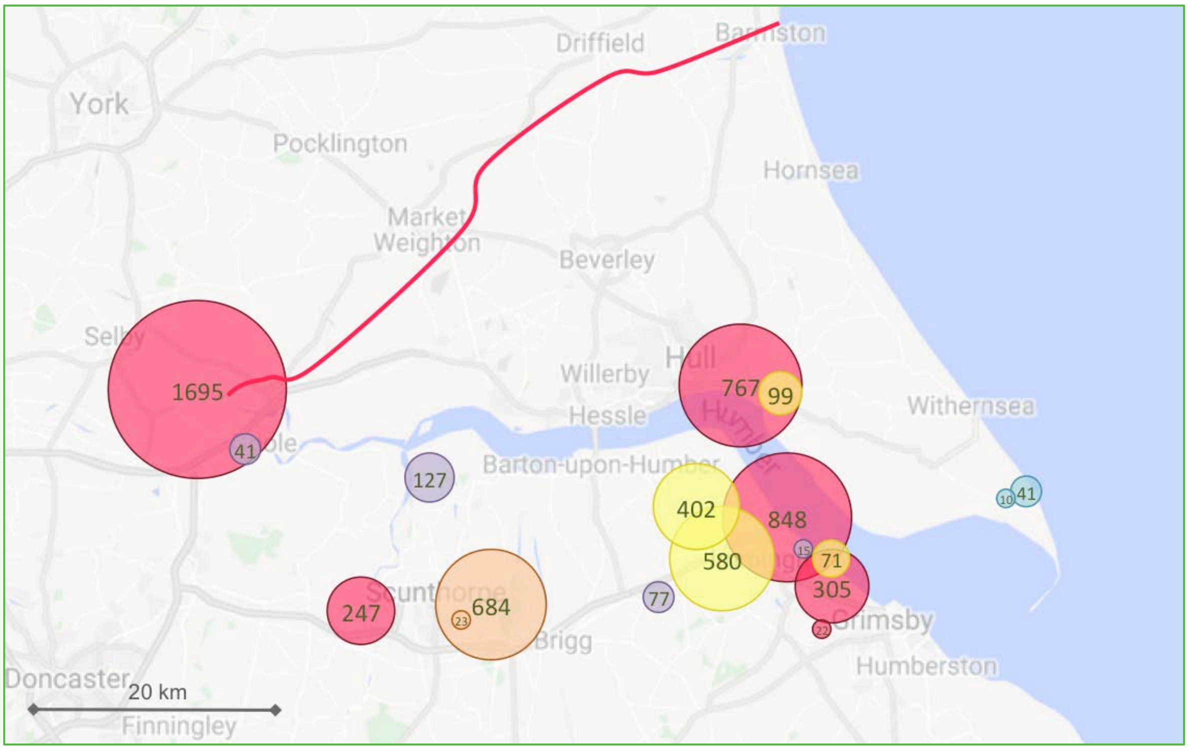

Figure 3-2 Large point-source emissions in Humberside area, figures in kt for 2017 (NAEI, 2019); power/CHP stations (red), steelworks (brown), refinery and chemicals (yellow), gas terminal (blue), cement and minerals (purple). Red line shows approximate pipeline route proposed in 2014 from Drax Power station. Base map from Google MyMaps™ - Map data ©2019 Google.

Table 3-1 Humberside cluster features

GROUP	Feature/ factor	Comment for cluster	Significance +,~,−
EMISSIONS	Emission location distribution	Main locus South Humber: Immingham refineries (2), several CCGTs, Scunthorpe steelworks. Also chemicals at Saltend on North Humber and Drax biomass PS inland.	+
	Emission volume distribution	Several large single point sources, also sites with multiple vents.	+
	Emission volume profile	Risk of closure of steelworks, CCGT operation varies with contracts, overall emission likely to remain high.	~
	Emissions type and quality	Mostly combustion emissions with some higher concentrations from steelworks and refineries	~
AREA	Industrial area character	Refineries, chemical, steelworks all adjacent to urban areas, other sites mostly rural. Major port activities also.	~
	Importance of industry	Major industrial area, large supply chain supported by heavy industries and docks; steelworks major employer (*c.*5000).	+
	Cluster recognition	Area subject to several studies, including White Rose project, but focus previously on coal power stations, now closing.	~
INDUSTRIES	Integration of industry	Refineries integrated for CHP, also Saltend complex and steelworks integrated within sites.	~
	Decarbonisation alternatives	Long-term potential for alternative steelmaking processes, potential for hydrogen fuel use at refineries, biomass in use with BECCS planned.	~
	CCU	Potential for syngas use from steelworks, for fuel re-synthesis. Potential in chemicals sector.	+
	Motivation for decarbonisation	Not clear for steelworks, not main concern, economics will dominate. Unknown for other industry sectors.	−
	Motivation for CCS	Strong for Drax, for negative emissions; not clear for other sectors.	+
RELATION-SHIPS	Stakeholders	Drax partnership, Local Enterprise Partnership, industry group (CATCH) all engaged with decarbonisation, however, only Drax clear support for CCS	+
	Policy position	Previous project (White Rose) had been a front-runner nationally. National policy supportive generally, not specific to area.	+
	Public position	Unknown, probably ambivalent, but no significant issues for earlier White Rose proposals.	~
INFRASTRUCTURE	CO$_2$ collection options	Previous studies considered pipeline networks north or south of Humber. Rail links to most major emitters, with active terminals.	~
	CO$_2$ consolidation options	Brownfield land at Immingham and Grimsby, limited within emitter sites. Ample greenfield area.	+
	Existing CO$_2$ infrastructure	SMRs at Saltend and at refineries, but not clear of CO$_2$ collection.	−
	Infrastructure reuse options	Existing offshore pipelines from gas terminals (Theddlethorpe, Easington) but prospect of availability unknown. Existing tanker berths on Humber at Saltend (2) and Immingham (7).	+
STORAGE	Storage accessibility	Closest at Endurance (*c.*80 km offshore) several other good options in Southern North Sea within 250 km.	+
	Storage capacity	Good, Endurance *c.*500 Mt; more distant sites may total several times this.	+
	Storage flexibility	Good, options for sequentially linking sites. Also options for shipping.	+
	Storage development integration	National Grid developed transport and storage plans for Endurance in White Rose project, and involved in current Drax project partnership, with Equinor also.	+

Table references: ETI, 2016; UKCCSRC, 2016a; Carbon Trust, 2018; Google, 2019; Humber LEP, 2019; NAEI, 2019).

3.2.2 Teesside

Teesside has almost everything positive in terms of forming an ICCS cluster. A tight geographical area with several large emitters, some with high-concentration CO_2 emissions including one with existing partial capture of CO_2 for sale. The main sites are well integrated with an existing pipeline network; there are good port facilities including an existing small CO_2 import/export terminal. As well as the technical advantages, perhaps the key strength of the area is the tight-knit relationships amongst companies and local agencies with a longstanding industry cluster organisation. This has developed from the collegiate relationships within Imperial Chemical Industries (ICI), which owned many of the main facilities in the past. Since its break-up, the level of cooperation between successor companies has remained high, with an ongoing motivation to succeed as an industrial cluster, as a way of supporting individual company success.

If there is a technical weakness for Teesside as an ICCS cluster it is the distance (*c*.155 km) from the area to the nearest CO_2 storage location. But this is not so great, and plans and costings for pipelines to both the Endurance site and to a site in the Central North Sea were developed as part of the Teesside Collective study (Teesside Collective, 2015). Since that study, the distribution of emissions in the cluster has also changed with the closure of the SSI steelworks at Redcar in late 2015; however, there are now plans for a large new-build CCGT power station with CCS at that site providing a replacement "anchor" for the cluster (OGCI, 2018). This again emphasises the importance for ICCS cluster plans to have flexibility, to allow for variation in CO_2 volumes with the changing industrial profile of the area. Teesside is believed to be considering use of CO_2 shipping for trunk transport, which would help provide such flexibility.

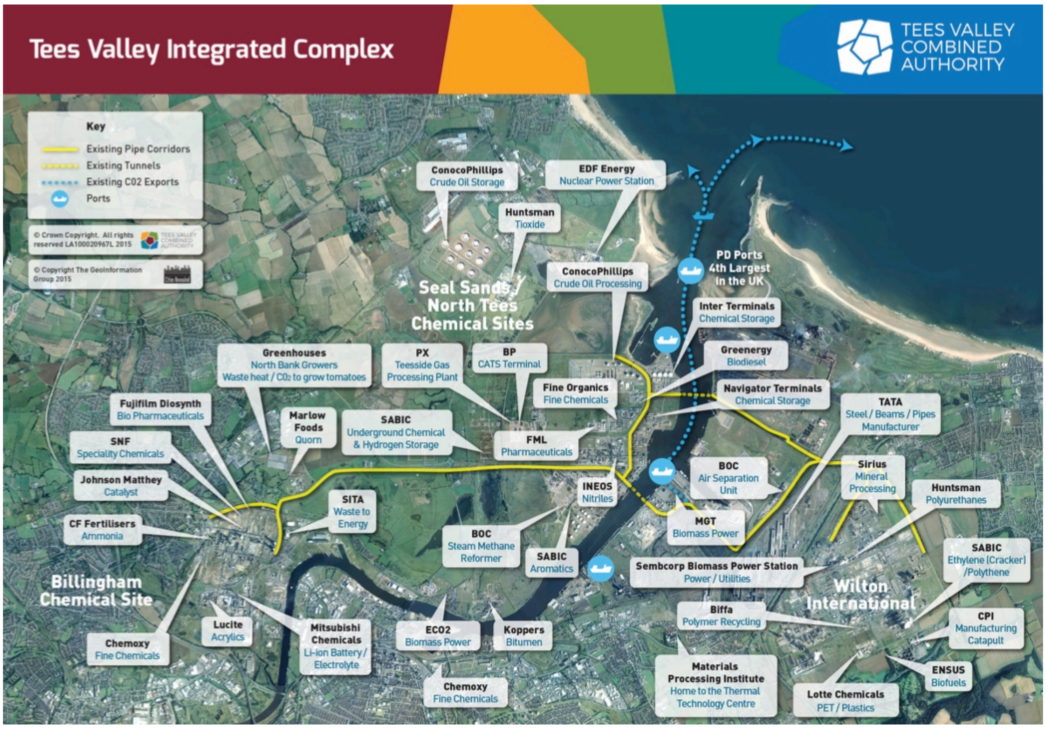

Figure 3-3 Teesside industrial cluster in 2016. The new CCGT+CCS development is proposed for the site of the now-closed steelworks, near the coast east of the river mouth (Tees Valley Combined Authority 2016, used with permission).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Table 3-2 Teesside cluster features

GROUP	Feature/ factor	Comment for cluster	Significance +,~,–
EMISSIONS	Emission location distribution	Fairly tight cluster (10 km) with three main areas, Billingham, Wilton and Seal Sands, along River Tees estuary.	+
	Emission volume distribution	Roughly 5 emitters in 100-500 kt/yr range, two in 750-1250 kt/yr range, but multiple vents, plus numerous smaller emitters.	+
	Emission volume profile	Significant reduction with steelworks closure in 2015, otherwise industry stable or growing with new large CCGT+CCS planned.	~
	Emissions type and quality	Large, high-concentration emissions from hydrogen production for ammonia and bulk supply, otherwise mostly combustion emissions.	+
AREA	Industrial area character	Large-scale industrial complexes, Billingham and Wilton close to urban areas; Seal Sands more distant, but with environmentally sensitive areas.	~
	Importance of industry	Teesside industry critical to both regional and national economy; employs >10,000, £4bn exports.	+
	Cluster recognition	Longstanding cluster recognition, originally as most was ICI. Since break up, North East Process Industries Cluster (NEPIC) formal body.	+
INDUSTRIES	Integration of industry	All three areas heavily integrated, common utility providers including process heat, extensive pipe networks including river crossing.	+
	Decarbonisation alternatives	Some biomass in use/planned, potential for hydrogen use, but large CO_2 process emissions.	+
	CCU	Potential in chemicals sector.	~
	Motivation for decarbonisation	Strong motivation in industry and community in general. Tees Valley Combined Authority (TVCA) have strategic low-carbon plan.	+
	Motivation for CCS	Strong, key element in TVCA plan, previous project laid groundwork.	+
RELATION-SHIPS	Stakeholders	Strong engagement, NEPIC, TVCA, Teesside Collective (CCS group)	+
	Policy position	Strong support from local/regional authorities. National policy supportive generally, national recognition of cluster’s importance.	+
	Public position	Generally supportive of industry as major employer. Good public engagement through Teesside Collective project work.	+
INFRASTRUCTURE	CO_2 collection options	Main emitters can be linked through existing pipeline corridors, designs existing. Previous rail network now mostly derelict.	+
	CO_2 consolidation options	Brownfield site for compressor station identified with design existing. Space available on riverside for L-CO_2 operations.	+
	Existing CO_2 infrastructure	Existing capture facility at CF Fertilisers, CO_2 liquefied for commercial supply. Existing L-CO_2 ship import/export berth with small storage capacity and road tanker filling point.	+
	Infrastructure reuse options	Two offshore gas pipelines, but unlikely to be available for CO_2. Extensive port facilities, several tanker jetties, space for new terminal, large gas storage caverns nearby.	+
STORAGE	Storage accessibility	Closest at Endurance (*c.*155 km offshore), other good options in Southern and Central North Sea all >300 km distant.	~
	Storage capacity	Good, Endurance *c.*500 Mt; more distant sites may total several times this.	+
	Storage flexibility	Good, either through linking from Endurance, or by shipping.	+
	Storage development integration	Partners in new CCGT+CCS project include O&G majors with storage development capabilities.	+
Table references: Teesside Collective, 2015; Google, 2019; NAEI 2019).			

3.2.3 Grangemouth and St Fergus – the “Scottish cluster”

The “Scottish cluster” is unusual; it comprises two separate industrial areas linked by an existing natural gas pipeline (known as Feeder 10) that has long been identified as being able to carry CO_2 (Scottish Power CCS Consortium, 2011). The availability of Feeder 10 for reuse with CO_2 at relatively low cost is a major advantage for potential capture developments at the Grangemouth refinery and petrochemicals complex, the largest Scottish emission cluster (Element Energy, 2014). The southern end of Feeder 10 is close to Grangemouth and several other large emitters are also close to the route (Brownsort, Scott and Haszeldine, 2016). The northern end of the pipeline is at St Fergus, a major natural gas processing complex where around one third of UK gas supply (domestic and imported) is landed. From St Fergus there are three existing offshore gas pipelines, which are suitable for carrying CO_2 onward to identified storage sites in the Central North Sea. One of these sites, the Acorn storage site, has been awarded a CO_2 appraisal and storage licence (OGA, 2018).

The main strengths, then, of the Scottish cluster are in the availability of pipeline infrastructure available for reuse and in the presence of large and well-understood CO_2 storage sites that are ready to be developed. This infrastructure is being positioned, through the Acorn CCS Project, to be able to accept CO_2 from capture at St Fergus itself initially, but also from Grangemouth through Feeder 10, and by ship import through Peterhead Port (close to St Fergus) from other UK or European capture developments (Alcalde et al, 2019). This flexibility will help to counter the somewhat slow engagement of industry in the area resulting largely from the current difficulty of making a business case for CCS.

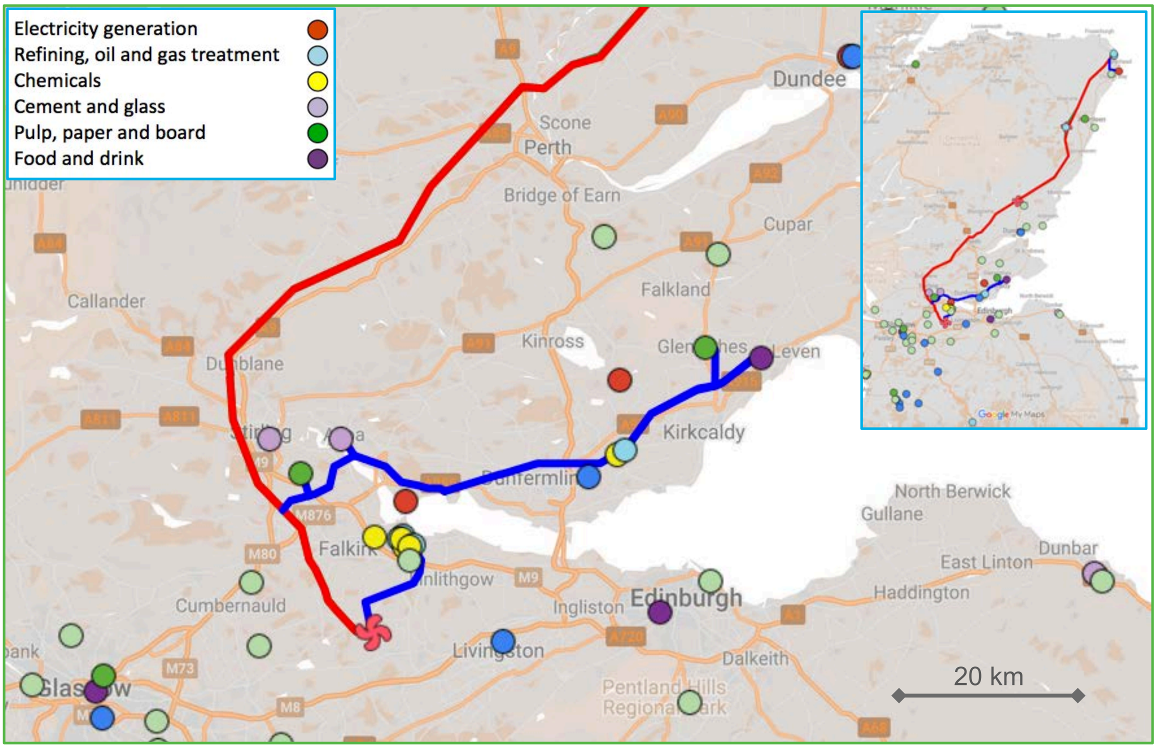

Figure 3-4 Map from Brownsort, Scott and Haszeldine (2016) showing emitters (as at 2014) in Central Scotland, with route of Feeder 10 (red) and potential collection networks (blue) serving Grangemouth and Fife. Inset map shows Feeder 10 route to St Fergus. Map data ©2019, Google MyMaps™.

Table 3-3 Scottish cluster features

GROUP	Feature/ factor	Comment for cluster	Significance +,~,–
EMISSIONS	Emission location distribution	Tight clusters at Grangemouth (5 km) and St Fergus (1.5 km) with looser grouping around Forth estuary and in Fife, fairly close to available pipeline.	+
	Emission volume distribution	Five large emitters at Grangemouth (300-1600 kt/yr), but including refinery, petrochemicals with multiple vents. Six other emitters 200-900 kt/yr close to available pipeline.	+
	Emission volume profile	Industry emissions steady, one gas-fuelled power station varies with contract.	+
	Emissions type and quality	Low to moderate volume of high-concentration process emissions at a few sites, otherwise mostly combustion emissions, some biogenic.	~
AREA	Industrial area character	Grangemouth complex adjacent to urban area, St Fergus and most other sites rural.	~
	Importance of industry	Refinery and petrochemicals sites critical to Scottish and UK economy; nationally strategic infrastructure (gas import at St Fergus, oil pipeline to Grangemouth).	+
	Cluster recognition	Industry cluster at Grangemouth long recognised; ability to include other industry in CCS cluster through use of existing pipeline recognised at least 10 years.	+
INDUSTRIES	Integration of industry	Most of Grangemouth complex well integrated for CHP and other utilities.	~
	Decarbonisation alternatives	Some biomass in use, potential for hydrogen fuel use, electrification limited scope but potential for e.g. glass kilns. Some process emissions.	+
	CCU	Potential for CCU in chemicals sector. Potential for CO_2-EOR in Central North Sea.	+
	Motivation for decarbonisation	Industry motivation varies with sector, strong where premium products (e.g. distilleries), refining and petrochemicals more sensitive to economics.	~
	Motivation for CCS	Patchy in industry, but strong for storage development opportunity.	~
RELATION-SHIPS	Stakeholders	Industry engagement improving, good engagement with Scottish Government (SG) and development agencies.	~
	Policy position	UK national policy supportive generally, SG policy strongly supportive but dependent on UK.	+
	Public position	Fairly ambivalent. Good public engagement through previous Longannet and Peterhead project work and current Acorn CCS Project.	+
INFRASTRUCTURE	CO_2 collection options	Grangemouth and most other main emitters can be linked through existing pipeline corridors. Several distant large emitters could be included using rail links.	+
	CO_2 consolidation options	Brownfield land available for compressor station at Grangemouth, or at gas pipeline node (Avonbridge). Potential for intermodal hub at Grangemouth docks.	+
	Existing CO_2 infrastructure	Small capture plant (mothballed) at NB Distillery, road tanker filling point. Sour gas separation plant at St Fergus.	+
	Infrastructure reuse options	Existing pipeline from Avonbridge, near Grangemouth, to St Fergus, and onward (3 pipelines) to potential offshore storage and EOR sites. Tanker jetties at Grangemouth (6 active, 1 redundant) and Peterhead (1 redundant) near St Fergus.	+
STORAGE	Storage accessibility	Very good, existing pipelines available accessing well-characterised storage sites, including one with development licence (Acorn), one with FEED complete.	+
	Storage capacity	Very good, Acorn site *c*.150 Mt, East Mey >500 Mt, plus other identified sites of several hundreds of Mt.	+
	Storage flexibility	Very good, alternative sites identified, others available, also potential for shipping.	+
	Storage development integration	Partners in Acorn CCS Project include O&G majors with storage development capabilities.	+
Table references: Element Energy, 2010; ETI, 2016; Brownsort, Scott and Haszeldine, 2016; ACT Acorn Project, 2019; Google, 2019.			

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

3.2.4 Merseyside – the Liverpool-Manchester cluster

Considering the Merseyside industrial area initially in the abstract, it has several strong, positive features for the formation of an ICCS cluster. A number of major emitters are located along a clear transport axis, some with high-concentration CO_2 emissions, some large single-point emissions. There is potential for pipeline reuse to access CO_2 storage sites close offshore, with options to extend capacity into other sites, or access alternative storage locations by shipping. Local agencies are supportive of industry decarbonisation, although without a clear focus on CCS, while CCU opportunities are being pursued by industry.

However, what makes the area unusual is the proposal being advanced by the HyNet Project to tackle decarbonisation for industry, and more generally, by a wholesale fuel-switch to hydrogen, replacing natural gas combustion for heat. The project proposes a hydrogen network covering, eventually, the wider Liverpool-Manchester area with hydrogen supplied from a centralised facility, probably by steam methane reforming at a site on the south shore of the Mersey estuary (Progressive Energy, 2017; Cadent, 2018). The network would initially supply industry through new hydrogen pipelines, hydrogen would be available as a transport fuel, and a percentage of hydrogen would be injected into the existing natural gas distribution network at a level not requiring change to consumer appliances. In the longer term transition to a 100% hydrogen distribution is envisaged.

The advantage of this approach is that the production of CO_2 is centralised to the location of the hydrogen supply facilities, reducing the number of separation and capture operations required, minimising any CO_2 collection network and reducing variables for design of trunk transport and storage facilities. Against these advantages one might set the risk of the more fundamental changes required to switch to a different fuel-gas. However, UK policy is supportive of exploring a switch to hydrogen, at least as an option, and other cluster areas and projects are also considering how hydrogen may be used in their developments.

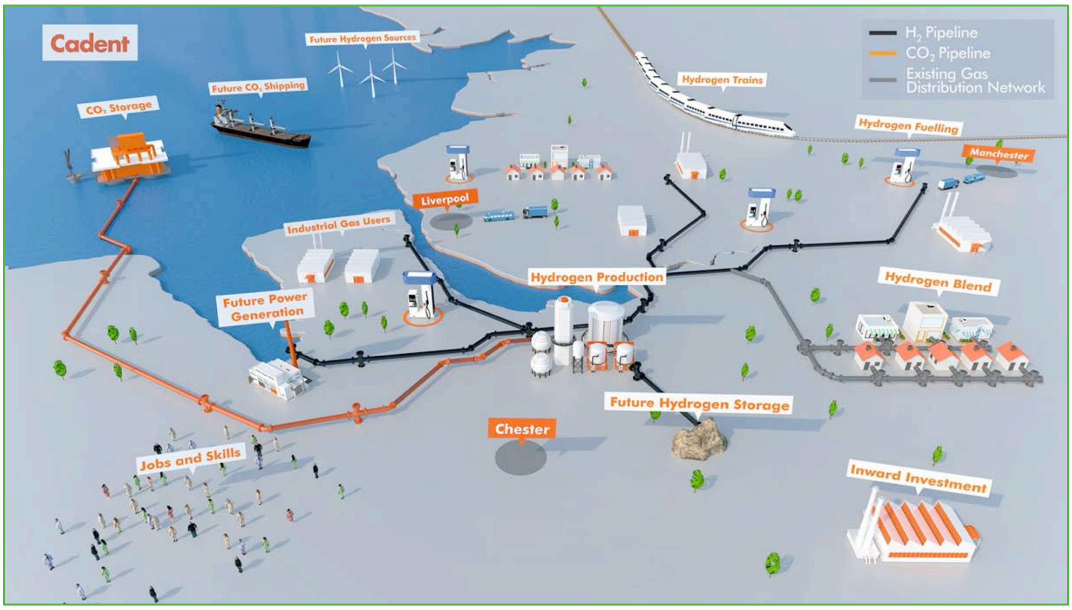

Figure 3-5 Overview of the HyNet Project for the Merseyside area. Image from Cadent (2018), used with permission.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 837754

Table 3-4 Liverpool-Manchester cluster features

GROUP	Feature/ factor	Comment for cluster	Significance +,~,–
EMISSIONS	Emission location distribution	Large conurbation (50 km) with industry largely focused on axis of Mersey and Dee estuaries and Manchester Ship Canal.	+
	Emission volume distribution	Large refinery >2000 kt/yr with multiple vents, three large power stations 1000-2000 kt/yr, roughly 10 emitters 100-700 kt/yr.	+
	Emission volume profile	Fiddlers Ferry coal-burning power station (2 Mt CO_2) planned to close 2020; otherwise unknown, but probably fairly steady.	~
	Emissions type and quality	Large, high-concentration emissions from hydrogen production for ammonia, some other process emissions, otherwise combustion emissions.	+
AREA	Industrial area character	Most industry close to or adjacent to urban areas, some more rural.	~
	Importance of industry	Major industrial area of national significance, refinery, chemicals, automotive, food and drink, glass, minerals and docks, all important.	+
	Cluster recognition	Recognition as chemicals cluster from history as ICI (*cf*. Teesside), HyNet project bringing recognition as potential hydrogen-based cluster.	+
INDUSTRIES	Integration of industry	Good within chemicals and refinery areas at Runcorn and Ellesmere Port, otherwise unknown.	~
	Decarbonisation alternatives	Area proposed for major fuel-switch to hydrogen, initially for major gas users, later for distributed gas users through gas grid.	+
	CCU	Potential in chemicals sector, recent announcement by Tata Chemicals of 40 kt/yr capture plant for reuse in sodium bicarbonate.	+
	Motivation for decarbonisation	Strong low-carbon focus from Local Enterprise Partnership, focussed on offshore wind, not clear for heavy industry but supporting HyNet.	+
	Motivation for CCS	Early recognition of area based on storage potential not followed through, but now again in focus for HyNet project, to provide low-carbon hydrogen.	+
RELATION-SHIPS	Stakeholders	Gas network and industry stakeholders behind HyNet proposals, project has engaged with local agencies, not clear of wider public engagement.	~
	Policy position	National policy supportive generally, including for hydrogen focus, but not specific to area.	~
	Public position	Generally supportive of industry as major employer, but otherwise probably ambivalent.	~
INFRASTRUCTURE	CO_2 collection options	Main emitters can be linked through existing pipeline corridors. Most also have rail links close by and several are sited on ship canal.	+
	CO_2 consolidation options	Some brownfield land near refinery, also at Point of Ayr gas terminal (pipeline beach crossing), and at Tranmere Terminal.	+
	Existing CO_2 infrastructure	Existing CO_2 separation at CF Fertilisers ammonia plant at Ince, but unclear of any capture for supply. Tata CCU project will capture CO_2 for own use.	~
	Infrastructure reuse options	Pipeline from Hamilton gas fields in Liverpool Bay to Point of Ayr identified as potential for future re-use. Limited tanker facilities at Tranmere Terminal, two active jetties, one derelict. Large gas storage caverns nearby.	+
STORAGE	Storage accessibility	Very good, Hamilton field close offshore (26 km), also Morecambe Bay fields further north (*c.*80 km).	+
	Storage capacity	Good, Hamilton estimated at 115 Mt, Morecambe Bay fields *c.* 1 Gt.	+
	Storage flexibility	Good, options for sequentially linking sites. Also options for shipping.	+
	Storage development integration	Not clear, assumed Cadent can draw on storage development expertise.	~
Table references: Cadent, 2018; ETI, 2016; Progressive Energy 2017; NAEI, 2019; Google, 2019; Tata Chemicals, 2019.			

3.2.5 South Wales

While the need to decarbonise the cluster of industries in South Wales is recognised (Welsh Government, 2019), consideration of using CCS to achieve this is at a very early stage (UKCCSRC, 2016b). Industrial emissions in South Wales are dominated by the Port Talbot steelworks, while the other major area of emission is at Milford Haven, with a refinery and other hydrocarbon industries, located some 90 km to the west.

The main potential strengths of the area as a CCUS cluster would include the presence of the steelworks, which could be an anchor to the cluster, with the possibility of off-gas utilisation for fuel re-synthesis. Also an existing pipeline linking Port Talbot to Milford Haven gives the possibility of infrastructure reuse to transport captured CO_2 to a port, for shipping to a storage site. However, these strengths are offset by the risk of closure of the steelworks, and, in particular, the distance to known CO_2 storage areas, with some uncertainties over storage options (CCC, 2017).

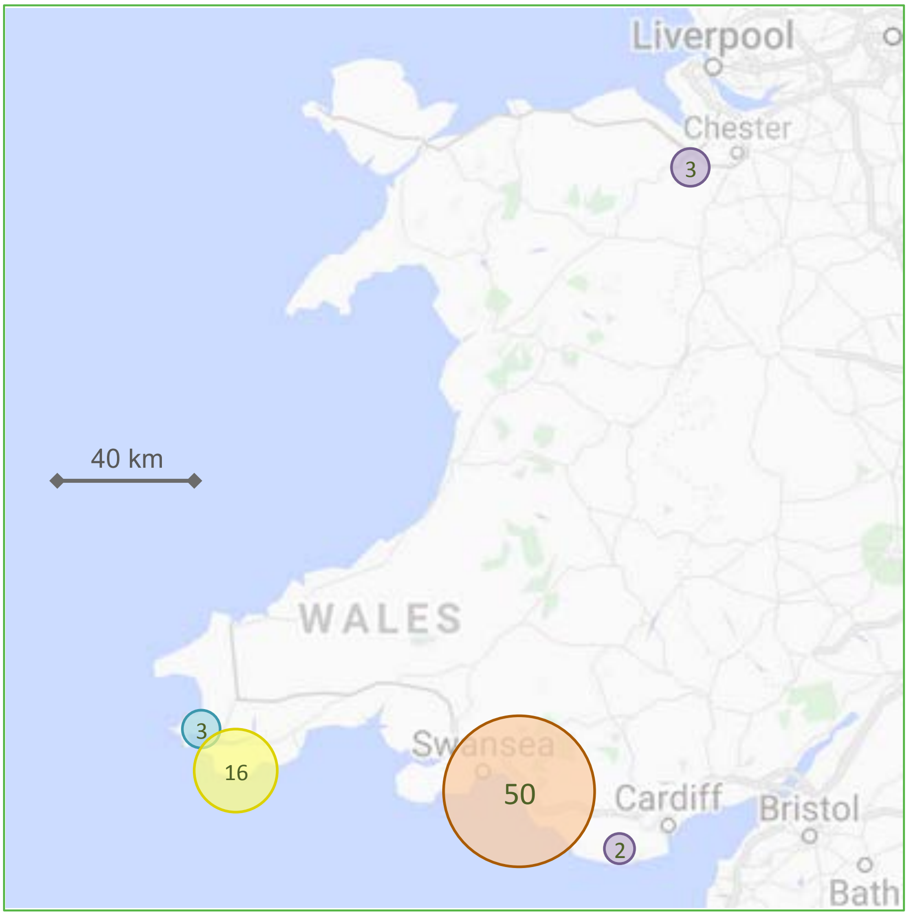

Figure 3-6 Location of large point-source industrial CO_2 emissions in Wales: steelworks (brown), refinery (yellow), LNG terminal (blue), cement works (purple); figures denote percentage of Welsh large point-source emissions (CCC, 2017), circle areas proportionate. Base map from Google MyMaps™ - Map data ©2019GeoBasics-DE/BKG (©2009), Google.

Table 3-5 South Wales cluster features

GROUP	Feature/ factor	Comment for cluster	Significance +,~,–
EMISSIONS	Emission location distribution	Two main loci, Port Talbot steelworks; Milford Haven refinery and major hydrocarbon terminal; each locus with multiple vents.	~
	Emission volume distribution	Steelworks emission dominates, potential anchor.	+
	Emission volume profile	Risks of significant closures - general issue of steel competitiveness and refinery overcapacity.	–
	Emissions type and quality	Mostly combustion emissions with some higher concentrations from steelworks and refinery	~
AREA	Industrial area character	Steelworks close to urban area, refinery rural, both coastal sites.	~
	Importance of industry	Steelworks major employer (>5000) but within mixed economy across area. Nationally significant LNG terminal at Milford Haven.	~
	Cluster recognition	Area at earliest stage of cluster "consciousness"	–
INDUSTRIES	Integration of industry	Within major sites, not between steelworks and refinery, unknown between refinery and Puma hydrocarbon terminal.	~
	Decarbonisation alternatives	Long-term potential for alternative steelmaking processes, potential for hydrogen fuel use at refinery.	~
	CCU	Potential for syngas use from steelworks, for fuel re-synthesis.	+
	Motivation for decarbonisation	Not clear, not main concern, economics will dominate.	–
	Motivation for CCS	Possibly, in combination with fuel re-synthesis from syngas.	+
RELATION -SHIPS	Stakeholders	Tata Steel engaged, but early awareness stage, not clear for refinery.	~
	Policy position	Some local support through FLEXIS project, but CCS not main focus. National policy supportive generally, not specific to area.	~
	Public position	Unknown, steelworks is major employer, probably refinery/terminal also.	~
INFRASTRUCTURE	CO_2 collection options	Pipeline corridor from Port Talbot to Milford Haven. Rail links to Port Talbot and Puma terminal, redundant link to Valero refinery. Possible L-CO_2 supply facility at BOC Port Talbot.	~
	CO_2 consolidation options	Unoccupied land within site boundaries at steelworks and Puma and Valero oil terminals (limited at refinery).	+
	Existing CO_2 infrastructure	Possible L-CO_2 supply from merchant hydrogen SMR facility at BOC Port Talbot.	–
	Infrastructure reuse options	Redundant pipeline connects Port Talbot to Milford Haven, unknown availability or condition. Numerous tanker jetties at Milford Haven, bulk ore import jetty at Port Talbot, limited space for additional jetty.	+
STORAGE	Storage accessibility	Closest at Kinsale (off Cork, *c.*300 km), next East Irish Sea (EIS) (450 km by sea, or awkward *c.* 50 km overland).	–
	Storage capacity	Kinsale has potential issues (uncertain); EIS considered suitable, Gt-scale.	~
	Storage flexibility	Yes, as above, or other more distant storage locations, using shipping.	~
	Storage development integration	Not clear, potentially Ervia (Cork CCS Project), or Cadent (HyNet Project, Merseyside) in longer term.	–
Table references: Tata Steel, 2017; Williams, 2019; Google, 2019.			

3.2.6 Rotterdam

Rotterdam is the most advanced large CCS cluster proposal in mainland Europe, also with a fairly long history of development. Earlier plans were based on an “anchor” capture project, the ROAD Project at the recently built, coal-burning Maasvlakte 3 power station, but this was cancelled following change in national policies regarding generation from coal. The cluster plans have always included a network connecting the large petrochemical and refining sites, based on the existing OCAP CO_2 pipeline, and this now remains as the focus of the ongoing Porthos Project.

A key strength of the cluster is leadership from the Port of Rotterdam Authority, which has set tough emission reduction targets and is actively developing the systems and infrastructure needed to achieve them. The Authority’s position is that it expects companies to invest and contribute to achieving these targets, making use of the infrastructure the Authority provides, or to cease their operations in Rotterdam. The infrastructure and systems being developed include energy efficiency, renewable energy, heat, steam and hydrogen networks as well as the CO_2 transport and storage network.

Rotterdam also holds a key position in Europe from its position as the interchange between mainland Europe and the North Sea Basin. Longstanding conceptual plans, together with some detailed studies, have considered the role of Rotterdam as a “super hub” for CO_2 transport from mainland Europe, using both pipelines and waterborne transport by barge on inland waterways, and by coastal shipping. Onward transport to the large storage capacity available in the North Sea Basin could be by both pipeline and shipping (RCI, 2011; Tetteroo and van der Ben, 2011).

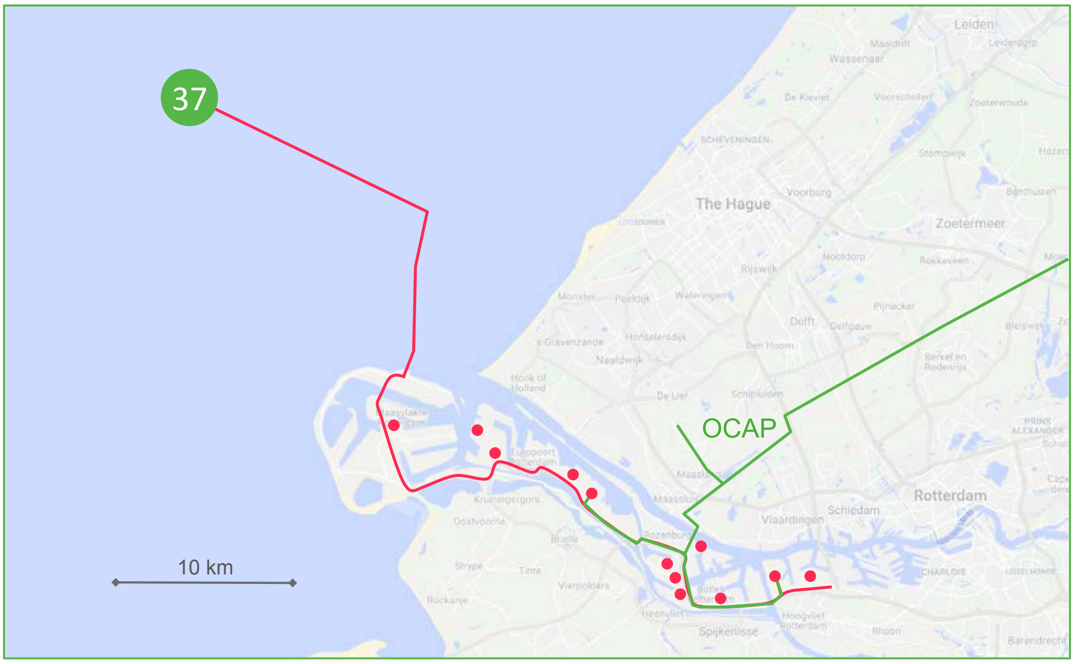

Figure 3-7 Existing OCAP CO_2 pipeline (green, approximate route) and extensions proposed by Port of Rotterdam Authority (red, one of two route options shown) to collect CO_2 from major emitters (red dots) and deliver it to offshore storage (green, figure - capacity in Mt) in depleted gas fields. Adapted from (Porthos, 2019). Map data ©2019, Google MyMaps™.

Table 3-6 Rotterdam cluster features

GROUP	Feature/ factor	Comment for cluster	Significance +,~,–
EMISSIONS	Emission location distribution	Elongated (35 km) cluster of industry along south bank of Maas estuary.	+
	Emission volume distribution	Two coal-burning and two gas-burning power stations, 4 refineries, major petrochemicals, multiple vents, plus other large emitters, major port.	+
	Emission volume profile	Coal power stations scheduled to close, mid-term. Otherwise unknown, but likely steady.	~
	Emissions type and quality	Large process emissions, some high-concentration at refineries and bioethanol plant; otherwise mainly combustion emissions.	+
AREA	Industrial area character	Very large scale industrial complexes, most along Maas estuary giving separation from city, but some urban contacts.	+
	Importance of industry	Globally significant port and one of largest European industry clusters.	+
	Cluster recognition	Strong, Rotterdam Climate Initiative, initiated by Port Authority in *c.*2006, including major industry and power emitters.	+
INDUSTRIES	Integration of industry	Refineries and petrochemicals well integrated within and between sites.	+
	Decarbonisation alternatives	Study of potential hydrogen network undertaken and major project being considered, initial supply through methane reforming with CCS.	+
	CCU	Good potential in chemicals sector.	+
	Motivation for decarbonisation	Strong, Port Authority has set target for CO_2-neutrality and expects companies in area to help achieve this – or move out.	+
	Motivation for CCS	Strong, Port Authority progressing Porthos Project to provide CO_2 transport and storage infrastructure, expecting companies to invest in capture.	+
RELATIONSHIPS	Stakeholders	Strong leadership from Port Authority with good engagement from industry, as well as government agencies.	+
	Policy position	National policy includes CCS as part of balanced climate action approach.	+
	Public position	Current climate focus and balanced approach giving more supportive position following previous public relations issues for CCS (onshore storage).	~
INFRASTRUCTURE	CO_2 collection options	Existing pipeline corridors run the length of the cluster. Potential to expand cluster inclusion through use of barge transport on inland waterways.	+
	CO_2 consolidation options	Site identified for compressor station at beach crossing, also for potential CO_2 trans-modal terminal for L-CO_2 transport by ship/barge.	+
	Existing CO_2 infrastructure	OCAP pipeline links bioethanol plant and capture at refinery hydrogen plant with greenhouses consuming CO_2 in South Holland.	+
	Infrastructure reuse options	OCAP pipeline planned to be included in extended collection network.	+
STORAGE	Storage accessibility	Very good, small initial shoreline site, then further depleted gas fields in P18 block close offshore (25 km), with more spread to north and east.	+
	Storage capacity	Five small sites close offshore have 200 Mt capacity, other larger potential further afield.	~
	Storage flexibility	Good, options for sequentially linking sites. Also options for shipping.	+
	Storage development integration	Porthos project partners include national gas infrastructure company, Gasunie, which is part owner of Cintra, CO_2 transport and storage developer.	+

Table References: RCI, 2011; Porthos, 2019; Vermulen, 2011; Neele et al, 2012; Google, 2019.

3.2.7 Norway

The Norwegian or Grenland cluster is an interesting case, as technically it is fairly unexceptional. The industry emissions are not particularly large; indeed Norway's entire industrial emission is small in international terms. Apart from a small cluster in Grenland (ICG, 2019), other emitters are scattered. Potential storage sites near to the emitters have not been extensively studied (Haugen et al, 2013) and well-characterised sites are a considerable distance away.

The current proposal for the Norwegian full-scale CCS project is for just two emitters initially to capture CO_2, the Norcem cement works at Brevik and the Fortum Oslo Varme waste to energy plant at Klemetsrud. CO_2 will be transported by ship some 600-700 km from these sites to a consolidation hub at Kollsnes, from where it will be piped to a storage site in the Johansen saline formation, near the Troll oil and gas field (CCS Norway, 2019). Two refineries in southern Sweden are also being evaluated for potential CO_2 capture projects with transport by ship under the same system (SINTEF, 2019).

This case shows that with strong government leadership and utilising Norway's strong offshore and engineering expertise, solutions to such technical challenges can be found. The choice of CO_2 transport by ship may be an obvious one for Norway, given its geography and tradition, and it is seen as enabling far more than just collection of Norway's own CO_2 for storage. There is a clear longer-term intention to import CO_2 from other countries for storage and this is seen as an economic opportunity for Norway in the future.

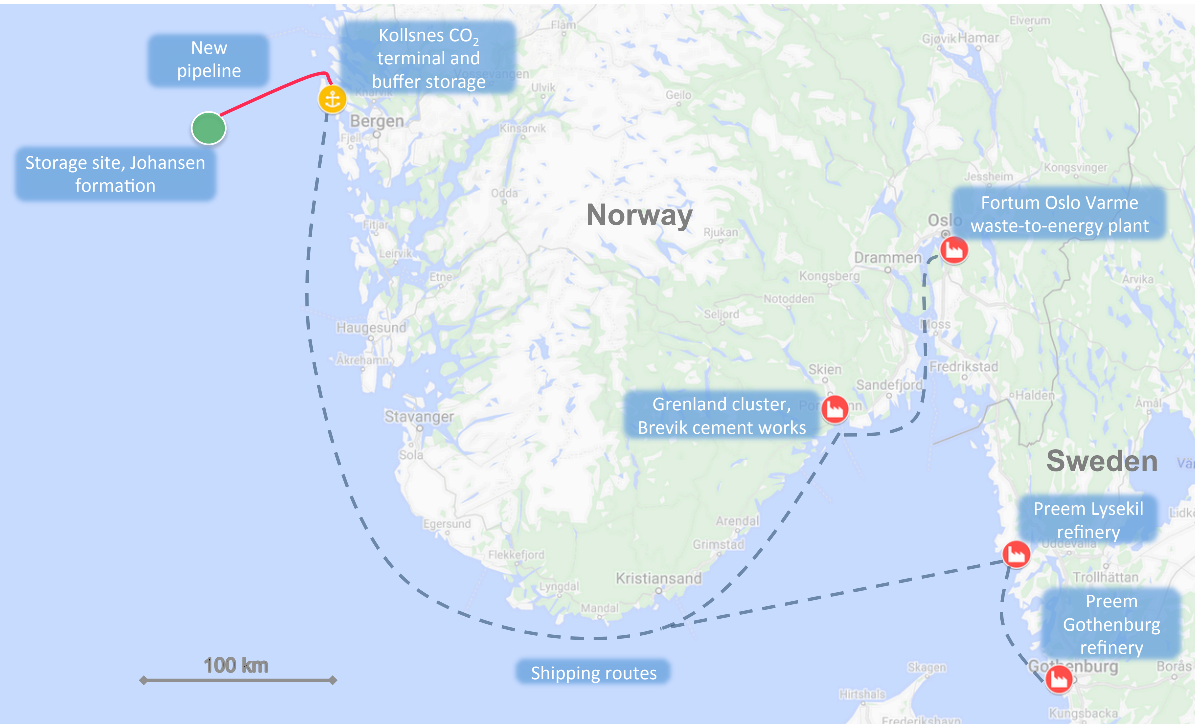

Figure 3-8 Map showing current proposals for full-scale CO_2 management in Norway, plus potential extension to include refineries in Sweden, including potential CO_2 capture sites (red), intermodal terminal (yellow) and storage site (green), with indicative shipping routes and new pipeline. Base map from Google MyMaps™ - Map data ©2019GeoBasics-DE/BKG (©2009), Google.

Table 3-7 Norway cluster features

GROUP	Feature/ factor	Comment for cluster	Significance +,~,–
EMISSIONS	Emission location distribution	Several emitters in Grenland clustered (10 km) around Frierfjorden, and at Herøya Industrial Park, near Porsgrunn, plus cement works at Brevik; other emitters further scattered around Oslofjord	+
	Emission volume distribution	Mostly mid-scale emitters, but up to *c.*1 Mt/yr; multiple vents at most main sites.	~
	Emission volume profile	Unknown, generally rising nationally.	~
	Emissions type and quality	High-concentration emissions from hydrogen production for ammonia, cement and other process emissions, also combustion emissions.	+
AREA	Industrial area character	Herøya Industrial Park and Klemetstrud energy from waste plant semi-urban; other sites rural, coastal.	~
	Importance of industry	Important nationally, relatively small but important export products - ammonia, silicon, polymers.	~
	Cluster recognition	Local cluster organisation (Industriclusteret Grenland, ICG) includes main emitters. Longstanding recognition for CO_2 capture trials at Brevik.	+
INDUSTRIES	Integration of industry	Good integration between companies in Fierfjorden and Herøya and within complexes.	+
	Decarbonisation alternatives	Alternative fuels possible for cement, some potential for hydrogen use for heat, but large CO_2 process emissions.	~
	CCU	Yara capture much of the CO_2 from ammonia production to supply to existing European industrial CO_2 market, and plan to grow this export.	~
	Motivation for decarbonisation	Specific companies, but clear that a strong general motivation exists.	~
	Motivation for CCS	Specific companies progressing CCS as part of Norwegian Full Scale Project, Norcem at Brevik, Fortum Oslo Varme at Klemetsrud, previously Yara.	+
RELATION-SHIPS	Stakeholders	Norwegian Gov and state-owned bodies leading on CCS, with specific companies also. Not clear of general engagement with industry or public.	~
	Policy position	National government has ambition to develop CCS and is supporting with funds and on international engagement.	+
	Public position	Unknown, probably ambivalent.	~
INFRASTRUCTURE	CO_2 collection options	Capture sites considered are coastal, collection by shipping being developed. One exception is Klemetsrud, requires short new pipeline or trucking.	~
	CO_2 consolidation options	Transport by ship proposed, expecting discrete pick-up points with consolidation occurring at Kollsnes, near Bergen, *c.*600-700 km away.	~
	Existing CO_2 infrastructure	CO_2 capture and liquefaction at Yara, Herøya with ship export terminal. Experience of CCS with Sleipner and Snøvit projects.	+
	Infrastructure reuse options	Tunnel containing pipeline links Herøya and Fierfjorden sites, potential for reuse if consolidation needed at either site.	~
STORAGE	Storage accessibility	CO_2 will be stored in Johansen formation, 80 km offshore, but *c.*600 km from Grenland.	–
	Storage capacity	Estimate of *c.*150 Mt in southern part of Johansen formation	~
	Storage flexibility	Other aquifers identified in area (near Troll field).	~
	Storage development integration	Gassnova is overseeing project, partnership of Equinor, Total and Shell are developing transport and storage.	+
Table references: USEIA, 2015; ICG, 2019; Equinor, 2018; CCS Norway, 2019.			

3.3 Relative importance of cluster characteristics

It is tempting to take the case studies above and compare one cluster to another to judge which is the strongest. This would be a misguided approach and is not the point of the exercise. The allocation in the tables above of symbols denoting the significance of cluster features is qualitative and intended to draw attention to more important features of each cluster, rather than as scoring system. All industrial clusters are different, and so approaches to developing ICCS clusters will also be different to take advantage of the strengths of an area and its connectivity. Also, some of the clusters described above have been under discussion for many years, others only for a short period, so direct comparison is not appropriate.

However, it is appropriate to reflect generally on the characteristics common to the ICCS clusters that are most highly developed and that are making best progress at present. One important characteristic is clear leadership from a suitably empowered authority, such as national or regional government, a port authority, or regional or local development agency. A clear vision for the cluster area in the future is an important part of this leadership. Of equal importance is the engagement with, or indeed leadership from industry in the area, and the cooperation between companies, the relevant authorities and public bodies. Good public relations, both for the industries involved and for developing ICCS cluster plans, are also important, at least to a level of public awareness and acceptance if not active support.

Considering more technical characteristics, for decarbonisation of an industry cluster through CCS, the ability to access well-characterised CO_2 storage with suitable long-term capacity is key. Other means may be available for decarbonising industry to an extent, but for deep-decarbonisation, especially where process emissions are involved, CCS is likely to be necessary meaning CO_2 storage is essential. Factors that reduce costs of establishing CCS are also important. Such factors include the presence of high concentration CO_2 emissions that will have lower costs of capture, or the availability of infrastructure suitable for reuse with CO_2, such as existing gas separation equipment, pipelines, or port facilities for CO_2 transport. The ability of a cluster to use shipping for CO_2 transport, at least in early phases, can also reduce the initial investment needed and provide flexibility.

Considering the characteristics of potential ICCS clusters explored in these case studies overall, the main observation is their diversity; all are different and there is no one best way to develop. Technical advantages can be important but it is suggested that the overriding factors leading to progress are the motivations, leadership and relationships present between the stakeholders in the industrial cluster area.

4 Data collection and analysis methodologies

In Section 2.2 a number of previous studies were summarised where methodologies for recording descriptions, or for the definition, of ICCS clusters were discussed. It was suggested that there are three general steps for definition of an ICCS cluster – determining what CO_2 may be captured, how it will be captured, collected and transported, and where it will be stored.

At this level, this approach is intentionally simplistic, as the objective is to define the information and data that needs to be collected to initiate activities in a potential ICCS cluster area. This outline methodology is shown schematically in Figure 4-1, and the main aspects are described in more detail, with examples and some discussion in the following Sections, 4.1 to 4.3.

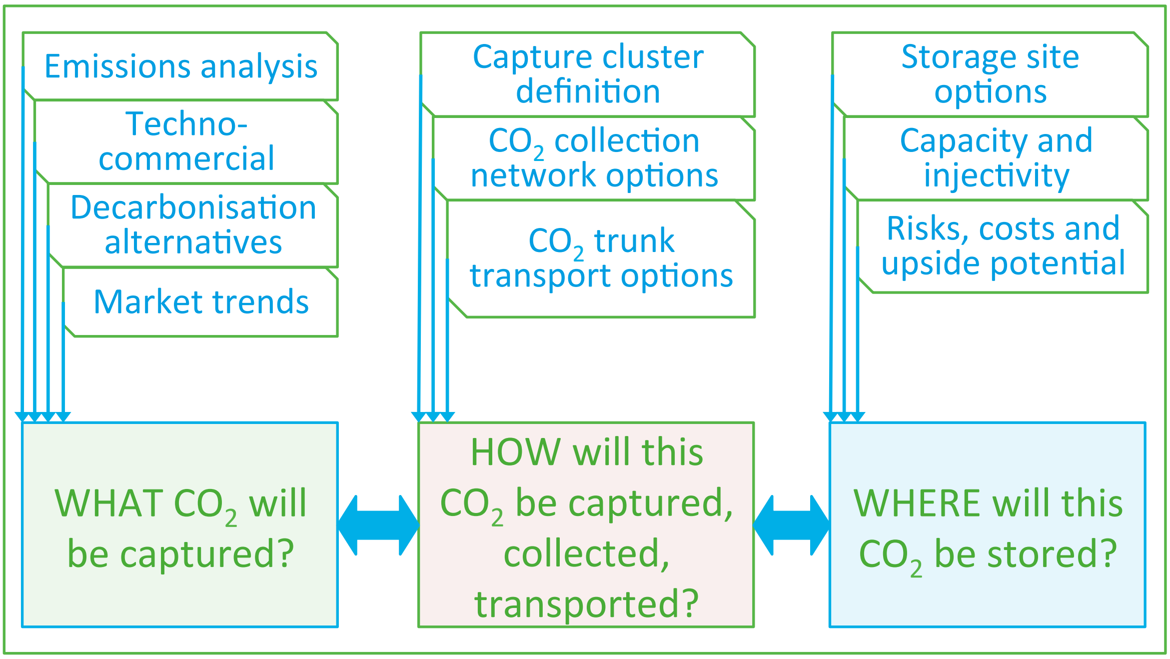

Figure 4-1 Cluster definition methodology – schematic outline.

This discussion is intended to highlight the objectives of the main sections of the suggested methodology and provide some examples of points to consider. However, it is clear that every industrial area is different and so the methodology and the considerations made in assessing an area's potential as an ICCS cluster will need to be adapted and developed for each case. Equally, the sources of information and data will vary with the area so cannot be defined completely here. The methodology is also generally described in a linear, sequential fashion, whereas in fact there will be numerous interactions between sections and knowledge of all aspects will be needed to define a realistic ICCS cluster proposal.

Sections 4.1 to 4.3 discuss information and data collection, and the objectives of the suggested methodology, in this general sense. A following section, 4.4, describes an overall flow for the methodology and gives a structure for assembling the data and information in a series of tables. Detailed lists of data and information that are considered likely to be necessary for definition of ICCS clusters are provided in Appendix A. These lists have been adapted by Universidade de Évora into a database system for collection of this information by local teams of the STRATEGY CCUS Project.

4.1 Determining what CO_2 may be captured

The objective of this part of the suggested methodology is to develop an understanding of the CO_2 that may be captured in the cluster area as part of an industrial emissions reduction programme using CCS. This is not only an inventory of current emission quantities and locations, but needs to take account of foreseeable influences such as the development of alternative decarbonisation technologies, economic factors, changes in societal behaviour, policy and markets.

The starting point is the definition of current CO_2 emission quantities in the cluster area, the locations of emitters and related details. Once this inventory of the CO_2 emissions that are currently occurring has been established, it is necessary to consider what portion of that may be appropriate to address using CCS. A number of factors may determine this portion and it is important to understand that there is no one “right answer”. These may be roughly divided into technical or techno-commercial factors, the options for alternative means for achieving the same emission reductions, and the market influences on production leading to the emissions, including policy, regulation and societal behaviour changes. Beyond identifying such factors, the influence they will have cannot be generalised, but will depend on the specific circumstances in any area being considered and at any particular time. Some examples will be given for illustration.

4.1.1 Emissions analysis – current emission inventory

There are usually various sources of emission data at different levels of detail. Large emitters report to the EU Emissions Trading System (ETS), but this data may be aggregated for a number of facilities or over a company and is sometimes difficult to interpret. More useful, may be local, regional or national data that will be collected by appropriate agencies for compilation into the national returns to the ETS.

In Scotland, for instance, the Scottish Environment Protection Agency (SEPA) collects data from all companies with emissions licences in Scotland and lists CO_2 emission quantities over a certain threshold in a publicly accessible database, the Scottish Pollutant Release Inventory (SEPA, 2017).

Locations of emitters may also be indicated by such public inventories, but sometimes only the company address is given and this may be an office address rather than location of the emitter. Some degree of checking may be required, using a tool such as Google Maps™, or by contacting the company, or other local knowledge, to determine the actual emission location. For sites with multiple vents, such as petrochemical complexes or steelworks, it is unlikely that data on individual vent streams will be available publicly, and it may be necessary to develop a good relationship with the company to obtain this data.

The objective of compiling a current emissions inventory for an area is to allow analysis of the emissions in terms of quantity and location, to identify the largest emitters and the areas with greatest density of emissions, as well as other information on emitters and their emissions that will help select the sites with greatest potential to deploy carbon capture and be involved in an ICCS cluster.

From this exercise of collecting emission quantity and location data, details such as the industries involved, the type of emissions (whether combustion or process emissions) and perhaps the fuel type may emerge, or may be deduced. For an initial conceptual study of a potential ICCS cluster, this level of information, essentially a “snapshot” of recent CO_2 emission sources and quantities, may be sufficient. However, for more in-depth assessment of an area’s potential for CCS or for more detailed feasibility studies, it is useful to understand details of the CO_2 “quality” in terms of composition (CO_2 content, other major gases, trace impurities), condition (temperature and pressure), as well as flow rate and flow profile (continuous, intermittent, seasonal).

4.1.2 Technical/techno-commercial factors

Techno-commercial factors follow from the detailed emission analysis for an area. For instance, facilities that have large emissions at high CO_2 concentration from a single vent may be more amenable to CCS technology than those that have numerous vents with low-concentration emissions – even if the overall quantity is high. In several cluster projects described to date (e.g. Teesside, Rotterdam, Grenland), the presence of large, high-concentration CO_2 sources, such as from hydrogen production for ammonia synthesis, or for refinery use, has been a strong feature. Conversely, the large number of vents that would need to be included in a comprehensive application of CCS to a refinery has been given as a reason for it being unjustifiable as a technology in that context (Simmonds et al, 2002).

Other technical factors that may limit the application of CCS include the need for space for capture equipment, potential effects on the production process and intermittency of emission (e.g. batch or campaign processing, seasonal production). Most of these are not technical “showstoppers” but make the application of CCS more difficult to justify commercially. Understanding these factors for the industries across a cluster area helps to identify the sites that have the greatest potential to join an ICCS cluster.

4.1.3 Alternatives to CCS for industrial decarbonisation

The main approaches recognised to achieve reduced CO_2 emissions from industry, assuming a constant level of production, are material and energy efficiency, fuel switching to give lower carbon intensity for the energy requirement, and the application of CCS. The degree to which the alternatives may reduce the emissions in an industrial area will affect the quantity of CO_2 to which CCS may be applied. This is important to understand in order to refine estimates of the scale of a potential ICCS cluster.

Material and energy efficiency – getting the same product output for less input – clearly is likely to have a business justification and so has a degree of priority. But this has been a main focus of industrial process development for a long period and so is unlikely to have large gains remaining available for established processes.

Fuel switching for energy requirement, for example electrification, use of biomass, biogas or hydrogen, may have a role to reduce CO_2 emissions in specific industrial applications and the degree to which this may happen needs to be assessed. Electrification, however, is not easily applicable to many important process industries, particularly those needing high temperatures at large scales. The use of biomass or biogas for energy in industry does have application in a number of areas, such as the pulp and paper, and food and drink sectors. But CO_2 is still produced, so while such fuels may be considered carbon neutral, the use of CCS as a means to reduce emissions further is not precluded.

Switching to hydrogen appears likely to be technically feasible for many industries where natural gas is currently the main fuel. If hydrogen is produced by electrolysis from renewable electricity there is no role for CCS. However, the bulk quantities of hydrogen needed for industry are likely to be most cost-effectively produced, in the near to mid-term at least, from natural gas by steam methane reforming (SMR). This process produces CO_2 as a by-product, which requires CCS to make the overall hydrogen energy system low-carbon.

4.1.4 Policy, regulation and societal change

The emissions from an industrial area are inevitably influenced by the level of production, and so by the market demand for the products of the area. The market is in turn influenced by policy, regulation and societal behaviours, which are themselves strongly linked. Where trends in the market can be clearly recognised it is appropriate to take account of them in assessing the potential for application of CCS in an industrial area, as again, these trends will affect the scale of a potential ICCS cluster in terms of CO_2 quantity.

For example, the drive to reduce CO_2 emissions from road transport, whether by electrification or use of hydrogen or other low-carbon fuels, is likely to change the market for liquid petroleum fuels in the future, with consequent effects on refinery operations. Similarly, the nature of some global markets, such as steel, is likely to lead to further rationalisation of steelmaking in Europe. It may not be possible to quantify such effects, or predict them with any certainty; however, it is sensible to include them in judgements on the suitability of an area for investment in CCS.

4.2 Determining how CO_2 will be captured, collected and transported

Once a picture is developed of the quantity and sources of CO_2 emissions in an industrial area that may be addressed by CCS in the foreseeable future, as outlined above, the key thinking that leads towards the recognition of a promising ICCS cluster is about how the cluster will be structured and operated. This needs to consider both the more technical aspects such as facilities involved, infrastructure, technology and routing decisions, and also some aspects of stakeholder involvement and interaction, all considered with a view to delivering to the area the desired CO_2 emission reductions alongside the benefits of a clustering approach.

The objective of this section of the suggested methodology is to develop the potential scope for an ICCS cluster in the area of interest. This should be done in a way that includes engagement with stakeholders, in order to gain support for development of the cluster. Developing a scope implies that some emission sources will be included in the scope while others will not be. This filtering process will be based on a number of considerations, or criteria, for including a facility in the scope and is covered in Section 4.2.1 below. To set fixed criteria for inclusion in the scope as part of a methodology would be counter productive, as it is not realistic to predict all the possibilities. At different times, or under different circumstances it may be appropriate to include different emitters in the scope of an ICCS cluster and several scenarios, or a phased progression of developments may be considered. The process of refining these to a concrete project proposal is likely to take a number of iterations.

The overall scope and the way it is presented need to show the benefits to an area of developing an ICCS cluster, not just in terms of the fundamental purpose of reducing climate-damaging CO_2 emissions, but also in terms of the potential benefits to different stakeholders, such as through sustaining value and employment from existing industries, potential to attract investment to an area, or improved air quality.

There are three main subject areas to consider within this overall cluster scoping: the CO_2 emitters that may participate in the CCS cluster and the CO_2 capture options for these sites; how the captured CO_2 will be collected together; and how the CO_2 will be transported to the proposed storage site. The first of these is, perhaps, the key part of the process of ICCS cluster definition. These areas are each discussed in the following sections. The discussion of trunk transport is limited to systems for individual ICCS clusters, no consideration has been given in this report to how a number of clusters may share transport infrastructure.

The scoping process also needs to take account of the availability and constraints of potential storage sites, at least in broad terms, in order that a realistic matching of capacity across the whole CCS chain – capture, transport and storage – is considered for the whole lifecycle of the facilities and infrastructure involved. This is touched on at a high level in Section 4.3, while the subject of methodology for CO_2 storage appraisal is covered in depth in the parallel report *Storage Resource Assessment Methodologies* (Cavanagh, 2019).

4.2.1 Capture cluster definition

Drawing on the emissions analysis described in Section 4.1, including the modifying factors described, the objective of this section of methodology is to identify companies and their facilities that may participate in a CO_2 capture cluster within an industrial area, in order to define the shape, scale and structure of the cluster. In terms of the general steps of the methodology, this section overlaps with, or is an iteration of, the question of WHAT CO_2 will be captured.

The outcomes of this exercise will include:

- A list of companies and facilities that may participate in a CCS cluster,
- Identification of appropriate capture technology for the facilities,
- Estimation of the quantity and profile of CO_2 captured,
- Indication of development phasing,
- Identification of relevant existing resources, infrastructure and operations.

There is no one, single way of going about this. It can be done, for instance, as a desk-based study, using the emissions analysis to identify emitting facilities considered most appropriate. These may be facilities that have the largest emissions, or those that have high concentration emissions. Or those facilities that have some other technical advantage, such as proximity to potential or actual CO_2 transport infrastructure, or a resource that can be used to reduce capture costs such as excess heat or an alkaline by-product stream.

The Scottish case study listed in Table 2-1 is an example of a desk-based study to identify a potential CCS cluster (Brownsort, Scott and Haszeldine, 2016). In this work emitters were selected for further evaluation on the basis of ongoing emission volume (>100 kt/yr) and proximity to an existing pipeline with potential for reuse with CO_2.

Or it may be that companies identify interest in forming a CCS cluster themselves, through, for example, a local industry organisation with an interest in reducing emissions of its members. This was the case in Teesside where the North East Process Industries Cluster (NEPIC) group launched a Process Industries CCS Initiative, which led to the Teesside Collective project (Teesside Collective, 2015). The group of emitters forming this cluster project included two sites where high-concentration CO_2 was already separated in large quantities as part of hydrogen production, but also one where market trends led to a need to reduce carbon intensity of its product.

In the STRATEGY CCUS project it is proposed that local teams within the project will collect information and data on emissions and facilities in their areas and also engage with industry and other stakeholders, forming new, or supporting existing, industry groups with a CCS interest. A combination of desk-based analysis and discussions with stakeholders will allow a view to be formed of the potential ICCS cluster that may be developed in an area, including the outcomes listed above.

This view may include recognition of companies or facilities within the cluster that may spearhead CCS development. These may be large-scale emitters that form an “anchor project” for the cluster (such as a power plant), facilities that currently emit high-concentration CO_2 (such as hydrogen production or fermentation plant), or sites where partial capture is advantageous (such as from a particular vent or process emission). These can potentially have lower unit cost of CO_2 capture and so help to initiate a cluster project and the development of transport and storage infrastructure.

Although selection criteria for industry involvement in an ICCS cluster will differ between areas and should remain flexible, some examples of criteria to consider are listed below.

- Facilities with emissions above a certain annual volume threshold.
- Very large emitters that could form an “anchor project”.
- Facilities with emissions of higher concentration CO_2 streams.
- Emission sources located close to potential CO_2 transport routes, or to CO_2 storage sites.
- Emission sources located near existing infrastructure that can be reused for CO_2 transport.
- Emission sources that have no alternative decarbonisation options.
- Emitters who have market opportunity for low-carbon intensity products.
- Emitters where environmental credentials form part of their marketing strategy.
- Emission sites where there is a resource available that can reduce the cost of carbon capture, such as heat (for amine regeneration) or alkaline waste streams (for CO_2 absorption).
- Emitters that are under regulatory, or fiscal policy pressure/incentive to reduce CO_2 emissions.

A view of the phasing of addition of further capture projects to an ICCS cluster, with the timings and CO_2 quantities involved, also needs to be developed. This may include consideration of alternative scenarios with differing timings and rates of build-up of capture volume. It is important to develop proposals that have the flexibility to allow new capture facilities to join the cluster later and that are robust to the loss of individual facilities.

Early work on the Acorn CCS Project (under the ACT Acorn Project funding) developed different scenarios for the potential build up of supplies of captured CO_2 (Dumenil et al, 2017) and considered how the initial CO_2 transport and storage infrastructure proposed by the project could support successive phases of "build-out" (Gomersall and Brownsort, 2018). This allowed a proposed business model with low initial risk and capital exposure, mid-term growth and maximum long-term use of assets (Murphy and Pilbeam, 2018). Figure 4-2 shows CO_2 supply volume profiles over time for the two scenarios considered.

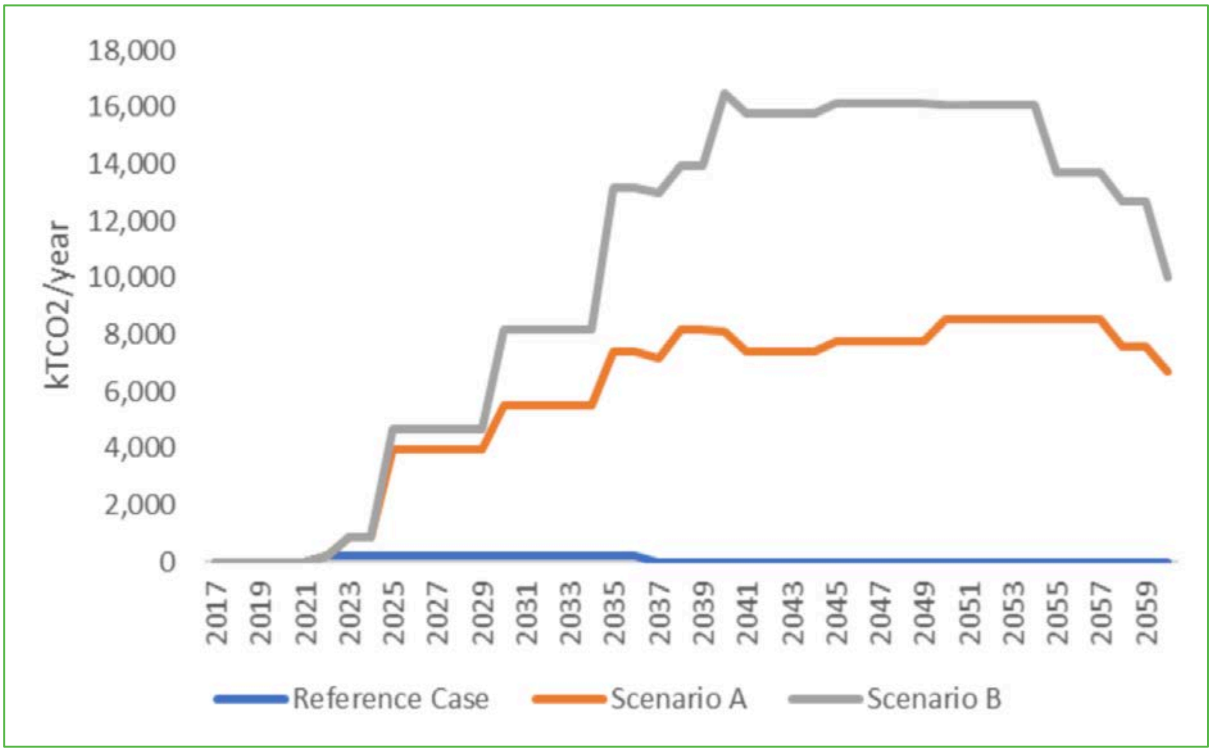

Figure 4-2 Comparison of CO_2 supply profile scenarios developed for the ACT Acorn Project (Dumenil et al, 2017). Reference case is minimal project capture volume from one unit at St Fergus.

As the scope of a potential ICCS cluster and the emitters involved becomes clear, an initial assessment of the capture technology options can be made. The choice of technology depends on the specifics of the emitting facility and process and is beyond the remit of this report. However, all three main technology groups – pre-combustion capture, post-combustion or post-process capture, and oxyfuel combustion – can have applications in industry (IPCC, 2005).

In estimating the quantity of CO_2 that may be captured from any industrial site or facility, a judgement needs to be taken on the proportion of the total emission that may be captured, often termed the "capture rate" (not to be confused with physical flow rate of captured CO_2) or "capture efficiency". A starting approximation may use a capture rate of 90% of total CO_2 emission treated, however, this figure may be higher (to approach 100%) or lower depending on the technical and commercial choices of the capture plant design (Feron et al, 2019).

Identification of facilities involved in a potential capture cluster inherently begins to address the next section of methodology, which is to define how the captured CO_2 is collected together within the area. This is discussed in the next section.

4.2.2 CO_2 collection network

From the locations of potential capture plant and the quantities of CO_2 that may be captured, the requirements for a collection network can begin to be defined. This is also influenced by the intended CO_2 storage location and by the intended method of trunk transport to the storage, which need to be considered in parallel, as they define the downstream delivery requirement for the collection system.

The objective of this section is to identify a cost-effective and efficient system to collect the CO_2 captured in an ICCS cluster, and deliver it to the entry point (or points) of a trunk transport system in the condition, quality and quantity required.

Outcomes of this section of methodology include:

- Proposal of CO_2 transport mode, or modes, to be used.
- Definition of collection points, routings, capacities, delivery points.
- Identifying options for any centralised facilities needed for the collection system.
- Information to allow cost estimates of collection system to be progressed.

A useful starting point is to catalogue existing transport infrastructure in the cluster area that has potential to be used, or is already used, for CO_2 transport. CO_2 is currently transported in Europe mostly using modular transport systems – road tanker, rail tank-car and coastal shipping – to service the existing market in L-CO_2 for industrial uses, including in the food and drink sector. There is also limited existing use of pipelines for CO_2 transport in Europe, such as in the Snøhvit Project (Norwegian Petroleum Directorate, 2019), while pipelines are extensively used in North America (Wallace et al, 2015). The current market for CO_2 in Europe, at a few million tonnes CO_2 per year, is small compared to the future volumes envisaged for CCS, and it is expected that pipeline CO_2 collection networks will be most appropriate for large ICCS clusters. However, modular transport modes may have applications in more widely-spread clusters, and to connect smaller or outlying capture sites to a collection network. Barge transport on inland waterways has also been suggested for CO_2 (Vermeulen, 2011).

Given this wide range of transport options, the range of potentially useful existing transport infrastructure is also wide. However, depending on the developing concepts for an ICCS cluster and on local/regional geography, it may not be necessary to collect information on all transport modes. Some examples of useful types of information for different modes of CO_2 transport follow.

For road transport, the location of existing CO_2 tanker filling stations, how these are supplied, what storage capacity is available, what space at the site is available, what road-tanker capacity is permitted, is all information that can help judge if that location could be adapted to a CO_2 collection centre to serve smaller capture projects within a cluster.

The existence of railway connections at many industrial sites may allow bulk CO_2 collection at sites that are more distant from the centre of a cluster area. Other liquefied gases, such as LPG and ammonia, are routinely carried by rail, and tank-cars suitable for L-CO_2 are available for lease in Europe (VTG, 2018). Status of branch lines, maximum train length for local rail system, tank-car capacity, availability of rail link to potential site for connection to trunk CO_2 transport system all need to be considered.

Many industrial areas in Europe are located on inland waterways or on the coast, and barge transport or coastal shipping of L-CO_2 have been proposed as collection systems, connecting to a trunk pipeline or bulk shipping system at a port-based collection hub (Vermeulen, 2011; Tel-Tek, 2012). Information such as port space availability, existing L-CO_2 terminals and storage at ports and maximum barge size for waterways is needed to judge potential for waterborne transport.

Pipeline networks may be considered as the default collection system for dense ICCS clusters, but the potential to use modular transport systems to include peripheral or smaller capture sites should not be overlooked. One significant difference of modular systems is that they transport refrigerated, liquefied CO_2, so space and services for liquefaction plant need to be available. Storage of L-CO_2 at the filling point, with holding capacity of at least one transport load is also needed. In contrast, a pipeline system only needs CO_2 compression at the point of entry to the collection network.

For potential pipeline collection networks, as well as the locations of capture sites and the proposed entry point to the trunk transport system, information on the intermediate geography of the area is needed. This includes topography, crossings required with other transport or water features, actual land use and planning zones, including existing or potential pipeline corridors and their capacity for additional pipelines. Models to estimate pipeline costs are available, some consider influence of terrain on costs (e.g. Grant et al, 2013), others give a simple “rule of thumb” for cost per kilometre (e.g. Haszeldine et al, 2010). However, both these types of model should be used with caution; they may be useful for comparing route options but are unlikely to give reliable absolute costs, for which a proper engineering assessment is needed.

Of course, if there is any existing, available pipeline either in use already for CO_2, or that is of a suitable specification and condition that it might be converted to CO_2 duty, detailed information on this should be obtained. An example is the OCAP pipeline in the Netherlands; this currently collects CO_2 from two capture sites in Rotterdam for delivery to glasshouses in central Netherlands. This pipeline will form part of the collection network for the proposed Rotterdam ICCS cluster (Ros et al, 2014; Porthos, 2019).

As well as the transport options for a CO_2 collection system, the collection point or hub where CO_2 is “bulked-up”, or “consolidated”, for trunk transport needs to be considered. For a L-CO_2 based modular collection system using road, rail or barge tankers, this will require refrigerated bulk storage of L-CO_2 to accommodate the batch-wise profile of deliveries, as well as transfer and/or reconditioning facilities to prepare the CO_2 for trunk transport. If the onward trunk transport is also as L-CO_2 by ship (see Section 4.2.3 below) then the storage needs capacity of at least one shipload to allow prompt filling of the ship. If onward trunk transport of collected L-CO_2 is to use a pipeline, then the CO_2 will need to be reconditioned by pumping to a higher pressure and warming to ambient temperature suitable for the pipeline.

If the collection system is a pipeline network, there may be no requirement for processing at the collection point, which may just be a pipeline junction. However, depending on the way the collection system is set up and managed there may be a need for centralised compression to trunk pipeline pressure, or for a centralised purification unit to achieve the required specification of CO_2 for transport and storage, for instance, achieving a sufficiently low moisture level.

Whatever the requirements for CO_2 processing at the collection hub, a suitable location and sufficient space for facilities, with availability of required services, needs to be identified. This should also take account of safety considerations for a potentially large inventory of CO_2.

4.2.3 Trunk CO_2 transport system

Options for trunk CO_2 transport from the collection hub serving an ICCS cluster to a storage site are more limited than for the collection network and are defined primarily by geography. Trunk transport overland is only likely to be by pipeline; however, as many future storage sites are offshore, there is a mode choice between pipeline and shipping to be made for offshore transport.

The outcomes of definition for the trunk transport system are similar to those for the collection network:

- Proposal of CO_2 transport mode, or modes, to be used.
- Definition of collection points, routings, capacities, delivery points.
- Definition of operating conditions for the trunk system.
- Information to allow cost estimates of the trunk system to be progressed.

At a basic level, much of the definition of the trunk CO_2 transport system comes from upstream and downstream of the trunk route itself, although definition of all parts of the CCS chain should be considered in parallel. Where the trunk system starts depends on the cluster location and collection network definition as discussed above, and where it finishes depends on the storage location being considered. The capacity needed depends on the capture quantity and profiles defined for the cluster, allowing capacity for the maximum flows expected. However, the phasing of capture quantity development over time may lead to decisions about transport mode where options are available. For instance, CO_2 shipping, where it is an option, may be appropriate for initial phases of a cluster development when quantities are lower, with transition to pipeline transport as capture quantity increases above a certain threshold.

The cost competitiveness of shipping compared to pipeline for trunk transport offshore depends on both scale and distance. In general, shipping is more competitive for lower volumes and longer distances while pipelines are favoured for larger volumes and shorter distances. However, the relative flexibility of shipping is an additional advantage, giving scope for stepped build-up in transport capacity by adding further ships to the fleet (Brownsort, 2015; Element Energy, 2018a).

Where shipping is considered as part of a trunk transport system, information on existing, or on the potential for new port facilities is needed to scope feasibility. Availability of quay space or tanker jetties close to a suitable site for temporary CO_2 storage, port experience with refrigerated liquids, port constraints such as depth, lock size, tidal streams or weather factors may all need to be considered.

For overland trunk transport by pipeline, the starting point and destination follow from CCS cluster location and the choice of storage site. The capacity requirement will follow from the consideration of CO_2 capture quantity, profile and the development phasing of the cluster as outlined above. This may lead to proposal of an “oversized” pipeline to allow for the phased development of a cluster without the need for further investment in trunk transport, however, this needs to be carefully justified due to the high capital costs of large pipelines.

As for a pipeline collection network, information such as distance, topography, infrastructure and water crossings, pipeline corridors, land use, planning zones, all need to be considered in deciding a trunk pipeline route. Detailed design, such as for pipe sizing, operating pressure or the need for booster compressor stations, follows from routing and capacity requirement. A useful reference manual on CO_2 pipelines, based on global experience, is published by IEAGHG (2014). A recent review of technical literature by SINTEF covers CO_2 transport by both pipeline and ship (Munkejord et al, 2016).

For both onshore and offshore transport there may be the potential, in some circumstances, to make use of existing pipelines, most likely existing natural gas pipelines, for some or all of the route. This could lead to very large capital cost savings in some cases, reducing the cost hurdles for CCS developments. For example, in Scotland the potential reuse of existing onshore and offshore natural gas pipelines to connect the Grangemouth industrial cluster to a storage site in the Central North Sea has been estimated to save over £140 million, compared to a new pipeline (Brownsort, Scott and Haszeldine, 2016; Alcalde et al, 2019). Given the scale of potential cost savings, the potential for pipeline reuse should be considered carefully, however, it is likely to depend on region and on timescale of the envisaged CO_2 transport development. Other studies focusing on Germany have concluded reuse of natural gas pipelines is unlikely in the timescale of initial CCS developments (CO_2Europipe project) (Santen et al, 2011).

Operating conditions for CO_2 transport are likely to be dependent on other elements of the CCS chain, rather than being primary design choices. For pipeline transport, CO_2 pressure in the section between the most downstream compressor and the injection well (for instance, the offshore pipeline leg) is determined by the reservoir properties. The compressor outlet pressure needs to be sufficient to deliver the required injection pressure at the entry point to the reservoir, after allowing for frictional pressure losses in the well and along the pipeline run. The compressor and pipeline also need scope to increase pressure over time from the initial conditions as pressure in the reservoir rises with progressive CO_2 injection. Upstream of the final compressor, there is more flexibility for pipeline pressures in both trunk and collection systems and so economic factors, plus constraints of any infrastructure being reused, will determine the optimum design pressure. Operating temperature for pipeline transport is usually based on the ambient temperature of the ground or sea surrounding the pipeline.

For ship transport of CO_2 a variety of conditions are possible with proposals ranging from low pressure, refrigerated liquid conditions near the triple-point of CO_2 to gas at high pressure and ambient temperature (Brownsort, 2015). Determining the best conditions requires economic and energy optimisation across the whole transport and storage system taking account of diverse factors including reservoir pressure, carrier tank design, availability of cooling and re-warming water (Krogh et al, 2012; Nam et al, 2013). Currently it looks likely that CO_2 conditions for ship transport will become standardised at so-called “medium pressure” conditions of around 15 bar and -30°C, similar to the conditions already in use for small scale commercial CO_2 transport by ship (Statoil, 2018).

4.3 Integration with CO_2 storage definition

For a developing ICCS cluster to achieve its main intended purpose of decarbonising industry in an area, options that provide a permanent sink for the captured CO_2 need to be defined in parallel, to allow creation of an integrated capture, transport and storage chain. The main option for storage is deep geological CO_2 sequestration, whereas very few CO_2 utilisation processes result in permanent storage.

The scoping of an ICCS cluster should have a view, at all stages, of the ability to access CO_2 storage of a "quality" suitable for the proposed capture operations as they are built up across an industrial area. In a study of potential storage sites in the UK, six factors were used to assess the quality of the sites (ETI, 2016):

- Capacity – estimate of absolute capacity, taken as P50 value from available estimates.
- Injectivity – a measure of how easily (quickly) CO_2 can be injected to the reservoir.
- Engineered containment risk – measure of risk from abandoned wells in the reservoir area.
- Geo-containment risk – measure of risk from naturally occurring geological features.
- Development cost factor – depending on transport distance to storage and reservoir depth.
- Upside potential – a sum of additional site capacity nearby, accessible using the same trunk pipeline.

While these and other factors, and the information needed to determine them, are covered in depth in the parallel report *Storage Resource Assessment Methodologies* (Cavanagh, 2019), the main interactions with ICCS cluster and CO_2 transport definition are discussed briefly here.

4.3.1 Capacity and injectivity

The availability of capacity sufficient to store the CO_2 that will be captured over the projected lifetime of, at least, the initial phases of development of an ICCS cluster, is an obvious essential requirement to decarbonise an industrial cluster successfully using CCS. Beyond initial CCS cluster developments, a strategic view of management of CO_2 storage resources for a region will be required assuming CCS develops to its full potential for decarbonising industry.

The rate at which CO_2 can be injected into a reservoir depends on the injectivity, on the number of injection wells used, and on pressure constraints. While it may be possible to use more wells or to manage pressure in the reservoir to increase total injection rate, this increases the costs of developing a storage site. The total rate of injection achievable needs to be matched with the total rate of capture in the ICCS cluster for a single CCS chain. The potential for variation in CO_2 flow, including temporary stoppage, also needs to be considered and designed for.

4.3.2 Containment risks

Understanding the risks to containment of CO_2 in a geological structure is key to choosing the best locations to develop as storage sites. Well-chosen locations will have minimal residual risks of CO_2 leakage through natural or man-made features. The process of selecting suitable storage locations may exclude certain sites where risks are recognised to be higher, and this may have implications for ICCS clusters if safe storage sites are at a greater distance, leading to higher costs for CO_2 transport.

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4.3.3 Development costs and upside potential

As above, the distance from an ICCS cluster to a suitable CO_2 storage location has a direct affect on costs of CO_2 transport, and so on the total cost of a CCS operation (although the affect is relatively greater on pipeline transport than on transport by ship).

The depth of a storage reservoir also has an affect on total costs by increasing cost of drilling wells. Storage must be at a depth greater than about 800 m to maintain the CO_2 in a liquid phase and typically suitable reservoirs are at depths between 1000 and 4000 m in the North Sea (de Kler et al, 2016).

Where there is potential to link a number of storage sites to a supply of CO_2 from the same trunk transport infrastructure, this may bring a benefit to the initial development, by allowing costs to be spread over a larger total scale of operation and/or a longer timescale. This may have implications for the optimum configuration of the transport system, whether pipeline or shipping based.

4.4 Methodology flow and data structure

The work of defining the composition and connections of a potential ICCS cluster spans a wide variety of areas as described in the previous sections. It has been noted that a flexible approach is needed to allow for the diversity of industrial areas, but there are some clear, logical links between the steps involved. Figure 4-3 shows the relationships between the main steps of the methodology described as a simple flow diagram.

The general direction of methodology flow, as represented in the diagram, is from top to bottom and from the sides towards the trunk transport definition, which can only follow from the definition of the cluster with its CO_2 collection system and the proposed CO_2 storage location.

To apply the methodology clearly requires the collection of much information and data on the industries in a cluster area and their operations, the potential for transport connections across the area and for access to the CO_2 storage options. Lists have been developed covering most of the data and information likely to be needed. These are provided as extracts from an initial spreadsheet in Appendix A.

These lists have been adapted by Universidade de Évora to create a database system for local teams of the STRATEGY CCUS Project to use for collection of data and information on their cluster areas. The database is formed of eleven tables grouping the data, spatial data and other information; the database table descriptions are given in Appendix B. The structure of these tables is related to the methodology flow and is represented in the block diagram Figure 4-4.

As with the rest of this methodology, these lists and the derived database should be used flexibly as appropriate to each cluster area. While these lists are thought to include most information needed for initial ICCS cluster definition and scoping, not all suggested entries will be appropriate for all areas. Equally, the lists only include limited information needed for more detailed studies such as business cases or environmental assessments; further rounds of data collection may be required as these studies define their needs within the STRATEGY CCUS Project.

A brief guidance note on the collection of data and the use of the methodology is also included in Appendix C.

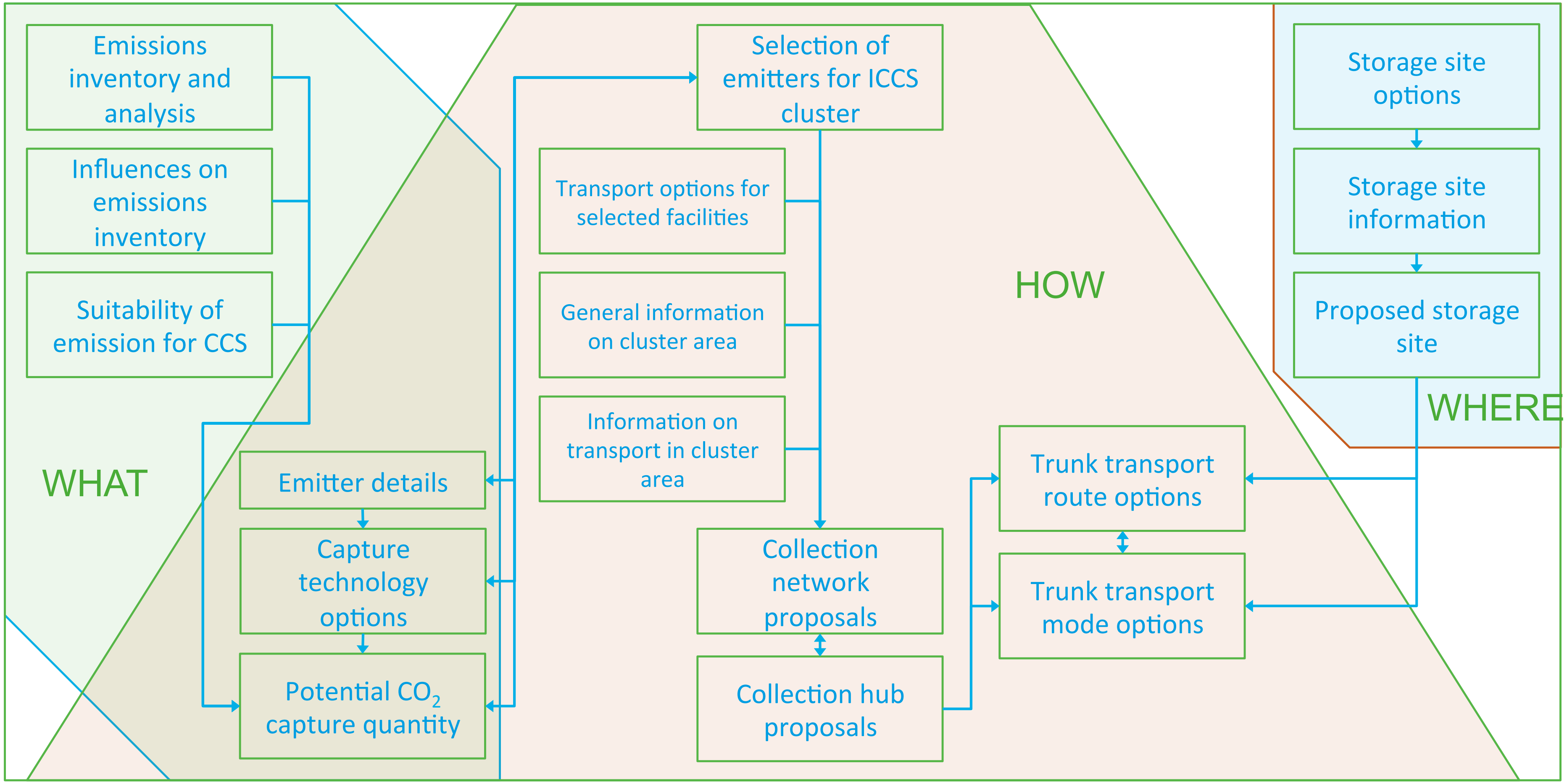

Figure 4-3 Outline of relationships between main steps of methodology. The three shaded areas highlight the three general steps proposed in Figure 4-1. The area of overlap, mid-left, represents information related to the second step, but specific to each emitter considered.

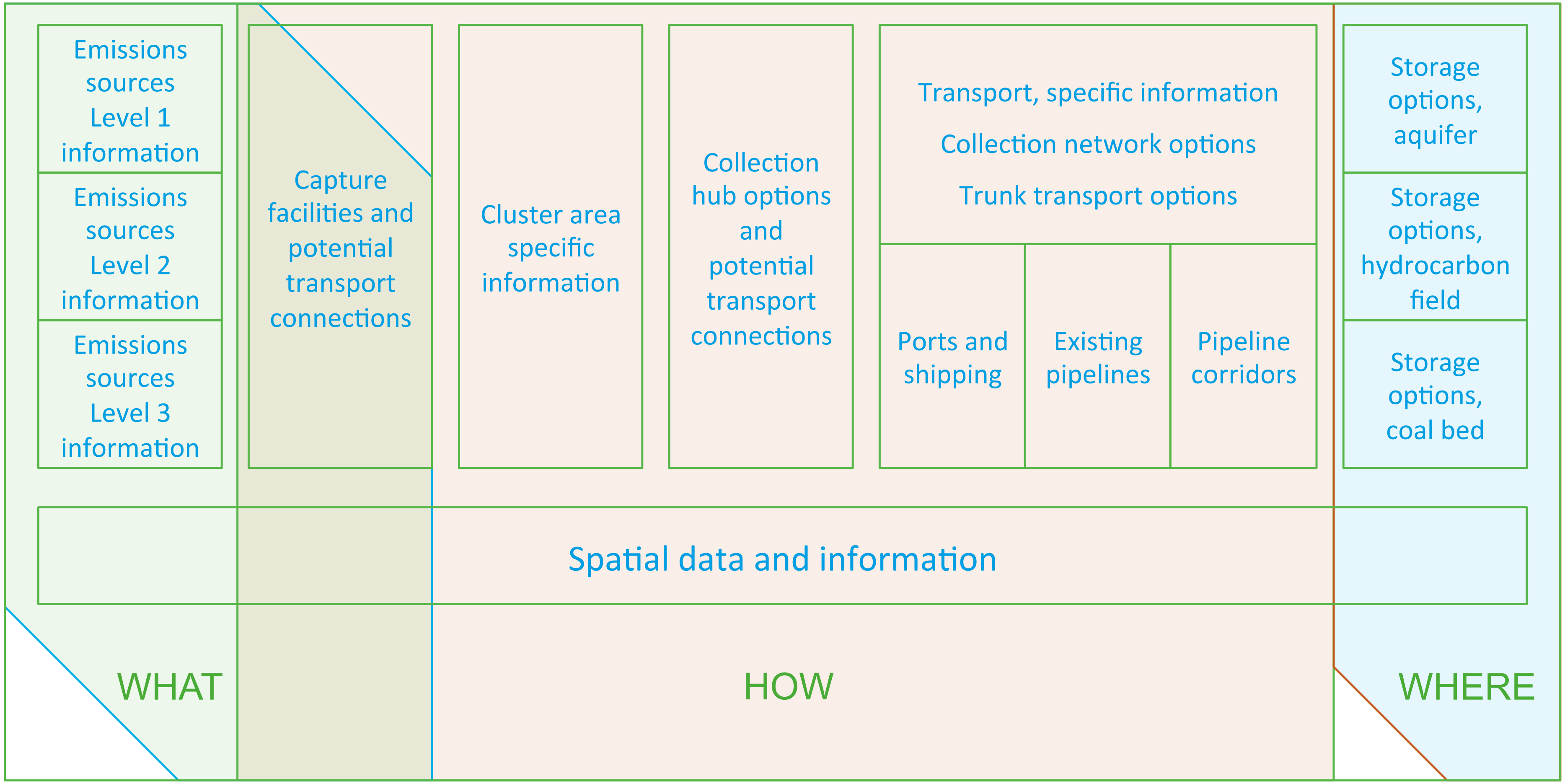

Figure 4-4 Block diagram showing layout of data tables. The three shaded areas again show the relationship of the data to the general steps of the methodology.

5 Engagement activities

In applying the methodology suggested above for definition of a potential ICCS cluster, and in taking this forward to further studies and towards deployment, it is implicit that many different forms of engagement will be involved. Indeed it is suggested above (Section 0) that relationships, developed through engagement activities, are among the key factors that affect the advancement of an ICCS cluster. Within the STRATEGY CCUS Project, Work Packages 3 and 6 focus specifically on stakeholder engagement and on strategic communication respectively so in this present report only a brief consideration of this area is given.

In this context, engagement activities are about what relationships need to be built in order to obtain the information and data described above, and on what is done with the outcomes of scoping an ICCS cluster and the analyses arising. This is all with the intention of moving forward towards deployment of a CCS a cluster to reduce CO_2 emissions from industry in the area. Some subjects for engagement activities and groups that may be involved are outlined below:

- Engaging industry interest in decarbonisation options
    - Existing industry groups, sectorial or location based
    - New groups with specific focus
    - Data collection for decarbonisation options, including CCS
    - Defining challenges and opportunities
- Engaging specific interest in CCS development
    - Industry – emitters, equipment supply chain, transport providers, storage operators
    - Public – clean air, employment retention, climate change mitigation
    - Regulators, environment agencies – pollution and emission reduction targets, transport standards, storage liabilities
    - Government – climate change mitigation targets, financial case, supporting industry
    - Regional authorities, planning authorities
    - Funders, investors
- Public awareness and engagement
    - Improving awareness of need for industry decarbonisation
    - Improving awareness of role of CCS
- Defining potential drivers for CCS
    - Policy, regulation, societal
    - Cluster interests – climate mitigation, wealth creation, employment retention, legal compliance

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6 Summary and conclusions

This report has been prepared to help local teams in the STRATEGY CCUS Project to define options and scope for potential industrial CCS clusters in their regions, including the CO_2 collection and trunk transport systems needed to connect to a CO_2 storage site. The report draws on experience from existing CCS cluster projects in Northern Europe and proposes a basic methodological approach for the definition of new industrial CCS clusters. A parallel report forming part of the same project deliverable covers assessment of suitable storage sites (Cavanagh, 2019). The aim of the STRATEGY CCUS Project is to enable the short- to mid-term development of CCUS through strategic planning of ICCS clusters in Southern and Eastern Europe, within the overarching context of emissions reduction for climate change mitigation.

A review has been carried out of seven industrial areas in Northern Europe where ICCS cluster development is under discussion or progressing. Each has been assessed against a list of characteristics or factors developed for this study that describe an area in the context of its potential for forming an ICCS cluster.

It was found that the areas all differ in their technical advantages and challenges, but that feasible options exist for ICCS in all cases. Technical characteristics that can be associated with the most actively progressing ICCS clusters include a clear means of access to a well-defined CO_2 storage site, and factors that can reduce unit costs of CO_2 capture and transport, such as high-concentration CO_2 emissions and infrastructure that may be reused for CO_2 capture or transport.

However, it appears that non-technical factors have the greatest influence on advancement of projects in the ICCS cluster areas reviewed. Clear leadership and vision from, most commonly, an empowered public authority for the area, or from a credible industry leader or group, appear to be key, together with good engagement of all stakeholders – industry, agency, and the public. It is the motivations, leadership and relationships amongst stakeholders that underpin an effective ICCS cluster development.

Considering other industrial regions in Europe that may have potential to develop as ICCS clusters, it is likely that they will be at least as diverse as the cluster areas reviewed for this study. As such, it is unlikely that there can be a single “best practice” method for defining an ICCS cluster for all areas; any methodology proposed must be adaptable to suit each area. However, there are some obvious fundamental steps required to start the process of defining an ICCS cluster; how a cluster then develops depends on the circumstances – the political will, industrial engagement, geographical opportunities and infrastructure of the area.

In this report a simple methodology is suggested, starting from two points at opposite ends of the CCS logistics chain before filling in the detail of the central portion. The starting points are, at one end, an analysis of existing and projected future CO_2 emissions leading to an initial estimate of the total CO_2 quantity that may be abated using CCS in an area; at the other end, an appraisal of CO_2 storage options to define sites having capacity for the estimated quantity. Following this, selection of the most promising emitters to join an ICCS cluster development, perhaps with different phases of inclusion, allows refinement of the CO_2 quantity estimate. Consideration of the CO_2 transport options within the industrial area leads to proposal of collection network options and a consolidation point or collection hub. Finally proposals of CO_2 trunk transport options to link this point with the identified storage options can complete definition of proposals for the full CCS chain.

Data and information that need to be collected for ICCS cluster definition has also been suggested as part of this methodology and is detailed in Appendix A. This has been adapted by the Universidade de Évora to create a database system for use by the local teams. Following from the observation that all clusters are different, this data collection will also need to be adapted as appropriate for each potential cluster area; it may be carried out in different phases and to different extents to suit the needs of the area.

Collection of data and information, and other aspects of the methodology proposed, will require identification of, and significant engagement with, the main stakeholders in a potential ICCS cluster area. Engagement activities and strategic communication are touched on very briefly in this report and will be a main focus of Work Packages 3 and 6 of the STRATEGY CCUS Project. Good stakeholder engagement takes time and cannot be rushed. This implies that, while some of the proposed methodology can be carried out quickly with little stakeholder engagement, the overall process of ICCS cluster definition may need to be spread over some considerable time, most likely in a number of iterations as initial ideas are formed, discussed, improved and revised.

The STRATEGY CCUS Project will address only a limited number of industrial regions in Southern and Eastern Europe. There are many more such regions in Europe and the rest of the world where industrial decarbonisation will be required to meet emission reduction targets and where industrial CCS may be one of the main options. It is hoped that the methodology suggested in this study is general enough to be useful across all regions, and that all industrial areas will take action to consider their best alternatives for decarbonisation. It is not acceptable that only the most favourable industrial areas are supported to decarbonise; this would risk loss of industry from other areas, by closure or by displacement to regimes with less-stringent emission reduction targets.

7 Glossary of Abbreviations

Abbreviation	**Meaning**
ACT	Accelerating CCS Technologies
BEIS	UK Government Department for Business, Energy and Industrial Strategy
bn	billion (for currency)
c.	*circa*, approximately
cf.	*confer*, compare with
CCC	Committee on Climate Change (UK)
CCGT	combined-cycle gas turbine
CCGT+CCS	combined-cycle gas turbine with carbon capture and storage
CCS	carbon capture and storage
CCU	carbon capture and utilisation
CCUS	carbon capture utilisation and storage
CHP	combined heat and power
CO_2	carbon dioxide
CO_2-EOR	carbon dioxide enhanced oil recovery
CSLF	Carbon Sequestration Leadership Forum
EIS	East Irish Sea
EOR	enhanced oil recovery
ETI	Energy Technologies Institute
ETS	emissions trading system
EU	European Union
FEED	front end engineering design
GCCSI	Global CCS Institute
Gov	government
Gt	gigatonne (10^9 tonnes, billion tonnes)
H_2	hydrogen
ICCS	industrial carbon capture and storage
ICG	Industriclusteret Grenland
ICI	Imperial Chemical Industries
IEAGHG	International Energy Agency Greenhouse Gas Research and Development Programme
IPCC	Intergovernmental Panel on Climate Change
km	kilometre
kt	kilotonne (thousand tonnes)
kt/yr	kilotonne per year
L-CO_2	liquid/liquefied CO_2
LEP	Local Enterprise Partnership
LNG	liquefied natural gas
LPG	liquefied petroleum gas

m	metre
Mt	megatonne (10^6 tonnes, million tonnes)
Mt/yr	megatonne per year
NAEI	National Atmospheric Emissions Inventory (UK)
NEPIC	North East Process Industries Cluster
O&G	oil and gas
OCAP	Organic CO_2 for Assimilation by Plants (OCAP Pipeline)
OGA	Oil & Gas Authority (UK)
OGCI	Oil & Gas Climate Initiative
P50	50% of estimates exceed the P50 value, 50% are less
PS	power station
RCI	Rotterdam Climate Initiative
SCCS	Scottish Carbon Capture & Storage
SEPA	Scottish Environment Protection Agency
SG	Scottish Government
SMR	steam methane reformer/reforming
SSI	Sahaviriya Steel Industries PCL
TVCA	Tees Valley Combined Authority
UK	United Kingdom
UKCCSRC	United Kingdom Carbon Capture and Storage Research Centre
USA	United States of America
USEIA	United States Energy Information Administration
yr	year
ZEP	Zero Emissions Platform

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Note: Links are provided to websites and "grey" literature, where available. These have been checked at the time of referral or final editing, but their ongoing validity cannot be guaranteed.

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Appendix A. Collection of data and information, original lists

STRATEGY CCUS Task 2.1

Filename: StratCCUS_T2-1_Appendix_A.xlsx
Based on: StratCCUS_T2-1_Cluster_Data_V051.xlsx
Update: 30/08/19
By: PAB

Suggested data requirements for ICCS cluster scoping

Source: Starting list from "COMET Sources Attributes.doc" (provided by Julio Carneiro), added to and adapted by Pete Brownsort, SCCS.
The column"Data Group" references Figure 4.4 of main report, the block diagram showing layout of data tables.

Level of information - explanation

Level 1	Basic information on facility, location and emission needed for initial emission analysis. This is likely to be available from public sources and is the initial information needed for cluster definition.
Level 2	Basic technical information on processes and current flue gas properties needed for developing capture cluster scenarios, plus any knowledge of appropriate capture technologies. This information unlikely to be available publicly, may take time to obtain through engagement with selected emitters.
Level 3	More detailed technical and production information needed for techno-economic and lifecycle analysis on selected facilities. This only needed for these further studies, but useful to collect if readily available. Some is likely to need industry engagement for actual data, or may be assumed from literature for TEA/LCA modelling purposes.

Data Group	**Emission source attribute name**	**Level**	**Description/explanation of attribute**	**Unit**	**Field type**
Emission sources	Unit identifier	1	Short, unique name for emitting facility		Text
Emission sources	Industry sector	1	Adapt from second level of NACE hierarchy		Text
Emission sources	NACE code	1	NACE code at most detailed level identified		Numeric
Emission sources	Company name	1	Company responsible for emission		Text
Emission sources	City	1	Closest city or town		Text
Emission sources	State or Province	1	State or province (or similar) of emission location		Text
Emission sources	Country	1	Country of emission		Text
Emission sources	Country Code	1	Two letter ISO country code		Text
Emission sources	Region	1	Name of STRATEGY CCUS Project region		Text
Emission sources	Longitude	1	X coordinates of emission location in WGS84 decimal degrees		Numeric
Emission sources	Lattitude	1	Y coordinates of emission location in WGS84 decimal degrees		Numeric
Emission sources	Status	1	Status of emission source		Text
Emission sources	CO2 reported	1	The reported CO2 emission from the source	tonnes	Numeric
Emission sources	Year reported	1	Year to which the report relates		Numeric
Emission sources	Report basis	1	Reference to data source and/or method of averaging if appropriate		Text
Emission sources	CO2 estimated	1	Estimated CO2 emission from source if actual data not available	tonnes	Numeric
Emission sources	Year estimated	1	Year to which the estimate relates		Numeric
Emission sources	Estimate basis	1	Estimation method or reference		Text
Emission sources	Emission trend	1	Trend in emission year on year		Text
Emission sources	Trend driver 1	1	What is leading to trend in emission?		Text
Emission sources	Trend driver 2	1	What is leading to trend in emission?		Text
Emission sources	Decarbonisation alternative 1	1	What decarbonisation alternative to CCS is practical?		Text
Emission sources	Decarbonisation alternative 2	1	What decarbonisation alternative to CCS is practical?		Text
Emission sources	Start year	2	The year the emissions started		Numeric
Emission sources	Shut year	1	The year the emission source closed or is projected to close		Numeric
Emission sources	CO2 concentration	2	Concentration of CO2 in emission, %v/v dry basis	%v/v	Numeric
Emission sources	Composition	2	Is more information on composition of emission available? Y/N		Text
Emission sources	Water content	3	Water impurity content in flue gas, agreed unit		Numeric
Emission sources	Hydrogen content	3	Hydrogen impurity content in flue gas, agreed unit		Numeric
Emission sources	Carbon monoxide content	3	Carbon monoxide impurity content in flue gas, agreed unit		Numeric
Emission sources	Methane content	3	Methane impurity content in flue gas, agreed unit		Numeric
Emission sources	Sulphur oxides content	3	SOx impurity content in flue gas, agreed unit		Numeric
Emission sources	Nitrogen oxides content	3	NOx impurity content in flue gas, agreed unit		Numeric
Emission sources	Other impurity content	3	Information on other impurity content in flue gas		Text
Emission sources	Temperature	2	Temperature of emission	°C	Numeric
Emission sources	Pressure	2	Pressure of flue gas prior to emission	barg	Numeric
Emission sources	Flow rate, average	2	Average volume flow rate of flue gas	Nm3/s	Numeric
Emission sources	Flow variation information	2	Is any information on emission flow variation profile available? Y/N		Text
Emission sources	Maximum flow	3	Maximum volume flow rate of flue gas	Nm3/s	Numeric
Emission sources	Minimum flow	3	Minimum operational volume flow rate of flue gas	Nm3/s	Numeric
Emission sources	Flow variation profile description	3	Description of flow variation profile, if known		Text
Emission sources	Process emission proportion	2	Approximate proportion of emission derived from process, rather than energy use	%	Numeric
Emission sources	Number of emission points	2	The number of vents/emission points included in the facilitiy's emission report		Numeric
Emission sources	Heat availability	2	Is there excess heat available at the facility or close by? Y/N		Text
Emission sources	Alkaline waste availability	2	Is there an alkaline watse stream available at the facility or close by? Y/N		Text
Emission sources	Capture technology options	2	What is most appropriate capture technology?		Text
Emission sources	Proportionate capture rate	2	Expected proportion of CO2 that mey be captured from reported emission	%	Numeric
Emission sources	Capture option basis	2	Reference to information source for capture technology and rate		Text
Emission sources	Main product	3	What is the main product of the facility?		Text
Emission sources	Production	3	Physical production of main product of facility, units in next entry	UoP	Numeric
Emission sources	Unit of production	3	Define usual unit for production (UoP) in industry sector		Text
Emission sources	Full load hours	3	Operational hours achieved in reporting year	h	Numeric
Emission sources	Capacity	3	Nameplate capacity of plant	UoP	Numeric
Emission sources	Unit of Capacity	3	Only if different from unit of production		Text
Emission sources	Emission factor	3	Emission to production ratio, t-CO2/UoP	t-CO2/UoP	Numeric
Emission sources	Net Generation Electricity	3	Net Generation Electricity	GWh/yr	Numeric
Emission sources	Net Generation Heat	3	Net Generation Heat	GWh/yr	Numeric
Emission sources	In house loads	3	In house loads	GWh/yr	Numeric
Emission sources	Gross generation	3	Gross generation	GWh/yr	Numeric
Emission sources	Co-product 1	3	Co-product identity		Text
Emission sources	Co-product 1 production	3	Co-product production	tonnes/yr	Numeric
Emission sources	Co-product 2	3	Co-product identity, further co-products added as required		Text
Emission sources	Utilities, electricity	3	Electricity usage	MWh/yr	Numeric
Emission sources	Utilities, water	3	Water usage	m3/yr	Numeric
Emission sources	Utilities,	3	Further utilities added as required		
Emission sources	Technology	3	The main technology used in facility.		Text
Emission sources	Main fuel	2	Main fuel used for facility energy requirement		Text
Emission sources	Other fuel	2	Alternative or additional fuels used		Text
Emission sources	Fuel use	2	Fuel consumption - unit needs to be rate, so Watts, not Joules	MW	Numeric
Emission sources	Information source	1	Primary source		Text
Emission sources	Information source	1	Alternative or additional sources, note any comments on validity		Text
Emission sources	Remarks	1	Any relevant comments about the facility, the emissions or the information used		Text

STRATEGY CCUS Task 2.1

Filename: StratCCUS_T2-1_Appendix_A.xlsx
Based on: StratCCUS_T2-1_Cluster_Data_V051.xlsx
Update: 30/08/19
By: PAB

Suggested data requirements for collection network scoping

Four areas of information that may need to be treated differently for database
a) Information and data related to the cluster area and collection network as a whole - one set of data per cluster area, first group in list below
b) Information and data on CO2 collection options for each emitter considered - a set of data for each emitter selected for "Level 2" information, second group
c) In some cases (particularly for pipelines) the same class of information/data is needed for both general and specific considerations - data fields duplicated in second group
d) For existing pipleines that may be reused, specific information and data is needed for the pipeline - third group
The column"Data Group" references Figure 4.4 of main report, the block diagram showing layout of data tables.

Data Group	**Collection network attribute name**	**Description/explanation of attribute or options**	**Unit**	**Field type**
	General to area/network			
Cluster area	Emitter distribution	Emitter location map(s), with indication of phasing and/or different scenarios		Text
Cluster area	Estimated cluster capture volumes	Totals, related to phasing and/or different scenarios	Mt	Numeric
Hub options	Collection hub location options	Hub options, may relate to phasing or scenarios		Text
Hub options	Processing requirement at hub	Purification, drying, compression, liquefaction, pumping, warming, cooling, refrigeration		Text
Hub options	Resource availability at hub location options	Cooling water (if liquefaction needed), excess heat (if rewarming needed), electricity		Text
Hub options	Transport connections at collection hub options	What connections are available: Road, rail, seaport, existing pipeline, pipeline corridor		Text
Cluster area	Trunk transport options	Shipping, existing pipeline, new pipeline		Text
Storage options	Storage location options			Text
Cluster area	Permitted road tanker load	General road transport restriction	tonnes	Numeric
Cluster area	Available rail tank-car capacity	This may be fixed data - only aware of one supplier - VTG	m3	Numeric
Cluster area	Rail tank-car length		m	Numeric
Cluster area	Permitted train length	Regional, national or international rail system limits	m	Numeric
Network pipelines	Existing pipeline availability	Compatability, MoC, condition, age, usage, availability,		Text
Cluster area	Existing pipeline routes	Include in cluster map as layer?		Text
Network pipelines	Existing pipeline capacity, estimate	As CO2	Mt/yr	Numeric
Cluster area	Pipeline corridors	Include in cluster map as layer?		Text
Network pipelines	Pipeline corridor usage - type	Are there any incompatible uses?		Text
Network pipelines	Pipeline corridor usage - space	How is "capacity" of corridor defined?		Text
Cluster area	Planning zones	Include in cluster map as layer?		Text
Cluster area	Land use	Include in cluster map as layer?		Text
Cluster area	Topography	Include in cluster map as layer?		Text
Cluster area	Crossings	transport, other pipelines, water features - rivers, lakes, marshes, estuarys, sea		Text
Cluster area	Constraints	Any constraints beyond planing restrictions, e.g. public concerns		Text
Cluster area	Industry interest group	Is there an existing industry stakeholder group with interest in CCS? Y/N		Text
	Specific to each facility and individual connection to network			
Capture connections	Facility location	Facility location, capture facility if location identified, otherwise emitter		Text
Capture connections	Estimated capture volume	Estimate of potential capture volume at facility	t/yr	Numeric
Capture connections	Space availability at facility	Beyond that for capture facility, for e.g. compressor, liquefaction plant, buffer stotrage		Text
Capture connections	Expected CO2 condition at facility	Pressure, temperature - depends on capture choices.		Text
Capture connections	Road access at facility	Confirm HGV access. Y/N		Text
Capture connections	Existing bulk liquid loading at site	Y/N		Text
Capture connections	Existing CO2 loading station nearby	If so, how supplied, what storage volume? Y/N + text if Y		Text
Capture connections	Permitted road tanker load	Any location-specific restricition	tonnes	Numeric
Capture connections	Road transport constraint	planning constraints, physical constraints, traffic consraints		Text
Capture connections	Rail access at facility	Potential rail access? Y/N		Text
Capture connections	Status of rail branch	Operational, mothballed, derelict - track in place, derelict - track removed		Text
Capture connections	Distance to branch from capture facility		km	Numeric
Capture connections	Existing rail terminal at site	Y/N		Text
Capture connections	Existing bulk liquid loading at site	Y/N		Text
Capture connections	Waterway access at facility	Potential water access? Y/N		Text
Capture connections	Port type	river, canal, estuary, coastal		Text
Capture connections	Port entry constraint	entry size, draft, entry lock, tidal gate, weather exposure, traffic constraint, other		Text
Capture connections	Ship/barge size limit	length, beam, draft (3 values or text?)	m	Numeric
Capture connections	Ship/barge weight limit	deadweight tonnage or equivalent	DWT	Numeric
Capture connections	Maximum ship/barge capacity	CO2 capacity, estimated/calculated	tonnes	Numeric
Capture connections	Distance to port from capture facility		km	Numeric
Capture connections	Existing bulk liquid loading at port	Y/N		Text
Capture connections	Existing CO2 terminal at port	Y/N		Text
Capture connections	Quay/jetty space availability	Y/N + text to qualify		Text
Capture connections	Land space availability at port	for buffer storage, loading pumps. Y/K + text		Text
Capture connections	Port development constraints	space, planning zones, safety zones, other developments		Text
Capture connections	Potential for pipeline access at facility	Potential pipeline access? Y/N		Text
Capture connections	Existing pipeline availability	Compatability, MoC, condition, age, usage, availability,		Text
Cluster area	Existing pipeline routes	Include in cluster map as layer?		Text
Capture connections	Existing pipeline capacity, estimate as CO2	Specific to a pipeline available to the capture facility	Mt/yr	Numeric
Cluster area	Pipeline corridors	Include in cluster map as layer?		Text
Capture connections	Pipeline corridor usage - type	Specific to a pipeline available to the capture facility		Text
Capture connections	Pipeline corridor usage - space	Specific to a pipeline available to the capture facility		Text
Capture connections	Distance to pipeline/corridor from capture facility	Specific to a pipeline available to the capture facility	m	Numeric
	For existing pipelines identified			
Network pipelines	Name of Pipeline			Text
Network pipelines	Description of the pipeline	P1 / P2 / P3		Text
Network pipelines	Infrastructure factor for crossing different types of Pipelines			Numeric
Network pipelines	Current Operator			Text
Network pipelines	Fluid conveyed	Oil / Gas / Other / No data		Text
Network pipelines	Is the pipeline on or off shore	Onshore / Offshore		Text
Network pipelines	Diameter of the pipe		m	Numeric
Network pipelines	Is the pipeline exposed	Yes / No / Unknown		Text
Network pipelines	Whether the pipe is currently active, not in use, planned etc	Active / Proposed /Pre-commission / Not in use / Unknown		Text
Network pipelines	Does the pipe piggy back another	Yes / No / Unknown		Text
Network pipelines	Is the pipeline in a bundle	Yes / No / Unknown		Text
Network pipelines	Any additional information (i.e. more details of fluid conveyed if Other entered in Fluid_Conv attribute field).			Text
Network pipelines	Country	Country Code i.e. PT = Portugal, MO = Morocco, SP= Spain		Text

STRATEGY CCUS Task 2.1

Filename: StratCCUS_T2-1_Appendix_A.xlsx
Based on: StratCCUS_T2-1_Cluster_Data_V051.xlsx
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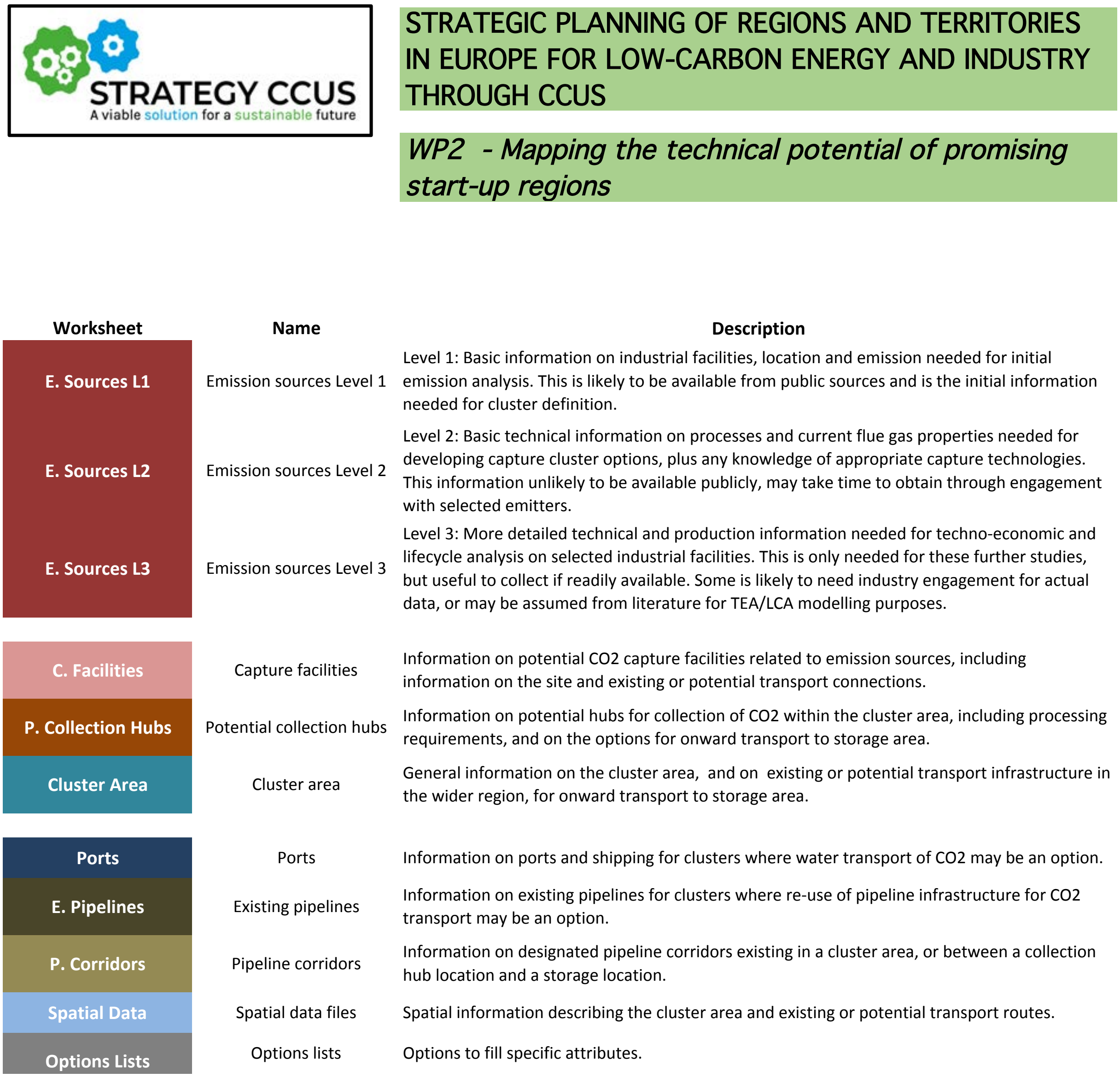
Suggested data requirements for trunk transport scoping

The column"Data Group" references Figure 4.4 of main report, the block diagram showing layout of data tables.

Data Group	Collection network attribute name	Description/explanation of attribute or options	Unit	Field type
	General routing			
Hub options	Collection hub/pipeline node location options	Hub/node options, may relate to phasing or scenarios		Text
Hub options	Transport connections at collection hub options	What trunk connections are available: seaport, existing pipeline, pipeline corridor other, none		Text
Storage options	Storage location options			Text
Trunk route	Onshore route sections	Y/N		Text
Trunk route	Onshore route length		km	Numeric
Trunk route	Offshore route sections	Y/N		Text
Trunk route	Offshore route length		km	Numeric
Trunk route	Route nodes?	Are there any clear points the route must include, eg junctions with other routes,		Text
Cluster area	Estimated cluster capture volumes	Totals, related to phasing and/or different scenarios	Mt	Numeric
Hub options	Expected CO2 condition at collection hub	Pressure, temperature - depends on collection system choices and trunk options		Text
Storage options	Storage tolerance for intermittent injection	Depends on reservoir properties/injection design		Text
	Onshore sections			
Trunk pipelines	Existing pipeline availability	Compatability, MoC, condition, age, usage, availability,		Text
Trunk pipelines	Existing pipeline routes	Include in trunk transport map as layer?		Text
Trunk pipelines	Existing pipeline capacity, estimate	As CO2	Mt/yr	Numeric
Trunk route	Pipeline corridors	Include in trunk transport map as layer?		Text
Trunk route	Pipeline corridor usage - type	Are there any incompatible uses?		Text
Trunk route	Pipeline corridor usage - space	How is "capacity" of corridor defined?		Text
Trunk route	Planning zones	Include in trunk transport map as layer?		Text
Trunk route	Land use	Include in trunk transport map as layer?		Text
Trunk route	Topography	Include in trunk transport map as layer?		Text
Trunk route	Crossings	transport, other pipelines, water features - rivers, lakes, marshes, estuarys, sea		Text
Trunk route	Constraints	Any constraints beyond planing restrictions, e.g. public concerns		Text
	Offshore sections - shipping option			
Trunk route	Port type	river, canal, estuary, coastal		Text
Trunk route	Port entry constraint	entry size, draft, entry lock, tidal gate, weather exposure, traffic constraint, other		Text
Trunk route	Ship size limit	length, beam, draft (3 values or text?)	m	Numeric
Trunk route	Ship weight limit	deadweight tonnage or equivalent	DWT	Numeric
Trunk route	Maximum ship capacity	CO2 capacity, estimated/calculated	tonnes	Numeric
Trunk route	Distance to port from liquefaction facility		km	Numeric
Trunk route	Existing bulk liquid loading at port	Y/N		Text
Trunk route	Existing CO2 terminal at port	Y/N		Text
Trunk route	Quay/jetty space availability	Y/N + text to qualify		Text
Trunk route	Land space availability at port	for buffer storage, loading pumps. Y/K + text		Text
Trunk route	Port development constraints	space, planning zones, safety zones, other developments		Text
Trunk route	Destination type	Port, direct offshore injection, offshore surface storage/conditioning unit, offshore surface conditioning unit		Text
Trunk route	Ship equipment required	Pumping, heating, dynamic positioning		Text
	Offshore sections - pipeline option			
Trunk pipelines	Existing pipeline availability	Compatability, MoC, condition, age, usage, availability,		Text
Trunk pipelines	Existing pipeline routes	Include in trunk transport map as layer?		Text
Trunk pipelines	Existing pipeline capacity, estimate	As CO2	Mt/yr	Numeric
Trunk route	Compressior station location			Text
Trunk route	Shore crossing location			Text
Trunk route	Other seabed user interactions			Text
Trunk route	Other marine user interactions			Text
Trunk route	Marine planning zones	Include in trunk transport map as layer?		Text
Trunk route	Seabed topography	Include in trunk transport map as layer?		Text
Trunk route	Seabed surface type	rock, boulders, gravel, sand, mud, clay,		Text
Trunk route	Crossings	cables, other pipelines,		Text
Trunk route	Constraints	Any constraints beyond planing restrictions, e.g. public concerns		Text
	For existing pipelines identified			
Trunk pipelines	Name of Pipeline			Text
Trunk pipelines	Description of the pipeline	P1 / P2 / P3		Text
Trunk pipelines	Infrastructure factor for crossing different types of Pipelines			Numeric
Trunk pipelines	Current Operator			Text
Trunk pipelines	Fluid conveyed	Oil / Gas / Other / No data		Text
Trunk pipelines	Is the pipeline on or off shore	Onshore / Offshore		Text
Trunk pipelines	Diameter of the pipe		m	Numeric
Trunk pipelines	Is the pipeline exposed	Yes / No / Unknown		Text
Trunk pipelines	Whether the pipe is currently active, not in use, planned etc	Active / Proposed /Pre-commission / Not in use / Unknown		Text
Trunk pipelines	Does the pipe piggy back another	Yes / No / Unknown		Text
Trunk pipelines	Is the pipeline in a bundle	Yes / No / Unknown		Text
Trunk pipelines	Any additional information (i.e. more details of fluid conveyed if Other entered in Fluid_Conv attribute field).			Text

Appendix B. Database table descriptions



STRATEGIC PLANNING OF REGIONS AND TERRITORIES IN EUROPE FOR LOW-CARBON ENERGY AND INDUSTRY THROUGH CCUS

WP2 - Mapping the technical potential of promising start-up regions

Worksheet	Name	Description
E. Sources L1	Emission sources Level 1	Level 1: Basic information on industrial facilities, location and emission needed for initial emission analysis. This is likely to be available from public sources and is the initial information needed for cluster definition.
E. Sources L2	Emission sources Level 2	Level 2: Basic technical information on processes and current flue gas properties needed for developing capture cluster options, plus any knowledge of appropriate capture technologies. This information unlikely to be available publicly, may take time to obtain through engagement with selected emitters.
E. Sources L3	Emission sources Level 3	Level 3: More detailed technical and production information needed for techno-economic and lifecycle analysis on selected industrial facilities. This is only needed for these further studies, but useful to collect if readily available. Some is likely to need industry engagement for actual data, or may be assumed from literature for TEA/LCA modelling purposes.
C. Facilities	Capture facilities	Information on potential CO2 capture facilities related to emission sources, including information on the site and existing or potential transport connections.
P. Collection Hubs	Potential collection hubs	Information on potential hubs for collection of CO2 within the cluster area, including processing requirements, and on the options for onward transport to storage area.
Cluster Area	Cluster area	General information on the cluster area, and on existing or potential transport infrastructure in the wider region, for onward transport to storage area.
Ports	Ports	Information on ports and shipping for clusters where water transport of CO2 may be an option.
E. Pipelines	Existing pipelines	Information on existing pipelines for clusters where re-use of pipeline infrastructure for CO2 transport may be an option.
P. Corridors	Pipeline corridors	Information on designated pipeline corridors existing in a cluster area, or between a collection hub location and a storage location.
Spatial Data	Spatial data files	Spatial information describing the cluster area and existing or potential transport routes.
Options Lists	Options lists	Options to fill specific attributes.

This is an extract from the spreadsheet “WP2 – Capture and Transport data description.xlsx”, which describes the eleven tables that form the database developed by Paulo Mesquita of Universidade de Évora. The full spreadsheet is available to members of the STRATEGY CCUS Project from Work Package 2 Leader, Júlio Carneiro, Universidade de Évora.

Appendix C. Brief guidance for data collection and use of methodology

This guidance follows the main steps of the methodology as set out in flow chart (Fig. 4.3 of main report) and the block diagram of data table structure (Fig.4.4), together with the spreadsheet of data descriptions “WP2 – Capture and Transport data description.xlsx”.

C.1 Determining what CO_2 may be captured

C.1.1 Emissions inventory and analysis

Data table: Emission Sources Level 1.

- Information collected for this table forms a basic list of emitters and inventory of emissions.
- Use this to analyse emissions in terms of quantity and location. Rank sites by emission quantity and identify areas of greatest emission density.

Outputs: emissions inventory, emissions analysis.

C.1.2 Influences on emissions available for CCS

Data table: Emission Sources Level 1.

Other inputs: knowledge of local industry, markets and policies.

- Look at year-on-year trends of emission from each site and assess what is driving the trend.
- Consider the industry sector and the specific site and assess what alternative options for decarbonising may be appropriate.

Outputs: understanding likely changes to emissions inventory; views on appropriate decarbonisation options; this contributes to initial estimate of potential CO_2 capture quantity from cluster.

C.1.3 Suitability of emissions for CCS

Data table: Emission Sources Level 2.

Other inputs: general understanding of CO_2 capture technologies.

- Information in this table contributes to selection of emitters as suitable for using CCS.
- This information is more difficult to obtain and is likely to need engagement with companies.
- Use the information to assess suitability of emitting site for development of CCS.
- Make initial assessment of appropriate capture technology options.
- Make initial rough estimate of potential capture quantity from emitting site.

Outputs: initial screening of sites suitable for CCS, initial estimate of potential CO_2 quantity from cluster.

Parallel activity: identifying CO_2 storage site options with capacity matched to estimate.

C.1.4 Techno-economic and life-cycle analysis

This does not form part of the methodology for initial CCS cluster definition but is part of the wider STRATEGY CCUS Project.

Data table: Emission Sources Level 3.

- Information in this table has been requested for use in techno-economic and life-cycle analyses by Work Package 4; it will also be needed for detailed design of capture facilities for selected sites.
- It is not essential for initial CCS cluster definition but some details may be useful to help selection of cluster participants.
- Please record any information that is available and add to it as knowledge of specific emitters develops through engagement activities.

C.2 Determining how CO_2 will be captured, collected and transported

Some of the data and information for this section can be obtained from public and industry sources; some will be derived or deduced through the process of this methodology as it transitions from data collection to identification of options and formulation of proposals.

The first four sub-sections below interact strongly together; the outputs are combined.

C.2.1 Selection of emitters for ICCS cluster

Data tables: Emission Sources Level 1, 2 & 3, Capture Facilities, Cluster Area.

Other inputs: other sections of this process, engagement with stakeholders in the area.

- Develop a set of selection criteria for emitters to participate in the CCS cluster. This needs to be tailored to the specific area and flexible – see main report.
- Generate a short-list of emitters that may participate. Consider potential different phases of development, or different scenarios with different lists of emitters; use separate rows in data input table for Cluster Area to segregate phases/scenarios.

C.2.2 Emitter details

Data tables: Emission Sources Level 1, 2 & 3, Capture Facilities.

- For emitters being considered for selection, ensure all information at Level 1 & 2 is available.
- Identify factors that may reduce costs of CO_2 capture or transport for specific facilities.
- Identify factors that may enable collection of CO_2 from specific facilities.

C.2.3 Capture technology options

Data table: Emission Sources Level 2.

- For emitters being considered for selection, confirm most appropriate capture technology.
- For each emitter determine or estimate proportion of emission that may be treated by carbon capture, and estimate the likely capture rate (efficiency).

C.2.4 Potential CO_2 capture quantity

Data tables: Capture Facilities, Cluster Area.

- For each selection of emitters generated, produce upgraded estimate of total CO_2 quantity that may be captured.

Outputs of the above four sub-sections:

- One or more list(s) of selected emitters that may participate in CCS cluster.
- If multiple selection lists, definition of what they each represent in terms of time phasing or different scenarios.
- Identification of appropriate capture technology for sites in each list.
- Estimate of total CO_2 capture quantity and flow profile for each selection list.
- Identification of specific factors that support or enable the CCS cluster development.

Parallel activity: review matching of CO_2 storage site capacity with revised total capture quantity estimate, taking account of time phasing or different scenarios.

The next five sub-sections below interact strongly together; the outputs are combined in the sub-sections on proposals for collection network and collection hub.

C.2.5 Transport options for selected facilities

Data table: Capture Facilities.

- For each CO_2 capture facility needed for the selected emitters participating in the cluster, identify the potential CO_2 transport links for the site.
- Consider road, rail, waterway and pipeline but don’t progress to the detail if a mode is obviously not appropriate.
- Catalogue any existing CO_2 transport infrastructure near the capture facility and determine any potential to use this for captured CO_2.
- Identify space availability at the emitting site, both for capture facility, but also for equipment related to transport mode choice (e.g. liquefaction plant).

C.2.6 General information on cluster area

Data tables: Spatial Data, Cluster Area.

- Assemble GIS spatial data and information covering the cluster area.
- Obtain any relevant region-wide information, including constraints, on transport modes being considered for CO_2 collection.

C.2.7 Information on transport in cluster area

Data tables: Capture Facilities, Potential Collection Hubs, Cluster Area, Ports, Existing Pipelines, Pipeline Corridors, Spatial Data.

- Collect sufficient information on relevant, existing transport systems in the cluster area with potential to be used to form a network for CO_2 transport.

- Consider road, rail, waterway and pipeline but don't progress to the detail if a mode is obviously not appropriate.

C.2.8 Collection network proposals and…

C.2.9 Collection hub proposals

These are the combined outputs of this group of sub-sections of the methodology.

Parallel activity: Consider the potential modes (shipping, existing or new pipeline) for trunk CO_2 transport from the cluster area to proposed storage location.

Inputs: information compiled on the CO_2 transport options for the cluster area, knowledge of the cluster area, and engagement with stakeholders in the area.

- Make a proposal for the transport mode, or combination of modes, to be used for the CO_2 collection network serving the ICCS cluster.
- Make a proposal for the location of the collection point or hub for the network.
- Define network routes and required capacity of network sections and branches.
- Define any shared or centralised facilities required to operate the proposed network (e.g. compression, reconditioning, purification), take account of space needed for such facilities when proposing location.

The final two sub-sections interact strongly and are combined.

C.2.10 Trunk transport route options and…

C.2.11 Trunk transport mode options

Data tables: Capture Facilities, Potential Collection Hubs, Cluster Area, Ports, Existing Pipelines, Pipeline Corridors, Spatial Data.

Inputs: total cluster CO_2 capture quantity and profile, proposed collection hub location, proposed CO_2 storage site location.

- Consider options and propose mode, or combination of modes (shipping, existing or new pipeline) for trunk CO_2 transport.
- Take account of time phasing and any alternative scenarios identified.
- Consider options; propose routes and define required capacity for trunk system.
- Identify approximate operating conditions for trunk transport.

Parallel activity: Definition of conditions required at storage site wellhead.

Pete Brownsort
SCCS, Edinburgh
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