High Level Report: CCUS in Europe

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Authors: Hans Bolscher, Peter Brownsort, Liliana Guevara Opinska, Kristin Jordal, Dennis Kraemer, Tom Mikunda, Philippa Parmiter, Lydia Rycroft, Jessica Yearwood

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EU CCUS PROJECTS NETWORK (No ENER/C2/2017-65/SI2.793333)

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About the CCUS Projects Network

The CCUS Projects Network comprises and supports major industrial projects underway across Europe in the field of carbon capture and storage (CCS) and carbon capture and utilisation (CCU). Our Network aims to speed up delivery of these technologies, which the European Commission recognises as crucial to achieving 2050 climate targets. By sharing knowledge and learning from each other, our project members will drive forward the delivery and deployment of CCS and CCU, enabling Europe's member states to reduce emissions from industry, electricity, transport and heat.

http://www.ccusnetwork.eu/

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Executive summary

The CCUS Projects Network comprises and supports major industrial projects under way across Europe in the field of carbon capture and storage (CCS) and carbon capture and utilisation (CCU). Our Network aims to speed up delivery of these technologies, which the European Commission recognises as crucial to achieving 2050 climate targets. By sharing knowledge and learning from each other, our project members will drive forward the delivery and deployment of CCS and CCU, enabling Europe's member states to reduce emissions from industry, electricity, transport and heat.

This first High-Level Report aims to provide an overview of the need for Carbon Capture Utilization and Storage (CCUS) in Europe, as well as a better understanding of its potential and recent developments in Europe. It also introduces all of the current CCUS Projects Network members and identifies the key aspects in which these projects are sharing knowledge.

CCUS technologies are necessary to achieve Europe's 2050 decarbonization goals. Further, CCUS has an important role to play in particular decarbonising industry but also in many other important areas of economic activity including generation of electricity and heat, and the production of hydrogen and synthetic fuels. Although the development of CCUS in Europe has been slow, the European Commission (EC) has been supporting CCS for over a decade through a number of funding, financing and other support mechanisms.

A number of ambitious European CCUS projects are being developed in order to close the gap between the limited existing capacity and the 2050 needs for CCUS. The role of the CCUS Projects Network is to support their successful development and implementation through facilitating knowledge-sharing from which the projects can mutually learn and benefit.

Currently, the knowledge sharing within the CCUS Project Network is based on discussions in three thematic groups: i) policy, regulation and public perception; ii) CO_2 capture and utilization; and) CO_2 transport, storage and networks. In the last chapter, the High Level Report details the key points that have and planned to be discussed within the Network per each of the thematic groups.

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CCUS in Europe

1 Introduction

1.1 The European CCUS Projects Network

The CCUS Projects Network comprises and supports major industrial projects under way across Europe in the field of carbon capture and storage (CCS) and carbon capture and utilisation (CCU). Our Network aims to speed up delivery of these technologies, which the European Commission recognises as crucial to achieving 2050 climate targets. By sharing knowledge and learning from each other, our project members will drive forward the delivery and deployment of Carbon Capture Utilisation and Storage (CCUS), enabling Europe's member states to reduce emissions from industry, electricity, transport and heat.

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1.2 The structure of this report

This report is structured as follows:

- Chapter 2 – Context of CCS and CCU in Europe, covering the need for CCUS, its potential in Europe, as well as the relevant policy context.
- Chapter 3 – Developments in Europe for CCS and CCU, and an introduction to the members of the European CCUS Projects Network.
- Chapter 4 – Key aspects relevant to CCUS projects emerging in the three Thematic Working Groups of the CCUS Projects Network: Policy, regulation and public perception; CO_2 capture and utilization; and CO_2 transport, storage and networks.

2 Context: CCU and CCS in Europe

2.1 Why does Europe need CCUS?

Carbon Capture Utilization and Storage (CCUS) technologies can and should play an important role in achieving Europe's 2050 decarbonization goals. In particular, carbon capture and storage (CCS) will arguably be necessary to achieve climate neutrality in Europe in a cost-efficient manner. However, both CCS and carbon capture and utilization (CCU) should be seen as mutually reinforcing solutions as both require similar infrastructure for capture and transport. All credible scenario modelling shows that CCS will be needed to meet the goals set out in the Paris Agreement.[1]

The industrial sector in Europe represents approximately one fourth of EU's GDP and provides about 50 million jobs. At the same time the European industry is responsible for producing more than 500 Mt of CO_2 emissions annually (including electricity and end-of life emissions). This represents around 14% of the EU's total emissions.[2] The deindustrialization of Europe due to mounting pressures for climate action would result in the loss of jobs, lead to diminished economic competitiveness, increased dependency from other global players and would have other macro-economic ramifications. In this context, CCUS represents one of the only available tools to support the decarbonization of industry while preserving industrial jobs and delivering low-carbon, essential products like chemicals, steel and cement. Moreover, based on available estimates, CCS could create 150,000 direct and indirect jobs by 2050.[3]

In addition, in the future, when coupled to gas-to-power or hydrogen technologies, CCS could facilitate a stable, flexible and low-emissions source of power. Thus, CCUS has an important role to play in industry but also in many other important areas of economic activity including generation of electricity and heat, and the production of hydrogen and synthetic fuels.

2.2 The potential for CCUS in Europe

Based on the EU's long-term strategic vision described in the "Clean Planet for All" communication[4], the 1.5°C compliant scenarios (1.5 LIFE and 1.5 TECH) depend on the deployment of CCS to achieve climate neutrality and foresee an important role for CCU. In these scenarios CCUS technologies are

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[1] Rogelj, J., D. Shindell, K. Jiang, S. Fifita, P. Forster, V. Ginzburg, C. Handa, H. Kheshgi, S. Kobayashi, E. Kriegler, L. Mundaca, R. Séférian, and M.V. Vilariño, 2018: Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)], p. 135.
European Commission (2018). *In-depth analysis in support of the Commission Communication COM(2018)773*, p. 192. Available from: https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_analysis_in_support_en_0.pdf

[2] Material Economics (2019). Industrial Transformation 2050" Pathways to Net-Zero Emissions from EU Heavy Industry

[3] IOGP (2019). The potential for CCS and CCU in Europe

[4] COM (2018) 773 – A clean planet for all – A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy.

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forecasted to remove between 281 and 606 Mt of CO_2 in 2050. However, at the moment only two-large scale CCS facilities operate in Europe. Both of them are located in Norway (Sleipner and Snøhvit) and jointly they remove a total of 1.55 Mt of CO_2 per year which is stored in an offshore geological storage.[5] In order to achieve the needs forecasted by the two scenarios described above, the CO_2 capture, storage or reuse capacity needs to increase by 181 to 391 times (depending on the scenario) by 2050.

In Europe, technical hurdles, the lack of a business case and public acceptance issues around onshore CO_2 storage are key difficulties that have prevented projects from moving forward. Nonetheless, there is sufficient potential for development of CCUS technologies and infrastructure at the scale required to achieve carbon-neutrality by 2050. Europe is already well positioned to benefit from CCUS based on the extensive existing pipeline infrastructure which can be used to transport CO_2, hydrogen and synthetic methane, and other renewable and decarbonised gases. In particular, large source emission clusters are good options to create economies of scale, by establishing shared CO_2 transportation infrastructure with third-party access for efficient use of the infrastructure by multiple users. In addition, Europe has extensive geological CO_2 storage capacity and subsea expertise, with countries such as Norway and the UK willing to enable shared access to their offshore storage facilities for CO_2 from EU industry.

Moreover, as can be seen from the information in section 3.3 (Members of the CCUS Projects Network), a number of ambitious European CCUS projects are being developed. The role of the CCUS Projects Network is to support their successful development and implementation through facilitating knowledge-sharing from which the projects can mutually learn and benefit.

2.3 The policy context for CCUS in Europe

Although the development of CCUS in Europe has been slow, the European Commission (EC) has been supporting CCS for over a decade. It recognised the role of CCS, and more recently CCU, as a crucial link in the combination of technologies necessary for the decarbonisation of heavy industry and fossil-fuel based power sector. To support the roll-out of the technology, the EC has implemented a number of regulatory and policy measures, listed below in chronological order:

- 2007 – Establishment of the SET Plan[6];
- 2009 – Funding through the European Energy Programme for Recovery (EEPR)[7];
- 2009 – Directive 2009/31/EC on the geological storage of carbon dioxide[8];
- 2009 – Establishment of the European CCS Demonstration Project Network[9];
- 2011 – The first call of the New Entrants Reserve 300 (NER300) financing instrument[10];

[5] Global CCS Institute (2019). Global Status of CCS 2019
[6] COM(2007)723: A European strategic energy technology plan (SET-plan)
[7] Regulation (EC) No 663/2009: establishing a programme to aid economic recovery
[8] DIRECTIVE 2009/31/EC on the geological storage of carbon dioxide
[9] EC (2010) DG for Energy. CO2 Capture and Storage: DEMONSTRATION PROJECTS

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- 2012 – Full inclusion of CCS in Phase III (2013-2020) of the EU ETS[11];
- 2013 – The second call of the NER300 financing instrument[12];
- 2016 – H2020 ERA-NET Cofund 'ACT' - Accelerating CCS Technologies[13];
- 2017 – SET Plan TWG9 CCS and CCU Implementation Plan[14];
- 2017 – Inclusion of CCU and CCS in ETS Innovation fund;
- 2017 – Financing support for CCUS as InnovFin Energy Demonstration Projects[15];
- 2018 – Establishment of the European CCUS Projects Network[16];
- 2018 – CO_2 transport Projects of Common Interest can apply for funding from the Connecting Europe Facility (CEF)[17].

The first dedicated policy mechanism which made financial grants available for EU CCS projects was the European Economic Recovery Plan (EERP), introduced in August 2009. The main goals of the EERP were economic recovery (after the 2008/9 financial crisis), energy security and greenhouse gas emission (GHG) reduction. Of the total budget of €200 billion, just under €4 billion was placed in a financial instrument for energy projects, termed the European Energy Programme for Recovery (EEPR)[18]. The EEPR set aside just over €1 billion for CCS projects although the largest part was never realised. The goals of the EEPR funding for CCS were to demonstrate the entire CCS value chain, lower the manufacturing and operational costs of second-generation technologies, and to accelerate the development and implementation of regulatory and permitting schemes. A total of six CCS projects received grants from the EEPR. These projects were located across six different Member States and demonstrated different types of CO_2 capture technologies. Although industrial CCS projects were eligible for EEPR funding, all six projects were associated with the energy sector, to be developed at existing, newly built or planned coal-fired power stations. Importantly, the EEPR regulation obliged all projects receiving funding to *"make a binding declaration that the generic knowledge generated by the demonstration plant will be made available to the wider industry and to the Commission to contribute to the Strategic Energy Technology Plan for Europe."* [19]

To facilitate the knowledge sharing between the six prospective demonstration projects, in 2009 the **European CCS Demonstration Project Network** was established by the European Commission. Its purpose was to foster knowledge sharing amongst large-scale European CCS demonstration projects and contribute to raising public understanding of the technology, and achieving commercially viable

[10] EC (2011) Corrigendum to Call For Proposals: established by Directive 2003/87/EC <https://ec.europa.eu/clima/sites/clima/files/ner300-1/docs/call_corrigendum_5_en.pdf>
[11] Regulation (EC) No 601/2012: on Monitoring and Reporting (MRR)
[12] EC (2013) Second call for proposals under Commission Decision C(2010) 7499: established by Directive 2003/87/EC
[13] http://www.act-ccs.eu/
[14] EC (2016) SET-Plan Declaration of Intent
[15] Commission Decision C (2017)7124 of 27 October 2017
[16] http://www.ccusnetwork.eu/
[17] https://ec.europa.eu/commission/presscorner/detail/en/IP_19_561
[18] Regulation 663/2009 establishing a programme to aid economic recovery by granting Community financial assistance to projects in the field of energy
[19] Article 18 para 1.(c) of Regulation 663/2009

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and safe CCS by 2020. To support these projects the Commission made funding available through the Seventh Framework Programme (FP7-ENERGY).

Funding was also made available under the NER300 fund with the aim to deliver substantial scale CCS projects. The projects ULCOS (France) and White Rose (United Kingdom) were the only CCS projects selected for the first and second calls of the NER300 fund. ULCOS had been awarded 18% of the first-round funding, White Rose had 30% of the second round, adding to around 565 million euros between both projects. However due to a variety of reasons neither of the CCS projects made it to financial closure.

Energy Projects of Common Interests (PCIs) are key energy infrastructure projects that connect the energy systems of EU Member States. PCI projects are mainly cross-border projects, that are expected to boost the energy markets and market integration in two or more EU countries. Therefore, these projects are considered crucial in finalising the European internal energy market, and for meeting the EU's energy policy and climate targets. On October 31st, 2019 the Commission adopted the fourth list of PCIs which includes five PCIs focused on developing cross-border CO_2 network transport infrastructure. This will be integral to the development of future CCUS facilities in the region. The CO_2 network transport PCIs are presented in the textbox below.

Textbox 1 List of PCIs focused on CO_2 network transport infrastructure

- **CO_2-Sapling Project** is the transportation infrastructure component of the Acorn (see description below) full chain CCS project (participating countries: UK, in further phases NL, NO)
- **CO_2 TransPorts** is set to establish infrastructure to facilitate large-scale capture, transport and storage of CO_2 from Rotterdam, Antwerp and the North Sea Port.
- **Northern lights project** – a project between several European capture initiatives (UK, IE, BE, NL, FR, SE) to transport the captured CO_2 by ship to a storage site on the Norwegian continental shelf.
- **Athos** the idea is to develop an open-access cross-border interoperable high-volume transportation structure. The project will transport CO_2 from industrial areas in the Netherlands and is open to receiving additional CO_2 from other countries such as Ireland and Germany.
- **Ervia Cork** project looks to repurpose existing onshore and offshore gas pipelines and construct new dedicated ones to transport captured CO_2 from heavy industry and combined cycle gas turbines to a storage facility.

In 2021 (the EC aims to launch the first call in 2020), the ETS Innovation Fund is expected to make available 450 million allowances from the EU Emission Trading Scheme (EU ETS) to support the

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demonstration of CCS, renewable energy and low-carbon innovation in the energy intensive industry, including carbon capture and utilisation (see section 4.1.1 for more information).[20]

[20] European Commission, Innovation Fund, Available at: https://ec.europa.eu/clima/policies/innovation-fund_en

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3 CCUS developments in Europe

This chapter provides a brief overview of the past developments and current status of CCS and CCU technologies in Europe. It also features the Networks' member projects which promise to revitalize the European CCUS landscape.

Worldwide as of 2019, there are 19 commercial CCS projects in operation with the combined capacity to capture and permanently store 40 Mt of CO_2 per year. [21] In Europe, two large-scale CCS projects are operational. Out of these, Sleipner was the world's first large scale dedicated CO_2 geological storage facility, storing CO_2 from natural gas processing since 1996. CCU covers a range of technologies at differing levels of maturity, cost and market size. The main developments in CCU and relevant current European projects are also described in this chapter.

3.1 CCS developments in Europe

As mentioned in chapter 2.2, there are currently 2 large-scale CCS projects operational in Europe. Both of these are located in Norway, at the Sleipner and Snøhvit sites, which combined store 1.7 Mt of CO_2 per year. Alongside these operational sites there are a further 10 large-scale European CCS facilities planned and in development which have the potential to store a further 20.8 Mt of CO_2 per year. In Europe, 300 Gt of geological CO_2 storage capacity has been estimated at a high-level (i.e.

Figure 3-1 CO_2 storage potential around the North Sea, in billion tons (Acatech, CCU und CCS-Bausteine fuer den Klimaschutz in der Industrie, 2018)

[21] Global CCS Institute (2019). Global Status of CCS 2019

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representing a theoretical not a practical capacity estimate[22]). In the European Commission's 1.5 TECH scenario, around 300 Mt of CO_2 per year must be captured and stored by 2050.

Most CCS projects currently being developed in Europe are being designed as cluster systems where numerous capture sources are utilised in industrial areas with a high concentration of CO_2 emissions to then be transported to a single storage site. For example, the Northern Lights CCS project presented in the textbox below. The Porthos project in the Netherlands is also based on a cluster system with capture from numerous industrial sources in the Rotterdam Port area and storage in depleted gas fields offshore in the Dutch North Sea. The development of clusters is likely to be economically beneficial as capturing CO_2 from clusters of industrial installations, instead of single sources, and using shared infrastructure for the transportation and storage network, will help lower costs across the CCS value chain.

Textbox 2 Example of CCS project: Northern Lights

The **Northern Lights** full-scale CCS project (being developed by Equinor, Shell and Total) includes capture of CO_2 from industrial capture sources in the Oslo-fjord region (cement and waste-to-energy). It then plans for the shipping of liquid CO_2 from these industrial capture sites to an onshore terminal on the Norwegian west coast. From there, the liquified CO_2 will be transported by pipeline to an offshore storage location subsea in the North Sea, for permanent storage.

Existing and developing European projects rely (mostly) on offshore CO_2 storage, given that negative public perception has prevented onshore projects from progressing. Due to this offshore focus, a key area of research in Europe currently is the potential for re-use of oil and gas infrastructure. The re-use of infrastructure has the potential to improve project economics by reducing capital investment required for new infrastructure and also allows the project to utilise well understood geological features which have already been established through oil and gas extraction.

Key research areas for CO_2 storage in Europe include the development and role of financial incentives (such as the European Innovation Fund and the EU Emissions Trading Scheme (EU ETS) which incentivises storage by capping the amount of CO_2 specific industries can emit). The design of cluster systems also requires a deeper understanding of how cross-chain risks (such as the potential for a variable supply of CO_2) and financial benefits from funding can be managed and spread across the whole chain.

The role of CSS alongside hydrogen production is also a key area of research within Europe. Many European countries are including hydrogen in their decarbonisation strategies in key sectors such as transport, industrial processes and domestic heat. Most countries plan to develop hydrogen production through steam methane reforming of natural gas which will still produce associated CO_2 emissions which CCS can help mitigate. For example, the Acorn CCS and hydrogen project at the St

[22] Bachu et al. (2007) "CO_2 Storage Capacity Estimation: Methodology and Gaps"

Fergus Gas terminal in Scotland provides an ideal location for the blending of hydrogen into the national grid and as part of a plan for decarbonising natural gas.

3.2 CCU developments in Europe

Carbon dioxide utilization (CCU) is a broad term for a multitude of different paths and technologies that can be used to make various chemical products using carbon dioxide as feedstock. Depending on the pathway chosen and final product produced the complexity, economic and environmental effects of CCU may vary significantly. Thus, also the motivations to use CO_2 as a raw material may differ and may not intrinsically have as goal the lowering of CO_2 emissions. This is the case for well-established CO_2 utilisation pathways, such as the production of urea, methanol, cyclic carbonates and salicylic acid (Kolbe-Schmitt synthesis). At present, the use of CO_2 as a chemical raw material amounts to approximately 110 Mt per year. Depending on the scenario, it is estimated that between 50 and 300 Mt of CO_2 emissions can reduced annually by using CO_2 as an alternative feedstock for new chemical pathways (without fuels applications).[23]

Thus, there has been massive research activity in the field of CCU, however, only few CCU processes have already found access to the market in Europe, these include Carbon Recycling International's Vulcanol or Covestro's Cardyon. This is due to the fact that many CCU pathways are not economically competitive in comparison to the fossil-base reference process. Furthermore, the technical maturity of CCU routes lies over the entire range of the TRL scale (Technology Readiness Level). Figure 3-2 depicts the different kinds of chemical products that can be produced from CO_2.

[23] Ausfelder/Bazzanella, Technology Study Low carbon energy and feedstock for the European chemical industry, DECHEMA, June 2017

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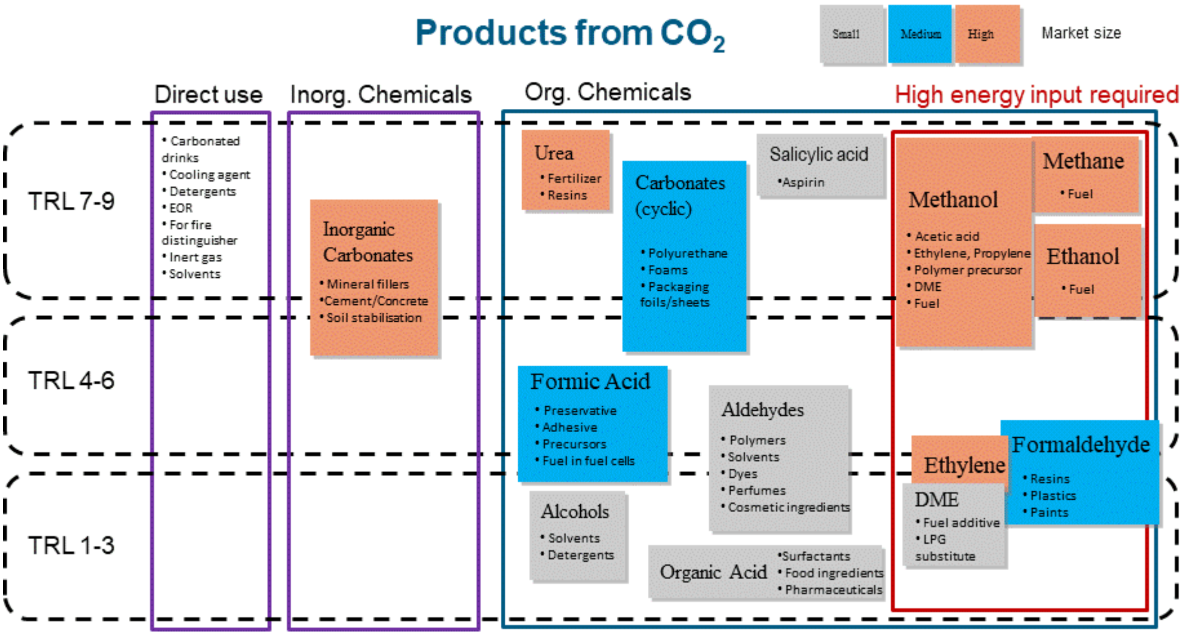
Figure 3-2 Products from CO_2 (by DECHEMA)



Given the large number of different synthesis routes, value chains and products in which CO_2 can be used as a carbon source, the use of CO_2 involves technological approaches that can only be compared to a limited extent. For example, the EU-funded CarbonNext project identified 71 different synthesis pathways for CO_2 use.[24] These pathways are currently being investigated in more detail by industry or science.

New approaches for using CO_2 as a raw material for the synthesis of basic and fine chemicals as well as polymers are being researched by many actors. Nevertheless, few projects are in the pilot or demonstration phase. Examples of more developed processes at higher TRLs (5-8) include the work by COVESTRO and Novomers on polymers. The production of dimethyl ether and methanol from CO_2 is also at a more advanced stage of TRL higher than 6. Both of these products can be used either as basic chemicals or as fuel.

The hydrogenation of CO_2 produces formic acid , an industrial chemical with a variety of uses in industry. In addition, formic acid is considered as a promising chemical for hydrogen storage, since it can easily decompose into hydrogen and CO_2 and thus enable efficient and safe hydrogen transport. The European market for formic acid is currently around 490 kt per year with a market value of € 267 million. Small demonstration plants with a capacity of up to 350 kg formic acid per year using CO_2 have already been successfully tested (TRL 5).

The construction industry offers another promising opportunity for utilizing CO_2; by incorporating CO_2 with silicates and oxidic minerals into inorganic carbonates, which in turn can be used for

[24] CarbonNext: The Next Generation of Carbon for the Process Industry, http://carbonnext.eu/

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building materials such as cement (binder for the production of concrete). This type of material use is an example of a **sustainable sink of CO_2**, as the carbonates formed remain stable over geological periods. The process takes place very slowly in nature and binds many millions of tons of CO_2 annually. In technical applications, the process must be accelerated significantly in order to be considered for industrial use. Production of carbonates with CO_2 is already used today when high purity standards are required. With regards to the impact of such processes on climate change, more research in the field is advisable.

Textbox 3 Examples of CCU projects in the construction industry

The British company **Carbon8** treats industrial waste with CO_2 to produce minerals that can be used as concrete aggregates or building materials. The patented Accelerated Carbonation Technology (ACT) offers a fast and inexpensive way to process waste and minerals. The CO_2 product can be used as concrete, technically developed bulk material or building materials with specialized properties.

The Belgian company **Recoval** uses CO_2 to produce granulates that can be used, for example, in road construction. The companies HeidelbergCement, Shell, Lafarge, Saint Gobain and ArcelorMittal are also researching the integration of CO_2 in building materials. In Germany, the BMBF is funding the CO_2MIN project, which is coordinated by HeidelbergCement. In addition, the new BMBF funding measure CO_2-WIN will support projects aimed at producing inorganic carbonates in order to bind CO_2.

A CO_2 gas stream can be passed through an aqueous solution of sodium hydroxide to produce sodium carbonate, sodium bicarbonate (baking soda) or a mixture of both. Sodium carbonate is used in the manufacture of glass, paper, soaps and detergents. The TRL of inorganic carbonates is 6 - 8.

Methanol is a widely used as basic chemical and can be synthesised by employing CO_2. As a raw material in the chemical industry, about 40% of methanol is processed into formaldehyde and then into pharmaceuticals, resins or dyes. There are commercialised processes for the production of a large variety of different products from methanol.[25] Methanol can also be converted into gasoline via the Methanol to Gasoline (MTG) process. On the other hand, methanol can in itself be used as a fuel and fuel additive and represents a real alternative to heavy oils used in, for example, the shipping industry. Accordingly, the annual production and consumption of methanol worldwide is approximately 110 and 100 million metric tons, respectively. The market volume of methanol from CO_2-based processes in Europe is already high and, according to Prodcom, is currently around 7.9 Mt per year worth around €1.5 billion. About 1 Mt of this is produced in Europe, the remaining 6.9 Mt are imported. It is expected that the quantity used will increase if methanol is used to produce

[25] For example in the production of urea, melamine and phenol formaldehyde resins, acetic acid (Monsanto and Cativa processes) and subsequent polymers via vinyl acetate to PVA (for paints and adhesives) or to cellulose acetates (films, textiles), and via the mobile process to aromatics (MTA - Methanol to Aromates) and to olefins (MTO, Methanol to Olefines).

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olefins, and even higher market volumes could follow if methanol is used as an oil blend and/or as a method for storing or importing renewable energy.

3.3 The Members of the CCUS Projects Network

This section introduced the members of the CCUS Projects Network, providing key project information as well as brief project descriptions and the key reasons to participate in the Network. An overview is presented in the figure below.

Figure 3-3 Overview of CCUS Projects Network Members

The Acorn Project | **ECRA** | **ERVIA CCUS** | **LEILAC**

Northern Lights | **Everest** | **TCM** | **CarbFix**

Drax Bioenergy & CCS | **Athos Consortium** | **Fortum Oslo Varme** | **KVA Linth**

Porthos Project

3.3.1 ACORN

Project information in short

Project Developer
Pale Blue Dot Energy Ltd

Project Location
St. Fergus, Scotland

Operational Status
Design & Engineering

Technology type and objectives
Storage & Transport
Offshore (saline aquifer) Storage
Permit Preparation Phase

CO_2 reduction potential
Capacity: 150Mt Capacity
Injection rate: 2Mt/yr

This project is financed by the European Commission under service contract No ENER/C2/2017-65/SI2.793333.

TRL: Starting at 9

Project Description

The Acorn Carbon Capture and Storage (CCS) Project is at phase development with initial industrial carbon capture at St. Fergus gas terminal for transport via existing, now redundant, gas pipelines and permanent sequestration below the UK North Sea. There are several subsequent build out options including the import and export of CO_2 by vessel at Peterhead Port, hydrogen production from natural gas with CCS at Fergus and connection via an existing gas transmission pipeline to the Grangemouth industrial cluster.

Reasons for Participating in CCUS Network

There are many areas where additional knowledge would be valuable for the Acorn CCS project. Specifically this would include any and all aspects of offshore CO_2 transport and storage, offshore pipeline reuse, well design and control systems, and subsurface modelling. Beyond this, other areas of deep interest include the full range of commercial aspects which can impact upon the business model development and also different policy arrangements in other member states which might be both useful and transferable.

3.3.2 ATHOS (Amsterdam-IJmuiden CO2 Transport Hub & Offshore Storage)

Project information in short

Project Developer
Athos Project Consortium
(EBN, Gasunie, Port of Amsterdam, Tata Steel)

Project Location
Amsterdam/ Ijmuiden, Netherlands

Operational Status
Design & Engineering (Transport & Storage)
Permit Preparation Phase (Storage)

Technology Type
Storage & Transport
Offshore (saline aquifer) Storage
PCI Status

CO_2 Reduction Potential
Injection rate: 7.5Mt/yr until 2030

TRL: Starting at 9

Project Description

The Athos Project (**A**msterdam-IJmuiden CO_2 **T**ransport **H**ub & **O**ffshore **S**torage) feasibility study has shown that a CCUS network is technically feasible in the North Sea Canal area. There are more than enough empty gas fields under the North Sea to store the captured CO_2. The study has also shown that there are no technical barriers to the project and that no new technologies need to be developed. In addition to reusing CO_2 in greenhouse horticulture, such as in Westland, there are opportunities for mineralization and reuse in the form of synthetic fuels.

Reasons for Participating in CCUS Network

Interested in developing knowledge on risk management, regulatory regime, lessons learnt from other projects and technical information

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3.3.3 CarbFix

Project information in short

Project Developer
Reykjavik Energy

Project Location
Hellisheidi, Iceland

Operational Status
Operational Phase

Technology Type
Onshore Storage
Pilot Scale
Part of full-chain CCS project

CO_2 Reduction Potential
At the end of 2018, 66,000 tons of sour gases had been captured and injected at Hellisheidi, 2/3rds of which were CO_2 and 1/3rd H_2S. This counts for over 40% reduction in emissions from the power plant.

Project Description

The CarbFix team has developed a secure, cost-effective and environmentally benign process and technology for permanent CO_2 mineral storage in the subsurface. The process was proven at the CarbFix pilot site, located 3 km southwest of Hellisheidi power plant in Iceland. There, the CarbFix team has demonstrated that over 95% of CO_2 captured and injected was turned into rock in the subsurface in less than two years. Industrial scale sour gas capture and injection have been ongoing at Hellisheidi power plant since 2014, with injection ongoing at the Húsmúli injection site, located ca. 1,5 km northeast of the power plant.

3.3.4 DRAX Bioenergy with CCS

Project information in short

Project Developer
Drax Group Plc

Project Location
The Humber Region, UK

Operational Status
Concept Development

Technology Type
Capture
BECCS

Project Description

In May 2019 Drax Group, Equinor and National Grid Ventures formed a new partnership to explore the opportunity to develop a large-scale CCUS and hydrogen cluster in the Humber Region of England. The vision is to create the infrastructure required to transform the region into the world's first 'net zero' carbon industrial cluster. It would also support other decarbonisation projects in the wider region such as the H21 project and Teesside industrial cluster.

Reasons for Participating in CCUS Network

Bio-energy with CCS (BECCS) is vital to achieve the goal of the Paris Agreement and negative emission technologies will have to be deployed in many EU Member States therefore, the DRAX project will help disseminate BECCS technology & innovation knowledge within the CCUS Network group. The project would also like to contribute and learn about CCUS innovation, policy and regulation, communication and about stakeholder engagement.

3.3.5 European Cement Research Academy (ECRA)

Project information in short

Project Developer
ECRA

Project Location
Europe

Operational Status
Concept Development

Technology Type
Capture (oxyfuel)
Cement industry

Project Description

ECRA (European Cement Research Academy) has been working for more than 10 years on the development of carbon capture technologies for the cement industry with a special focus is on oxyfuel technology. Within the last 10 years an oxyfuel cement kiln has been developed to a level, which allows to demonstrate this technology on industrial scale. Furthermore, ECRA is involved in Heidelberg Cement's CCS project in Norway.

Reasons for Participating in CCUS Network

ECRA is keen to share and gain knowledge on CO_2 purification and compression, specifications for CO_2 with regard to different options, CO_2 transport, possible utilization areas and options for CO_2 transport and storage in Europe.

3.3.6 Ervia

Project information in short

Project Developer
Ervia

Project Location
Cork, Ireland

Operational Status
Concept (Full-chain)

Technology Type
Full-chain CCS
Offshore Storage
PCI Status

Project Description

Ervia is investigating the potential for a large-scale CCS project in Ireland to capture the CO_2 from a number of gas-fired CCGT power plants so that they provide low-carbon electricity. Initial findings

This project is financed by the European Commission under service contract No ENER/C2/2017-65/SI2.793333.

suggest that CCS is technically and economically viable for Ireland and over the next few years Ervia will continue detailed feasibility studies into the technology.

Reasons for Participating in CCUS Network

Ervia are keen to engage with further knowledge sharing especially regarding local community communication and public engagement. Evia also want to develop further knowledge on potential storage collaboration and back-u potential and any cross-border transportation potential and regulatory concerns.

3.3.7 Everest

Project information in short

Project Developer
Tata Steel

Project location
Ijmuiden, Netherlands

Operational Status
Concept

Technology Type
Capture
Pre-combustion
Industrial Sector (Steel)
Part of full-chain project

CO_2 Reduction Potential
Capture rate: 95% of process emissions
Aims to reduce Tata Steel Ijmuiden's emissions by 4Mtonne/yr

TRL: Starting TRL 7 / Target TRL 9

Project Description

The Everest project (Enhancing Value by Emissions Re-use & Emissions Storage) will utilise carbon monoxide and hydrogen by-products from steel production for conversion into chemicals and also capture waste CO_2 for storage in North Sea gas fields.

Reasons for Participating in CCUS Network

To develop insight on how CCU can be developed under the EU ETS, develop ideas on societal acceptance and discuss potential funding developments.

3.3.8 Fortum Oslo Varme

Project information in short

Project Developer
Fortum Oslo Varme

Project Location
Oslo, Norway

Operational Status
Design & Engineering (Capture and Transport)

Technology Type
Capture
Ship Transportation
Part of full-chain CCS project

CO_2 Reduction Potential
Total capture: 400,000 tonnes

This project is financed by the European Commission under service contract No ENER/C2/2017-65/SI2.793333.

Project Description

The Norwegian Government has initiated a full-scale CCS project in Norway. The Fortum Oslo Varme waste-to-energy plant in Oslo is one of the two capture projects that are part of the pre-engineering project. The Norwegian Parliament has approved the revised national budget for the second half of 2018 and it includes funding for Fortum Oslo Varme's projects to begin advanced planning. The facility plans to capture around 400,000 tons of CO_2.

Reasons for Participating in CCUS Network

The FOV facility is close to a densely populated area of Oslo. Large efforts have been made to inform and include the general public and representatives of local associations in the various planning and permitting processes along the way. FOV will be pleased to share our competence and experiences for future projects.

3.3.9 KVA Linth

Project information in short

Project Developer
KVA Linth

Project Location
Niederurnen, Switzerland

Operational Status
Engineering and Design

Technology Type
Capture

CO_2 Reduction Potential
Capacity: Potential to mitigate 120,000 tonnes per year CO_2

Project Description

KVA Linth is a waste-to-energy plant located in Switzerland with an incineration capacity of approximately 115000 tonnes of waste per year, resulting in about 120,000 tonnes of CO_2 emission (50% of which are biogenic). KVA Linth have been investigating the possibility for CO_2 capture from the flue gas.

Reasons for Participating in CCUS Network

KVA Linth have plans for a total renewal of the plant in 2023-2025. Engineering design of the capture plant is currently underway with a design and preliminary costs expected by May 2020. KVA Linth are keen to look into the potential and economic viability of transportation and storage of the separated CO_2.

3.3.10 LEILAC

Project information in short

Project Developer
Calix

Project Location

Technology type and objectives
Capture
Pilot-scale
Industrial Sector

This project is financed by the European Commission under service contract No ENER/C2/2017-65/SI2.793333.

Lixhe, Belgium

Direct Separation

Operational Status
Operational

CO_2 reduction potential
Capture rate: 95% of process emissions, 80 tonne/day

TRL: Starting TRL 6 / Target TRL 6

Project Description

The LEILAC project is based on a technology called Direct Separation, which aims to enable the efficient capture of the unavoidable process emissions. Calix's technology re-engineers the existing process flows of a traditional calciner, indirectly heating the limestone via a special steel vessel. This unique system enables pure CO_2 to be captured as it is released from the limestone, as the furnace exhaust gases are kept separate. It is also a solution which requires no additional chemicals or processes, and requires minimal changes to the conventional processes for cement as it simply replaces the pre-calciner tower. A pilot has been built, and is being tested, to prove the concept, processing 10 tonnes per hour of cement meal. This ultimately aims to allow the cement and lime industries to capture their CO_2 emissions for minimal environmental or economic burden.

Reasons for Participating in CCUS Network

To provide insight on the LEILAC project regarding CO_2 capture technology advances, CO_2 quality, economics, and requirements for future commercial application.

3.3.11 Northern Lights

Project information in short

Project Developer
Shell, Equinor and Total

Project Location
Fornebu, Norway

Operational Status
Design & Engineering

Technology type and objectives
Storage & Transport
Offshore storage
Ship transport
Industrial Development Phase
Storage Permitted
PCI Status

CO_2 reduction potential
Capacity: 100Mt Capacity
Injection rate: 5Mt/yr

TRL: Starting TRL 7/ Target TRL 9

Project Description

The Northern Lights project is part of the Norwegian full-scale CCS project. The full-scale project includes capture of CO_2 from industrial capture sources in the Oslo-fjord region (cement and Waste-to-Energy) and shipping of liquid CO_2 from these industrial capture sites to an onshore terminal on the Norwegian west coast. From there, the liquified CO_2 will be transported by pipeline to an

This project is financed by the European Commission under service contract No ENER/C2/2017-65/SI2.793333.

offshore storage location subsea in the North Sea, for permanent storage. This set-up, using ships from the CO_2 capture sites to the Northern Lights onshore site, is a unique solution and enables accommodating large CO_2 volumes – from across Europe – that would otherwise have been emitted.

Reasons for Participating in CCUS Network

To develop knowledge on the status of capture projects in need of storage, and their corresponding CCS maturity at the current time. To provide insights from the Northern Lights project on storage capacity, interface between capture, transport and storage, tariffs for transport/storage and CO_2 specifications.

3.3.12 Porthos

Project information in short

Project Developer
Rotterdam CCUS Consortium
(Port of Rotterdam Authority, EBN, Gasunie)

Project Location
Rotterdam, Netherlands

Operational Status
Design & Engineering (Transport & Storage)
Permit Preparation Phase (Storage)

Technology Type
Storage & Transport
Offshore (depleted gas field) Storage
PCI Status

CO_2 Reduction Potential
Capacity: 37Mt Capacity
Injection rate: 2-5Mt/yr

TRL: Starting at TRL9

Project Description

The Porthos Project concept is based on a collective pipeline of approximately 30-33 km that runs through Rotterdam's port area. This pipeline will serve as a basic infrastructure that a variety of industrial parties can connect to in order to dispose of the CO_2 captured at their facilities. A share of this CO_2 will be used for greenhouse farming in the province of South Holland. Most of the CO_2 will be put under pressure in the compressor station for offshore transport. Via a pipeline it will be transported to an empty natural gas field 20-25 km off the coast under the North Sea. By 2030, we expect to be able to store between 2 and 5 million tonnes of CO_2 every year.

3.3.13 Technology Centre Mongstad

Project information in short

Project Developer
Gassnova, Equinor, Total, and Shell

Project Location
Mongstad, Norway

Project Status
Operational

Technology Type
Capture
Post-combustion

CO_2 Reduction Potential
TCM has two capture units each approximately 12 MWe in size with a combined total capturing capacity of 100,000 tonnes CO_2 per year.

This project is financed by the European Commission under service contract No ENER/C2/2017-65/SI2.793333.

TRL Level Progression
To develop technologies from TRL4 to TRL6 (I.e. from laboratory to relevant environment testing).

Project Description

Technology Centre Mongstad (TCM) is the world's largest facility for testing and improving CO_2 capture technologies, a vital part of the carbon capture and storage (CCS) route to market. TCM aims to help reduce the cost and risks of CO_2 capture technology deployment by providing an arena where vendors can test, verify and demonstrate proprietary CO_2 capture technologies. TCM aims to be the preferred verification partner for CO_2 capture technologies internationally.

Reasons for Participating in CCUS Network

TCM are keen to share information regarding CO_2 capture technology development where possible and gain knowledge on technology cost and risk reduction.

This project is financed by the European Commission under service contract No ENER/C2/2017-65/SI2.793333.

4 Key aspects relevant to CCUS projects emerging from the Thematic Working Groups of the CCUS Projects Network

This section of the report follows from discussions at the European CCUS Projects Network's knowledge-sharing events for members. It provides an overview of the key aspects discussed within the Thematic Working Groups which are relevant for CCUS projects (and other stakeholders). Additional, future work on these topics from the CCUS Projects Network is foreseen.

4.1 TWG 1: Policy, regulation and public perception

The Thematic Working Group on policy, regulation and public perception identified the following three aspects as key areas of interest:

- The adequate design of the Innovation Fund;
- The London Protocol; and
- Leverage on lessons learnt from projects dealing with public perception.

These aspects are further detailed below. Overall, risks and uncertainties related to regulation and policy, and how to address these regulatory risks, are of key importance to the TWG1. Additional work could explore how to reduce regulatory risks and identify the opportunities and value for Europe in the context of the Green Deal, a Just Transition and industrial policy, retention of high-value jobs and industry in Europe.

4.1.1 The EU Innovation Fund

The Innovation Fund is a European funding program for the demonstration of low-carbon technologies. The fund is expected to amount to approximately €10 billion with the European Commission aiming to launch the first call in 2020, followed by regular calls until 2030. The Innovation Fund aims to be larger and more extensive than its predecessor, the New Entrants Reserve 300 (NER300) Programme, as it is also open to projects from energy intensive industries, has a flexible funding scheme, and aims to have a simpler selection process with stronger synergies with other EU funding programmes.

The Innovation Fund will cover a variety of projects and focuses on:

- Innovative low-carbon technologies and processes in energy intensive industries, including products substituting carbon intensive ones;
- Carbon capture and utilisation (CCU) ;
- Construction and operation of carbon capture and storage (CCS);
- Innovative renewable energy generation; and
- Energy storage.

The Innovation Fund represents an important source of potential funding for many of the CCUS Projects Network members, and at the second knowledge sharing event (October 2019), time was devoted to an open discussion on the details of the Innovation Fund and its suitability for successfully funding CCUS projects.

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In general, the structure of the Innovation Fund was welcomed by all members. It is clear that the European Commission has acted on some of the challenges faced by the NER300, launched in 2011, which failed to support any CCUS projects through to implementation. For example, the Innovation Fund allows up to 40% of funding to be provided during the design, engineering and construction phase of the project, supporting the cash flow of projects during their development. Furthermore, a 2-stage proposal process has been introduced, meaning that potential projects can submit an initial expression of interest which is expected to be considerably less arduous than the immediate submission of a full proposal.

Open issues

However, despite the many improvements over the NER300, members did have a few concerns and points for clarification. A project's expression of interest will be evaluated against three criteria (see points a, b and c in Figure 4-1). Although further guidance is expected from the Commission before the launch of the Innovation Fund in 2020, members raised the importance of developing clear methodologies for calculating the GHG emissions avoidance for CCU and part-chain CCS projects. For example, whereas calculating the GHG emissions avoided from an integrated full-chain CCS project may be quite simple, how would you calculate emissions avoided for a standalone pipeline or a storage site?

Clarifications are also sought for demonstrating project maturity. At what stage should a project be in when it applies for funding? It is clear from the Innovation Fund regulation, that a project must become operational within four years of being awarded a grant, but guidance on demonstrating maturity, for example through the phase of engineering (pre-FEED, FEED etc) or permitting would be useful. There was also a general consensus amongst members that the criteria of scalability (d) is perhaps more important than degree of innovation (b), as technologies that can be scaled-up and replicated can have the greatest impact on overall carbon abatement.

Figure 4-1: Overview of the application process and evaluation criteria for the EU Innovation Fund

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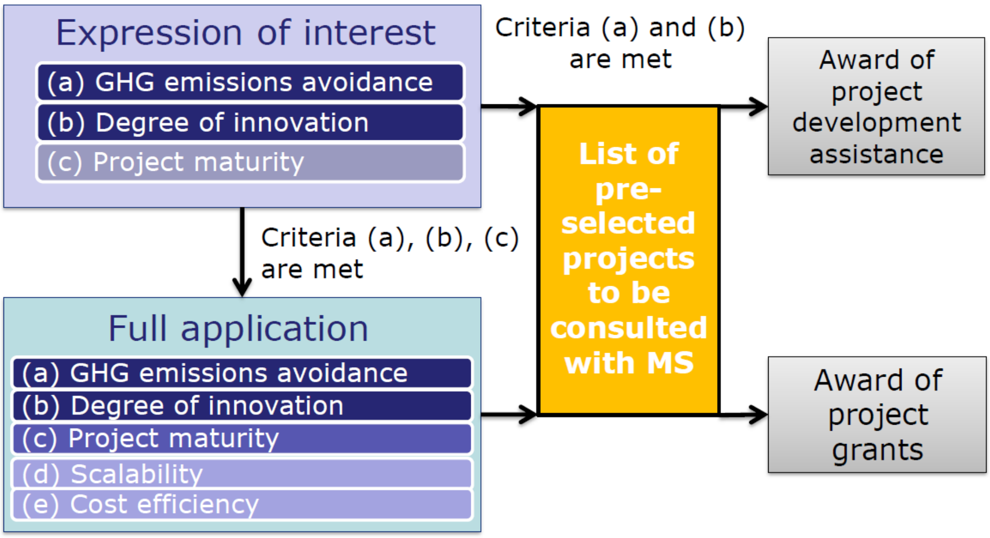

One final concern was that funding for CO_2 storage seems to be overlooked by current policies for CCS development. Whereas the Innovation Fund seems to have a focus on full-chain and capture projects, and the TEN-E regulations cover CO_2 transport (cross-border), there are no policies to incentivise the preparation and operation of CO_2 storage sites. Members raised the point that storage sites take multiple years to reach permit approval, and multiple sites may be required to be developed in parallel to meet demand or to provide operational flexibility.

4.1.2 International Maritime Organization (IMO) – London Protocol

The Network Members were encouraged to hear that through the provisional application of an amendment to Article 6 of the London Protocol, CO_2 can now be transported for storage between parties of the aforementioned Protocol. Although offshore CO_2 storage in subsurface formations is included in the London Protocol, the transfer of CO_2 between parties had been prohibited which represented a considerable legal barrier to the development of a number of CCS projects, particularly CO_2 transport Projects of Common Interest. The intention to enact a provisional application of a previously introduced resolution to remove this barrier was presented by Norway and the Netherlands.

4.1.3 Public perception

The first knowledge sharing event raised the need for a review of learning from public engagement of previous CCUS projects; both successful and less successful experiences. It was proposed that this could be achieved through various routes, including a review report, but also practical demonstrations and input from experts, as depicted in Figure 4-2.

Figure 4-2: Sharing knowledge on public perception and engagement activities.

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A report reviewing techniques and learning across previous projects will be produced. In addition, it is proposed to also conduct workshops on materials and methods for engaging with public, such as using chocolate bars to explain carbon storage, and other practical visualisation techniques.

Textbox 4 Previous experience with public acceptance

SCCS have been provided by Shell with a 3D visualisation headset that has been used at multiple public science events; and there are mobile phone apps and other materials ready-prepared. SCCS developed a video for the CO2Multistore project that has been used across Europe[26] and in the meeting the ERVIA project showed their newly produced video to the Network members[27].

Experience both within existing projects and past projects will be shared, including from current North American projects and member projects, through webinars, virtual meetings and workshops.

4.2 TWG 2: CO_2 capture and utilization

The Thematic Working Group on CO_2 capture and utilization identified the following three aspects as key areas of interest:

- Clustering of CO_2 capture and harmonization of CO_2 purity limits;
- The evident technical feasibility of CO_2 capture; and
- The operation and monitoring of amine capture plants.

These are further detailed below.

[26] CO2Multistore video, last accessed 12 December 2019, https://www.sccs.org.uk/expertise/reports/co2multistore-joint-industry-project
[27] ERVIA Vision 2050 video, last accessed, https://www.youtube.com/watch?v=e9xcaA4M2SM&feature=youtu.be

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4.2.1 Clustering of CO_2 capture and harmonization of CO_2 purity limits

Clustering of CO_2 capture can be seen as necessary to develop efficient transport infrastructure. In this sense, the formation of clusters could be a natural development in advanced stages of CCUS deployment. Cluster development should be done with a long-term perspective, otherwise there is a risk to develop inefficient networks and infrastructures. Cross-sectorial and trans-regional coordination is of primary importance, in view of an effective development of a continental CCS infrastructure to support large scale deployment.

The TWG2 has identified the potential need to **harmonize the CO_2 purity and impurities limits**. Heterogenous CO_2 product streams can typically be expected in a cluster due to the presence of different CO_2 sources and capture technologies. Purity specifications exist but are different for different CO_2 disposal methods, though storage has relatively standardized specifications (see section 4.3). The specifications related to utilisation are very much dependent of the type of process considered, introducing an additional degree of complexity. They could be either particularly stringent (e.g. food grade purity) or perhaps even more relaxed than those for storage. Therefore, defining universal quality standards for the CO_2 product streams would not be useful or could even be detrimental, given the different framework conditions in which various clusters may be operating. The required CO_2 purity may also be dependent on the transport mode of the captured CO_2 (truck, ship, train, pipeline or combinations thereof). Altogether, it may be beneficial for an industrial cluster to think upfront about the most suitable strategy to deal with the CO_2 purity issue. CO_2 purification may be centralised: a first CO_2 gathering/transport system accepting different CO_2 qualities from different sources before purification to transport/storage/use standards.

In this context, it can be mentioned that the TWG2 will follow the work to be done by CO_2 Value Europe (https://www.co2value.eu/) on **mapping the purity requirements for CO_2 for different applications in products.**

A potential synergy that should be exploited when planning industrial CO_2 capture clusters is the **utilisation of available waste heat to support CO_2 capture processes.** Some industries in a cluster might have an abundance of steam which could be used in capture processes (for e.g. solvent regeneration). Low-grade heat from steam condensed in a solvent capture process can be useful in e.g. district heating networks.

4.2.2 Technical feasibility of CO_2 capture

The TWG2 agrees that there is evidence of **the technical feasibility of CO_2 capture**, i.e. this is not a hurdle for CO_2 capture implementation today. Rather, the main hurdles for CO_2 capture are on financing, business cases, and having access to an infrastructure that can receive the captured CO_2.

According to the Global CCS Institute (GCCSI), 19 CO_2 capture facilities are currently operating world-wide[28], thus evidencing that CO_2 capture indeed is feasible. Improvements can nevertheless be

[28] Global CCS Institute, 'Facilities Database', 2019. [Online]. Available: https://co2re.co/FacilityData.

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beneficial for realising the implementation, regarding e.g. energy consumption, CAPEX, OPEX, footprint and water usage. In the future, new capture technologies are expected to be developed, contributing to such improvements. However, amines are foreseen to still have an important role, especially in those cases where there is excess heat of sufficient quantity and temperature available.

Several CO_2 capture projects are currently being developed across Europe, some of them are focusing on capture only, and others are being developed as part of a full chain CCS project. A non-exhaustive list of emerging CO_2 capture projects in Europe, focusing on the members of the CCUS Projects Network, is provided below. Amine capture is the technology most frequently considered, but others are emerging, such as indirect calcination (LEILAC technology) and oxyfuel, both of them for cement kilns.

Table 1 Overview of CO_2 capture projects in Europe

Project (country)	Type of CO_2 source	CO_2 capture capacity	Capture technology
Fortum Oslo Varme (NO)	Waste to Energy	400 kt CO2/year	Amine (Shell)
Norcem Brevik (NO)	Cement	400 kt CO2/year	Amine (Aker Solutions)
LEILAC/Lixhe (BE)	Cement	76 tonnes CO2/day (intermittent)	Indirect calcination
Drax Bioenergy and CCS (UK)	Biofuelled energy	4 x 4 Mt CO_2/year	Amine or non-amine chemical considered
KVA Linth (CH)	Waste to Energy	100 kt CO2/year	Amine
ECRA CCS, Colleferro (IT) and Retznei (AT)	Cement	842 ton CO2/day (Colleferro); 1231 ton CO2/day (Retznei)	Oxyfuel
Acorn (UK)	Gas processing and H_2 production	Gas processing 340 kt/year, H_2 production 500 kt/year	Several proven commercial CO2 capture technologies are being considered.
Ervia and Gas Networks Ireland (IE)	Nat.gas fired power and oil refinery	Envisages to begin with 2.5 Mt CO2/year	Not yet decided/ disclosed

Some of the CCUS Projects Network members report that they are considering several commercially proven CO_2 capture technologies, thus proving the availability of several technology providers on the market.

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4.2.3 Operation and monitoring of amine capture plants

Efficient and purposeful monitoring and operation of amine capture is important. In this area, CCUS Projects Network member Technology Center Mongstad (TCM)[29] has substantial experience and expertise from its open test campaigns, that is available for sharing with the CCS community. For instance, TCM stresses the importance of continuous measurements to identify impurities, and that it is important to know *what* components to measure in a flue gas. Furthermore, amine capture must be operated with the aim to keep amine consumption under control. Even a minor loss of amine could have consequences for environment, OPEX and plant logistics.

4.3 TWG 3: CO_2 transport, storage and networks

Key topics relevant to the Thematic Working Group on CO_2 transport, storage and networks are:

- Developing CO_2 storage pilots and developing operational storage plans; and
- Managing standards for transportation and storage networks.

TWG3 will aim to cover technical, regulatory and financial aspects of all three of these areas. The technical focus of TG3 will be on R&D elements, and the technical insight pilot projects can give and the current knowledge gaps they should be investigating. Regulatory aspects include how to manage numerous stakeholders across the transport and storage network and establishing who should be responsible for which aspects, e.g. within supply contracts and flexible CO_2 supply management. Financial aspects will also be discussed including how to increase operational flexibility and the impact this may have on associated transport and storage costs.

4.3.1 Developing CO_2 storage pilots and developing operational storage plans

Developing operational plans for CO_2 storage sites requires a risk management plan for the entire CCS chain. This requires an approach to incorporate along chain management and manage risks at each stage in the chain from capture to storage. A key element of this across chain risk is a varying supply of CO_2. CCS operations need to incorporate flexibility into their CO_2 transport and storage network to allow a fluctuating supply of CO_2 from the capture facilities. There is still knowledge required on how to manage this operational flexibility and the costs that might be associated with increasing flexibility (i.e. developing surplus storage resource to be operationally ready throughout the project in case of an increase in CO_2 supply). Operational plans also become more complex in a cluster system with numerous capture sources and supply streams being utilised, which may require more flexibility in the transport and storage network.

Developing CO_2 storage pilots is a key target in the SET plan, with the aim of three new storage pilots being developed to unlock European storage capacity. TWG3 have identified that the definition of a pilot project compared to a demonstration project is not yet well defined. Also how to effectively transition from R&D pilot projects to commercial project development is unclear. For

[29] http://www.tcmda.com/en/

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example, a key knowledge gap TWG3 aims to address regards the risk management aspects of CO_2 supply. These risks may not be easily answered through developing pilot project as these are likely to have one, constant volume source of CO_2. Therefore there are still knowledge gaps on how pilots can be utilised to answer the remaining question on commercial scale development and risk management. TWG3 will therefore discuss in what settings and for what objectives pilot projects should be developed. Also the insights that pilots can make on commercial operation elements such as batch-wise injection and supply risk management. There is also the overarching question of how to deliver the new pilots required to meet the SET plan objectives.

TWG3 will also discuss the learning from demonstration projects that never reached operational phase, such as the ROAD project, as there are important lessons to be learnt regarding what can go wrong and how to incentive new projects.

4.3.2 Managing standards for transportation and storage networks

In general, discussions amongst the Member Projects suggest a reasonable level of specific knowledge on the subject of standards for transportation and storage networks but perhaps a less clear view of how the specifics interact in a whole system. It is recognised that there is less need for common standards where transport systems are localised, such as a simple source-to-sink pipeline system, than when they are interconnected, such as a shipping system. The difference between a refrigerated liquid CO_2 transport system and an ambient temperature, compressed dense phase system is also recognised, with a view expressed that the process of liquefaction ensures that CO_2 is produced at high purity (not necessarily strictly the case).

It was generally agreed that systems should be optimised across the whole chain, and the optimisation should be on the basis of safety and cost primarily. Also, that regulatory standards defining CO_2 composition may actually hinder the optimisation of individual systems. It was noted that the ISO Standard (ISO 27913:2016) is rather arbitrary and it may be too early in the development of CO_2 supply chains for this to be imposed. However, this is the stage of supply chain development for open discussion of composition and operational standards as there is still scope for optimising designs, once systems are in operation that flexibility may be lost.

The discussion led to the definition of a simple remit for a short report to summarise the CO_2 specifications currently in use, to explain how they have come about and by whom they are used. This report was completed in November and the section below provides a brief overview.

TWG3 Output: Briefing on CO_2 Specifications for Transport

The resulting briefing was delivered to the EC at the end of November and will be made available to Member Projects in advance of the next Knowledge Sharing Event where the questions it raises will be discussed. The briefing summary is reproduced here.

> *"There are two types of specification generally relevant to carbon dioxide (CO_2) transport, the product specification for end use and the requirement specification for transport. There are also two classes of transport system for CO_2 that can be distinguished, modular transport and pipeline transport.*
>
> *"Modular transport, using tanks carried by truck, train or ship, generally carries CO_2 as a refrigerated liquid for bulk supply to industrial and specialist gas users, including the strictly regulated food and beverage markets. Product specifications exist for a number of "pure" grades ranging from 99.5% to*

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99.9995% CO_2. Quality recommendations for the transport of liquid CO_2 are available but not widely discussed; in general, purification by the producer to meet product specifications will ensure that the requirement specification for transport is met.

"Most transport of CO_2 by pipeline is for use in enhanced oil recovery (EOR), which has a relatively low quality requirement; geological storage has similar requirements. Specifications for pipeline transport generally concern the requirement for safe and effective transport in the pipeline system. There is no commonly agreed specification for CO_2 transport by pipeline. Regulations require pipeline operators to make their own assessments and set entry requirement specifications accordingly, leading to minimum CO_2 purity levels ranging between 93.5% to 96% (or wider) with significant differences in allowed levels of other constituents.

"A number of areas are identified where further information would be useful and may be available to CCUS Projects Network members to contribute through knowledge-sharing events."[30]

Questions raised by the briefing include, for **CO_2 ship transport**: confirming the quality of liquid-CO_2 currently transported and the design requirement specification for existing CO_2 carrier ships; if possible, understanding the CO_2 specification for shipping projects currently in design; and understanding if there is scope for relaxing the CO_2 requirement specification when shipping for geological storage.

Questions related to **pipeline transport** include: confirming the approach taken by the ISO Standard; discussing whether current regulatory approaches for pipeline transport of CO_2 are satisfactory and/or desirable; or whether there is a need for a better defined specification, now or in the future.

And for both transport modes, shared understanding of any ongoing policy or regulatory discussions on CO_2 specifications in Europe would be helpful.

[30] Brownsort, P.A. 2019. *Briefing on carbon dioxide specifications for transport.* CCUS Projects Network.

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