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2013/14 Situation Report on the European Large Scale Demonstration Projects

Executive Summary

The *European CCS Demonstration Project Network* since its foundation has been a unique community of leading large-scale carbon capture and storage (CCS) projects. It is dedicated to knowledge sharing and the development of the CCS technology. The Network currently consists of four CCS projects in Europe: former Compostilla (Spain), Don Valley (UK), ROAD (The Netherlands) and Sleipner (Norway).

This second edition of the *European CCS Demonstration Project Network*: *Situation Report 2013/14* includes the findings related to the participating projects from both the knowledge sharing events, presentations, and the internal survey conducted via the Information and Experience Gathering (IEG) questionnaire. The report covers progress made by the projects in capture, transport, storage, regulatory development, public engagement and knowledge sharing within and beyond the Network.

Little has changed from previous reporting for the projects in terms of planning and following timelines. Almost all of them have experienced delays with various permits and with reaching a final investment decision (FID). In 2013, two projects, Porto Tolle and Compostilla received a negative FID. Ciuden, the academic partner of Compostilla project, remains however with collaborative status in the Network. The current timeline for the ROAD project suggests that they could be operating and injecting CO_2 by 2017. For Don Valley project this is planned for 2018.

The Network is composed of one oxyfuel power project (former Compostilla), one IGCC power project which may also include gas oxyfuel technology (Don Valley), one post-combustion power project (ROAD) and a gas processing project (Sleipner). Sleipner is the only project currently in operation. All will capture over 1 million tonnes of CO_2 per annum, at a capture rate of over 90%. SOx and NOx are quoted by the projects as the most common and expected impurities in the slip stream gas.

Three projects (Don Valley, ROAD and Sleipner) use, or intend to use offshore pipelines. Collectively pipeline inlet pressure will be between 129 and 180bar, and inlet temperature will be up to 80 ^{o}C. This high temperature is required only for the initial phase of the ROAD project, to avoid freezing temperatures during the build-up back-pressure in the depleted gas field (initially with a pressure below 20 bar).

For the CO_2 storage, a range of sites are being used or investigated by the projects, ranging from onshore saline formations, to offshore depleted gas reservoirs and EOR operations. Projected bottomhole pressures are reported to be up to 300 bar, and injection rates ranging up to 70kg/second.

Public engagement is one of the key management activities for the projects, with the proponents concluding that direct engagement is the most effective form of interaction and that consistent messaging is very important.

With regards to permitting and regulatory developments throughout 2013, the ROAD project's storage permit was successfully reviewed by the European Commission and in September 2013 the final storage permit became definitive. The Compostilla project experienced a long wait time to get to the finalisation and implementation of the transport and storage regulatory regimes by the respective authorities. The Porto Tolle project resubmitted their Environmental Impact Assessment for the base plant, but decided not to proceed to full scale construction and operation.

Securing funding for these initial large scale CCS projects continues to be the key barrier to deployment of the technology across Europe. While globally there is a ground swell of international support for the technology and a growing awareness of the importance of investing now in enabling infrastructure and research, the funding challenges in Europe are preventing the wide scale deployment of the technology and threatening to greatly increase the cost of the future decarbonisation of the European economy.

The diversity of the Network projects in designs, volumes, locations, etc. provides a wealth of information. It should be noted, however, that the data and summaries should be treated with caution. Please contact the Secretariat if any discrepancies are discovered.

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Acknowledgements

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Introduction

It is well established by now that carbon dioxide (CO_2) is the main greenhouse gas responsible for climate change.[1] Fundamentally, Carbon Capture and Storage (CCS) can significantly reduce the emission of carbon dioxide and is one of a number of crucial technologies for combating climate change. It can capture emissions from the power sector (either using gas, coal or biomass as a fuel), and is the only way of substantially reducing the emissions from the industrial sector (steel, iron, cement, chemical, fertilisers, ethanol, gas processing, paper, etc.). The successful deployment of this technology will allow the creation of sustainable and flexible industrial opportunities. It is expected that this technology will have a large market opportunity, as it will allow Europe to have an environmentally and economically sustainable industrial base. Consequently, job retention and creation in multiple industrial areas within Europe could be promoted. Without CCS the cost of meeting Europe's climate change targets by 2050 would significantly increase, by over 40% in the power sector alone (largely due to capacity factors and electricity demand profiles), and would be literally 'priceless' for most industrial sectors that have no other option than CCS.[2]

The European CCS Demonstration Project Network (the Network) was established in 2009 as an initiative of the European Commission (EC) to support and accelerate large-scale CCS projects across the continent in a safe and commercially viable way. As part of an initiative of the European Commission, the intention of the Network has been to establish a community of leading CCS demonstration projects. This world-first knowledge sharing Network brings together leading CCS project operators and proponents to exchange both technical data and hold workshops on specific topics for mutual benefit. By sharing experiences this community of projects helps de-risk project proposals and reduce their costs, seeking to achieve the wide deployment of successful, safe and economically viable CCS.

The *European CCS Demonstration Project Network: Situation Report 2013/14* is the second edition of the annual publication launched last year, reporting on the progress, challenges and lessons learnt from the Network. This report is intended for those interested in some of the specific technical, regulatory and project management considerations of CCS as a technology, and is primarily based on the data shared via the projects survey. The main conclusions from the multiple workshops that have been held have also been incorporated, providing a holistic and useful examination of the member projects and the lessons that have been learnt.

[1] http://ec.europa.eu/clima/policies/brief/causes/index_en.htm

[2] IEA, *Technology Roadmap: Carbon Capture and Storage*, 2013

The European CCS Demonstration Project Network consists of a unique collection of large scale, early-mover CCS projects. However, the overall project progression has been difficult for a number of reasons, such as finances and regulatory and permitting issues.

Information is provided on a wide variety of technical, management and regulatory topics. It is hoped that this report can prompt conversations, discussions and further learnings between interested and relevant stakeholders. Moreover, this report aims to promote the sharing of knowledge and experiences acquired within the Network with the broader public.

The role of CCS

Climate scientists and parties to the UNFCCC have agreed that deep cuts in emissions are required, and that future global warming should be limited to below 2.0 °C (3.6 °F) relative to the pre-industrial level "to prevent dangerous anthropogenic interference with the climate system".[3]

However, the International Energy Agency World Energy Outlook (IEA WEO, 2012) report suggest that the 2°C target is becoming more difficult and costly with every year that passes[4]. The report also suggests that to achieve the 2°C limit, globally no more than one-third of proven reserves of fossil fuels prior to 2050 can be consumed unless CCS is widely deployed.

The IEA Technology Roadmap for CCS (IEA, 2009) suggests that the costs to half emissions by 2050 rise by 70% in the electricity sector if CCS is not implemented.[5] The IEA proposes that under existing and announced new policy commitments, the 2°C limit will not be achievable and proposes the policy actions required to achieve the 2°C limit (the 2DS scenario) will require 14% of the total abatement of emissions to come from CCS by 2050.

The European Commission's Communication on the Future of Carbon Capture and Storage in Europe also acknowledged that capital costs to reach the greenhouse gas targets required for a maximum 2 degree Celsius rise in global temperatures in the power sector might increase as much as 40% without CCS.[6]

[3] http://unfccc.int/essential_background/convention/background/items/1349.php
[4] World Energy Outlook 2012 *http://iea.org/publications/freepublications/publication/English.pdf*
[5] *IEA, 2009. Technology Roadmap: Carbon Capture and Storage*
http://www.iea.org/publications/freepublications/publication/CCS_Roadmap.pdf
[6] COM(2013) 180 final. Brussels, 2013 http://ec.europa.eu/energy/coal/doc/com_2013_0180_ccs_en.pdf

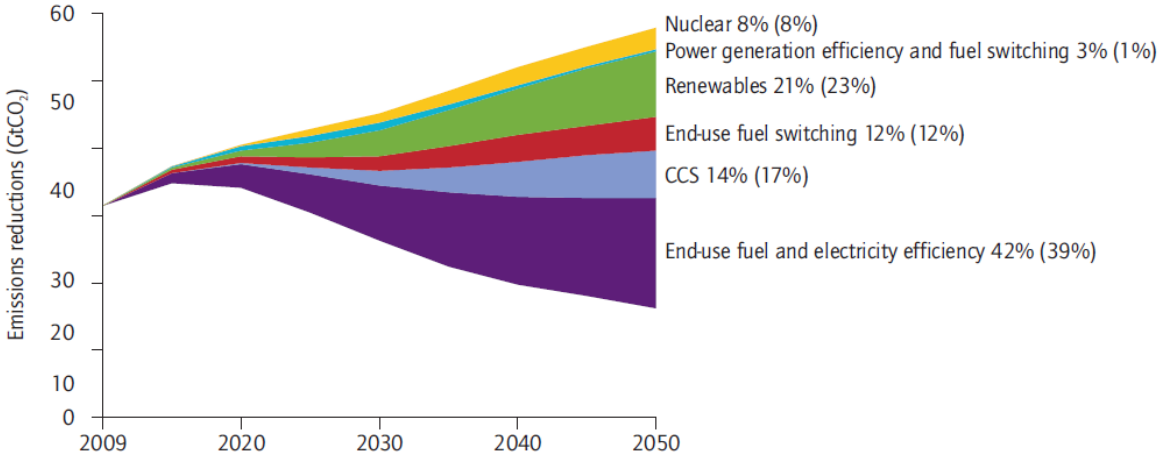


Figure 1. Global CO_2 emissions reduction by technology[7]

In the Energy Roadmap 2050 for the EU there have been a number of different scenarios proposed by the European Commission to meet the stringent 2050 emissions reduction targets.[8] Four out of the five decarbonisation scenarios proposed require a significant contribution from CCS, with a contribution of up to 32% in power generation in the case of constrained nuclear production. The only scenario proposed without CCS relies on 97% of the electricity consumption being produced from renewables which however require electricity storage.

It is also worth noting that the Energy Roadmap solely focuses on energy generation. CCS and CCUS are the only technologies that can reduce emissions from the industrial sector (the steel industry, gas processing, refining, paper and pulp, cement etc. sectors). Through the use of biomass together with CCS it is the only technology that can be 'CO_2 negative' and actually extract CO_2 from the atmosphere.

The EC, in the Roadmap for moving to a competitive low-carbon economy in 2050 suggest that if investments in low carbon technology are postponed, they will cost more from 2011 to 2050 and create greater disruption in the longer term, highlighting the need for CCS to be demonstrated and implemented without delay .[9]

[7] IEA 2013. Technology Roadmap: Carbon Capture and Storage

[8] *Energy Roadmap 2050, The European Commission: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0885:FIN:EN:PDF*

[9] *Roadmap for moving to a competitive low-carbon economy in 2050, The European Commission: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0112:FIN:EN:HTML*

Finally, the latest report released from the IPCC working group III[10] highlights that the mitigation scenarios[11] that reach atmospheric concentrations of about 450ppm CO2eq by 2100 entail mitigation costs that can increase substantially if CCS is not considered.

Many of the technologies that make up CCS have been around for decades[12]:

- CO_2 capture is already practised on a small scale, based on technology that has been used in the chemical and refining industries for decades
- Transportation is also well understood: CO_2 has been shipped regionally for over 20 years, while a 5,000 km pipeline network has been operating in the USA for over 30 years for Enhanced Oil Recovery (EOR)
- CO_2 storage projects have been operating successfully for over a decade, e.g. at Sleipner (Norway)
- The industry can also build on knowledge obtained through the geological storage of natural gas, which has also been practised for decades

CCS, therefore, can become a game-changing technology for tackling climate change, while maintaining sustainable and flexible industrial opportunities. CCS applications are expected to form a market to be worth trillions (SINTEF, 2013) allowing job retention and creation in multiple industrial areas within Europe.

The European CCS Demonstration Project Network

The successful operation of CCS demonstration projects is seen as crucial for enabling widespread commercial application of zero emission power plants or industrial installations to meet EU and global climate goals.

The European CCS Demonstration Project Network, initiated by the EC in the first instance, brings together the demonstration projects that are underway in Europe. The Network provides added value to European projects by:

- Facilitating the identification of good practices, lessons learnt and recommendations with respect to large-scale CCS demonstration and enabling knowledge sharing amongst projects
- Providing a common EU identity to Network Members
- Leveraging experience gained from projects and the evidence generated by them, in order to build public confidence about the feasibility and safety of CCS
- Promoting CCS, EU leadership and cooperation potential to third parties/countries

Collectively, the Network projects have, or will, demonstrate many of the different technological and infrastructure elements that CCS as a green technology encompasses.

[10] IPCC, 2014: Summary for Policymakers, In: Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change

[11] Under the absence or limited availability of technologies

[12] European Technology Platform for Zero Emission Fossil Fuel Power Plants, 2012

- **Capture** – the projects cover all of the main capture approaches: post-combustion flue gas scrubbing and natural gas processing, pre-combustion (hydrogen production in an IGCC plant), and novel oxy-fuel combustion

- **Transport** – a range of elements are covered, from short point-to-point pipelines, to clustering concepts where the infrastructure may be appropriately sized to anticipate future demand

- **Storage** – both on-shore and off-shore solutions are being investigated, including deep saline formations, depleted gas reservoirs and the use of CO_2 Enhanced Oil Recovery (EOR) in oil reservoirs

This diversity has allowed the Network to bring together a wide set of learnings for mutual benefit, investigating both the differences and the synergies on a variety of topics.

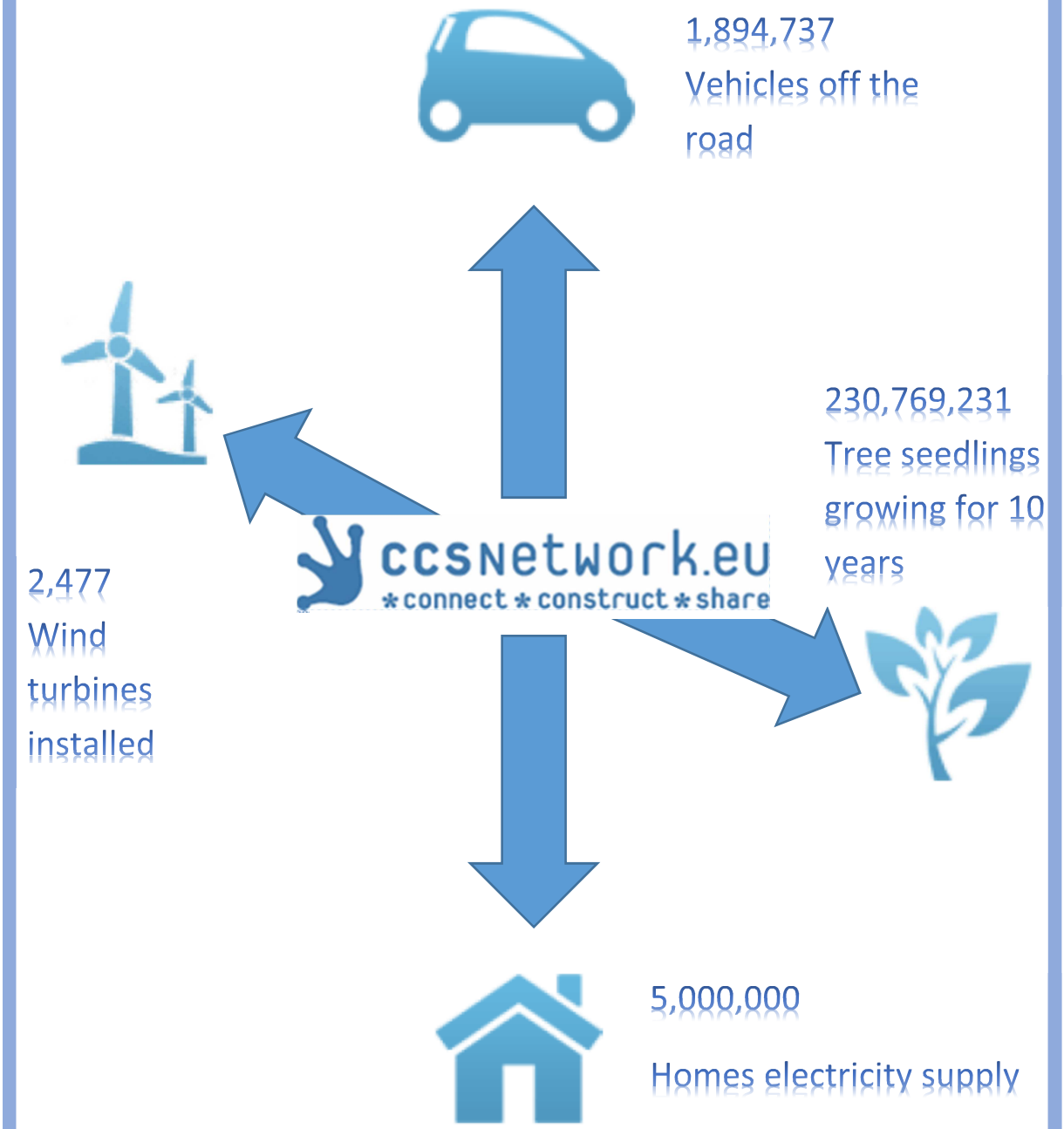
The efforts of these early mover projects alone has the potential to make a substantive impact on CO_2 emissions. The Sleipner Project captures and stores around 1 million tonnes of CO_2 per annum from its light oil and gas field. If all of the other member projects developed, the Network would have an installed clean electricity generating capacity of 1,460 MWe. The box bellow puts the Network in context of practical contribution.[13,14]

[13] Based on a typical consumption estimation: http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results

[14] Based on a typical domestic consumption figure: https://www.ofgem.gov.uk/ofgem-publications/39337/review-typical-domestic-consumption-values.pdf

The Network in context

If fully developed, in total the Network would permanently store nearly 9 million tonnes of CO_2 per year which is the equivalent of:



How the Network has evolved in 2013-2014

The Network secretariat comprises of The Global CCS Institute[15], IFPEN[16], TNO[17] and SINTEF[18]. All four of the partners have worked well together, pooling expertise and cooperating on all tasks.

No new members joined the Network in 2013. Almost all of the projects have had difficulty planning and following timelines. This was mainly due to the fact that they have experienced delays with various permits and with reaching final investment decisions. The Compostilla Project completed their FEED study which was distributed to the Network and is available on the Network's website. As a result of a negative FID, the project will now no longer proceed to full scale construction. Both the CO_2 capture pilot and the CO_2 storage pilot associated with this project wish to continue operations. The Porto Tolle project faced severe delays due to the annulation of the environmental permit for the Porto Tolle power plant, as well as project's difficulties in achieving closure for its financial structure. It was finally terminated in 2013. An updated map of the participating projects of the Network is shown in Figure 2. The Crown Estate (UK) has also joined the Network with a collaborative status.

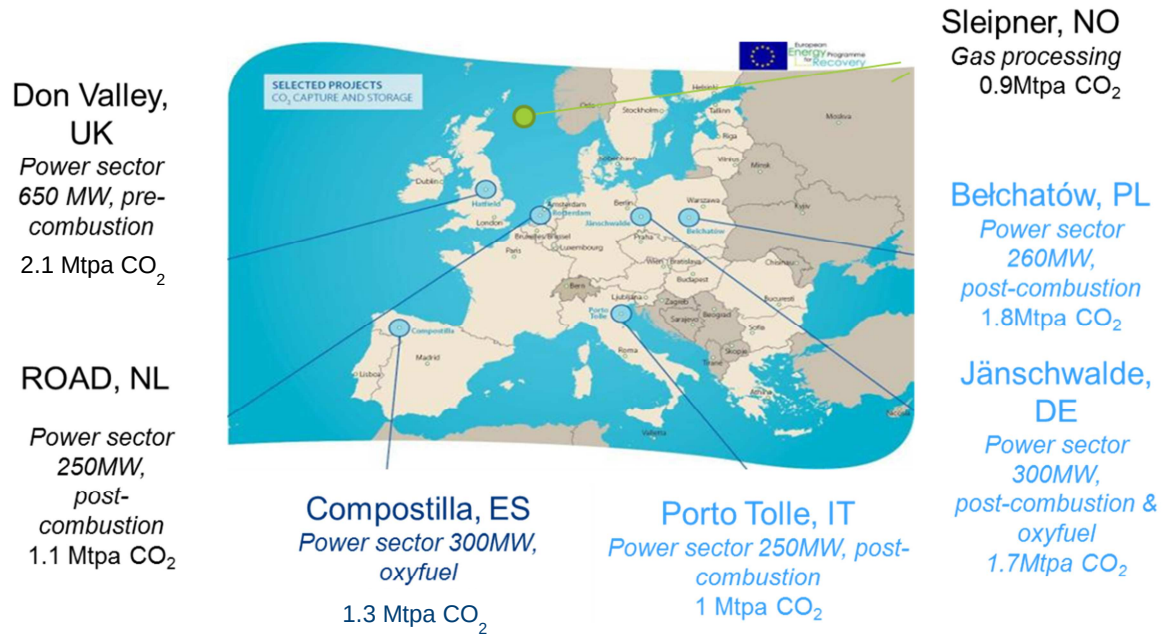


Figure 2. The European CCS Demonstration Project Network on the map[19]

[15] http://www.globalccsinstitute.com/
[16] http://www.ifpenergiesnouvelles.fr/
[17] https://www.tno.nl/?Taal=2
[18] http://www.sintef.no/home
[19] Light blue represents cancelled projects and darker blue represents collaborative partner status

The Network

European demonstration Network member's overview

Compostilla

Summary

The Compostilla project would be based in El Bierzo, Spain. The project operator was Endesa, in partnership with Ciuden and Foster Wheeler. The OXYCFB 300 Compostilla project, completed the work that it had committed to carry out under the terms of its EEPR grant by October 2013, when the FEED study was also released.[20] Subsequently the decision taken was not to proceed to full-scale demonstration because of regulatory and economic obstacles. The project would operate on a 300 MWe Circulating Fluidised Bed (CFB) supercritical oxy-fuel coal-fired power plant. The plant would be constructed next to the existing coal-fired power plant of Compostilla. The CO_2 capture efficiency could be 91%. The CO_2 captured would be transported by a 120km pipeline to an onshore deep saline formation. The project could store 1.6 $MtCO_2$/year.

Progress during 2013-2014

- Commissioning of the CFB boiler for oxy operation has been completed along with integration of units. Test conducted yielded positive preliminary results
- Preliminary characterisation of subsurface structures has been well advanced.
- Economic and risk assessment was finalised in 2013
- FID in October 2013, resulted in the cancellation of the project proceeding to full scale
- The capture and storage pilots at $esCO_2$, Ciuden facilities in Ponferrada, Spain are wishing to continue operations

Don Valley

Summary

The Don Valley project is based in Yorkshire, UK. 2Co Power (Yorkshire) Limited (Yorkshire) is responsible for the power generation and capture plant and National Grid is responsible for the onshore and offshore transport system and storage site. The project went through a period of restructuring in 2013-2014. The aim was to reducing the initial capital costs and phase the construction of the power and capture plant. This would reduce the initial volumes of CO_2 being handled. National Grid is also

[20] http://ccsnetwork.eu/publications/oxycfb300-compostilla-carbon-capture-and-storage-demonstration-project-knowledge-sharing-feed-report

looking to develop the initial CO_2 storage in the North Sea saline formation as a store for a cluster of projects in the North and North East of England (including White Rose). The project is expecting to store up to 10.6Mt CO_2 across the first 5 years of operation and approximately 103Mt during the project's lifetime. With an additional oxy-turbine train these values will increase to 12.6Mt and 125Mt respectively.

Progress during 2013-2014

- De-selection from UK competition has led to a 2-year delay. FID is now anticipated at the end of 2015/early 2016 with commissioning late 2018/2019.[21]
- Offshore EOR/storage feasibility study was completed but the uncertainty over the timing and volumes of CO_2 availability that has followed de-selection from the UK competition means National Grid's saline formation is currently the intended CO_2 storage site for Don Valley.
- Successful intrusive appraisal drilling programme of the saline aquifer storage site (known as '5/42') completed, with the work receiving the award for innovation at the prestigious Gas Industry Awards 2014
- Project milestone decision taken to select the 5/42 site as the storage solution for the project, with work on the EOR solution discontinued
- National Grid's initial public consultation for onshore section of pipeline is complete and a preferred onshore route has been announced.[22] The Development Consent Order (DCO) application to the UK Planning Inspectorate for the 'Shared User' pipeline, from the Camblesforth Multi-Junction site to the coast at Barmston, has been submitted and accepted by the Authority
- Discussions continue with the UK Department of Energy and Climate Change to secure a Contract for Difference to support the premium power price
- In early 2014, 2Co started a process to find new or additional investors for the power plant and in July entered exclusive discussions with a Norwegian company, Sargas, for the disposal of "Co Power (Yorkshire) Ltd and the Don Valley project
- Further development of the Don Valley power plant project is delayed due to the potential change in project ownership and possible subsequent changes to the project configuration and technology choices that might follow
- In the interim, 2Co is maintaining all the principal permits and licences such as the grid connection, water supply licence etc

[21] While the project is being restructured to include a phased development and the potential introduction of an oxyfuel gas train, while also retaining the IGCC option, it has not been possible to update all data for the power project in this report.
[22] http://www.ccshumber.co.uk/Assets/downloads/whiterose_report.pdf

Porto Tolle

Summary

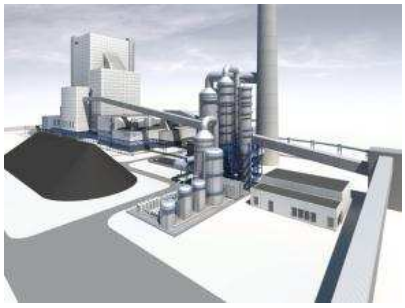
The Porto Tolle Project was based in Veneto, Italy. The project operator was Enel. In August 2013, the Porto Tolle CCS Project was cancelled. This was due to delays in project delivery, after the decision of the Italian State Council to annul the environmental permit for the Porto Tolle power plant. Moreover, the project faced difficulties in achieving closure for its financial structure.

The project would retrofit a new 660MW coal-fired power-generation group equipped with a post-combustion CO_2 capture system at the Porto Tolle plant with a capacity of 250MWe (capture efficiency >90%). The CO_2 captured would be transported via pipeline to an offshore saline aquifer. It was expected that the project would capture 1Mt of CO_2 per year.

Progress during 2013-2014

- During 2013, the project promoters took the decision to cancel the project. Enel wishes to continue to work on CCS in the pilot plant in Brindisi.

ROAD



Summary

The ROAD project is based in the Port of Rotterdam in the Netherlands. The project operator is a 50:50 joint venture between E.ON Benelux in partnership with GDF Suez Nederland. TAQA Energy B.V. will provide CO_2 injection and permanent CO_2 storage. The project will apply post combustion capture to a 250 MW slipstream from new 1,070 GW coal and biomass power plant. The CO_2 captured will be transported in a 26km pipeline to offshore depleted gas reservoirs which are located in block P18 of the Dutch continental shelf. The pipeline has a transport capacity of around 5 million tonnes per year. The depleted gas reservoirs are at a depth of around 3,500 m under the seabed of the North Sea and have an estimated storage capacity of approximately 35 million tonnes. The project is expected to capture 1.1MtCO_2/year.

Progress during 2013-2014

- Detailed engineering of the capture unit has been completed
- Pipeline route engineered and 'flow assurance study is completed
- 'Tie-ins' with power plant have been installed
- Permitting procedures finalised
- Capture permits are definitive and irrevocable
- Storage permits are definitive and irrevocable

- The storage permit will need to be updated before injection starts (in particular monitoring plan, corrective measures and financial security will be reviewed)
- The final investment decision is awaiting resolution of the pending financial closure

Sleipner

Summary

The Sleipner Project is based in the North Sea 250 kilometres west of Stavanger, Norway. The project operator is Statoil in partnership with Total and Exxon Mobil. It is a gas processing project, the only non-power project in the Network. The natural gas produced at the field is stripped via a conventional amine capture of its high (~9%) CO_2 content. The CO_2 stream is then injected into a deep saline aquifer via a 1km pipeline. The project commenced in 1996 and has captured approximately 15Mt of CO_2 to date.

Progress during 2013-2014

- Some 1Mt/y of additional CO_2 will be injected following the tie-in of the Gudrun field in 2014. Oil & Gas from Gudrun will be piped to the Sleipner site and CO_2 separation will take place at SleipnerT
- Apart from minor operational fluctuations, the main reason for annual changes in injection was found to be the gradually declining CO_2 content of the produced gas
- A continuous monitoring programme is in place. To date eight repeat 3D seismic surveys have taken place

Project Quick Reference

Table 1. CCS project quick reference table (All available data displayed).

	Compostilla	Don Valley	Porto Tolle	ROAD	Sleipner *
Production plant type	Power plant	Power plant	Power plant	Power plant	Natural gas processing
Installed production capacity (MW_e)	300	650	260	250	N/A
Fuel Type (for power production)	Coal	Coal / natural gas	Coal / biomass	Coal / biomass	N/A
Net efficiency (lower heating value) of the power plant without CCS at full load	41.1%		44.0%	46.3%	N/A
Net efficiency (lower heating value) of the power plant with CCS (full load value)	35.4%		38.2%	43.9% (36.1 % slipstream to capture plant)**	N/A
Capture Type	Oxyfuel	Pre combustion	Post combustion	Post combustion	Amine
Transport Pipeline Length (km)	135	175	100	25	1
Storage	Onshore saline formation	Offshore EOR or saline aquifer	Onshore saline aquifer	Offshore depleted oil and/or gas reservoir	Offshore saline aquifer
Planned CO_2 Capture Mt/yr	1.3	2.1 average across first 5 years	1	1.1	0.9

*Project in operation, ** Includes compression

Timelines and project management

CCS has been demonstrated for decades, in different configurations and in various sectors. Fully integrated projects demonstrating the successful application of the technology at commercial scale are planned to go online this and next year in the United States. These projects, as first mover projects had to manage unforeseen problems and it is also the case for European projects to face significant risks and costs.

The capture element, requires careful engineering as it is associated with large capital costs regardless if newly designed carbon capture plants or retrofitting a capture unit to an existing plant, is considered. While such costs are expected to greatly decrease with technological developments and experience, they represent areas that require careful planning. It is also very important for a project proponent to ensure that the added capture processes do not adversely, or unexpectedly, impact the plant's normal operation. Although the Network projects had to apply problem solving with regards to technical issues, no significant disruptions were experienced. The Don Valley project has been under restructuring, however mostly aiming to overcome financial barriers.

The transport and storage aspects of a project, while less operationally costly, have large up-front development costs and prolonged timelines. Activities such as screening, characterising, monitoring and testing sites, are extremely important for all projects to ensure that safe and appropriate storage solutions are chosen. Moreover, working very closely with regulators and competent authorities to obtain the permits required to explore and then operate such infrastructure are also undertaken by the projects.

The Network's early mover projects have been taking on many of the costs, time and effort required to develop suitably scaled infrastructure that anticipates the future demand for safe and viable storage of CO_2. Although this is vital for the larger and longer term deployment of CCS, they have to face increased risk and upfront investment costs.

The currently active projects' timelines suggest that the average time possibly required between taking their FID and commencing operation is approximately 3 years.

CO_2 Capture

Capture

Status Brief

- ✓ The Network is actively composed of post-combustion, oxyfuel and IGCC power projects and a gas processing project
- ✓ All projects capture or will capture, over 1 million tonnes of CO_2 per annum, at a capture rate of nearly 90%
- ✓ The total energy demand for capturing CO_2 for the power generation projects is reported to be up to 0.43 MWh/tCO_2

Summary

The European CCS Demonstration Projects Network aims at demonstrating the full CCS chain by capturing and storing at least one million tonnes of CO_2 per year. Three out of four of the current Members of the Network represent CCS projects in the coal power generation sector. The Sleipner Project is the only one that demonstrates the CCS chain in natural gas processing.

The projects within the Network are aiming to demonstrate different capture technologies. The development and deployment of those technologies is crucial to promote the viability and cost effectiveness of CCS. The capture technologies to be incorporated in the projects include:

- Using absorbent solvents (i.e. 'post-combustion' capture). This option will be important for retrofitting existing plants as it can be undertaken without significant modifications)
- Using a water-gas shift reaction process on a syngas process stream and physical solvent for the CO_2 capture process (i.e. 'pre-combustion' capture at a gasification/IGCC plant)
- Using oxygen required for the combustion separated from air prior to combustion (e.g. oxy fuel combustion where the final flue gas consists of a more concentrated CO_2 stream for easier separation)

Within each of these basic capture technologies there are multiple design choices and numerous factors that need to be carefully considered. The type of fuel being used, the climate conditions, the availability of resources (such as water) at the chosen locations, and the operational requirements of the plant are just some of them.

The capture process is an integral part of the CCS chain but there are significant costs associated with it in comparison to the other two elements (transport and storage). Within

the power sector, it has been illustrated that it can hold the highest share of the cost associated with CCS, often in terms of both capital expenditure and operational expenses. In gas processing, petrochemical and refining industries, there is often a requirement to capture the CO_2 even if it is not going to be stored. In all cases, therefore, improving and refining capture technology in all aspects remains a key goal for any CCS project.

The data presented in this section, are of significant value in terms of real life experiences of CCS. It should, however, be noted that due to differences in slip stream diverted from the exhaust gas duct for cleaning and the plant sizes of these projects, it is hard to compare the operational data and to characterise the impacts of CCS on the performance indicators. In particular, this applies to electricity production, energy penalty and efficiency depending on the mode of operations (i.e. with or without CCS).

Base power plant information and fuel

The Network contains a range of base plants from which the CO_2 will be captured. Although it primarily consists of coal-based power plants, including IGCC, PC, and oxyfuel designs, there is also a natural gas-processing plant. The differences in design, volumes, slip stream and plant size of these projects obviously differentiates them from each other. Given this, comparing the operational data and characterising their impacts of CCS on the performance indicators requires particular caution.

For the power plants projects, the reported carbon content of the fuels used varies from 62.36% to 75.6% by weight (dry basis).[23]

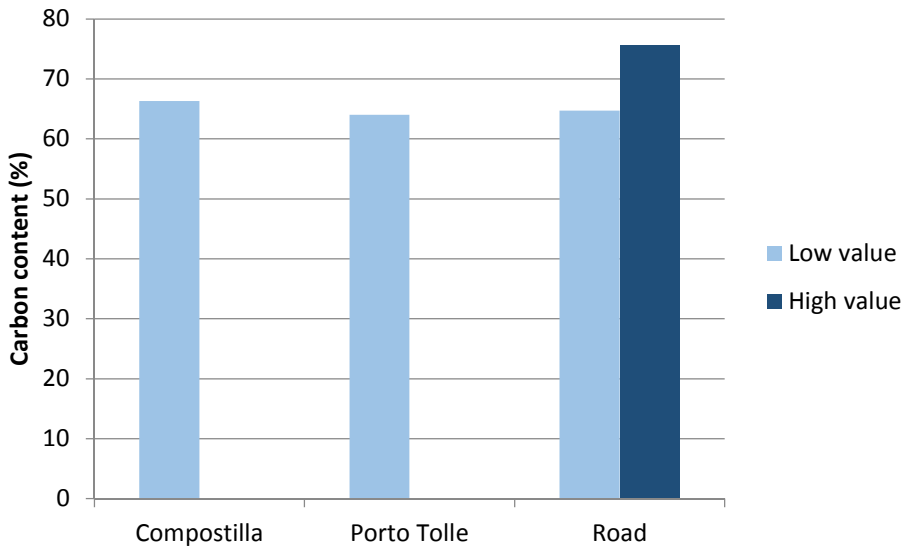


Figure 3. Current and historical data of Carbon content of the fuel used by each project (All available data displayed)

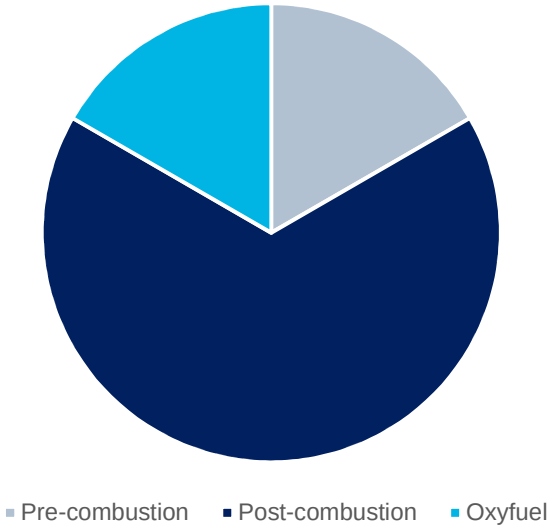
[23] European CCS Demonstration Project Network Situation Report 2012 http://ccsnetwork.eu/publications/situation-report-2012-public-report-outlining-progress-lessons-learnt-and-details-european-ccs

The ROAD project offers the option for co-firing with biomass. ROAD also offers extended fuel flexibility, as it may burn coal with carbon content up to 75.6%.

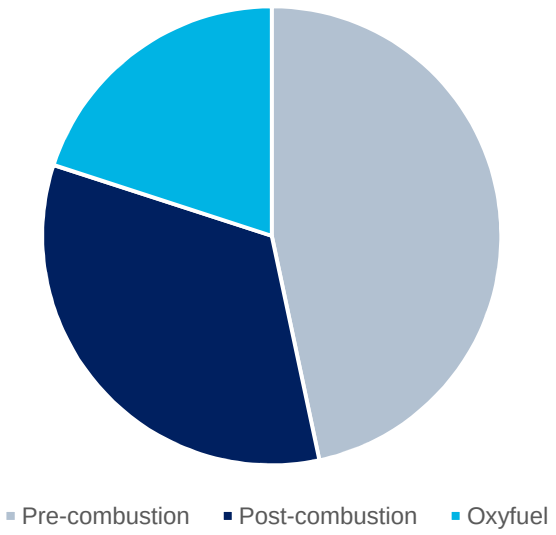
It is expected that the base plants, depending on the load profiles, will be available for 75-90% of the time.

Capture technology in the Network

Since its foundation, the Network has incorporated projects with capture plant designs that have span through various CO_2 capture technologies available. Figure 4 illustrates how the Network power projects have compared with the status of CO_2 capture technologies globally. It can be illustrated that the majority of the Network projects use or intend to use post combustion capture. The global figure includes CCS projects developed in the United States which, in their majority, are incorporating pre combustion methods for CO_2 capture. This justifies the difference between the CO_2 capture technologies used globally and by Network.



a)



b)

Figure 4. Network (a) and global[24] (b) capture technology trends

Project Summary

Although the projects have been progressing, it is Sleipner only that is capturing CO_2. The total energy demand for capturing CO_2 for the power sector is estimated by the projects to be up to 0.43 MWh/tCO_2.

The **Compostilla** project would have been using Flexi-Burn circulating fluidised bed (CFB) technology. The academic partner in the project (Ciuden) successfully commissioned a 30MW boiler and testing so far has yielded positive results.

The original **Don Valley** FEED study for the power plant was completed several years ago and work on an update, and further definition, was halted when the project was de-selected from the UK competition in late 2012. The Project has been undergoing a restructuring to phase the development of the project and to potentially introduce oxyfuel gas technology. The owner has also now entered discussions to potentially sell the project which may result in further changes to the project technology choices and configuration.

The **Porto Tolle** project completed a FEED study with Aker. The project was aiming to use amine capture technology in post-combustion. Enel have also been running the Brindisi pilot facility, to increase its know-how prior to the construction of Porto Tolle. The pilot can treat 10,000Nm^3/h of flue gas for the separation of 2.5 t/h of CO_2.

The **ROAD** project has finalised the design of the capture unit. The CO_2 capture technology will be using primary amines in post-combustion. The detailed engineering of the plant is completed.

[24] Global CCS Institute 2013, The Global Status of CCS: 2013, Melbourne, Australia

Sleipner, the only non-power project in the Network is an offshore natural gas processing project that has been operating since 1996. Its main purpose is to reduce the CO_2 content of the produced gas in compliance with the commercial requirements of the European natural gas system. Sleipner makes use of an advanced amine high-pressure absorption/desorption technique without fuel conversion (i.e. no combustion).

Energy demand for capture, plant efficiency changes, and capture rate

The projects are inevitably subjected to a decrease in net efficiency when in CCS mode. This net efficiency decrease is shown in Figure 5 and reflects the fact of the systems operating on a limited slip stream of their operating base production units.

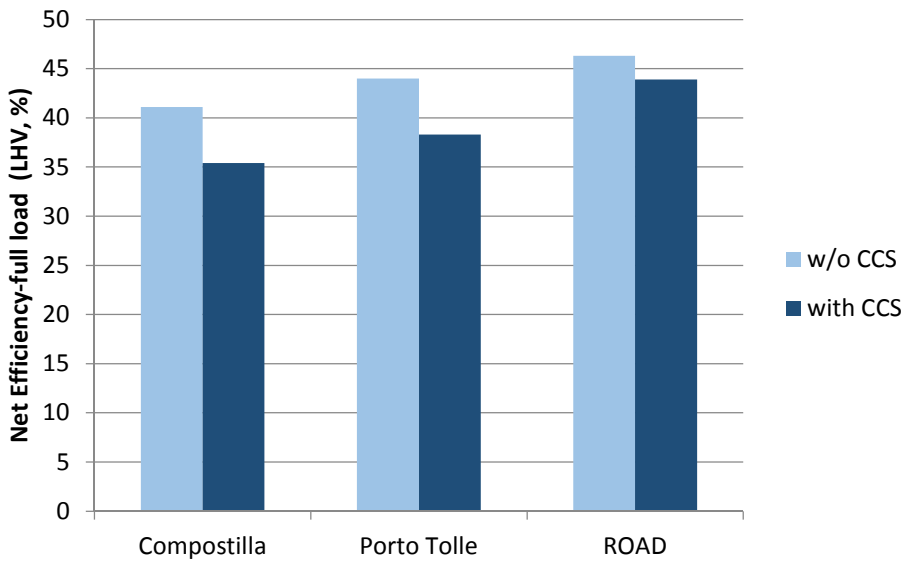


Figure 5. Historical and current data for net efficiency of power projects at full load (LHV, %) without and with CCS (All available data displayed)

Solvent requirement and degradation

Table 2 presents data on the solvent type and requirements for CO_2 capture, as reported by the power projects.

Table 2. Solvent use by Network project

Project	Compostilla	Don Valley	Porto Tolle	ROAD	Sleipner
Solvent (No/Yes)	No	Yes	Yes	Yes	Yes
Physical/Chemical	N/A	Physical	Chemical	Chemical	Chemical

Capture plant product composition – Airborne emissions

Gaseous stack emissions such as SOx, NOx, O_2, H_2O, MEA, HCl, HF, CxHy, Dust, and NH_3 are expected from the power production plants contained within the Network. These emissions

would result from a variety of different process streams, after the CO_2 has been captured. The projects will produce a pure CO_2 stream which will be transported and stored. The following sections of this report provide an overview of these activities undertaken by the Network.

CO_2 Transport

Transport

Status Brief

- ✓ Three projects use or intend to use offshore pipelines
- ✓ Pipeline inlet pressure will be up to 180bar.
- ✓ Pipeline inlet temperature will be up to 80 °C
- ✓ Pipeline length can be as short as 25 km for power projects

Summary

Transportation of CO_2 and other gases already occurs in many parts of the world and is not expected to be a major barrier to CCS.[25] CO_2 can be transported as a solid, liquid, gas, or a dense-phase liquid by a variety of means. For most large-scale projects, pipelines are the favoured method of moving the CO_2 between the capture and storage sites, providing the lowest cost, safest and most efficient option. In such cases the CO_2 is usually compressed until it reaches the supercritical phase (Figure 6). This state is efficient for pipeline transport. Compression in this state also greatly reduces the volume of CO_2, allowing smaller pipes to be used.

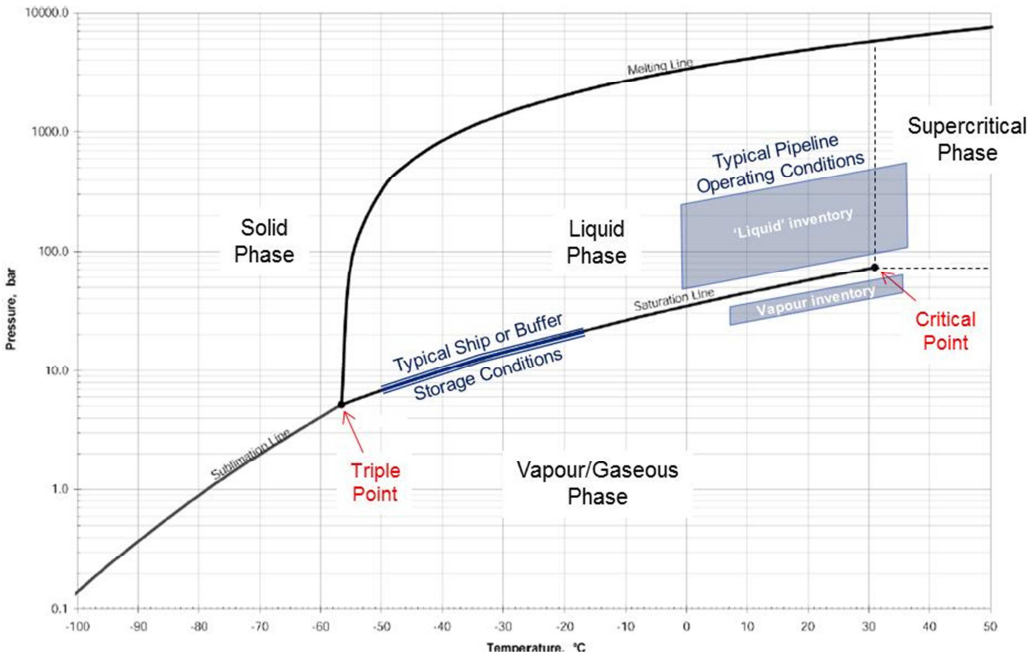


Figure 6. CO_2 phase diagram (DNV, 2013)

Almost all of the currently operating CO_2 pipelines are onshore in the USA, and many are routed through sparsely populated areas. The existing pipelines primarily transport CO_2

[25] Intergovernmental Panel on Climate Change: *Special Report on Carbon Dioxide Capture and Storage* (2005)

from natural sources or from industrial sources that tend to contain a very low level of impurities. The impurities that will arise from capturing CO_2 from coal, gas, biomass plant in the power sector, and certain industrial sectors such as steel manufacturing, can impact the way in which the CO_2 behaves. This, in turn, has an impact on the design choices of any pipeline. This situation may be even more complicated for 'shared' pipelines that have different capture sources.

The associated safety requirements for pipelines in densely populated areas necessitates new regulations for the emerging CCS pipelines. Due to that, all of the projects have carried out extensive investigation on the potential pipeline corridors and pipeline materials. Furthermore, most of the projects have undertaken public engagement activities in the areas surrounding the pipeline corridor.

All of the Network's projects are using, or planning to use, pipelines to deliver the captured CO_2 to the storage site. Don Valley, Porto Tolle, ROAD will all require offshore, subsea pipelines to reach the storage location. Sleipner is already using a subsea pipeline. It is worth noting that all the projects are within the global average pipeline length[26] ranges both onshore and offshore (Figure 7).

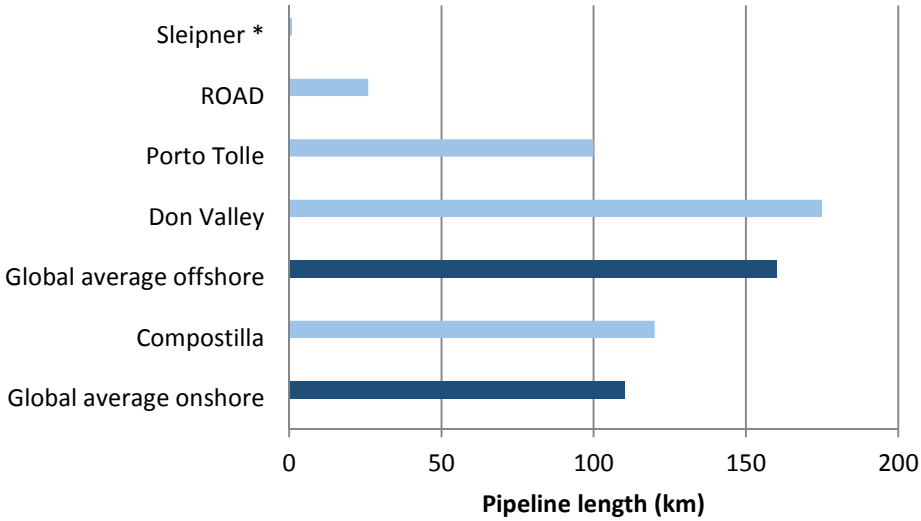


Figure 7. Pipeline lengths of the projects compared with the global average pipeline length (All available data displayed)

Compression

Compression work is reported as the required power per ton of CO_2 compressed. The pipeline inlet pressure of Compostilla project has been reported to be higher than that of ROAD. However, historical data has shown that the higher system pressure of the pipeline in

[26] As estimated from data extracted from Global CCS Institute 2013, *The Global Status of CCS: 2013*, Melbourne, Australia.

Compostilla is not causing significant differences in compression work for the two projects. Porto Tolle was expecting to require the largest amount of compression work but had estimated one of the lowest pipeline inlet pressures. Obviously, the compression work is estimated taking into account different assumptions such as different concentrations of impurities in the CO_2 stream, with regards to the content of inert gases. Additionally, the design of the compression train, especially the number of compressor stages, interstitial cooling (temperature and pressure drop), and the level of dehydration of the CO_2 stream, as well as the use of CO_2 pumping instead of compression beyond the critical pressure can affect the compression work estimations.

The Network's average pipeline inlet pressure and the average maximum pipeline temperature are shown in Figure 8. The resulting range of pipeline inlet pressure will be between 129 and 185 bara, with an inlet temperature ranging between 38 and 80 ^{o}C.

In order to compress the CO_2 to achieve the expected average pressure and temperature conditions of 155 bara and 59 ^{o}C, the projects anticipate relevant energy requirements. This cost is relatively low, compared to the energy requirements of capturing the CO_2, and is in part a reflection of the capture design and transport and storage requirements.

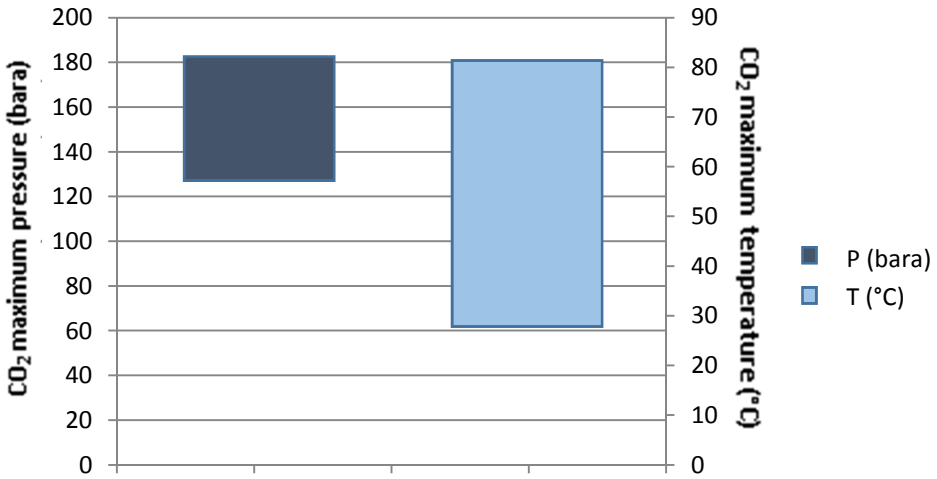


Figure 8. Current and historical data ranges of Network projects' maximum pipeline inlet pressures (bara) and the maximum pipeline inlet temperatures (°C) (All available data displayed)

Impurities concentrations

One of the other key considerations for all elements of CCS, but particularly transport, is the issue of CO_2 composition as it influences the design of the pipeline network. Figure 9 demostrates the expected CO_2 purities from the projects along with the typical CO_2 product concentration for different CO_2 capture technologies.

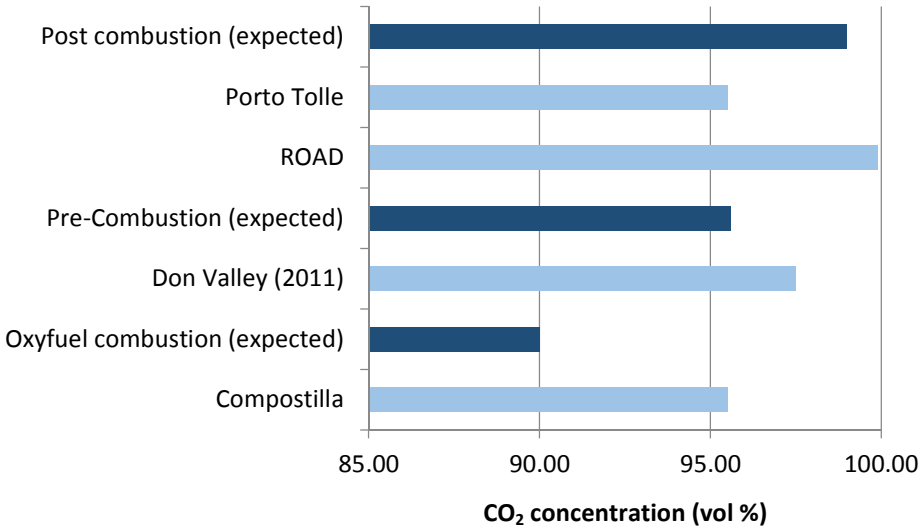


Figure 9. CO_2 concentration (vol %) in product stream

By-products, or impurities, in the purified CO_2 stream can have a profound affect on the behaviour of the CO_2 stream, and therefore the design of the whole CCS system. Elements such as nitrogen, methane, hydrogen, etc. can impact the density and critical pressure of the CO_2 in particular. Impurities in the gas stream can damage compressors and pipelines by causing hydrates, valve degradation and corrosion. Additionally, impurities can causes changes to a pipelines fracture propagation and capacity. It is therefore particularly important to understand the characteristics of these elements, and how they interact with each other.

For each project in the Network, with varying environmental and process contexts, the management of such impurities has influenced the design of the whole CCS system. In some cases additional cleaning processing steps are required at the capture plant (for example the inclusion of dehydration units to reduce the water content). The transport design and engineering may be profoundly influenced, potentially requiring larger pipelines (lower density CO_2 will require a much larger pipeline diameter for the same flow rate), more expensive materials, pipeline insulation, increased compression/booster requirements, etc.

Furthermore, impurities can have a significant effect on the injection and storage of CO_2. The injection and storage elements may require further cleaning steps, compression, heating, more injection wells, chemical additives, filters etc. The possible impacts of impurities are reservoir-specific and depend on the mineralogical composition of the rocks and of course the type of impurity and its concentration. The impacts may include reduced permeability and increased pore pressures. Impurities may also cause a lower gas density which would fill the storage site faster causing high costs and more frequent mobilisation of injection equipment.

The projects have reported their expected operating results, and expected generic results have been provided for comparative purposes (Table 3). Taking into consideration the different capture plant and operating contexts, the impurities, and how they are managed, varies considerably per project.

Table 3. Current and historical balance data of components in the CO_2 stream before transport (All data available)

	Compostilla	Oxyfuel combustion (expected)	Don Valley	Pre-Combustion (expected)	ROAD	Porto Tolle	Post combustion (expected)
O_2		<3 vol%		Trace	50 ppmw	2,000 ppm	<0.01 vol%
H_2O	<500 ppm	0.14 vol%	< 50 ppm	0.14 vol%	50 ppmv	500 ppm	0.14 vol%
H_2		trace		<3 vol%			Trace
H_2S	<200 ppm	trace		<3.4 vol%		200 ppm	Trace
CH_4		-		<0.035 vol%		100-1,000 ppm	<0.01 vol%
CO	2,000 ppm						
N_2						<4 vol %	
EOR						<2 vol %	
Ar		<5 vol%		<0.05 vol%		<4 vol %	Trace
H_2		<7 vol%		<0.6 vol%		<4 vol %	<0.17 vol%
SO_x	100 ppm	<0.25 vol%		-		100 ppm	<0.001 vol%
SO_2							
SO_3							
NO_x	100 ppm	<0.25 vol%		-		100 ppm	<0.005 vol%
Total Incondensables (CH_4, H_2, N_2, CO, Ar etc.)	<4 %vol		< 4 vol%		Balance (N_2 and Ar)		

CO_2 Storage

Storage

Status Brief

- ✓ All projects have completed their screening and selected their storage sites
- ✓ The projected bottomhole pressures for the projects range from 80 to 300 bar, and injection rates are up to 70kg/second
- ✓ Storage capacity and injectivity values are highly site specific
- ✓ Groundwater and soil gas monitoring and 3Ds are the preferred methods of monitoring in the Network

Summary

The safe and permanent storage of CO_2 is vital in ensuring that CCS can achieve its potential as a key climate change mitigating technology. Since the Network projects will be operational for decades before being fully decommissioned, they have to undertake extensive subsurface characterisation, monitoring and assurance processes. The projects related activities are more than has ever been required from other subsurface users. This is mainly due to the fact that the projects are in their early stages of the development. For sites where little or no data exist from previous exploration activities such as oil and gas exploration and production particular effort is required.

Each geological site is unique and the legal and regulatory frameworks that are delivering the required licences and permits are still under development. For this reason it is likely that it could take several years before a decision can be made to proceed with a commercial project.

The below **project status table** for the projects in the Network (except Sleipner since all boxes would be marked as completed) presents a summary of their current status:

Table 4. Project Storage status table

	Compostilla	Don Valley saline	ROAD	Don Valley EOR	Porto Tolle	Hontomin
Site screen	✓	✓	✓	✓	✓	✓
Site select	✓	✓	✓	✓	✓	✓
Feasibility study	✓	✓	✓	✓	✓	✓
Appraisal drill and/or seismic	✓	✓	**n/a**	n/a	○	✓
Baseline surveys	✓	□	**n/a**	○	✓	✓
FEED	✓	□	○	○	○	✓
LT monitor plan	✓	□	○	○	○	□
Storage License application	○	□	✓	○	○	**n/a**
CO_2 Injectors	2-3	**2-3**	**1**	5-6	1	**1**
Injection backup?	yes	**yes**	**no**	yes	no	**no**

○ not started □ in progress ✓ complete project suspended

It is interesting to note that each project follows a different programme for its site selection and characterisation. For example, Compostilla and Hontomin have finalised their site selection, performed seismic surveys at pre-selected sites, drilled appraisal wells, acquired significant baseline data and the operational phase has started at the Technology Development Plant. ROAD on the other side has completed its site selection and feasibility study but has not acquired any new field data specifically for the project. Data acquisition programmes, definition of tasks within each stage of the project, and decision-making processes are clearly driven by the specifics of each site.

There are several factors pertaining to performance management and risk control which need

to be considered in the long term storage of CO_2. From the pore volume available for storage capacity, the subsurface characteristics permitting injection–injectivity, and the containment, injectivity is a key factor during the operational phase. The injectivity index will vary with flow rate, pressures, absolute and relative permeability and the nature of the injected fluid. Measuring and controlling the bottom hole injection pressure is important to calculate and adjust injectivity and avoid excessive pressures , e.g. reaching fracture pressure, that could damage the storage.

The projected bottom hole pressures for the Network projects range from 80 to 300 bar. These figures are lower than the Quest Project in Canada which calculated an achievable bottom-hole pressure between 31 and 32 MPa (310-320 bara) , depending on the density of the CO_2.[27]

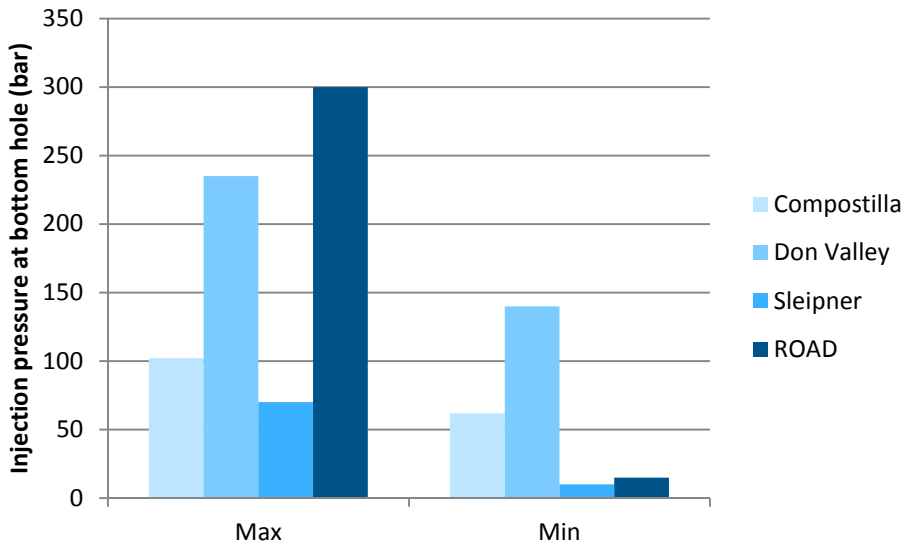


Figure 10. Current and historical data of bottom-hole injection pressure (All data available)

The injectivity rate (Figure 11) is the injection rate at a specified pressure, lower than the fracture pressure that permits to inject the CO_2 fluid into a given reservoir and the ability of the CO_2 plume to migrate away from the injection well. Don Valley has the highest injection rate from projects which provided data. Sleipner historically reported the lowest minimum bottom-hole pressure.

[27] Quest CCS project http://s09.static-shell.com/content/dam/shell/static/can-en/downloads/aboutshell/our-business/oil-sands/quest/quest-d65-updatejune2011.pdf

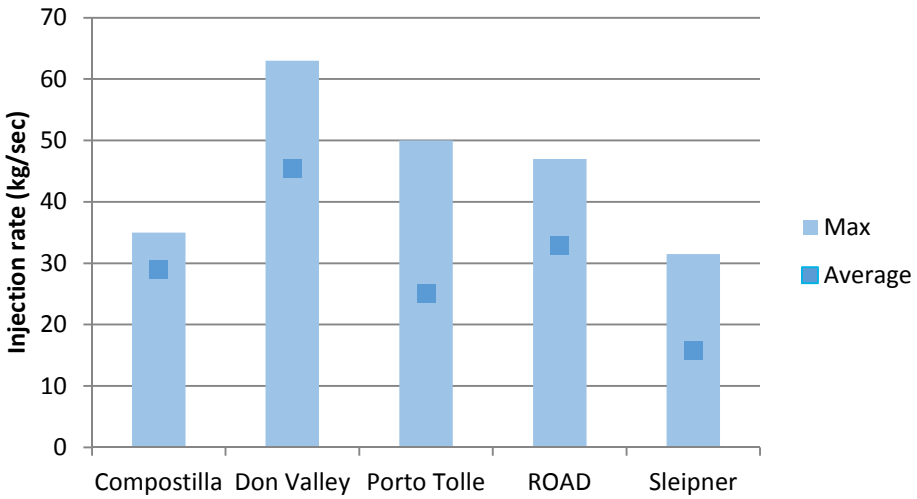


Figure 11. Current and historical data of maximum and average injection rate at each project. (All available data displayed)

During the lifetime of injection operations, the reservoir pressure could increase. The largest reservoir pressure over the reservoir volume figure was expected by the Compostilla project from the data received (Figure 12).

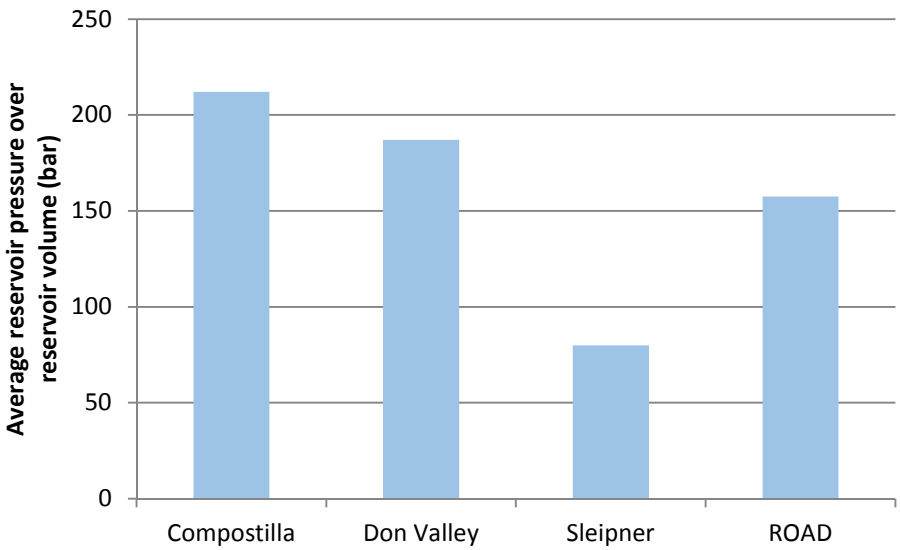


Figure 12. Current and historic data on reservoir pressure over the reservoir volume.

Each project has to model the storage capacity of the intended reservoir. Figure 13 presents the modelled capacity capacity of the storage complex over the projects' lifetime. ROAD are planning to use the smallest reservoir. The projects have used a variety of modelling programs to complete the model of the storage capacity but the most popular are Eclipse 100 and Petrel as shown in Table 5.

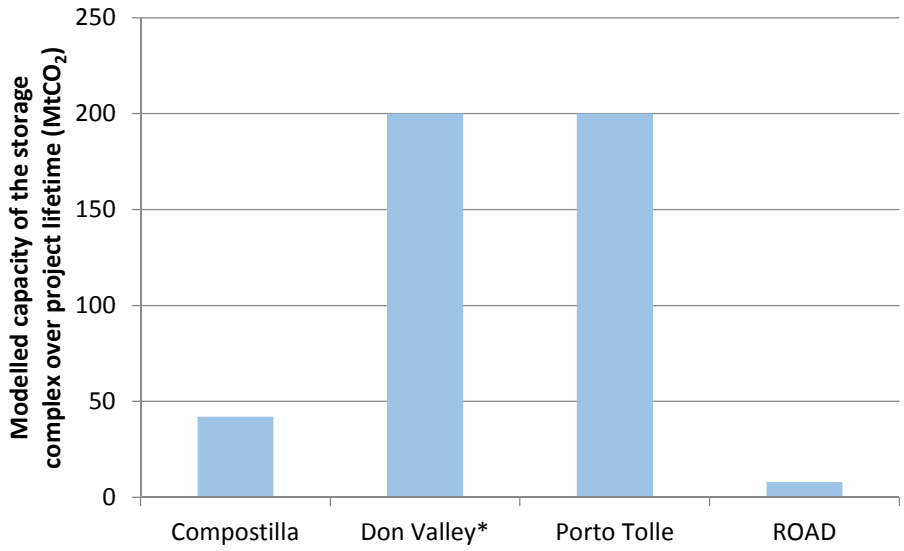


Figure 13. Current and historical data of the modelled capacity of the storage complex over the project lifetime (All data available). * indicates the dynamic capacity. Other projects have not specified if the capacity is dynamic or static.

Table 5. Modelling software used to define storage and well engineering solutions

	Static/Dynamic	**Static**			**Dynamic**		
	Modelling software used for defining storage and well engineering solutions.	Petrel	GoCad	Kingdom Suite	Eclipse 100	Gems	PROSPER
Project	**Compostilla**	Y	Y	Y	Y	Y	Y
	Don Valley	Y			Y	Y	Y
	ROAD	Y				Y	Y

Project updates

Compostilla – Duero and Andorra sites

The project continued and finalised the FEED for the Duero site in Sahagún, in the North West of Spain. The main focus for the Compostilla Project has been on completing the FEED last year, the baseline monitoring and establishing the monitoring risk and management plan. The baseline data acquisitions were completed, including thorough gas and fluid sampling and analysis for a solid hydro-geo-chemical baseline. The storage site is on the flank of a synclinal. Data collection concerned the surface, the vadose zone and the deeper subsurface.

The current exploration licence remains valid for 3 years under the current mining law and 5 years under storage law. To maintain it, monitoring activities need to be performed at site such as geochemical and microseismicity measurements.

The storage licence application could only be submitted after a positive FID was taken, which was not the case for the Compostilla Project. Under the Spanish law, the project developer needs to make an upfront payment equivalent to 10 to 20% of the total cost of the project to the authorities when applying for the storage licence. It is hoped that the implementation of new rules will allow the start of a second phase of the project in the future.

Compostilla – Hontomin Technology Development Plant

CIUDEN continued to carry out its plans at the technology development plant. The Spanish government committed to 2 years of operations at Hontomín (until the end of 2015). Injection of CO_2 should start in the autumn of 2014. Baseline characterisation and monitoring continues.

The project completed the drilling of the injection well and of the monitoring well mid-October 2013. Using percussion shallow drilling combined with a mining rig for the deeper part, saved the project 60% on drilling costs compared to those associated with the traditional oil sector drilling methods.

After the drilling of two wells (injection and monitoring) the site construction has been completed. The injection and water treatment plants are being commissioned with the testing and calibration of monitoring devices. During the commissioning phase some 200 tonnes of CO_2 have been injected during various tests.

Don Valley Power Project – Saline Formation

Originally, the Don Valley Project was to capture, transport and store 4.7 Mtpa (now adjusted to 2.5 Mtpa in Phase 1). Added to the 2.6 Mtpa of the White Rose project and other emissions capture anticipated in the region, this requires a 17 Mtpa – 24 inches diameter - pipeline to collect the CO_2 and store it offshore. Power Generation and Industrial output in the area is in the order of 60 Mt/year.

Regarding the Yorkshire & Humber Project, UK the formal consultation process along the proposed onshore pipeline route has been completed. A 1 km wide offshore survey has been conducted along the proposed pipeline route including environmental surveys and side scan sonar. National Grid is continuing with development work for the store and aims to use this project to help create a business model that attracts other players. Early results, that at least 100Mt of CO_2 could be injected without pressure relief. With capture from each of the White Rose and Don Valley Projects expected to be approximately 2.5 Mt/yr, many years of production data would have been collected before any pressure relief should be required.

Don Valley – CO_2 EOR

The Don Valley Project was planning to use CO_2 for EOR and storage but de-selection from the UK CCS competition means development of the project will have to be phased and initial volumes of CO_2 will be insufficient for EOR. The potential for CO_2 EOR to be used in North Sea oil fields is considerable. The base case for storage is now National Grid's deep saline formation site.

- EOR storage of the smaller CO_2 supply could be enabled by:
  - Combining the Don Valley supply with CO_2 from another source
  - Development of an EOR project matched to a smaller CO_2 supply – reduced capex, no new platform, extensive re-use of facilities and wells
  - Longer timeframe to develop options
- An initial CO_2 supply with saline storage, offers advantages for later EOR developments:
  - CO_2 supply de-risked before substantial capital commitment to EOR
  - Potential to divert CO_2 from the saline store to short-term injection tests of pilot developments would probably require shipping capability
  - Alternative storage to cover long-term outage of EOR storage
  - 'Buffer storage' of CO_2 used later for EOR
- However, a later EOR development would have to balance additional costs for saline storage against reduced risk

ROAD

From a technical point, the project is in 'slow mode'. The project has been granted its storage permit and this is irrevocable. From filing the application in 2010 (under the previous regulation) to receiving the permit under the CCS Directive regulation took 3 years. This was due to time to include the CCS regulation in Dutch law and the need to obtain the transport and permits combined, i.e. the 2 components. Obtaining permission for transport slowed down the permit for the project. Finally it was decided that storage could be lifted out of the package and be granted permission.

Injection could start in 2018 or before. It would take 8 years to fill the P18 reservoir, equivalent to 8 Mt of CO_2. The new power plant on the back of which ROAD will capture the CO_2 is being commissioned. The local community is supportive. The Dutch government is in favour of the project but has limited additional funding. It is trying to change the current grant agreement. Many efforts have been deployed at a European level, but for several months now the project has been in slow mode.

The permit will need a detailed update before injection starts. All plans (monitoring, corrective measures, etc.) will have to be finalized and Financial Security, as required by the CCS Directive, be put in place. The Financial Security (FS) will need to remain in place for up to 5 years after the injection has stopped. It would correspond to more than 1€/t injected. It could be either an escrow deposit or a parent Company guaranty. The transfer of responsibility mechanism remains an issue as elaborated in the study conducted by the project.[28] Definitions of the storage site and storage complex are important issues as well.

Sleipner

Operations continue since 1996 with demonstration of safe storage. Statoil is conducting a full storage system review. Repeated Seismic monitoring in Sleipner has allowed for significant improvements in understanding CO_2 flow dynamics. The simulation results clearly indicate that the plume beneath the caprock is gravity-dominated, and apparently close to equilibrium at every observation point.

Highlights of the knowledge sharing workshops in 2013/14

The progress of Don Valley's 'Saline Formation' is very promising as well as the progress of Compostilla, which was the only remaining onshore project in Europe. The participation of Statoil ASA, sharing its experiences and lessons learnt from Sleipner but also from Snøhvit is of great value to the Network.

- One of the major highlights was the successful drilling, coring and testing of the offshore appraisal well by National Grid (Don Valley Project)
- Hontomín site of the Compostilla project managed to progress as planned despite the major restructuring it went through following the change of government in Spain
- The Dutch government granted the storage permit has been granted to the ROAD project. The project can start construction as soon as sufficient funding is secured
- Operations at Sleipner continue smoothly, Statoil continues to successfully demonstrate storage and actively engage with R&D projects, institutions as well as with all active NGOs
- The external presentation from DNV regarding the validation, verification and certification of CO_2 geological storage sites and projects, gave overviews and insights in providing assurance to stakeholders
- Don Valley presented a business models for CO_2 storage and discussed the conditions to be met to make Transport and Storage a viable business

[28] http://decarboni.se/sites/default/files/publications/111356/case-study-road-storage-permit.pdf

Overviews and detailed findings can be found in the relevant thematic reports produced from the Network.[29]

[29] http://ccsnetwork.eu/publications/?f[0]=sm_field_publication_category_14796%3A9

Public engagement

Public Engagement

Status Brief

- ✓ Public engagement activities are progressing well for the projects
- ✓ Direct engagement has been the best method for public interaction
- ✓ Public engagement best practice has been demonstrated practically by the projects
- ✓ Consistent, clear messaging when communicating with the public has been shown to be vital
- ✓ Operational demonstration plants will act as a beacon in the context of future conversation and communication

Public engagement activities are of fundamental importance for new initiatives using new technologies. In a number of recent cases, the public's perceptions of a project have been shown to have a highly influential role in determining the success or the failure of a project. The Network projects have learned from experience the importance of positioning communication and engagement as a fundamental part of project planning from the outset, starting early to strategically engage with influential stakeholders to build awareness and trust in a project. Another key learning is the importance of continually monitoring stakeholders to help address any queries before they become issues, and to demonstrate a willingness to listen to their ideas and take reasonable actions to improve areas of the project that are causing stakeholder challenges.

The Network projects have all identified the levels of public engagement risk associated with the local communities impacted by their CCS project. The Compostilla Project initially identified low levels of public engagement risk associated with their project, but acknowledged that the risk levels were likely to increase when starting operations related to CO_2 Storage. CCS projects have to overcome numerous communication and engagement challenges due to the variety of processes and disciplines involved in a CCS project, as well as the geographic spread of many projects. The Network lesson learnt is the importance of really committing to proactive communication and engagement activities to build and strengthen key stakeholder relations.

The Network projects have undertaken a number of activities to promote public engagement best practice. This includes a focus on the concerns and perceived risks raised by the public to the Network's projects, the identification and management of key stakeholders, followed by messaging and tools for communication.

A special Communication Workshop was held in May 2013 and follow up discussions were held between the technical groups on communicating CCS at the Knowledge Sharing Event that took place later that year.[30] The workshop brought together a collection of international experts that were interviewed for the report– "Identifying the benefits, managing risk and maintaining the trust of stakeholders".[31] A video summary of the Communication and Engagement workshop is available on YouTube: www.youtube.com/watch?v=r8P_ssf2OW0

Moreover, CIUDEN, the academic partner in Compostilla project, gave an engaging talk about their outreach work with Local Councils in Hontomin. Following this presentation, CIUDEN were invite by the Global CCS Institute to participate in an expert webinar and have worked to translate and publish all of their existing education and outreach activities.[32,33]

The projects reported that the most frequent concerns of the public are over the continued use of fossil fuels and over the cost and actual benefits of CCS. Concerns regarding CO_2 transport and storage have been raised with the projects as well. Direct engagement with the public through face-to-face meetings and site visits was found to be the preferred and most effective tool for engagement.

The Compostilla Project took into account publications from the US Department of Energy, CSIRO/GCCSI and the World Resources Institute when shaping their public engagement strategy. Don Valley project has found particularly useful the National Energy Technology Laboratory's Best Practices for Public Outreach and Education for Carbon Capture and Storage Projects. The projects initiatives are in alignment with the guidelines, conclusions and recommendations on 'golden rules'[34,35] for CCS communication.

The Don Valley project has also achieved a major milestone with the submission, and subsequent acceptance by the UK Planning Inspectorate, of National Grid's Development Consent Order (DCO) application for the 'Shared User' pipeline. This was in accordance with the two-phased consenting strategy for the onshore pipeline which would see the 'spur' pipeline from the power station to the 'Shared User' pipeline consented at a later date under the Town and Country Planning Act 1990 once the generation and captured technologies have been determined. This approach helps to maintain stakeholder

[30] http://ccsnetwork.eu/blog/2013/07/10/international-communication-and-engagement-workshop
[31] http://decarboni.se/sites/default/files/publications/92266/communications-carbon-capture-storage.pdf
[32] http://www.globalccsinstitute.com/insights/authors/kirstyanderson/2013/12/17/engaging-local-communities-hontomin-spain
[33] http://www.globalccsinstitute.com/get-involved/webinars/2013/12/17/public-engagement-lessons-learnt-hontomin-experiences-onshore-co2
[34] Source: CCS and Community Engagement, WRI, http://pdf.wri.org/ccs_and_community_engagement.pdf
[35] Communication, project planning and management for carbon capture and storage projects: An international comparison, CSIRO, http://cdn.globalccsinstitute.com/sites/default/files/publications/8187/overview-summary-ccs-projects-incl-append-2011.pdf

confidence and critical path. Don Valley was clearly identified in the DCO application as a follow-on load and a primary user of the 'Shared User' pipeline.

Stakeholders:

The significance of early stakeholder identification in a project is well understood, particularly for helping early project developers to prioritize their stakeholder interaction, depending on the influence and interest of these stakeholders. Building up a rapport over time can also enable the developer to address stakeholders concerns more easily. The Network projects have developed detailed stakeholder maps which include (amongst many) national and local governments, NGOs, landowners and the general public.

The style of language and communication tools used have also been identified by the projects as of particular importance too. The projects have already drawn conclusions and could provide meaningful recommendations when identifying, managing and communicating with stakeholders.

Messengers:

The projects highlight the importance of team communication training and of using a wide variety of tools to deliver their project messages. While it is considered vitally important that there is a consistency in messaging associated with a project (across JV partners/ funders/ project supporters), there is also recognition of the importance of listening, and being able to comfortably adapt communication styles to meet stakeholder needs.

The projects have all reported benefits from team training and from investing in dedicated communication and engagement resources who communicate about the project both as a standalone entity and within a wider corporate context.

Projects have reported particular benefits when partnered with academic institutions to undertake communication. It can be worth giving universities and academics access to project data, as their independent findings provide impartial credibility. However, communications experts are necessary so that scientific language is translated into something that can be easily understood.

Conclusion and recent developments

The slowdown in CCS developments in mainland Europe do not appear to have directly impacted local community perceptions of the existing Network projects. However, the cancelation, lack of political support and frequent delays of associated with CCS projects is sending misleading messages to stakeholders, undermining confidence in the viability of the technology. There has been a notable decrease in media activity around CCS in the last year, which helps to perpetuate the general lack of public awareness of the technology and the wider issues that it is designed to help tackle. All the Network projects agree that it is vital to

get more demonstration projects kick started in the region to allow interested stakeholders and the public to come and experience a real Carbon Capture Plant in the making.

Policy and Regulations

Policy and Regulatory Update

Status Brief

- ✓ CO_2 storage directive: All of the EU Member States representing the Network projects notified transposition measures to the Commission. Those are consisting mostly of a combination of new legislation and amendments to existing legislation. Norway conducted stakeholders' consultation with a view to transposing the EU CO_2 storage directive into national framework
- ✓ Permitting procedures have been finalised for the ROAD project. Capture and Storage permits are definitive and irrevocable. Transport permits are agreed, with expected imminent publication
- ✓ CCS was formally included in the UK Energy Act and is eligible for a Contract for Difference. The Electricity Market Reform Delivery Plan scenarios envisage CCS capacity of between 5 and 13 GW by 2030
- ✓ Negative FID was taken by the Compostilla project at the end of the EEPR – funded phase of the project, on October 31st 2013

Timeline of key EU regulatory milestones October 2013 – October 2014:

- October 2013: all Member States notified transposition measures to the Commission
- January 2014: the EC issued the 2030 climate and energy policies framework with a reference to CCS among a number of 'key complementary policies'[36]
- January 2014: the European Parliament (EP) adopted a report prepared by Chris Davies on 'Developing and applying carbon capture and storage technology in Europe'[37]
- May 2014: the EC started the CCS directive review

The European Commission has supported and encouraged CCS with a number of policy instruments. The most important policy in the EU is the Storage Directive (Directive 2009/31/EC), one of the most comprehensive examples of CCS specific legislation. The EC Communication on the future of CCS in the region released in 2013 has highlighted the need for substantial improvement with regards to Member State transposition of the EU Storage Directive. The formal transposition deadline of 25 June 2011 was missed by all but one

[36] A policy framework for climate and energy in the period from 2020 to 2030 http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0015&from=EN

[37] Implementation report 2013: 'Developing and applying carbon capture and storage technology in Europe' http://www.europarl.europa.eu/sides/getDoc.do?type=REPORT&reference=A7-2013-0430&language=EN

Member State (Spain) and the EC commenced infringement cases for non-communication against 26 Member States. Some Members States only amended current legislation, however most Member States decided to issue new specific legislation accompanied by amendments to existing legal framework.

The Directive creates a framework regime, allowing the capture and transport of CO_2 to be regulated under existing legislation and establishing a regulatory permitting regime for the storage of CO_2. The Directive establishes liability, responsibility and sets a range of obligations including storage site selection, operating, closure and monitoring activities, and the process regarding the site transfer to the relevant competent authority. However, there is a concern among the Network project members that the current manner of implementation of the Directive presents a significant financial hurdle for attaining a feasible project such as the uncertainty for the operator with regard to calculating potential financial liability in case of CO_2 leaks from the site. The EP report urged the Commission to address this disincentive when revising the EU CCS Directive.

A number of projects within the Network have faced difficulties with these regulations and permits.
The main challenges for the **Compostilla project**, for example, were not only economic but also the lack of a suitable regulatory framework for CO_2 capture and transportation. The Compostilla project achieved its exploration permits for storage, and the full storage permit would have followed if a positive FID had been taken. Since the EU CCS directive was transposed in 2010, the project requested the Ministry on several occasions to develop specific regulation, or to present another workable solution for permits application. Due to lack of the CO_2 transport regulation the transport permit application based on natural gas transport regulation has been rejected. The project was advised to start with the EIA (Environmental Impact Assessment) for CO_2 transport. The EIA has been obtained and later denied since it could not be proved that CO_2 was covered under environmental permitting. Due largely to these administrative problems, the envisaged start date of the FID process had to be postponed until the decision was made to end the project in October 2013.

Don Valley project was not amongst the two projects selected by the UK government to receive funds from the UK competition.[38] However, the project has been in discussions with DECC to identify a route to access a Contract for Difference to support the plant's cost of power. The project will have to work towards FID without having any grant that could have been available in the UK competition. The project continues to benefit from the EEPR grant that has now been amended and extended by two years through to the end of 2015. It has been amended to allow for the inclusion of an oxy-fuel gas option.
The commitment from DECC to discuss potential access to a Contract for Difference (CfD) is the next key milestone. Until that issue becomes clearer the 2Co team concentrates on

[38] See page 63 for more details on the UK CCS Commercialisation Programme.

preserving the project. National Grid's permitting of the CO_2 pipeline and appraisal of saline storage site continues with positive progress: the Development Consent Order (DCO) process is broken down into two phases. Phase 1 covers the 'trunk' pipeline from Multi junction site in Camblesforth through to the Barmston pumping station. A number of public consultations were carried out and there is a continuation of engagement with stakeholders such as local authorities and councils. Phase 2 is the consent for the interconnecting pipeline from Don Valley to the Camblesforth Multi-junction which also includes the compressor station.

The White Rose CCS project, at the proposed Drax power station, will also connect to the 'trunk' pipeline at the Camblesforth Multi-junction site. Due to uncertainty regarding the technology selection for Don Valley, coupled with the need to maintain critical path activities and stakeholder engagement throughout the DCO process, the White Rose project was detailed in the application as the 'anchor load', with Don Valley highlighted as a 'follow-on load'. This was not as originally planned but necessary to preserve the Don Valley project and the value that had been accrued in the project to date. This two-phased approach has also been reflected in the recent amendment to the EEPR Grant Agreement. To preserve the integrity of the EEPR grant, the interconnecting pipeline from the White Rose project to the Multi-junction has been funded from other sources than the EEPR, while the works on consenting related the Cross Country Pipeline from the Camblesforth multi-junction to the shore can be funded through the EEPR as a part of the shared infrastructure.

The **Porto Tolle project** which aimed at finalisation of permitting in 2014 had been severely delayed because of the decision from the State Council to annul the first environmental impact assessment (EIA), requiring a new EIA to be produced for the change of use of the base plant (from oil to coal combustion). The project was terminated on 11 August 2013 at the request of the developer due to delays in project execution caused by the decision of the Italian State Council mentioned above for the Porto Tolle Power Plant. This is not in any way a reflection on the CCS component, but the CCS project was directly impacted by the delay.

The **ROAD project** achieved a considerable milestone when its storage permit was successfully reviewed by the European Commission. In September 2013 the final storage permit became definitive. The basic design of the capture plant has been completed, and irrevocable capture plant permits have been obtained. The Engineering, Procurement and Construction (EPC) contract is ready to be signed, and the project is awaiting its final investment decision.

The **Sleipner project** is regulated under the Norwegian Act Pertaining to Petroleum Activities (under the Ministry of Petroleum and Energy) and the Pollution Control Act (under the Ministry of Environment). The building and operation of pipelines, exploration of offshore reservoirs for permanent storage, the need for an environmental impact

assessment, monitoring, or third party access to pipelines or storage will fall under new regulations in the Continental Shelf Act.
In April 2014, Norway launched the stakeholder's consultation with a view to transposing the EU CCS directive into national framework. Two draft documents were submitted for comments till the end of May 2014, one related to resource management from the Ministry of Oil and Energy (MOE) and the other one dealing with environmental issues prepared by the Ministry of Climate and Environment (MCE)

The new regulations from MOE will be for new developments only. Sleipner, Snøhvit and Gudrun[39] are therefore exempt from these new regulations. The update of the environmental permit, otherwise known as the storage permit, will be applicable for all installations. However existing installations will have a 'grace period' till 1st January 2016 to adapt to these new regulations.

CCS Directive Review

The Storage Directive review process is in the remit DG CLIMA. The first step was to complete the Implementation Report on transposition of the Directive in Member States (MS) in February 2014[40]. The Commission began the work on the review process in May 2014 with a stakeholder consultation, conducted by independent consultants that the Network contributed to with inputs from majority of projects. The consultation will continue with stakeholders meetings and interviews. In March 2015 the Commission will issue a report based on recommendations from the consultants, which if deemed appropriate, will be followed by a proposal for a revision or other measures.

Timeline of the Review

Independent consultants:

- May 2014: registration of stakeholders opened
- May 16th – end of July 2014: online consultation and interviews
- 1st half of September 2014: stakeholders meeting
- Early December 2014: final consultants' recommendations

European Commission:

[39] In April 2014 Statoil reported start of production from Gudrun field tied in to Sleipner, for which the development concept was approved in 2010

[40] REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL on the implementation of Directive 2009/31/EC on the geological storage of carbon dioxide http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0099&from=EN

- 31st of March 2015: deadline to submit the next Implementation Report to the European Parliament and to the Council as a review report on the implementation of the CCS Directive

The main objective of the review is to assess the effectiveness and legal practicality of several of the CCS Directive provisions. The review will also involve considerations of wider EU energy and climate change policy and CCS related policies.

Throughout 2013, the Network's Regulatory Group identified several key issues of the storage permitting process - these have been addressed in the case study report which was produced regarding the storage permitting process of the ROAD Project. The report identified the following priority areas for possible revisions.

- Storage complex and storage site
- Financial Security
- Financial Mechanism
- Transfer of responsibilities
- Legal liabilities

  There are four different legal regimes under which liability may arise for storing CO_2:

  1. EU-ETS: operator is liable for damage to the climate in case of the release of CO_2
  2. Environmental Liability Directive: operator is liable for damage to the environment
  3. Civil liability: operator is liable for damage to third parties (damage to persons and/or goods)
  4. CCS Directive: operator is liable to the competent authority in case it does not undertake sufficient monitoring and corrective measures in case of leakage

ROAD concluded that the liabilities arising from the EU ETS Directive are the main concern.

The regulations and accompanying document on a storage permit (the CCS Directive, Guidance Documents, Opinion on Dutch draft storage permit) are new and some key details can be interpreted in a variety of ways.

Table 6. CCS Directive guidance documents and opinion

Document	Scope
Guidance document 1	CO_2 Storage Life Cycle Risk Management Framework
Guidance document 2	Characterisation of the Storage Complex, CO_2 Stream Composition, Monitoring and Corrective Measures
Guidance document 3	Criteria for Transfer of Responsibility to the Competent Authority
Guidance document 4	Financial Security (Art. 19) and Financial Mechanism (Art. 20)
Commission opinion	Opinion relating to the draft permit for the permanent storage of carbon dioxide in block section P18-4 of block section P18a of the Dutch continental shelf

In total the storage permitting process took almost two years for the ROAD project. The Dutch competent authorities gave a strong support for the project. The outcome of the storage permitting process seems to be one of the most important factors for CCS projects. In particular, the requirements regarding the financial security and financial mechanism, for example, could be a key reason for an organization to stop its involvement in a project.

Network's submission to the CCS Directive consultation

The key points from the submission to the CCS directive on-line consultation made on behalf of the Network projects were as following:

1. The directive also generates overly heavy liabilities and risks for the operators of early projects. For example, the lack of clear criteria in the provisions on Transfer of Responsibility enable Member States to postpone the handover *ad infinitum*; the costs of financial contribution related to the Financial Mechanism are difficult, if not impossible, to estimate.

   The experience shows that national steps are required to limit unreasonable burdens. For example the Dutch industry representatives and the relevant ministry have reviewed alternatives to solve the issue of liability for CO_2 Storage Operators to purchase and submit EUAs to match volumes of CO_2 leaked from storage complexes to the atmosphere.

2. The Network supports development of CCS standards in the longer term perspective and based on actual projects experience, because the premature standardisation could limit flexibility in the development phase of a technology. Due to limited experience in commercial scale CCS in Europe it is too early to assess the required scope of standards.

3. The Network strongly supports the ETS as the long term driver for investment and welcomes the recently proposed structural reform of the ETS. However, these structural measures are scheduled to be implemented only as of 2021 and any impact on ETS price will take even longer. Therefore, complementary financial measures to bridge the gap between 2014 and 2021 will be necessary.
4. The Network supports funding on a pan-European level (extended NER300 or Innovation Fund) but more tailored to the industry's and Member States' requirements. National level support should to a large extent be tailored to the specific energy and climate policies – this could be done through national decarbonisation pathways outlined by the Commission in the 2030 framework communication.
5. The Network supports the ETS reform and the CO_2 price ramp to be delivered through an increase in the linear reduction factor to 2.2% per year from 2021, as proposed by the Commission in the 2030 framework. However, early low-carbon technologies like CCS will need additional support in short term in order to mature. But, until the ETS delivers a strong carbon price, CCS investment will require transitional support measures for both capital and operational expenditure. Early projects cannot be realised with support schemes that only fund one element. Capital expenditure (CAPEX) support could include direct funding for the storage element – such as the European Energy Programme for Recovery (EEPR) grant for the storage E&A in the Don Valley project, and the capital support for pre-investment in pipeline capacity (which can be also delivered through long term contract). Operational expenditure can be supported through policy measures that give investors' confidence in revenue over the life of a CCS project the Contract for Difference mechanism adopted in the UK as one of the example.
6. CCS certificates could potentially be another form of an incentive, but only if the scheme is carefully designed. The Network doubts whether this option could be implemented in short term, and whether such certificates would cover the risks associated with early movers. Emission performance standards (EPS) will not incentivise CCS in Europe in the short term and it is important not to introduce EPS before CCS is established as a best available technology (BAT) for low carbon generation.

CCS Funding, incentives and costs

Funding, incentives, and costs

Despite the numerous and extensive benefits of CCS, the successful development of a business case for early large-scale CCS projects is difficult and complex. There are effectively two elements, revenue and cost, that project proponents need to address when making their business case. These are important regardless of whether the project is intended as a technical demonstration[41] or commercial operation.[42]

For first mover projects the costs and risks can be significant. These are more pronounced for CCS projects, compared to alternative low-carbon technologies, because of the scale of such projects. However, it is expected that for these projects economies of scale apply, potentially achieving cost reductions of approximately 40% by scaling the plant three times up (Figure 14 15).

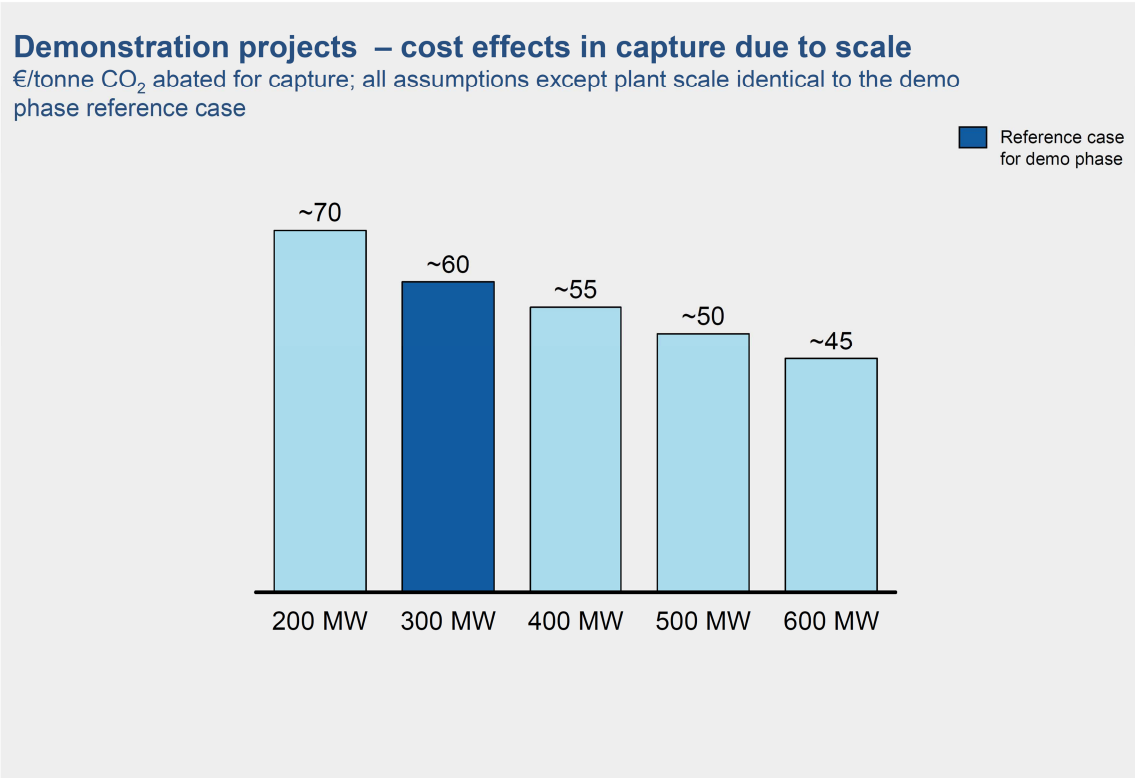


Figure 14. Cost reductions with plant scale up[43]

CCS projects have large up-front capital costs. Building a suitable business case for a CCS project is still a key barrier to deployment, and despite funding, it is the main reason for delays in the development of projects in the Network.

[41] Case responding to a changing regulatory or operating environment, and seeking future market leadership. The project proponent is willing to make less of a return on the investment than normal

[42] A certain rate of return is expected for the investment

[43] **"Carbon capture & storage: Assessing the economics"**. McKinsey & Company, Sep 2008

Funding

Globally

Renewable energy sources such as solar and wind are expected to contribute 15% of the CO_2 abatement needs by 2020. By comparison CCS is expected to contribute 4% of the CO_2 abatement needs by 2020. In 2012, the total new investment for renewable energy was $244.4 billion.[26] Proportionately, CCS should have received approximately ¼ of the investments allocated to renewables, i.e. $61 billion. The global investment in CCS projects, however, was $2.8 billion.[44]

Moreover, IEA reported that investment in CCS between years 2004 and 2012 was $20 billion while investment in all clean energy was $1,670 billion for the same time span. These figures clearly demonstrate the disproportionate allocation of investments, not in favour of CCS. The table below presents the trends in global CCS and clean energy investments. While the overall investment in clean energy fell between 2011 and 2013 the global investment in CCS projects, has remained relatively steady since 2010 (Table 8).

Table 7. Figures from Bloomberg New Energy Finance[45]

Year	Global investment in CCS projects	Global investment in clean energy
2010	2.7 billion	N/A
2011	$3 billion	$317.9 billion
2012	$2.8 billion	$286.2billion
2013		$254 billion

IPCC's latest report presents the change in annual investment flows from the average baseline over the next two decades, for mitigation scenarios that stabilise concentrations within the range of approximately 430-530 ppm CO_2eq by 2100. As can be seen from the figure below, IPCC reports that there is a positive change potential in investments for CCS. However, investment in power plants with CCS remains low compared to investments in other clean technologies.

[44] GLOBAL TRENDS IN RENEWABLE ENERGY INVESTMENT 2013, Bloomberg New Energy Finance data

[45] http://about.bnef.com/press-releases/clean-energy-investment-falls-for-second-year/

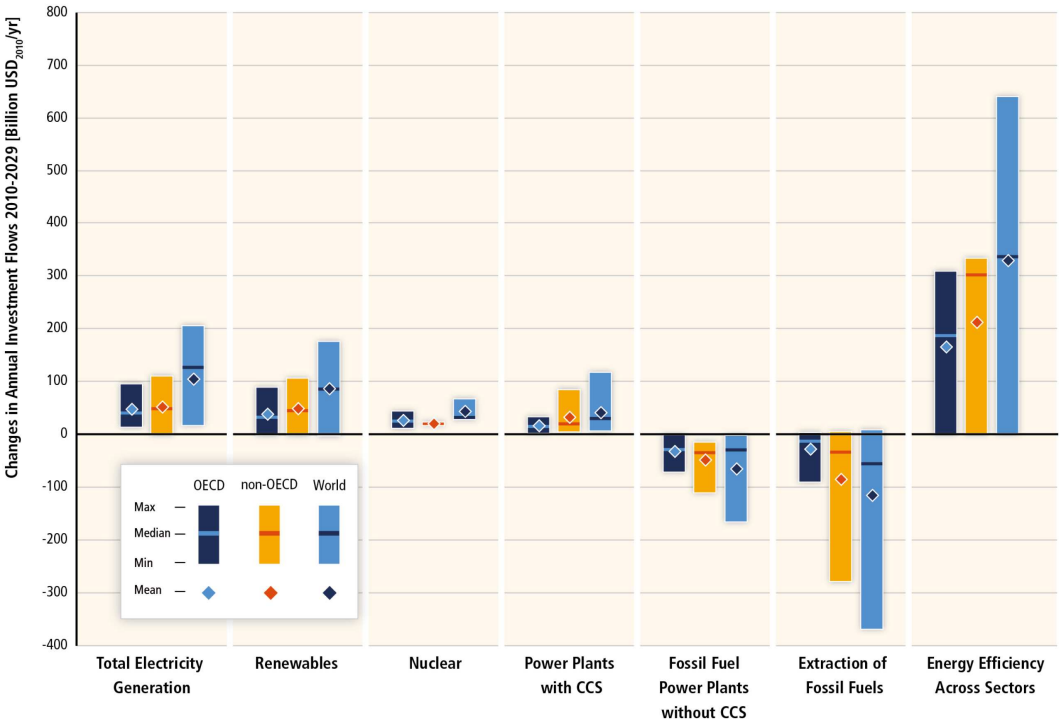


Figure 15. Change in annual investment flows from the average baseline level over the next two decades (2010 to 2029) for mitigation scenarios that stabilize concentrations within the range of approximately 430–530 ppm CO_2eq by 2100[46]

Europe

Both the European Union, and a number of countries within Europe, have recognised and acknowledged the important role CCS should play in the future development of the European power sector and industry. Within Europe a number of funding schemes have been established to aid the development of CCS and are briefly described below.

European Energy Programme for Recovery

The European Energy Programme for Recovery (EEPR) was set up in 2009 to co-finance projects that would increase reliability in energy supplies while reducing greenhouse emissions. The goal of the EEPR was to boost Europe's economic recovery. EEPR programme's total budget of €4 billion has been used to support 59 projects, six of which are CCS projects. The Network's founding member projects were all awarded funding, ranging from €100 (Porto Tolle project) to 180 million (Belchatow, Compostilla, Don Valley, Janschwalde, and ROAD). We don't expect that the unspent funds on the cancelled projects will be reallocated to the ones in operation.

NER300

The original goal of this scheme was to fund 8 commercial-scale CCS demonstration projects along with 34 innovative renewable energy projects. 13 CCS projects were submitted to the NER300 call, 2

[46] Climate Change 2014: Mitigation of Climate Change, Summary for Policymakers, IPCC

of which were CCS projects in industrial applications and 11 in the power generation sector, covering 7 Member States. It turned out that in the first round of funding, no CCS projects were given funds. The reasons for this were on the member-state level and include funding gaps (national and/or private funding contribution), delays with the permitting procedures or, an on-going national funding competition that did not allow the UK government to confirm its support in line with the requirements of the NER300 Decision.[47]

The European Investment Bank (EIB) is in charge of selling emissions allowances under the NER 300 programme. Its goal is to finance innovative renewable energy and carbon capture and storage projects. It ran two auctions to date – the first run was in September 2012, when EIB raised more than €1.5 billion out of which €1.2 billion was awarded to 23 projects out of 79 applications examined. No further sales will take place under the NER300 initiative now that the full volume has been reached.

Table 8. NER300 procedures and information

NER 300	N° of applications	CCS awards	RES (Renewable Energy Sources) awards	Amount
Phase 1	79	0	23	€1.2 billion
Phase 2	33	1	18	€1 billion

The second auction started mid –November 2013 and lasted for 5 months; when the monetisation of the remaining 100 EUAs auction yielded €548 million. The European Investment Bank received a total of 33 project applications. The European Commission announced details of awards to projects in July 2014.[48] Amongst the successful project is a CCS Project, the White Rose CCS, based in Yorkshire, UK which was awarded €300 million.

Currently, the Commission is considering a New Innovation Facility, a post-2020 funding mechanism for low-carbon technologies. The new facility would be an upgrade to the NER300 both in terms of the amount of funding available and the scope, which would cover industrial-level demonstration projects both in power and industry sectors. The Network projects called for a similar extension of the NER300 scheme in a position paper submitted to the government representatives in advance of the European Council in June 2014.[49]

[47] http://ec.europa.eu/energy/coal/doc/com_2013_0180_ccs_en.pdf
[48] http://ec.europa.eu/clima/policies/lowcarbon/ner300/index_en.htm
[49] Recommendations on the 2030 climate and energy framework from the European CCS Demonstration Project Network http://ccsnetwork.eu/blog/2014/06/27/recommendations-2030-climate-and-energy-framework-european-ccs-demonstration-project

UK CCS Commercialisation Programme

The UK CCS Commercialisation Programme is a £1 billion (€1.2 billion) direct funding support mechanism for the design and construction of CCS projects. In October 2012, the UK Department of Energy and Climate Change (DECC) shortlisted four projects eligible for funding while deselecting the Network's Don Valley project. In March 2013, DECC announced that the two projects were awarded to the Front End Engineering Design study (FEED) Peterhead (Aberdeen, Scotland) and White Rose (Yorkshire, England). Under the Commercialisation Programme, projects are also able to benefit from the reforms being made simultaneously to the electricity market to bring forward investment in low carbon electricity generation, including a CCS Feed-in-Tariff (based on a Contract for Difference).

Incentives

European Member States are not currently providing operational support or subsidies to CCS as with comparable clean technologies. Nevertheless certain key long-term steps have been taken.

EU - Revenues from carbon allowance auctions

The Emissions Trading System (ETS) directive was supposed to give direct incentives for CCS by pricing carbon. Under this system, each ton of CO_2 that has been successfully captured and stored will be viewed as 'not emitted', therefore reducing operators' obligation to purchase a European Union Allowance (EUA). Most projects are not anticipating obtaining sizable revenue from CO_2 'use'.

The current price expectation for EUAs is well below the 2008 assessment for the Climate and Energy Package, which projected 2020 prices in the order of €30 (2005 prices). Today's prices of about €6 do not incentivize fuel switching from coal to gas and increase financial costs into low-carbon investments.[50]

EU ETS could be an important incentive mechanism for CCS, but there are various problems associated with it, such as price volatility and uncertainty about auction revenues. The 2008 economic downturn (in addition to the initial over-allocation of the market) has led to a surplus of EUAs. This resulted in a low price of carbon allowances and consequently in reduced investment incentives. If allowance auction revenues are high enough, programmes such as NER 300 would could yield funding for CCS and for renewable energy projects. The problems is – they are not. And even if they were, project investments would still depend on market fluctuations.

[50] €6.13 on 9 September, 2014. Data: Thomson Reuters Point Carbon

UK – Carbon Price Floor

In the UK a Carbon Price Floor (CPF) was introduced on 1 April 2013. This is a top-up tax introduced incentivize the UK companies participating in the ETS scheme to reduce their emissions. The Carbon Price Floor introduces a minimum price of emissions for the UK power generators. If the EUAs price drops below this level, companies pay the difference to the UK Treasury.

The carbon price floor will be capped at £18 per tonne from 2016-17 to 2019-20.[51] Additional measures include a Feed-in-Tariff (FiT) scheme supported though technology-specific 'Contract for Difference' (CfD) for low-carbon energy and an Emissions Performance Standard (EPS). The CfD will probably have the greatest impact on CCS, and provide a stable revenue stream by removing a power plant's exposure to price volatility, thereby granting investment certainty. Generators will have a stable so called 'strike price' for the low carbon electricity they produce. If the market price falls below the strike price they will get a top-up payment from suppliers. Eight renewable energy projects were recently unveiled from the UK government, allocating the first CfDs that are being introduced through the Electricity Market Reform programme.

Norway

Norway adopted a simple and effective incentive mechanism - CO_2 tax. When the CO_2 tax rate was introduced in 1991, it ranged from 97 NOK (€12) per tonne CO_2 for heavy fuel oil, and 259 NOK (€32.05) per tonne CO_2 for petrol. Currently, two large-scale CCS projects are incentivised entirely by this tax and the EU ETS and they do not receive any other public support: Sleipner project has been operating since 1996 and storing around 15 million tonnes of CO_2 to date, and Snohvit project which started injection in April 2008 and stored nearly 3 million tonnes of CO2 to date. In January 2013 this carbon tax increased from NOK210 (about €28) to NOK410 (about €55) per ton of per tonne of CO_2.

[51] https://www.gov.uk/government/publications/carbon-price-floor-reform

CCS in cost context: Comparison with other low carbon options

Unlike the power sector, where renewables can provide an alternative form of emissions reductions, for the industrial sector (steel, iron, ethanol, natural gas processing, chemical, paper etc.) CCS is the only technology available to significantly reduce their emissions.

Within the power sector, CCS allows both fossil fuels (gas, coal etc.) and renewable fuels to be used without emitting carbon dioxide into the atmosphere. Without using CCS in the power sector, it is estimated that the cost of generating clean electricity in sufficient quantities will increase by at least 40%.

Levelised Cost of Electricity is a tool used to produce comparative assessments between power generation alternatives. It represents the per kilowatt-hour cost (in real monetary units) of building and operating a generating plant over an assumed financial life and duty cycle.[52] Although CCS has been claimed to be an "expensive" option for power generation, the figure below illustrates that is far cheaper than many other alternatives.

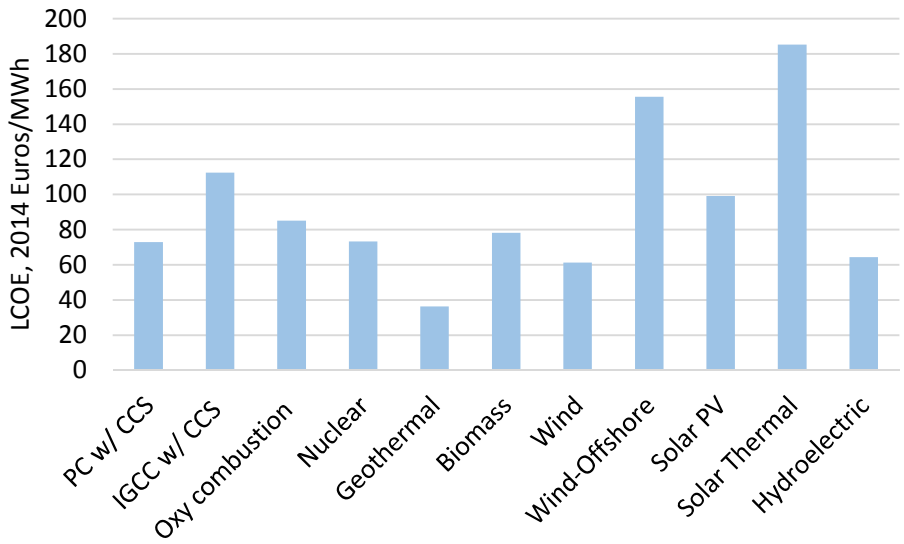


Figure 16. Average LCOE by technology[44,53]

Notes

1. *The data above are **NOT** Network data. The figure serves solely as an illustration indicating LCOE of technologies of similar CO_2 capture concept to those that the Network projects use or intend to use.*
2. *It should also be noted that LCOE is regionally and geographically sensitive. LCOE values can also vary across time as technologies evolve and fuel prices change.*

[52] Levelised Cost and Levelised Avoided Cost of New Generation Resources in the Annual Energy Outlook 2014. Available at: http://www.eia.gov/forecasts/aeo/pdf/electricity_generation.pdf

[53] DOE/NETL-2007/1291

Costs

Costs associated with CCS have been a topic of significant interest over the years. The high up-front investment and operating costs along with minimal incentives for storing CO_2 are the primary reason for CCS not yet been widely deployed. The Network projects can share cost information for mutual benefit and provide (by anonymous aggregate) a fact-based input to policy makers for well informed decision making.

A full chain capture plant, transport infrastructure and storage site construction requires large capital expenditure (CAPEX). The estimated operational cost is also significant and is further impacted because of the various uncertainties associated with first-of-a-kind projects. The cost of a CCS plant depends on many factors including, but not limited to, the targeted CO_2 capture rate, the technologies incorporated, the fuel type and composition, the plant size and efficiency, the plant location etc.

The IPCC reported that for most large sources the cost of capturing CO_2 is the largest component of overall CCS costs. Figure 17 represents the average share in cost of each element within the CCS chain for early commercial projects. The Network projects data concurs with this for both the CAPEX and OPEX, however the cost of capture can vary greatly depending on the technology used.

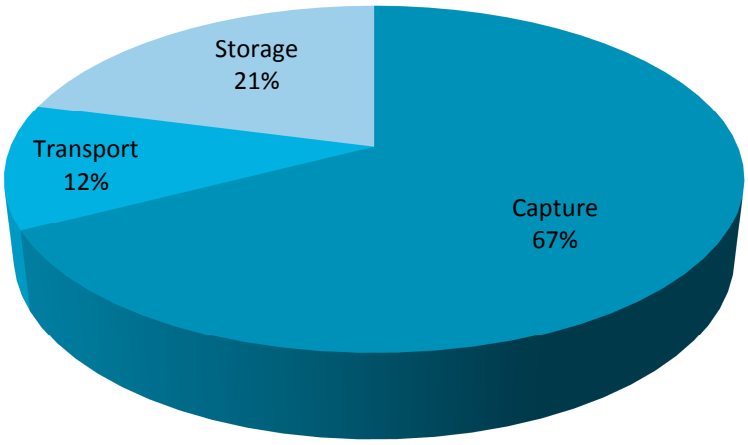


Figure 17. Average cost break of CCS for early commercial projects[54]

[54] As estimated by data from "**Carbon capture & storage: Assessing the economics**". McKinsey & Company, Sep 2008

Historical Network data have suggested, in line with expectation, that the largest spread between maximum and minimum for both CAPEX and OPEX costs is for storage of the CO_2. This is largely a reflection of the different storage solutions being investigated or operated by the projects, ranging from on-shore storage, and the reuse of existing injection wells, to more capital intensive extensive offshore operations requiring multiple new wells for monitoring and injecting.

Knowledge Sharing

Outreach and Global Knowledge Sharing

The deployment of carbon capture and storage (CCS) as a climate change mitigation technology is strongly dependent on the levels of knowledge sharing occurring on a global basis. During the 4th EU-US Energy Council held in Brussels, in December 2012, both sides highlighted the importance of knowledge sharing. This approach was adopted by the 2014 EU-US Summit as well, as both sides agreed "to strengthen knowledge-sharing on carbon capture and storage, and on the sustainable development of unconventional energy resources".

Knowledge sharing between the Network projects has proven to be of significant importance not only regionally but also adding valuable knowledge and experiences to the global CCS industry. All publically available outputs are accessible through the Network's website www.ccsnetwork.eu.

The European CCS Demonstration Project Network has built up a considerable track record in peer-based project knowledge sharing. During 2013/14 the Network has engaged in a number of events including the Global CCS Institute EMEA Members meeting. Network members also participated in the Platts conference and attendance in GHGT-12 conference is planned in Texas, US, later this year.

Both the Global CCS Institute and Network have been very active in knowledge sharing for a number of years. The initiatives in response to the calls for a 'global project knowledge sharing network' have been established and further actions are in place to broaden the existing project knowledge sharing activities that have taken place at a regional level.

The Network has also invited a number of external speakers to the knowledge sharing events. ECCSEL[55] (Centres of Excellence on Carbon Capture and Storage research) gave a brief overview of the new pan-European initiative during the Network's 4th Advisory Forum meeting (October 2013). Bellona and ZERO, two Norwegian CCS supportive NGOs, participated at the plenary session of the Network knowledge sharing meeting in Stavanger (October 2013). The two gave talks on the steps required to get the North Sea CO_2 storage back on track and on the ways to improve the EU CCS policy and legal framework, respectively. Also in Stavanger, the DNV representative presented at the Storage group workshop, work on validation, verification and certification of CO_2 geological storage, tested on a number of international projects such as Quest and CarbonNet.

[55] A research consortium made from 10 countries across Europe

Proposed topics for further investigation by the research and development community

Introduction

The European CCS Demonstration Project Network can contribute to the research and development (R&D) community's efforts with 'real life' experiences and provide a perspective on the major issues identified by the projects within the Network.

It collates the identified topics that the projects feel that further work is required, captured in the 2013/14 knowledge sharing events and surveys of the projects.

More details regarding the activities of the projects, particularly with regards to their own research, can be found in the thematic reports produced every six months by the Network. These can be found on the website www.ccsnetwork.eu.

Suggested topic areas

General comments

- The primary technological issue the projects are facing is the integration of the different technologies within the various steps of the value chain. While individual technologies to be used (though often involving scale-up) are not reliant on the outcome of research, further investigation into the flexible operation of all components would be of use

- Utilisation of biomass with CCS is the only technology to create negative emissions. The need to review the incentives for biomass firing with CCS is explicitly referred to under the CCS Directive. This was also addressed in the latest IPCC report, highlighting however, that there are issues to consider, such as the sustainability of practices and the efficiency of such systems.[56] Co-firing biomass with CCS can potentially be an attractive option. ROAD project reported that it can offer 44% more power with the same emission reduction as with plain bio-CCS. Co-firing therefore appears to be the cheapest and most carbon-negative way of converting biomass to electricity. Investigations into the net negative emissions balances, sustainability and methods for inclusion under the ETS all require further attention

- Pre-normative research is needed in order to improve the understanding of unresolved transport phenomena and behaviour – especially when it comes to phase-change phenomena and residual components (impurities)

[56] IPCC, 2014: Summary for Policymakers, In: Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Capture

The capture element of CCS projects has been extensively investigated. However:

- Cycle optimisation and energy efficiency improvements are required to reduce the capture cost. This applies to all elements of the systems being investigated by the projects (liquid solvents, solid sorbents, membranes, Water Gas Shift (WGS) catalysts, compressors etc.)
- Materials selection and equipment size is another area that would merit further clear investigation and elaboration
- Process optimisation is a subject that would benefit from further attention, particularly when potentially coupled with the need for operational flexibility. (For example WGS integration, Air Separation Unit (ASU) optimisation, reduced steam requirements)

Transport

The pipeline transport of CO_2 is an area primarily facing mainly regulatory issues. On a technical side, some of the areas to look at are: Flow assurance, metering (including calibration), sub-sea completion, pigging operations, dynamic impacts, corrosion and crack arrest.

Storage

Storage continues to be one of the areas that would benefit from research and development work.

- A number of areas could be investigated, but one are that would benefit from elaboration continues to be the adaptation, application and reliability of CO_2 monitoring systems

Conclusions

Conclusions

The European CCS Demonstration Project Network, since its foundation, has had a unique portfolio of projects, covering the principal capture technologies in the power sector, a range of transport options, and a variety of on and off shore storage sites. It has shown a strong commitment to knowledge sharing, discussing a wide range of topics that are crucial for the wide deployment of this low-carbon technology.

During 2013 and 2014 a large number of expert knowledge sharing workshops were held. These workshops included discussions covering technical aspects, public engagement activities, as well as regulatory and permitting developments.

Collectively the Network has stored 1 million tonnes of carbon dioxide during 2013. The projects within the Network working towards operational status continue to be developed, despite adverse delays due to permits and the unfavourable conditions for making final investment decisions.

In 2013 the Network was comprised of one oxy-fuel power project (former Compostilla), an IGCC power project (Don Valley), two post-combustion power projects (Porto Tolle and ROAD) and a gas processing project (Sleipner). All of the Network projects have profound understanding of the technologies they have chosen and have been able to provide some very detailed data for the systems. Each and every project will capture over 1 million tonnes of CO_2 per annum, at a capture rate of over 90%. While projects are anticipating a CO_2 product of high purity, SOx and NOx are reported to be the most common expected impurities in the slip stream gas.

The currently active Network projects (Don Valley, ROAD and Sleipner) use, or intend to use offshore pipelines. For storage, a range of sites are being used or have been investigated, ranging from onshore saline formations, to offshore depleted gas reservoirs.

Public engagement is one of the key management activities for the projects, with the proponents concluding that direct engagement is the most effective form of interaction and that consistent messaging is very important.

In terms of permitting and regulatory development, Don Valley remains in discussions with DECC to identify a route to access an individual Contract for Difference to help close the funding gap for the further development of this project.

ROAD achieved a considerable milestone when its storage permit was successfully reviewed by the European Commission. In September 2013 the final storage permit became irrevocable.

Two of the Network's projects, Compostilla and Porto Tolle will not be proceeding to large scale demonstration. Both were well developed and very credible projects and wishing to continue pilot activities.

The overall deployment of projects has been largely delayed for two reasons. There is currently too much policy uncertainty within Europe as a whole. CCS has large capital costs and development times with investors requiring long-term certainty that they can invest in CCS. Regional and national climate and energy policies must provide long-term clarity on the way forward. Short, medium and long term incentive mechanisms should be introduced that are consistent with policy positions. While the UK and Norway have taken active and practical steps in this direction, other countries need to follow such examples.

Current deployment and incentive mechanisms for CCS are insufficient. Short-term measures need to be introduced that enable first mover projects to enter operation, supported by appropriate market mechanisms that drive large scale deployment. Unlike other forms of low-carbon technologies, there has been a lack of similar or appropriate incentives and support for CCS. This is a major issue to be addressed given the recognised necessity of CCS as part of an energy mix capable of maintaining energy security and achieving environmental targets.

Appendix 1 - Glossary

Ar	Argon
BAT	Best Available Technique
CCGT	Combined Cycle Gas Turbine
CCS	Carbon capture and storage
CCS Directive	European Directive 2009/31/EC on the geological storage of carbon dioxide
CCSR	CCS ready
CCUS	Carbon capture use and storage
CDM	Clean Development Mechanism
CEM	Clean Energy Ministerial
CER	Certified Emission Reduction unit
CfD	Contract for differences
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
DCO	Development Consent Order
DECC	Department of Energy and Climate (UK)
EC	European Commission
EEPR	European Energy Programme for Recovery
EOR	Enhanced oil recovery
EPC	Engineering, procurement and construction
EPS	Emission Performance Standards
ETS	European Directive 2009/29/EC on the greenhouse gas emission allowance trading scheme of the Community
EU	European Union
EUA	European Union Allowances - 1 EUA represents the right to emit 1 tonne of CO_2
FEED	Front end engineering design
FID	Final investment decision
FIT	Feed-in tariff
FS	Financial Security
GHG	Greenhouse gas
Gt	Gigatonne
H_2S	Hydrogen sulphide
IEA	International Energy Agency
IGCC	Integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
km	Kilometre
kW	Kilowatt
LCOE	Levelised cost of electricity
NH_3	Ammonia
MEA	Monoethanolamine

MMV	Monitoring, measurement and verification
MVA	Monitoring, verification and accounting
Mtpa	Million tonnes per annum; million tonnes a year
MW	Megawatt
MWe	Megawatts electrical capacity
MWth	Megawatt thermal
N_2	Nitrogen
NER300	New Entrants' Reserve 300
NGCC	Natural gas combined cycle
NGO	Non-government organisation
NOx	Nitrogen oxides
O_2	Oxygen
PC	Pulverised Coal
ppm	Parts per million
R&D	Research and Development
SO_2	Sulphur dioxide
SOx	Sulphur oxides
TWh	Terawatt hours

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The European CCS Demonstration Project Network was established in 2009 by the European Commission to accelerate the deployment of safe, large-scale and commercially viable CCS projects. To achieve this goal, this community of leading demonstration projects is committed to sharing knowledge and experiences. The successful deployment of this key technology will allow Europe to reach its environmental objectives, stimulate job creation, and generate a sustainable economic and industrial base.

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