Carbon Sequestration Leadership Forum
www.cslforum.org

CARBON SEQUESTRATION LEADERSHIP FORUM TECHNICAL GROUP

Task Force on Clusters, Hubs, and Infrastructure and CCS Results and Recommendations from "Phase 0"

April 2019

”CCUS infrastructure is key to unlocking huge clean growth potential in the UK and can contribute to a cost-effective pathway for reducing UK CO_2 emissions”

(**UK CCUS Cost Challenge Taskforce Report July 2018)**

The Five Keys to Unlock CCS Investment. No.4: ”Build CO_2 networks and accelerate CO2 storage assessments in key regions.”

(IEA https://www.iea.org/media/topics/ccs/5KeysUnlockCCS.PDF)

1. Background

1.1. CSLF Technology Group recommended target and strategy

The CSLF Technology Roadmap 2017 (TRM) recommends that the CSLF Ministers adopt the following target for CO_2 storage by 2025 to keep the global temperature increase from anthropogenic CO_2 emissions to 2°C or below:

Long-term isolation from the atmosphere of at least 400 megatonnes (Mt) CO_2 per year by 2025 (or have permanently captured and stored of 1,800 Mt CO_2).

To achieve this the TRM recommends ten strategic actions that are deemed necessary, of which the following four are regarded to fall under the Technical Group’s responsibilities:

- Facilitate CCS infrastructure development.
- Leverage existing large-scale projects to promote knowledge-exchange opportunities.
- Drive costs down along the whole CCS chain through RD&D.
- Facilitate innovative business models for CCS projects.

The TRM puts obligations on the Technical Group to, trough its Projects Interaction and Review Team (PIRT):

- Monitor the progress in CCS in relation to the Recommended Priority Actions.
- Report the findings at Ministerial meetings.
- Suggest adjustments and updates of the TRM.

1.2 Task Force objectives and mandate

At the CSLF Technical Group (TG) meeting in Melbourne, Australia, 17 October 2018, it was decided to establish a task force on Clusters, Hubs, and Infrastructure. This task force will conduct only preliminary “Phase 0” activities to review progress made on the topic since the CSLF Technology Roadmap 2017 (TRM) was issued. The task force will present a recommendation on whether or not to continue past the preliminary phase at the next Technical Group meeting.

Task force members for the preliminary phase are Norway (lead), Australia, Brazil, Canada, and the United Kingdom.

Topics that could be addressed by the task force include:

- Brief review of networks, existing or in construction
- Identifying and reviewing projects that have moved forward toward technically and financially
- Identifying and reviewing new studies and concepts

- Identifying and reviewing publications that aim to progress the implementation of CCUS networks

Thus, this note addresses the progress of the first of the strategic actions.

1.3 Some definitions

It is useful to have a common understanding of the concepts discussed in this note. Here follow some definitions.

Cluster From GCCSI, 2016)

- An industry cluster is a geographic concentration of interconnected businesses, suppliers, and associated institutions in a particular field. Clusters can emerge for many different reasons, including proximity to raw materials, to transport options such as ports, to labour supply, and to markets.

Hub (from GCCSI, 2016)

- CCS hubs are the central collection or distribution points for CO2. One hub would service the collection of CO_2 from a capture cluster or distribution of CO_2 to a storage cluster
- Hubs could be located at the capture end or the storage end of a multi-user pipeline (forming capture/collection or storage hubs), or both.

Network (from GCCSI, 2016)

- A CCS hub and cluster network (network for short) brings together many of the elements along the CCS value chain (CO_2 source, capture, transport, injection, storage) with multiple co-located (clustered) source capture facilities (of the same or different types) supplying CO_2 to a shared ‘oversized’ transport and storage system.

Infrastructure

- The physical parts of the network (single or shared capture facilities; temporary storage facilities; injection facilities, pipelines, ships)

Note that the definitions apply onshore as well as offshore.

Note also that according to these definitions, a plant or facility can be part of network without being part of a cluster.

1.4. Existing and in construction networks

Based on IEAGHG (2015), GCCSI 2016), and indirectly COCATE (2013), the TRM identified 12 cluster and hub locations (Figure 1), including three existing networks in USA and one in construction in Canada, as well as initiatives or plans for CO_2 networks in Australia, Europe (the Netherlands and the United Kingdom), and the United Arab Emirates. In Europe, several studies had identified CCS hubs or infrastructures. For example, ZEP (2013, 2016, 2017); Jakobsen et al. (2017); Bellona (2016); and Brownsort, Scott, and Hazeldine (2016), the last by reuse of an existing oil pipeline.

1.4.1. United States of America and Canada: Onshore networks

Three networks are in operation in USA - the Denver City (inception 1985), Gulf Coast (inception 1999), and Rocky Mountain (inception 1986) hubs - all in the United States. These are CO_2-EOR systems where clusters of oilfields are fed by a network of pipelines. The Alberta Carbon Trunk Line, Canada, was, and still is (early 2019), in construction (Figure 2).

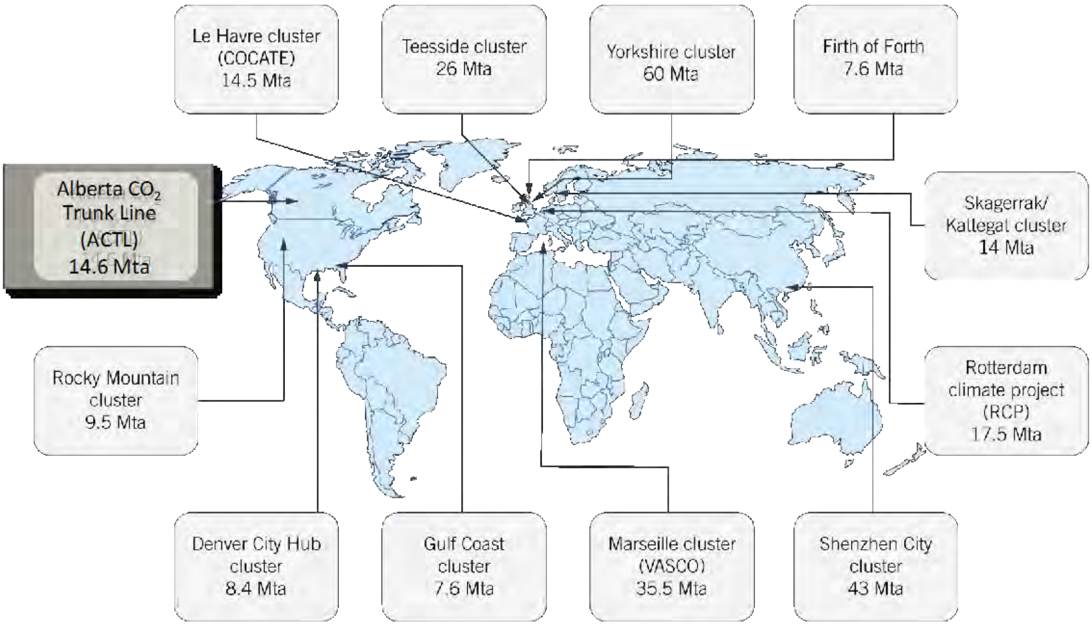


Figure 1. Some Industrial clusters, from GCCSI (2016, adapted from IEAGH, 2015, and ZEP, 2014)

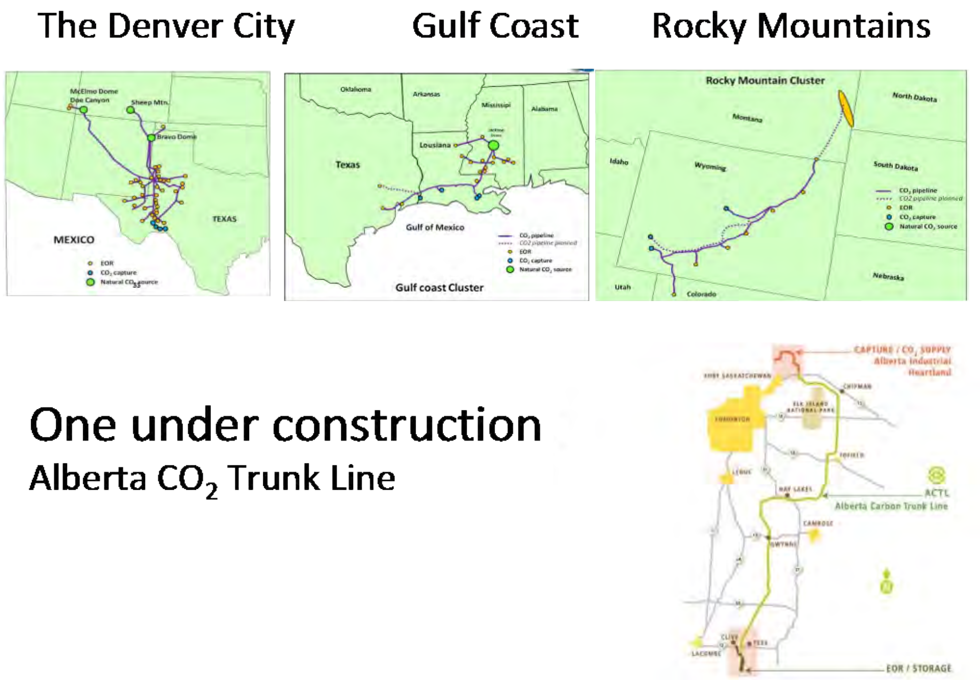


Figure 2. Operational and in-construction CCUS networks in North America

1.4.2. Brazil: An offshore CCUS network

The Petrobras project "Offshore Pre-Salt Santos Basin project" can be classified as a "CCUS hub and cluster network". Here, a set of FPSOs unit that incorporates CO_2 separation and injection facilities, specifically, CO_2 capture from natural gas and reinjection system for enhanced oil recovery (EOR) purposes (Figure 3).

1. For the offshore pre-salt Santos Basin development, the Petrobras has committed to avoiding CO_2 venting to the atmosphere in natural gas production operations. In 2014 Petrobras and its partners have started offshore EOR CO_2 injection at Lula oil field, located in the Santos Basin ca. 300 kilometres of Rio de Janeiro coast.
2. CO2 reinjection: Currently, this process is carried out by nine FPSOs using membrane permeation modules for CO_2capture. In December 2017, Petrobras reached the milestone of 7 MM tonnes of CO_2 separated from natural gas and re-injected in the Santos Basin Pre-salt - for enhanced oil recovery (EOR) purposes.
3. The CO_2 cumulative injection is estimated to reach the milestone of 40 MM de ton of CO_2 separated from natural gas and re-injected in the Santos Basin Pre-salt by 2025.

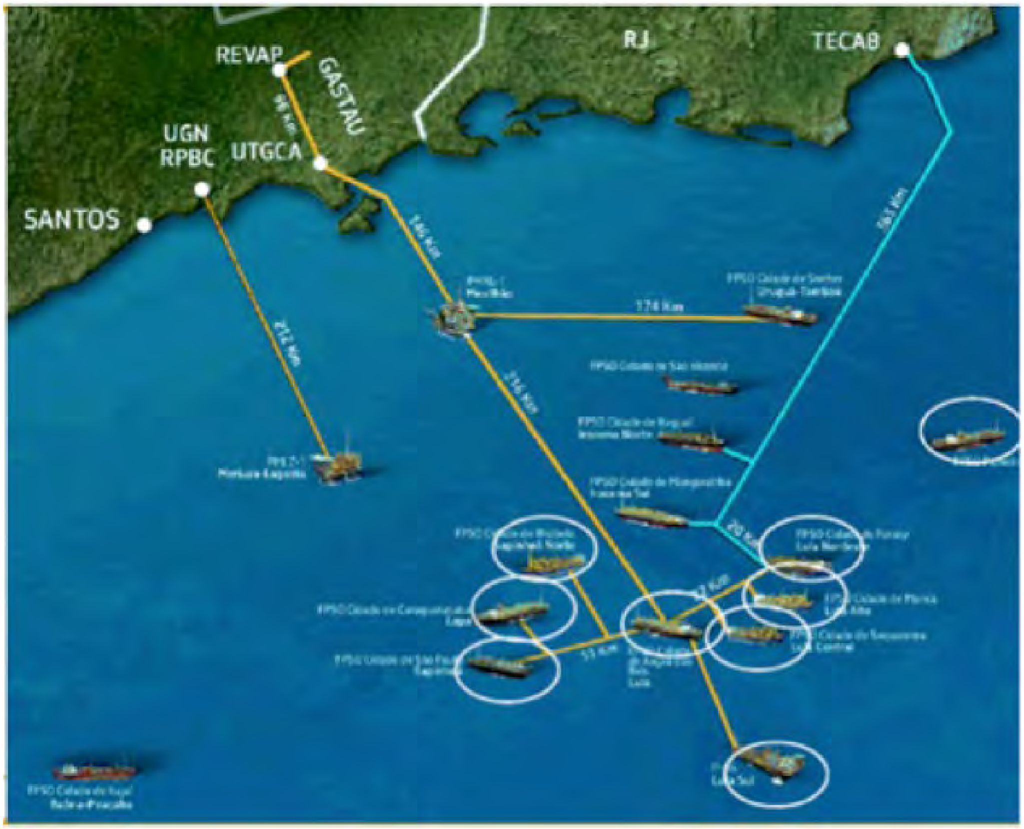


Figure 3. The network FPSOs with CO_2 separation and injection facilities for enhanced oil recovery (EOR) in the Santos basin, offshore Brazil. Courtesy: Grava, W.M. 2018. "Technology for Offshore Gas Production". The 4th Brazilian Congress on CO2 in the Oil, Gas and Biofuels Industries, Rio de Janeiro.

1.5. Importance of clusters, hubs and infrastructure

The TRM summarises several potential benefits of developing hubs and infrastructure for clusters of CO_2 sources form several sources, including GCCSI (2016), ZEP (2013), and IEAGHG 2015):

- Cost sharing
  - Lowering costs in building early infrastructure by utilizing benefits of connecting low-cost industrial sources with storage sites.
  - Distributing investment and operational costs by sharing infrastructure, i.e. the cost per unit CO2 transported will be lowered.
- Lowering the entry barriers for participating CCS projects, such as emitters with small-volume sources and emitters with limited or no access to local storage.
- Securing sufficient and reliable CO_2 for CO_2-EOR and other CO_2 utilisation projects, which is likely to be an important element of some clusters because of the revenue it can contribute.

- Minimizing the environmental impacts associated with infrastructure development, as well as the impact on communities.
- Minimizing and streamlining efforts in relation to planning and regulatory approvals, negotiations with landowners, and public consultations.
- Sharing and utilizing surplus heat in the capture processes of industrial clusters.

The Norwegian Full Scale Project can serve as an example of the cost benefits of a CCS network. Osloeconomics and Atkins (2016) showed cost per tonne CO_2 stored for the network described below in Section 2.2.1 for one, two and three industrial sources in southeast Norway, with a common fleet of ships for transport to terminal at the Norwegian west coast and common pipeline transport to offshore storage. The network solution with all three sources was estimated to be 18 -41 % cheaper than from a single source, depending on the amount of CO_2 captured at the single source.

The United Kingdom CCS Cost Reduction Task Force (CCSA 2013) found that CO_2 transport costs could be reduced by more than 50% with the deployment of large and efficiently utilized pipelines.

Transportation of CO_2 represents a smaller part of the total costs for a CCS chain than capture. The impact on the total cost of a CCS chain may be moderate, particularly for onshore pipelines (IEAGHG 2015). However, the cost may be significant in absolute money terms (Roussanaly, Brunsvold, and Hognes 2014).

Most gaps, risks, and challenges are commercial and political in nature and may include the cooperation of different industries across the CCS value chain, the lack of project-on-project confidence, the completion of projects on cost and on schedule, operational availability, flexibility, reliability, financing and political aspects, and last but not least, lack of business models for larger CCS systems. Some thinking on business models has started that includes the separation of CO_2 capture at the sources from the transport and storage parts (Esposito, Monroe, and Friedman 2011; Pöyry and Teesside Collective 2017; Banks, Boersma, and Goldthorpe 2017; Norwegian Ministry of Petroleum and Energy (MPE), 2016; Element Energy, 2018a,b; Pale Blue Dot, 2018; UK Government, 2018).

1.6. TRM Recommendations on clusters, hubs, and infrastructure

Based on the above, the TRM made the following recommendations (quotes):

1.6.1. Priority Recommendation to decision makers

Facilitate CCS infrastructure development

1.6.2. Specific recommendations for CO_2 hubs and clusters

Governments and industry should work together to:

<u>Towards 2020:</u>

- Design and initiate large-scale CO_2 hubs that integrate capture, transport, and storage, including matching of sources and sinks.
- Develop commercial models for industrial and power CCS chains.

<u>Towards 2025:</u>

- Implement the first large-scale (i.e., >10 Mt CO_2/year aggregate throughput) CCS chains in power, industrial, and bio-CCS. These should be focused in industrial regions that have the potential to share infrastructure, rather than focusing on individual projects.
- Implement initial shared infrastructure for a limited number of plants within industrial clusters. This should recognize that in the initial phases, volumes within these clusters may be less than one million tonnes per annum, but that expansion from this initial start will occur.

<u>Towards 2035:</u>

- Continue progressive rollout and expansion of full-scale CCS chains and clusters in power, industrial, and bio-CCS. This includes large-scale CO_2 transport networks that integrate CO_2 capture, transport, and storage, including matching of sources and sinks. 3. CCUS Infrastructure/Networks Projects that passed a milestone or were secured funding summer 2017 – end 2018.

2. CCUS Infrastructure/Networks Projects not in the TRM

2.1. Europe

2.1.1. The European Commission SET Plan – Projects of Common Interest (PCI)

Projects of common interest (PCIs) are key cross border infrastructure projects that link the energy systems of EU countries. They are intended to help the EU achieve its energy policy and climate objectives: affordable, secure and sustainable energy for all citizens, and the long-term decarbonisation of the economy in accordance with the Paris Agreement. CCS and CCUS targets and ambitions of the European Commission are outlined in the document Strategic Energy Technologies (SET) Technical Working group (TWG) 9 implementation plan. Several industrial clusters are mentioned. Four were shortlisted and two have been funded.

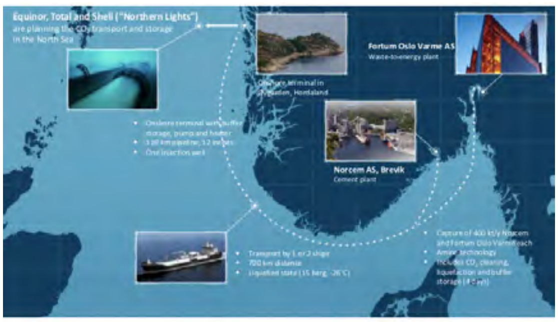
EU SET plan CCUS Implementation

- Target 4 in Plan
  - At least 1 active Project of Common European Interest for CO2 transport infrastructure, for example related to storage in the North Sea
  - Mechanism: EU Projects of Common Interest (PCI) for CO_2 transport infrastructure
  - Status. Four applicants, two received grants

Project	Promoter	Status
Teesside CO_2 Hub	Tees Valley	
CO2Sapling Transport and infrastucture	Pale Blue Dot Energy Ltd	Funded by EC
Port of Rotterdam	Rotterdam Port Authority	Funded by EC
CO_2 cross-border	Equinor	

2.1.2. A Norwegian CCUS network

The Norwegian Full Scale project involves CO_2 capture at one cement factory at Brevik (ca. 150 km south of Oslo) and one waste-to-energy plant in Oslo. The CO_2 will be transported by ship to a hub/CO2 storage terminal on the west coat of Norway and from there by pipeline to a storage site in the North Sea. The project describes what can be considered a CCS network. The cement plant is part of an industrial cluster but so far the only facility that will take part (a nearby fertilizer plant was involved in the pre-studies buy is no longer part of the project).



The project was granted funds for Front End Engineering Development (FEED) in 2018 and the plan is to reach a final investment decision (FID) in 2020/21. The industrial plants as well the Norwegian government and consortium of oil companies contribute to the funding.

For more information, see MPE (2016) and Carepenter (2019).

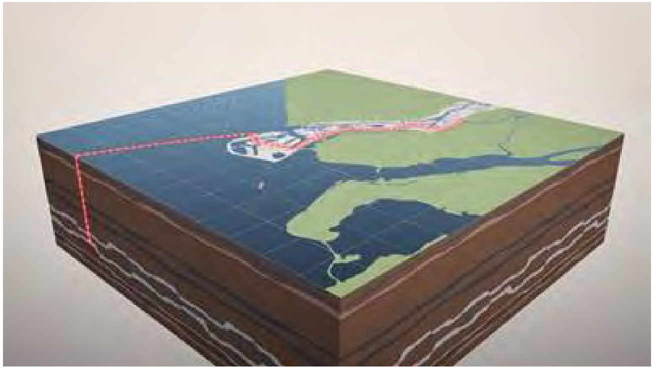
2.1.3. A CCUS Network in the Netherlands

The Port of Rotterdam CCUS Backbone Initiative (Porthos) aims to develop basic infrastructure to collect captured CO_2 from various industrial sources in the Rotterdam port area and transport it to the North Sea for storage.

The Porthos project was granted € 6.5 mill. by the European Commission as a Project of Common Interest (PCI) as well as receiving funds from industry.

A feasibility study was completed in April 2018. The project leaders will continue to consolidate the business case and work towards an investment decision in 2019.

For more information, see Port of Rotterdam (GCCSI, 2018).



2.1.4. A UK CCUS network – CO_2Sapling

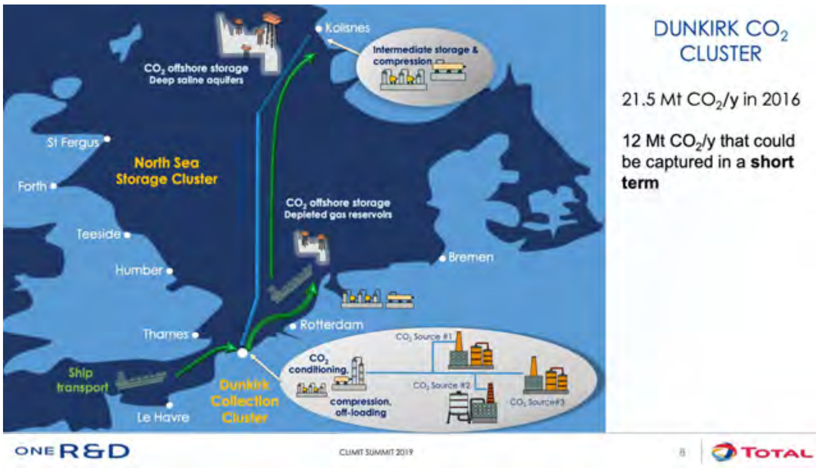
The CO_2Sapling project is a CO_2 transportation infrastructure project that has grown from and will build on the project ACORN, a full chain CCS project in the portfolio of the European programme Accelerating CO_2 Technologies (ACT)

CO_2Sapling was granted € 3 mill. by the European Commission as a Project of Common Interest (PCI) as well as receiving funds from the UK and Scottish Governments and industry in late 2018. The project will work on a feasibility study with the aim to start Front End Engineering Development (FEED) in 2019.

2.1.5. The Dunkirk CO_2 cluster

This network could potentially capture 12 Mt CO_2/year from industrial sources in the Dunkirk area and transport it offshore for storage in depleted gas reservoir or ship it to Kollsnes, the location of the intermediate storage and compression facility of the Norwegian full-scale project. A collection hub at

Dunkirk could also receive CO_2 from other sources by ship before being sent to storage.



Source: David Nevicato, Total CCUS Research Programme Manager, presentation at CLIMIT Summit 2019, Oslo, Norway, 26-27 February 2019 (http://www.climit.no/no/PublishingImages/presentasjoner-fra-climit-summit-2019/David%20Nevicato,%20Total.pdf)3.

2.1.6. Align – an European Commission Network Project

The Align project is an ACT (Accelerating CCS Technologies) project funded by the European Commission and led by the Netherlands. Its goal is to transform six European industrial regions into economically robust, low-carbon centres by 2025. A strong focus of the transport work package is ship transport of CO_2.

2.1.7. Ireland (GCCSI, 2018)

The Ervia Cork CCS project plans capture CO_2 from a number of emission-intensive companies located in Cork, with initial consideration being given to the two modern gas-fired, combined-cycle gas turbine power stations Whitegate and Aghada and Ireland's only oil refining business: Irving Oil Refinery (75,000 barrels per day). The captured CO_2 is planned to be transported via an existing pipe network, which includes 54 kilometres offshore pipeline, to the potential CO2 storage sites in the Kinsale Gas Field.

2.1.8. Clean Gas Project and Teesside Collective

The Clean Gas project will combine CO_2 capture from new efficient low-carbon power generation and local industrial emitters in Teesside. This is led by the Oil and Gas Climate Initiative Climate Investments in a strategic partnership with BP, ENI, Equinor, Occidental Petroleum, Shell, and Total (OGCI CI, 2018)[1]. The infrastructure created would also enable wider industry on Teesside and to capture and store CO2 from their processes (previously proposed by the Teesside Collective). The Teesside Collective project was qualified as EU PCI project, but was not awarded funds in late 2018.

2.1.9. Two UK hydrogen networks

H21 North of England

Although a network for distributing hydrogen, H21 is included here as an example of a new gas network that involves CCS.

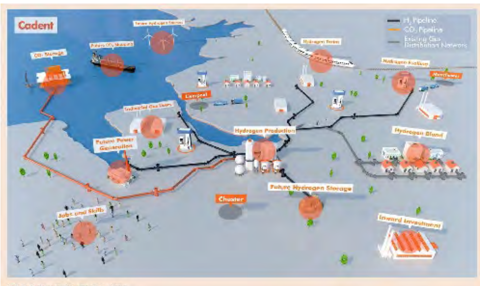
---

[1] The OGCI is led 13 oil companies and responsible for a more than $1billion fund, investing in technologies and business models which lower the carbon footprint of the energy and industrial sectors.

The H21 North of England aims to decarbonise power, heat and transport across the North of England. It will convert the UK gas grid from natural gas to CCS decarbonised hydrogen, converting 3.7 million metering points across Leeds, Bradford, Manchester, Liverpool, Hull, York, Teesside and Newcastle. The clean hydrogen will be produced from large- scale production plants with 12.15 GW capacity, with integrated CO_2 capture processes to capture up to 20 Mtpa CO2 by 2035 in several phases. CO_2 storage is planned to be in saline aquifers and depleted gas fields in the Southern North Sea. A feasibility study was submitted to the UK authorities in November 2018.

Hynet

Again a hydrogen network, the HyNet North West is a CCUS-equipped hydrogen production and distribution network developed by the UK gas distribution company Cadent together with Progressive Energy and ENI. The facility will produce hydrogen from natural gas that will then be supplied to industrial sites, to households for heat supply and serve as transport fuel. Natural gas will be converted to hydrogen gas via auto-thermal reforming to supply a core set of major industrial gas users and industrial sites. With this facility, Cadent is developing CCUS infrastructure.



2.2. Australia

2.2.1. CarbonNet

This project is investigating the feasibility for a commercial-scale, multi-user CCS network in Gippsland, Victoria, Australia. It is jointly funded by the Australian and Victorian Governments to 2020, with significant research investment from, among others, ANLEC R&D. Knowledge sharing takes place via GCCSI, and CarbonNet is working collaboratively with industry to secure customers and investors in a CCS service. Feasibility studies completed, project development ongoing with the aim to transit to private sector around 2020/2021. CarbonNet includes plans for hydrogen production in cooperation with Japan.

(http://earthresources.vic.gov.au/earth-resources/victorias-earth-resources/carbon-storage/the-carbonnet-project;

https://www.cslforum.org/cslf/sites/default/files/documents/Melbourne2018/CarbonNet_Project_Presentation_to_Technical_Group.pdf)

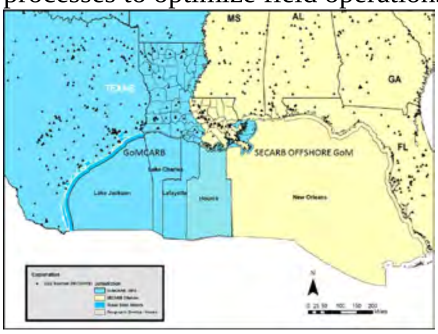
2.2.2. South West Hub

(http://www.dmp.wa.gov.au/South-West-Hub-CCS-1489.aspx;
https://www.cslforum.org/cslf/sites/default/files/documents/Melbourne2018/South_West_Hub.pdf)

This is project that so far has focussed on a storage hub in the heart of the industrial area of south west Australia. It is a staged project that involves collecting and analysing data and samples from the Lesueur Sandstone formation, to test its feasibility as a CO_2 reservoir. The South West Hub is a partnership between government and industry. Research into the geo-sequestration is being funded by the Australian Government and the Western Australian Government through the Department of Mines, Industry Regulation and Safety (DMIRS).

2.3. Offshore United States of America

Gulf of Mexico Partnership for Offshore Carbon Storage (GoMCarb) focuses on the assessment of offshore (sub-seafloor) geologic carbon storage beneath the Gulf of Mexico. It will identify CO_2 offshore transport and delivery options, logistics, risks
and regulations in the gulf region, including assessing the feasibility of decommissioning and re-purposing existing infrastructure to facilitate offshore CO_2 storage. Existing infrastructure such as pipelines, platforms, and wells will be assessed, collated, and mapped to the location of potential offshore storage reservoirs. GoMCarb will link source-transport-storage options in the Gulf of Mexico, from transportation from the source of CO_2 to the offshore storage wellhead, and identify processes to optimize field operations, reservoir response, and operation costs. Funded by US DoE.



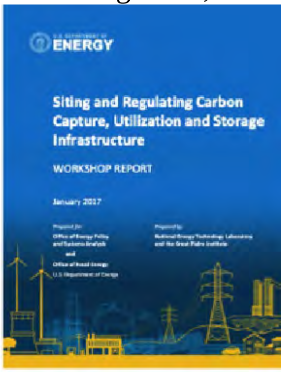
2.4. China

The Sinopec Zhongyuan Oil Company CCUS project, started from April, 2009 may be considered an infrastructure project. CO_2 (capacity of 500,000 t/yr) is captured from Kaifeng, Xinlianxin and Zhongyuan Refining and Chemical plants and transported to an oil field for EOR.

3. Other reports or very early initiatives

US Department of Energy: Siting and Regulating Carbon Capture, Utilization and Storage. Workshop report January 2017 The Department of Energy (DOE) sponsored a technical workshop in April 2016 in Washington, D.C to identify and promote best practices for siting and regulating CO_2 infrastructure (pipelines, EOR, and other geologic CO_2 storage sites). The purpose of the workshop was to foster communication, coordination, and sharing of lessons learned and best practices among states and entities that are involved in siting and regulating CO_2 infrastructure, or that may have CO_2 infrastructure project within their borders in the future.

The scope of the technical workshop also included discussions around regulation and management of CO_2 storage sites, which serve as critical infrastructure for entities capturing CO_2.



IEAGHG, 2018. Enabling the Deployment of Industrial CCS Clusters. IEAGHG Technical report 2018-01. February 2018.

The study included investigation of four different ICCS cluster business models:

- Public transport and storage (T&S) company
- T&S as regulated assets
- Anchor CCS project with 3rd party access
- CO_2-EOR

One finding is that Industrial CCS (ICCS) is not yet commercially mature.

Private investment is likely to occur if the following four key enablers are addressed:

- Mitigate the risk of carbon "leakage"
- Provide the emitters with margin certainty through appropriate subsidies
- Decouple the business cases for capture and infrastructure
- Share the key risks with government through guarantees

The study also found that the necessary level of government support is high. However, without ICCS, governments might need to rely on more expensive solutions to meet decarbonisation targets.

Element Energy 2017. Deployment of an industrial carbon Capture and Storage cluster in Europe: A funding pathway.

This study focused mainly on a possible industrial hub with common transport of CO_2 to an offshore location. Some key messages:

- Industrial CCS clusters are key to European industrial decarbonisation
- The first industrial CCS clusters in Europe can be operational in the early 2020s
- European CCS clusters can be unlocked with grants, subsidies and guarantees
- Member State support and contribution is vital in the short-term
- Important European funds can be made available to industrial CCS clusters
- With government support, European industrial CCS clusters could be fully funded

UK CCUS Cost Challenge Taskforce Report, Delivering Clean Growth. July 2018.

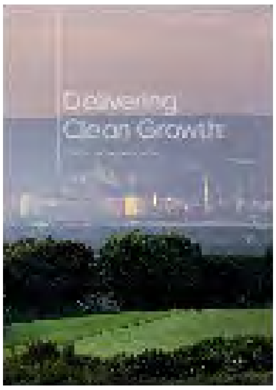
In this report, the Taskforce proposes a range of measures and actions to inform a new approach to CCUS deployment that will enable cost reductions to be secured. The study demonstrates that CCUS can deliver decarbonisation across industry, power, and provide solutions for heat and transport, by focusing on building a long term, commercially sustainable and cost-effective decarbonisation service industry for the UK. This may offer new industrial opportunities, secure long term jobs, deliver new economic development across industrial heartlands and secure international competitiveness through new decarbonised products and services.

The Taskforce identified several large industrial clusters in the UK as candidates for the development of CO_2 infrastructure and networks for capturing CO_2 and transporting it offshore in the North Sea and East Irish Sea for long term storage. The set of clusters include Teesside, Merseyside, Humberside, Scotland, and South Wales. However, the Task Force was not proposing specific projects; rather the UK government is committed to work with projects as they come forward in these clusters.

Among the conclusions of the study:

- Cost-effective CCUS can be achieved through industry and Government working together to:
    - Unlock early investment

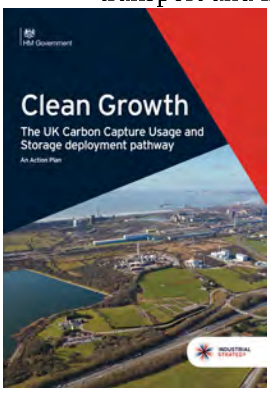
- Develop business models for CO_2 transport and storage infrastructure:
- Create CCUS clusters



UK Govternment Clean Growth. The UK Carbon Capture Usage and Storage deployment pathway. An Action Plan

This document highlighted the potential of clusters and committed to

- Report on the scope of the opportunity for maximising economies of scale by sharing T&S infrastructure and storage
- Set out and consult on a business model for transport and infrastructure in 2019.



4. Discussion – progress of hubs and clusters in relation to target

By the end of 2018 the world captured and stored approximately 35 Mt CO_2, the majority for EOR purposes. The cumulative injection was estimated to more than 230 Mt CO_2. The injection rate increased from the previuos year by around 1 Mt CO_2/year, represented by one -1 - project that came on line in 2018 (CNCP Jilin, China).

To reach the storage target by 2025, there is need for a10-fold increase in annual storage capacity the next six years. The Gorgon, Australia, and Alberta CO_2 Trunk line (ACTL) were delayed but may add 6 Mt CO_2/y in 2019. Only two other capture and storage facilities are in construction, both in China, adding a total capacity 1+ Mt CO_2/y. Even projects in advanced or early development will not add sufficient capacity by 2025, only 35 -40 Mt CO_2/y. These projects include the hubs and infrastructure projects described above.

All numbers from the Global Status of CCS, 2018 (GCCSI, 2018).

5. Conclusion and recommendations

The statement "CCUS infrastructure is key to unlocking huge clean growth potential in the UK and can contribute to a cost-effective pathway for reducing UK CO_2 emissions" (UK CCUS Cost Challenge Taskforce Report July 2018) seems to be supported by documents and projects reviewed above. However, despite all plans and studies it is noted that:

1. Only an offshore CCUS network has come online the last 15 years, no onshore infrastructure/network projects
2. Only one CCUS network is in construction, with anticipated start up in 2019, increasing capacity by 6 Mt CO_2/y
3. No project passed the Final Investment Decision (FID) gate in 2018
4. Projects in advanced or early development will only add 35 -40 Mt CO_2/y by 2025, at best.

The conclusion is clear: Progress on infrastructure development is lacking far behind what is necessary to reach the storage target. Strong action is required.

Recommendation 1:

- The Task Force continues to monitor the development of networks for CCUS, including clusters, hubs and infrastructure.
- The task Force updates this note on an annual basis (no need for an extensive Task Force report)

Recommendation 2:

CCUS networks are important to reach the target. To this end, decision makers from in industry and governments should work together to

  - Bring infrastructure projects in advanced stage of development (FEED) to investment decision (FID)
  - Develop and implement business models
  - Accelerate planning of other infrastructure projects

Workshops in cooperation with GCCSI, IEAGHG, International CCS Knowledge Centre, CO2GeoNet, MI, others could be a contribution to this.

6. References

Banks, J. P., T. Boersma, and W. Goldthorpe. 2017. "Challenges related to carbon transportation and storage – showstoppers for CCS?" GCCSI web publication (6 January). https://www.globalccsinstitute.com/publications/challenges-related-carbon-transportation-and-storage-—showstoppers-ccs

Bellona. 2016. Manufacturing Our Future: Industries, European Regions and Climate Action – CO_2 networks for the Ruhr, Rotterdam, Antwerp & the greater Oslo Fjord. (13 October). http://bellona.org/publication/manufacturing-our-future-industries-european-regions-and-climate-action

Brownsort, P., V. Scott, and R. S. Hazeldine. 2016. "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." International Journal of Greenhouse Gas Control 52: 130–138. http://www.sciencedirect.com/science/article/pii/S1750583616302948**.**

Carpenter, M. 2019. Creating an industrial CCS hub – øatest developments in Norway. IPIEAC webinar 22 Januray 2019. https://on24static.akamaized.net/event/19/10/40/5/rt/1/documents/resourceList1548173001792/creatinganindustrialccshuball1548173074836.pdf

CCSA (Carbon Capture and Storage Association). 2013. *CCS Cost Reduction Task Force: Final Report*. London (16 May).

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/201021/CCS_Cost_Reduction_Taskforce_-_Final_Report_-_May_2013.pdf

COCATE, 2013 Final report summary – COCATE (Large-scale CCS transportation infrastructure in Europe. https://cordis.europa.eu/project/rcn/93104/reporting/en

Element Energy 2017. Deployment of an industrial carbon Capture and Storage cluster in Europe: A funding pathway. http://i2-4c.eu/wp-content/uploads/2017/10/i24c-report-Deployment-of-an-industrial-CCS-cluster-in-Europe-2017-Final-.pdf

Element Energy, 2018a. Industrial carbon capture business models. Report for The Department for Business, Energy and Industrial Strategy. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/759286/BEIS_CCS_business_models.pdf

Element Energy, 2018b. Policy Mechanisms to support the large- scale deployment of Carbon Capture and Storage (CCS). https://ieta.org/resources/COP24/Misc%20Media%20Files/Dec5/Dec5SE2_4.pdf

Esposito, R. A, L.S. Monroe, and J. S. Friedman. 2011. "Deployment Models for Commercialized Carbon Capture and Storage." *Environ Sci Technol* 45(1): 139-46. doi: 10.1021/es101441a. http://pubs.acs.org/doi/pdfplus/10.1021/es101441a**.**

GCCSI (2016e). Understanding Industrial CCS Hubs and Clusters. June. http://www.globalccsinstitute.com/sites/www.globalccsinstitute.com/files/content/page/123214/files/Understanding%20Industrial%20CCS%20hubs%20and%20clusters.pdf

GCCSI (2018) Global Status of CCS: 2018. https://www.globalccsinstitute.com

IEAGHG (2015). *Carbon capture and storage cluster projects: Review and future opportunities*. 2015/03. April 2015**.** http://www.ieaghg.org/docs/General_Docs/Reports/2015-03.pdf.

IEAGHG (2018) Enabling the Deployment of Industrial CCS Clusters. IEAGHG Technical report 2018-01. February 2018. http://documents.ieaghg.org/index.php/s/YKm6B7zikUpPgGA?path=%2F2018%2FTechnical%20Reports

Jakobsen, J., M. Byseveen, E. Vågenes, C. Eickhoff, T. Mikunda, F. Neele, L. Brunner, R. Heffron, D. Schumann, L. Downes, and D. Hanstock. 2017. "Developing a Pilot Case and Modelling the Development of a Large European CO_2 Transport Infrastructure – The GATEWAY H2020 Project." *Energy Procedia* 114: 6835–6843. http://www.sciencedirect.com/science/article/pii/S1876610217320222**.**

MPE (Norwegian Ministry of Petroleum and Energy). 2016. Feasibility study for full-scale CCS in Norway. Ministry of Petroleum and Energy. http://www.gassnova.no/en/Documents/Feasibilitystudy_fullscale_CCS_Norway_2016.pdf**.**

OGCI, 2018. https://oilandgasclimateinitiative.com/climate-investments-announces-progression-of-the-uks-first-commercial-full-chain-carbon-capture-utilization-and-storage-project/

Osloeconomics and Atkins, 2016. Kvalitetssikring (KS1) av KVU om demonstrasjon av fillskal fangst, transport og lagring av CO2. Report to the Norwehǵian Ministry of Petroleum and Energy. https://www.regjeringen.no/contentassets/f967f4d7533a4ab0af75fe9bad3d1910/rapport-ks1-co2-handtering-003.pdf

Pale Blue Dot, 2018**.** CO_2 Transportation and Storage Business Models Summary Report

10251BEIS-Rep-01-04 January 2018.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/677721/10251BEIS_CO2_TS_Business_Models_FINAL.pdf

Pöyry and Teesside Collective. 2017. *A business case for a UK industrial CCS support mechanism*. A Pöyry report on behalf of and in partnership with the Tesside Collective. February. http://www.teessidecollective.co.uk/teesside-collective-report-a-business-case-for-a-uk-industrial-ccs-support-mechanism/

Roussanaly, S., A-L- Brunsvold, and E. S. Hognes. 2014. "Benchmarking of CO_2 transport technologies: Part II – Offshore pipeline and shipping to an offshore site." International Journal of Greenhouse Gas Control 28: 283–299. http://www.sciencedirect.com/science/article/pii/S1750583614001765**.**

UK Carbon Capture and Storage Cost Reduction Task Force (2013). The potential for reducing the costs of CCS in the UK. CCS cost reduction taskforce final report. Available at https://www.gov.uk/government/publications/ccs-cost-reduction-task-force-final-report (Accessed 15 March 2019).

UK Cost Challenge Task Force (2018) Delivering clean growth.
https://www.gov.uk/government/publications/delivering-clean-growth-ccus-cost-challenge-taskforce-report

UK Government (2018). Clean Growth. The UKCarbon Capture Usage and Storage deployment pathway. An Action Plan. https://www.gov.uk/government/publications/the-uk-carbon-capture-usage-and-storage-ccus-deployment-pathway-an-action-plan (Accessed 15 march 2019)

ZEP (2013). Building a CO_2 transport infrastructure for Europe.
http://www.zeroemissionsplatform.eu/news/news/1610-eu-must-urgently-invest-25-billion-in-co2-transport-infrastructure.html**.**

ZEP (2016). Identifying and Developing European CCS Hubs. April.
http://www.zeroemissionsplatform.eu/library/publication/262-zepeuhubsclusters.html**.**

ZEP (2017). Fast Track CO_2 Transport and Storage for Europe.
http://www.zeroemissionsplatform.eu/library/publication/275-fasttracktas.html