European Carbon Capture and Storage Demonstration Project Network

Situation Report 2012

A public report outlining the progress, lessons learnt and details of the European CCS Demonstration Project Network

Cover Image: The Sleipner A Platform, as seen from the Sleipner T carbon dioxide treatment platform.

Preface

The *European Carbon Capture and Storage Demonstration Project Network - Situation Report 2012* is a new publication from a community of large scale projects dedicated to knowledge sharing (the Network). This report is intended for those interested in some of the specific technical, regulatory and project management considerations of carbon capture and storage (CCS) as a large-scale, low-carbon technology for the electricity generation and industrial sectors (steel, iron, chemical, methanol, gas process, cement, etc.).

This report provides both a brief outline of the major elements within the development and running of a CCS project, and specific details generated by the Network. While a number of thematically specific reports are regularly made public by the Network, this report attempts to provide an overall outline of the technical details, lessons learnt, challenges and progress facing the carbon capture and storage (CCS) projects within the Network.

The *Situation Report 2012* covers developments during 2012. Primarily drawing on the data provided by the projects within a six monthly survey, information is also taken from the eight knowledge sharing workshops held by or with the Network, and specific reports generated by this body of large-scale projects.

The European Commission's leading role in both establishing this knowledge sharing Network, and aiding the development of CCS is gratefully recognised. The Network's project proponents' willingness to share their experiences with the wider community – with the sole aim of accelerating the deployment of this key low-carbon technology that will be so vital in combating climate change – is acknowledged with gratitude.

The Network's Secretariat, funded by the European Commission, comprises the Global CCS Institute, IFPEN, TNO and SINTEF.

Contents

Acknowledgements 7

Executive Summary 9

Introduction 12

- The role of CCS 13
- The European CCS Demonstration Project Network 15
- How the Network has evolved in 2012 16

European demonstration Network member's overview 20

- Bełchatów 20
- Compostilla 20
- Don Valley 21
- Jänschwalde 23
- Porto Tolle 23
- ROAD 24
- Sleipner 24
- Project Quick Reference 26
- Timelines and project management 27

Capture 31

- Summary 31
  - Base plant information and Fuel (if applicable) 32
  - Capture technology progress in the Network. 33
- Summary per project 33
- Costs 34
  - Energy demand for capture, plant efficiency changes, and capture rate 34
  - Solvent requirement and degradation 35
  - Airborne emissions 35

Transport 38

- Summary 38
- Network summary 39
  - Transport distances and methods and flow rates 39
  - Compression and inlet conditions 39
  - Impurities, their impact, managing them, and Network concentrations 41
  - Operational impacts to pipeline design and flow rates 44

Storage 47

- Summary 47
- Project activity highlights 48

Storage Site Characterisation Overview 50
Applied Geosciences 51
Exploration wells and engineering 52
Impurities, and the impact on storage 56
Monitoring 57
Key learnings 59
Communication and Engagement 63
Context 63
Network summary 63
Network approach and lessons learnt 64
Stakeholders 65
Communications 65
Messengers 66
Project organisation 67
Recent developments 67
Policy and Regulatory Update 70
Project regulatory updates 71
Case Study of a storage permit 72
The business case for CCS 79
Summary of costs and risks 79
Funding and incentives 82
Investments globally 82
CCS in context. A comparison with other low-carbon options 83
Funding for CCS in Europe 84
Incentives 85
Making the business case 86
Outreach and Global Knowledge Sharing 89
Proposed topics for further investigation by the research and development community 89
Introduction 89
Suggested topical areas 90
Conclusions 94
Appendix 1 – Raw data from the Network 96
Appendix 2 - Glossary 96
Appendix 3 - Bibliography 99

Figure List

Figure 1 IEA: Global energy-related CO_2 emissions abatement in the 450 Scenario (required to limit global warming to 2 degrees) relative to the New Policies Scenario (which assumes announced climate policies are introduced).[1] 13

Figure 2 Share of CCS (%) in power generation towards 2050 in the Energy Roadmap, European Commission's 2050 Energy Roadmap. 14

Figure 3 Map of the European CCS Demonstration Project Network 16

Figure 4 National Grid – "The Humber Cluster". Map showing potential CCS infrastructure. 22

Figure 5 – The planned average time line (in months) between taking an FID and commencing operation for the Network's projects. 28

Figure 6 - Carbon content of the fuel used per project 32

Figure 7 Number of projects using each capture technology compared to the global number of projects in operation or development. 33

Figure 8 - Net efficiency at full load (lower heating value) in %. Figures are shown without and with CCS. (All available data displayed). 34

Figure 9 Solvent requirement and CO_2 captured per year for ROAD, Porto Tolle and Bełchatów. (Note that the solvents operate at different temperatures and CO_2 exposure levels.) 35

Figure 10 Pipeline lengths of the projects compared with the global average pipeline length per CCS project. Red indicates onshore pipelines. Blue indicates offshore pipelines. 39

Figure 11 The compression work (kWh/tCO_2), the average maximum pipeline inlet pressure (bara) and the average maximum pipeline inlet temperature (^oC) for the projects. 40

Figure 12 CO_2 phase diagram (DNV, CO2RISKMAN, 2013). The green box shows the Network projects' range of maximum inlet pressures and temperatures. 41

Figure 13 Sleipner CO_2 Time-lapse Seismic Data. 51

Figure 14 Compostilla's appraisal well. 53

Figure 15 Range and average bottom hole injection pressure in bara. 54

Figure 16 Maximum and average injection rate at each project. (All available data displayed). 54

Figure 17 Reservoir pressure (estimated and actual) over the reservoir in bara. 55

Figure 18 The modelled capacity of the storage complex over the project lifetime in MtCO_2. * chosen Don Valley Saline storage solution, and indicates the dynamic capacity. Other projects have not specified if the capacity is dynamic or static. 56

Figure 19 Don Valley's results from experiment regarding hydrate formation temperatures and pressures in CO_2-CH_4 mixtures saturated with H_20. 57

Figure 20 Porto Tolle's deep laboratory station. 58

Figure 21 Porto Tolle's online tour - www.portotolleproject.com/visita_centrali/visita_centrale_portotolle 66

Figure 22 Members of staff involved in public engagement. *numbers of casual staff are approximate. # All staff work for the operator's wider communications team and dedicate a percentage of their time to CCS, number of staff is approximate. (All available data displayed). 67

Figure 23 Don Valley's capital cost details. 79

Figure 24 Don Valley's operating costs by share. 80

Figure 25 - The expected percentage of energy requirement for the ROAD project. 81

Figure 26 - Total investment in 2011 in clean technologies, Bloomberg New Energy Finance, compared to anticipated contribution to the IEA's WEO 2012's 450 scenario (derived data). 82

Figure 27 The projected electricity production from 1710MW installed capacity for each technology per year. 83

Table List

Table 1 CCS project quick reference table. * Project in operation. (All available data displayed). 26

Table 2 Components in the CO_2 stream prior to entering the transport pipeline 43

Table 3 Project Storage status table (October 2012). 48

Table 4 Indicates only discussed (simplified) techniques per project during the conference. (The table does not reflect all of the tools that a project is currently using /will be using). 59

Table 5 The expected energy requirement for each technology in the chain. In the case where the figure has not been calculated, the box has been left blank. (All available data displayed). 80

Acknowledgements

The Secretariat acknowledges the many contributors who were instrumental in authoring, reviewing and designing this report. Daniel Rennie, Sarah Macintosh, and Angeline Kneppers were the primary authors of this report.

This report was guided by the Network's Steering Committee, which also provided important reviews and comments that helped to improve this publication, and thanks goes to Mike Gibbons, Hans Schoenmakers, Martin Sanz Madrid, Cristiana La Marca, Andrew James Cavanagh, Philip Ringrose and Vladimir Zuberec.

Through various means, all project participants of Network have contributed either directly or indirectly to this report. However, particularly thanks goes to Kirsty Anderson, Ilinca Balan, Julian Barnett, Andrew Cavanagh, Rohan Desilva, Anna Dubowik, Manuel Alonso Fernandez, Meade Harris, Jens Hetland, Jonny Hosford, Tom Jonker, Marc Kombrink, Sonsoles Fernandez Ludeña, Cristiana La Marca, Filip Neele, Ricardo Fernandez Nieto, Adas Pangoins, Hervé Quinquis, and Adam Richards.

Executive Summary

Founded in 2009, the *European Carbon capture and storage (CCS) Demonstration Project Network* (Network) is a unique community of leading large-scale CCS projects dedicated to sharing knowledge and aiding the development of this clean, low-carbon technology.

Fundamentally, CCS can significantly reduce the emission of the carbon dioxide (CO_2) into the atmosphere – the main greenhouse gas responsible for global warming – and is one of a number of crucial technologies for combating climate change. It captures emissions from the power sector (either using gas, coal or biomass as a fuel), and is the only way of substantially reducing the emissions in the industrial sector (steel, iron, cement, chemical, fertilisers, ethanol, gas processing, paper, etc.). The successful deployment of this green 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 – allowing job retention and creation in multiple industrial areas within Europe. 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.[1]

During 2012 the Network comprised the six leading European large scale CCS projects, either operating or in development, which all aim to demonstrate the commercial deployment of the technology, address any issues that arise, and pave the way for the wide-spread use globally of this clean way of generating electricity and industrial production. In 2012 the Network's projects were: Bełchatów (Poland)[2], Compostilla (Spain), Don Valley (UK), Porto Tolle (Italy), ROAD (The Netherlands), and Sleipner (Norway).

This is the first edition of a new annual publication on the progress, challenges and lessons learnt from the Network. The report is essentially based on the data from six-monthly project surveys and is complemented by information from the multiple Network webinars, workshops and knowledge dissemination events held during 2012. These workshops were an important aspect of peer-based learning and were often held with other large scale projects, both within Europe and internationally, and with a number of research projects. A wide range of topics were covered, including discussions regarding CO_2 monitoring techniques, public engagement activities, regulatory and permitting developments, and storage characterisation.

The report is structured to provide a general overview of the need for CCS, the European context, the Network, and individual project summaries. The second section is more thematically based, detailing the progress and lessons learnt by these six projects in the areas of capture, transport and storage, as well as in the enabling instruments for CCS deployment such as regulatory development and public engagement. In each of these thematic sections a general set of information is provided to set the context in which these pioneering projects are developing, before relating specific data

[1] IEA, *Technology Roadmap: Carbon Capture and Storage*, 2013
[2] Project was cancelled in early 2013

and learnings from the Network projects. Finally the report shares details on the framework for operating, and making a business case, within Europe.

The report highlights that the projects are making progress towards deployment, but not as quickly as originally anticipated. While some are facing delays in obtaining permits, most of the projects under development face major challenges in attempting to reach a final investment decision (allowing the projects to be constructed and become operational) due to the lack of appropriate funding and incentives that will allow this key low-carbon technology to be demonstrated at scale in Europe. While there are no technical obstacles or risks associated with deployment, CCS has not been previously deployed at scale in the power sector. Projects in the US, Canada, Australia and China are being actively developed – and while initially holding the lead in project and technological development, European projects are slowing in their progression. Not actively developing CCS will be a risk for Europe and its long-term competitiveness in a carbon-constrained future.[3]

The Network itself has gone through a number of changes during 2012. An operational project has joined the Network (Sleipner) which turned out to have a wealth of information for the other projects, helping accelerate their deployment. Regrettably one project left the Network because it has been put on hold (Jänschwalde) – followed by the cancellation of a second project (Bełchatów) in early 2013. There was also a change in Secretariat of the Network, which now comprises of The Global CCS Institute, IFPEN, TNO and SINTEF.

The Network is composed of two post-combustion power projects (ROAD, Porto Tolle), a gas processing project (Sleipner), one oxy-fuel power project (Compostilla), and one integrated gasification combined cycle (IGCC) power project (Don Valley). Sleipner is the only project currently in operation. All will capture over 1 million tonnes of CO_2 per annum each, at a capture rate of over 90%. The capture component incurs the largest capital and operational costs. SOx and NOx (impurities of sulphur and nitrogen) are quoted by the projects as the most common expected impurities in the slip stream gas.

All of the Network's projects will use pipelines to transport the CO_2 they capture. Four projects (Don Valley, Porto Tolle, 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 between 30 and 80 ^{o}C.

For storage, a range of storage sites are being used or have been investigated, ranging from onshore saline formations, to offshore depleted gas reservoirs and the use of CO_2 EOR operations. Operational and projected bottom-hole pressures for Compostilla, Don Valley and Sleipner range from 80 to 248 bara, and injection rates vary between 30-70 kg/second.

The Projects consider that public engagement is one of the key management enabling activities to support the deployment of capture, transport and storage infrastructure. As a general conclusion the proponents believed that direct engagement is the most effective form of interaction, and that consistent messaging is very important.

In terms of permitting and regulatory development, the ROAD project's storage permit has been successfully reviewed by the European Commission, which has given its first opinion of a permit

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

submitted under the CCS Directive (a second opinion will be given prior to injection) in February 2012. The Don Valley project has obtained its storage appraisal licence for the target saline storage site in the southern North Sea. This is the first such licence awarded in the UK and pursuant to this intrusive appraisal drilling has been successfully undertaken in summer 2013. The Bełchatów and Compostilla project still require further finalisation and implementation of the transports and storage regulatory regimes by their respective authorities. The Porto Tolle project needs to re-submit the Environmental Impact Assessment for their base plant.

The diversity in designs, volumes, locations, etc. contained within the Network provides a wealth of information – though as a result it should be noted that the data and summaries outlined within this report should be treated with caution. Limitations with the current set of data obtained have been discovered, and work is currently underway to improve the Network's future output.

Introduction

In 2009 the European Commission (EC) established the European Carbon Capture and Storage (CCS) Demonstration Project Network in order to support and accelerate the deployment of this crucial low-carbon technology. 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 2012* is the first edition of a new annual publication 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 six monthly 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.

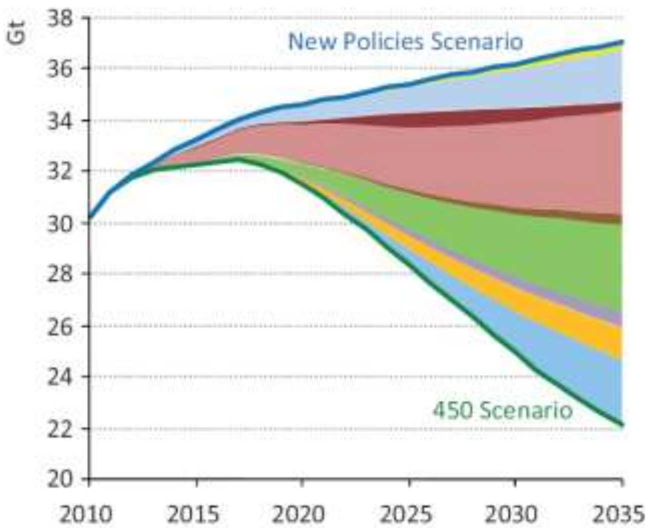
The European CCS Demonstration Project Network holds a unique collection of large scale, early-mover CCS projects, representing a broad portfolio of capture, transport and storage elements. However, progression by many of the projects has been difficult for a number of reasons. The Network is striving to address the most pressing issues and this report contains the main findings. Information is provided about many technical, management and regulatory topics covered during 2012. Please note that there will be more up-to-date information released from the Network during 2013.

Any interpretation, or misinterpretation, of the data contained within the body of this report is the Secretariat's. All of the public raw data that has been provided during 2012 has been aggregated and placed in its raw form within Appendix 1.

The role of CCS

Climate scientists and parties to the United Nations Framework Convention on Climate Change (UNFCCC) have agreed that deep cuts in greenhouse gas 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."[4]

However, the International Energy Agency World Energy Outlook reports suggests that the 2°C target is becoming more difficult and costly with every year that passes.[5] 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 suggests that in order not to exceed a 2°C average global warming 17% of the total abatement of emissions needs to come from CCS in 2035. (This rate of abatement is expected to continue to increase, reaching a cumulative contribution of 14% by 2050.[6])



CO_2 abatement	2020	2035
Activity	2%	2%
End-use efficiency	18%	13%
Power plant efficiency	3%	2%
Electricity savings	50%	27%
Fuel and technology switching in end-uses	2%	3%
Renewables	15%	23%
Biofuels	2%	4%
Nuclear	5%	8%
CCS	4%	17%
Total (Gt CO_2)	**3.1**	**15.0**

Figure 1 IEA: Global energy-related CO_2 emissions abatement in the 450 Scenario (required to limit global warming to 2 degrees) relative to the New Policies Scenario (which assumes announced climate policies are introduced).[1]

In the Energy Roadmap 2050 for the European Union (EU) there have been a number of different scenarios proposed by the Commission to meet the stringent 2050 emissions reductions targets.[7] 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 share of CCS in decarbonisation of the power sector is estimated at 19% to 24% in other three scenarios.

[4] United Nations, *United Nations Framework Convention on Climate Change*, 1992
[5] IEA, *World Energy Outlook 2012*, page 253
[6] IEA, *Technology Roadmap: Carbon Capture and Storage*, 2013
[7] The European Commission: *Energy Roadmap 2050,* 2011

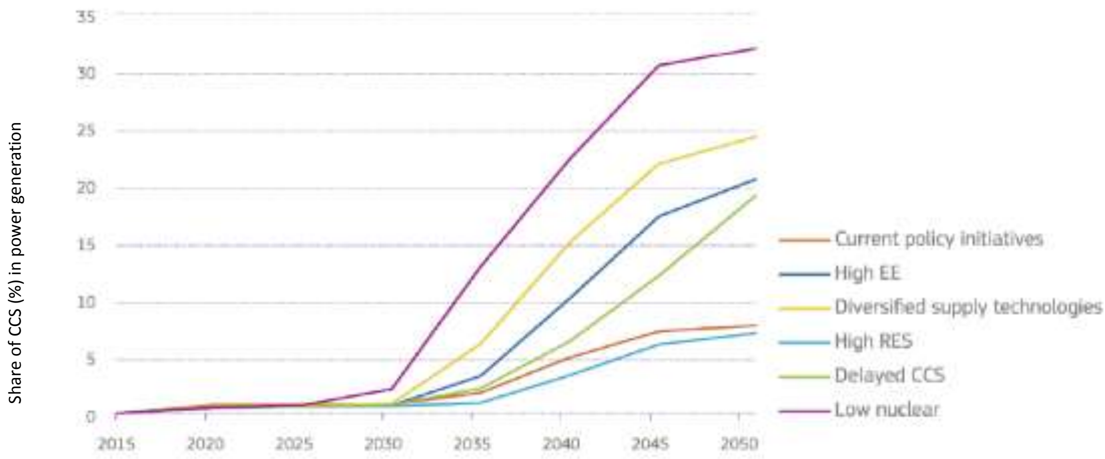


Figure 2 Share of CCS (%) in power generation towards 2050 in the Energy Roadmap, European Commission's 2050 Energy Roadmap. [8]

It is also worth noting that the Energy Roadmap solely focuses on electricity generation. The EU's Roadmap for moving to a competitive low carbon economy in 2050 indicates that CO_2 emissions from the industrial sector need to be reduced by 83% to 87% by 2050 compared to the 1990 levels. It is extremely important to note that CCS is the only technology capable of substantially reducing the emissions from the industrial sector (the iron and steel industry, gas processing, ammonia production, refining, paper and pulp, cement etc.).

It is also noteworthy that CCS, when used in conjunction with biomass, is capable of addressing existing emissions. The use of biomass with CCS is the only technology that can be 'CO_2 negative' and actually extract CO_2 from the atmosphere.[9]

While CCS projects have large up-front costs, the IEA's Technology Roadmap for CCS suggests that the capital investments needed to meet an average 2°C limit rise by at least 40% in the electricity sector if CCS is not implemented.[10] This is supported by analysis from the European Commission which suggests that if investments in low carbon technology are postponed, they will cost more and create greater disruption in the longer term. The recent IEA's World Energy Outlook special report released in 2013 also points to the fact that CCS will act as an asset protection strategy enabling continued commercialisation of fossil fuels even under a 2 °C scenario, whereas a delay in its deployment would increase the cost of decarbonisation of electricity sector by $1 trillion.[11]

It is lastly worth noting that the benefits of deploying CCS will vary by country, with some benefiting particularly from increased energy security, while others from having a more competitive and

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[8] The European Commission, *Roadmap for moving to a competitive low-carbon economy in 2050,* 2012

[9] Bellona, *http://bellona.org/ccs/technology/future-solutions-and-business-opportunities/carbon-negative-removing-co2-from-the-atmosphere.html*, for a good overview. For more detail, ZEP and EBTP, *Biomass with CO_2 Capture and Storage (Bio-CCS) – The way forward for Europe*, 2012, and Stanford University, *Global Climate & Energy Project: Assessment Report from the GCEP Workshop on Energy Supply with Negative Carbon Emissions*, 2012

[10] *IEA, Technology Roadmap: Carbon Capture and Storage*, 2009.

[11] *IEA, World Energy Outlook Special Report 2013: Redrawing the Energy Climate Map*

sustainable industrial base. Individual country roadmaps are being produced, illustrating the role that CCS can play on a more localised basis.[12]

The European CCS Demonstration Project Network

The European Union aims to stimulate the construction and operation of CCS demonstration projects through a number of financial, regulatory and knowledge sharing measures. The successful operation of these first large-scale 'demonstration' projects is seen as being crucial for enabling widespread commercial application of near zero emission power plants and industrial installations by 2020 to meet EU and global climate goals.

The European CCS Demonstration Project Network (hereafter referred to as "the Network"), initiated by the EC in 2009, brings together a number of leading projects that are both under investigation and operation in Europe.

It functions by bringing together experts from each project on a regular basis to discuss specific topics for mutual benefit. Detailed technical data is also shared, in addition to procedures, approaches, experiences and management strategies. Such meetings are often private and peer-based to ensure that a free dialogue is held – with as many of the learnings as possible from each workshop being made public by the Secretariat on a regular basis. External participants are invited to almost every meeting, ranging from other projects proponents, Non-Governmental Organisations (NGOs), technical experts, to researchers and developers. The general outcomes of these workshops and data sharing are contained, or referenced, within this Situation Report.

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

- **Capture** – the projects cover all of the main capture approaches – post-combustion flue gas scrubbing and natural gas processing, pre-combustion (clean 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.

[12] Bellona has produced a number of roadmaps, including for Poland, Romania, Hungary and Greece, and DECC have produced the UK government's roadmap for CCS.

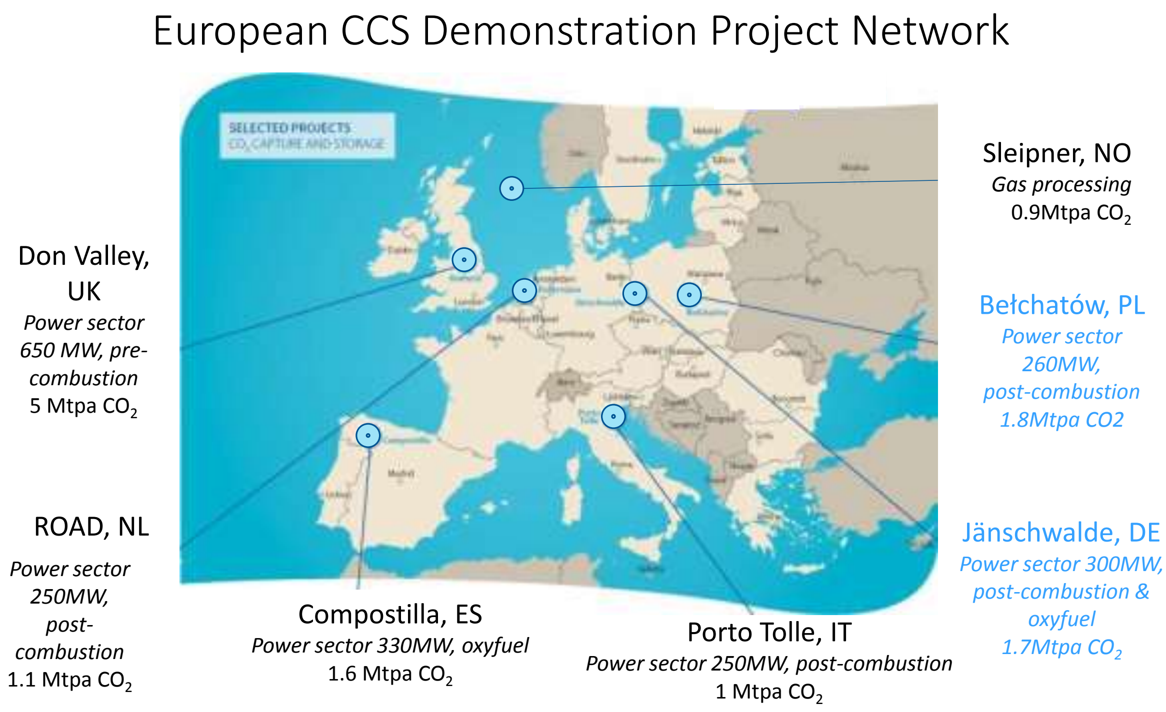

Figure 3 Map of the European CCS Demonstration Project Network

The efforts of these early movers alone will make a substantive impact on CO_2 emissions. The Sleipner project currently captures and stores around 1 million tonnes of CO_2 per annum from its offshore gas processing plant. If all of the other member projects are developed, the Network would have an installed clean electricity generating capacity of 1,740 MWe, producing potentially 12,000 GWh per annum of clean, low-carbon energy – enough to supply 3.6 million homes with electricity. If fully developed, in total the Network would permanently store nearly 11 million tonnes of CO_2 per year – the equivalent of taking 2 million cars off the road.

The Network actively encourages new members to join, primarily based on their scale and commitment to knowledge sharing. All interested stakeholders, smaller projects, and Research and Development (R&D) initiatives are also welcome to participate.

How the Network has evolved in 2012

A new member, the Sleipner project, joined the Network which has been extremely beneficial for the other projects as the Sleipner project has been in operation since 1996. More information about Sleipner can be found in the next section.

Unfortunately, the Network also lost a project during 2012. The Jänschwalde project was one of the founding members of the Network and recipient of European Energy Programme for Recovery (EEPR) funding. However due to the prolonged impasse in the adoption of a suitable German CCS law, Vattenfall, the project proponent, decided to halt plans for its CCS demonstration project in Jänschwalde. Consequently the project left the Network. Prior to their departure the Network members were fortunate to be able to discuss the lessons learnt from this project with the project operator. Certain Front End Engineering Design (FEED) documents from this project have been released and are available on the Network website, including an English overview document of the project produced by the Secretariat.[13] It should also be noted that while under development in 2012, the Bełchatów project was also cancelled in early 2013.

A new Secretariat for the Network took over from DNV on the 21st March 2012. The secretariat now comprises of the Global CCS Institute[14], IFPEN[15] TNO[16] and SINTEF[17].

[13] European CCS Demonstration Network, *Lessons Learnt from the Jänschwalde project: Summary t*, 2012
[14] The Global CCS Institute http://www.globalccsinstitute.com/
[15] IFPEN http://www.ifpenergiesnouvelles.fr/
[16] TNO http://www.tno.nl/
[17] SINTEF http://www.sintef.no/home/

The Network

European demonstration Network member's overview

Bełchatów[18]

Summary

The Bełchatów CCS project was based in Łódź, Poland. (The project was cancelled in early 2013, but all relevant data has been used within this Situation report as the project was fully under development during 2012). The project proponent was Polska Grupa Energetyczna (PGE) in collaboration with their partners, Alstom, Dow Chemical, PGI, Gazoprojekt and Schlumberger. The project was planning for a 260MWe post-combustion capture system to be integrated with the newly-built (2011) 858 MW unit at the 5,053 MW lignite-fired Bełchatów Power Plant. The CO_2 capture efficiency was expected to be >80% utilizing the Advanced Amine Process. The CO_2 captured would have been transported by a 141 kilometre pipeline to an onshore deep saline formation. The project was expected to store 1.8 $MtCO_2$/year.

Progress during 2012

- A comprehensive FEED study for the capture component has been completed.
- Capture Ready status for new-built 858 MWe Power Plant was obtained.
- Building permits were in place for the capture plant, but complications arose due to procurement rules.
- The storage site selection had been completed and a feasibility study for transport had been completed.
- There were outstanding issues relating to the transposition of the CCS Directive.
- The project operators carried out an extensive public engagement campaign.
- The lack of appropriate financing was the key issue for the project (and ultimately led to its cancellation).
- The project was a candidate for NER300, but due to the lack of commitment from the Polish government the project did not receive NER300 funding.
- The project was cancelled in early 2013.

Compostilla

Summary

The Compostilla project is based in El Bierzo, Spain. The Compostilla Project is being developed by a consortium of ENDESA, CIUDEN and Foster Wheeler. The Project is based on a 300 MWe Circulating Fluidised Bed (CFB) supercritical oxy-fuel coal-fired power plant which will be constructed next to the existing coal-fired power plant of Compostilla, property of the utility. The CO_2

[18] Project was cancelled in early 2013

capture efficiency is expected to be 91%. The CO_2 captured will be transported by a 147km pipeline to an onshore deep saline formation. The project is expecting to store 1.6 $MtCO_2$/year.

As indicated above, the Project has been divided into two distinct phases to reduce the economic and technical risks.

- Phase I. Technological Development (2009 - 2012). Pilot scale technology development of the capture, transport and storage elements of the project. This includes a new 30 MWth pilot Plant, which in October 2012 demonstrated the world's first carbon dioxide capture from a CFB oxy-fuel power plant. A pilot storage operation will take place at Hontomín in late 2013.
- Phase II. Demonstration (2013 - 2016). Following a financial investment decision, the full-scale project will enter construction for completion by 2016.

Progress during 2012

- The project is still waiting for regulation on plant operation and transport to be put into place.
- Commissioning of the CFB boiler for oxy operation has now been completed and integration of units and testing is on-going, with positive preliminary results.
- Pipe design and trace has been concluded.
- The preliminary characterization of subsurface structures is well advanced.
- Final Investment Decision (FID) is expected in October 2013, and the project should be operational by 2016.

Don Valley

Summary

The Don Valley project is based in Yorkshire, UK. 2Co Power (Yorkshire) Limited is responsible for the power generation and capture plant and National Grid is responsible for the onshore and offshore transport system and saline storage site. The project will use pre-combustion capture technology which will capture at least 90% of the CO_2 from the full plant at a new-build integrated gasification combined cycle (IGCC) power plant close to the site of Hatfield Colliery. During the course of project development, the partners have evaluated alternative storage options including permanent storage in conjunction with EOR. Following a milestone decision in December 2012 the partners have decided to proceed solely with the southern North Sea saline storage solution being developed by National Grid, in respect of which the UK Department of Energy and Climate Change (DECC) has awarded its first ever CO_2 storage licence. The total pipeline distance from the Don Valley Power Project site to the storage site known as 5/42 is approximately 175km. The store is believed to be large enough to support multiple capture plants within the Humber cluster including Don Valley, White Rose at Drax and others. Furthermore the design concept is for an offshore hub enabling future interconnection (e.g. to accommodate incoming CO from elsewhere in Europe or for future offtake to EOR). The project is expecting to store 5$MtCO_2$/year.

Progress during 2012

- The offshore EOR/storage feasibility study has been completed.
- Milestone decision in favour of saline storage site known as 5/42 with drilling appraisal scheduled for summer 2013.
- Award of storage licence by DECC and signature of Agreement For Lease with The Crown Estate
- Based upon feedback from National Grid's second public consultation, the location for above ground transport infrastructure (pumping station, block valve installations etc.) has been announced.
- The project applied for NER300 funding and bid for the UK government's CCS commercialisation programme. It was ranked in first place of the round 1 of the NER300 funding programme, but unfortunately did not make the shortlist for the UK DECC funding. As they did not receive backing from the UK government they were not eligible for the NER300 funding.

Figure 4 National Grid – "The Humber Cluster". Map showing potential CCS infrastructure.

Jänschwalde

Summary

The Jänschwalde project, based in Brandenburg, Germany, was halted in 2012. The project proponent was Vattenfall. The project planned to add a 50MWe (gross) post combustion capture unit to an existing 500 MW lignite block of the power station and build a new 250MWe (gross) oxy-fuel capture unit. The CO_2 captured would have been transported via a 52km pipeline to an onshore saline formation or gas field. The project was planning to store 1.7MtCO_2/year.

Progress during 2012

- Due to the prolonged impasse in the approval of a relevant German CCS law and permitting regime Vattenfall decided to halt plans for its project plans for the time being.
- Unfortunately the project has now left the Network.
- Lessons learnt from this project were shared with the other Network members at the Network knowledge sharing event on the 24-25th of May 2012.
- Vattenfall has produced a number of Engineering Design documents for the project which are available on the Network's website.[19]

Porto Tolle

Summary

The Porto Tolle project is based in Veneto, Italy. The project proponent is Enel. The project will retrofit the previous oil-fired power plant with coal-fired units. A slip stream of a new 660MW unit will be equipped with a post-combustion CO_2 capture system with a capacity of 250MWe (capture efficiency >90%). The CO_2 captured will be transported via ~100km pipeline to an offshore saline formation. It is expected that the project will capture 1Mt CO_2/year. Enel is currently running a small-scale pilot project at the Brindisi power station in order to test CO_2 capture before it is applied to the full-scale demonstration project.

Progress during 2012

- The Pilot in Brindisi has run for over 5,000 hours (resulting in promising results in the energy consumption and environmental results).
- Transposition of the CCS Directive has been accomplished.

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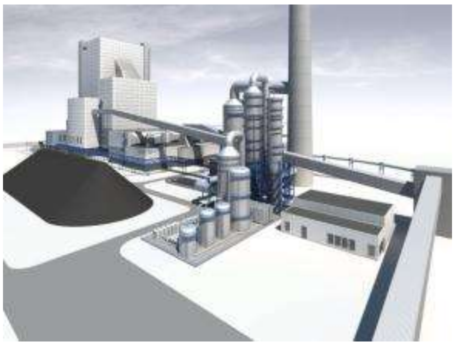
[19] Jänschwalde and Network secretariat *http://www.ccsnetwork.eu/blog/vattenfall-release-their-front-end-engineering-and-design-feed-studies-for-the-janschwalde-project/#more-136*

- The Front End Engineering Design (FEED) for the capture has been completed, as well as the basic design of the transport and injection systems.
- The project has been severely delayed because the Italian courts initially refused granting Enel an operating license. Enel is currently re-applying for an Environmental Impact Assessment for the base plant, which is expected to be completed by 2015.

ROAD

Summary



The ROAD project is based in the Port of Rotterdam, Netherlands. The project proponent is E.On Benelux in partnership with GDF Suez. The project will apply post combustion capture to a 250 MW slipstream from new 1GW 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 will capture 1.1MtCO_2/year.

Progress during 2012

- Design of the capture unit has been completed.
- The storage permits have been awarded.
- The final investment decision was due to be made in 2012, but has now been delayed to 2013 due to financial constraints.

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 Exxon Mobile and Total. It is a gas processing project, the only non-power project in the Network. The natural gas is stripped via a conventional amine capture of its high (~9%) CO_2 content, and then the CO_2 is injected into a deep saline formation via a 1km pipeline. The project commenced in 1996 and as of January 2013 has captured and stored 14Mt of CO_2.

The storage site is monitored in accordance with OSPAR and the London Protocol amendments for CO_2 storage, the baseline seismic survey having been acquired in 1994. The storage site operates under sovereign regulation (Norwegian Act relating to Petroleum Activities), and the monitoring data is placed in the public domain.

Progress during 2012

- The project joined the Network in 2012.
- Work continues to extend operations to include gas production from the Gudrun field, capturing and storing an additional 0.1 – 0.2 Mt of CO_2 per year.
- The eighth repeat seismic survey since the 1994 baseline, planned for December 2012, was acquired in early 2013 due to a weather delay.
- This brings the total number of geophysical surveys to sixteen (9 seismic, 3 gravimetric, 1 electromagnetic and 3 seafloor mapping surveys). A gravity survey is planned for 2013.

Project Quick Reference

	Bełchatów (Cancelled in 2013)	**Compostilla**	**Don Valley**	Jänschwalde (Cancelled in 2012)	**Porto Tolle**	**ROAD**	**Sleipner ***
Production plant type	Power plant	Power plant	Power plant	Power plant	Power plant	Power plant	Natural gas processing
Installed production capacity	260 MWe	300 MWe	650 MWe	300 MWe	250 MWe	260 MWe	N/A
Fuel Type (for power production)	Lignite	Coal	Coal	Lignite	Coal / biomass	Coal / biomass	N/A
Clean electricity production (CCS component), annualised - MWh/year		1,416,600	6,900,000	1,285,900		1,293,000	N/A
Net efficiency (lower heating value) of the power plant without CCS at full load	41.76%	41.10%		36%	44.00%	46.30%	N/A
Net efficiency (lower heating value) of the power plant with CCS (full load value) ***Based on various degrees of slip streams (i.e. numbers are not commensurate)***	39.70%	35.4%		36%	38.20%	43.90%	N/A
Capture Type	Post combustion, amine	Oxy-fuel	IGCC	Oxy-fuel and post combustion	Post combustion	Post combustion	Amine
% Increase in Fuel Consumption		8.50%		0% (compared to existing unit - 7-8% compared to new unit)		5.30%	N/A
Transport	140km pipe	147km pipe	175km pipe	52km pipe	100km pipe	26km pipe	1km pipe
Storage	Onshore saline formation	Onshore saline formation	Offshore saline formation	Onshore saline formation/ gas field	Offshore saline formation	Offshore gas field	Offshore saline formation
Planned CO_2 stored Mt/year	1.8	1.6	5	1.7	1	1.1	0.9 (14 to date)*

Table 1 CCS project quick reference table. * Project in operation. (All available data displayed).

Timelines and project management

Although CCS has been demonstrated for decades, in various forms and for a variety of sectors, there are only a few examples of where it has been applied at commercial scale or fully integrated. As a result, first mover projects face significant risks and costs.

For the capture element, this requires careful engineering as there are large capital costs when either designing a carbon capture plant or retrofitting a capture unit to an existing plant. As indicated in table 1, 2, figure 4, and the following chapters, there are also potentially significant operational costs. 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 new added capture processes do not adversely, or unexpectedly, impact a plant's production activities.

The transport and storage aspects of a project, while less operationally costly, have large up-front development costs and timelines. It is extremely important for all projects to ensure that safe and appropriate storage solutions are chosen, resulting in many years of work – screening, characterising, monitoring and testing sites, and working very closely with a country's regulators and competent authorities to obtain the permits required to explore and then operate such infrastructure. The Network projects have shown that the time required to develop a storage site can be up to 10 years (6 to 8 years prior to Final Investment Decision (FID) and approx. 2 ½ to 3 years after FID).

Two of the Network's early mover projects (Don Valley and ROAD) are 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 few incentives for doing so (other than excellent economies of scale), and face increased risk and upfront investment costs.

The timeline below provides a view on the average time the projects are collectively planning to need between taking their FID and commencing operation (approximately 3 years). It also provides an indication of the average number of months each milestone will take during the construction phase for these projects.

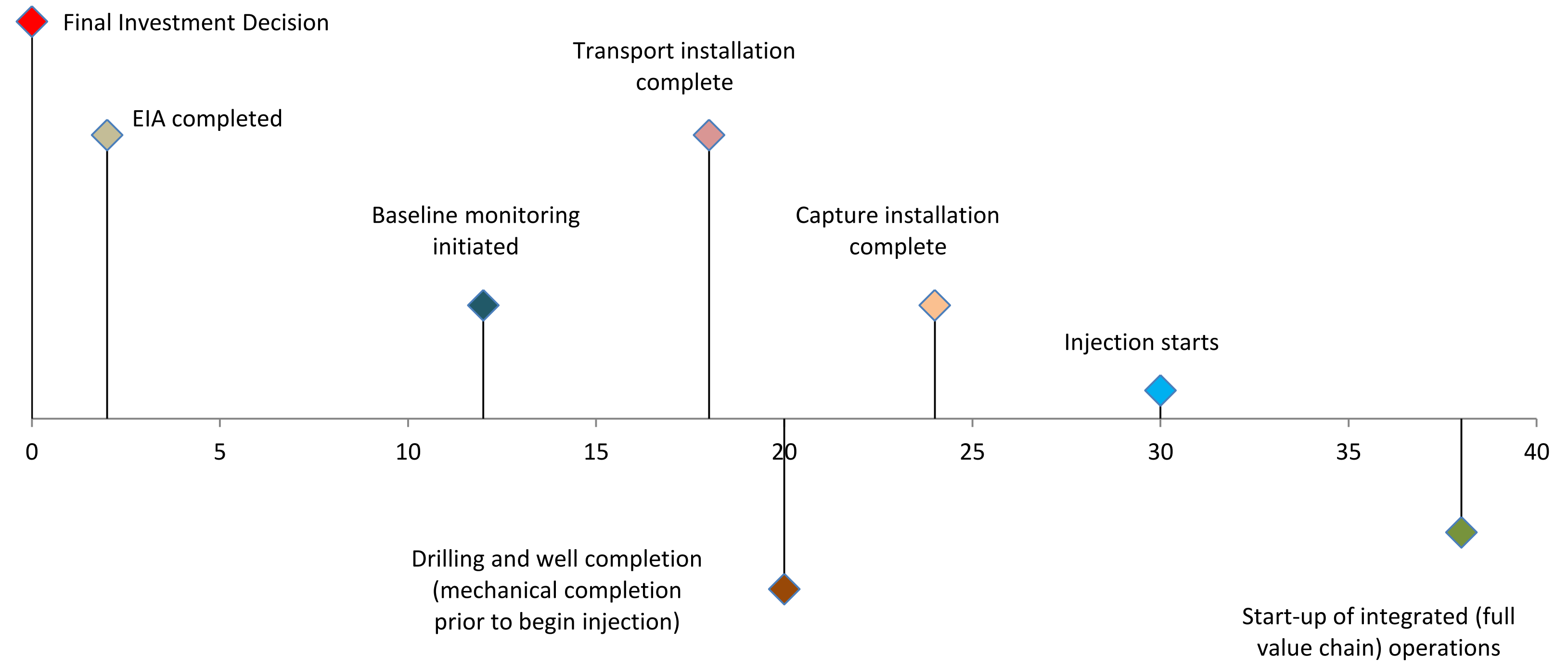


Figure 5 – The planned average time line (in months) between taking an FID and commencing operation for the Network's projects.

The range of time to reach operation having taken a final investment decision collectively varies for the Network's projects between 18 months and 60 months, with the average being illustrated above.

All of the projects under development have had difficulty planning the development of their timelines through to taking their FID. This has mainly been due to delays caused by permitting and funding issues.

Capture

Photo: The Brindisi pilot capture plant. Being used to develop the Porto Tolle plant

Capture

Situation Vitals

1. The Network is composed of 3 post-combustion power projects, one oxy-fuel power project, one IGCC power project and a gas processing project.

2. All will capture over 1 million tonnes of CO_2 per annum each, at a capture rate of over 90%.

3. The total energy demand for capturing CO_2 for the power sector is estimated by the projects to be between 0.08 and 0.4MWh/tCO_2 (though note that the assumptions and elements reported varies per project, and very different capture techniques are being used).

Summary

The European CCS demonstration projects aim at demonstrating the full CCS chain by capturing and storing at least one million tonnes of CO_2 per annum. Except for one project, the natural gas processing plant Sleipner, the current members of the Network represent capture projects in the coal power generation sector.

Within the power sector the capture process has significant costs associated with it – often in terms of both capital expenditure and operational expenses. Within 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 improving and refining capture technology remains a key goal for any CCS project.

The projects within the Network will demonstrate a diverse range of capture technologies, the development and deployment of which will be very important for the uptake of CCS. All of the main technologies for removing CO_2 from a process stream are presented, including:

- **CO_2 stripping**, or scrubbing, usually using absorbent solvents, adsorbents or membranes (e.g. power 'post-combustion' capture, and well-established acid-gas removal (lower volume / higher pressure)).

- **Oxy-fuel combustion.** Using near pure oxygen in the production process as the primary oxidant (rather than air). As no nitrogen is involved in the combustion process, the resulting flue gas produces water and CO_2 – which can be separated by cooling and compression, and a further purification process.

- **Clean hydrogen production**. Using a water-gas shift reaction process on a syngas process stream (e.g. 'pre-combustion' capture at a gasification / IGCC plant).

Within each of these basic capture technologies there are multiple design choices – all impacted by the type of fuel being used, the environmental conditions, the availability of resources (such as water) at the chosen locations, and the operational requirements of the plant.

It should be noted that the current format of the Network's survey reporting are mainly formed to comply with conventional power cycles, particularly post-combustion schemes. For this reason, the questionnaire does not cope with the characteristics of differing schemes such as oxy-combustion and pre-combustion. Nor does it fit with industrial processes such as Sleipner. For this reason it has not been possible for projects to fully, or consistently, provide usable data.
A proposal is currently being made to amend the current questionnaire.[20]

Base plant information and Fuel (if applicable)

The Network contains a range of base plants from which the CO_2 will be captured. Primarily coal-based power plants, including integrated gasification combined cycle (IGCC), pulverised coal (PC), and oxy-fuelled designs, there is also a natural gas-processing plant. Due to the questions asked, the differences in design, volumes, slip stream and plant size of these projects it is hard to compare the operational data and to characterise their 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).

For the power plants, the carbon content of the fuels used by the projects varies from 62.36% to 75.6% by weight (presumed on a dry basis) (Figure 6 - Carbon content of the fuel used per project). As carbon is currently the only component reported, it is impossible to characterise the fuel in more detail (moisture and ash content).

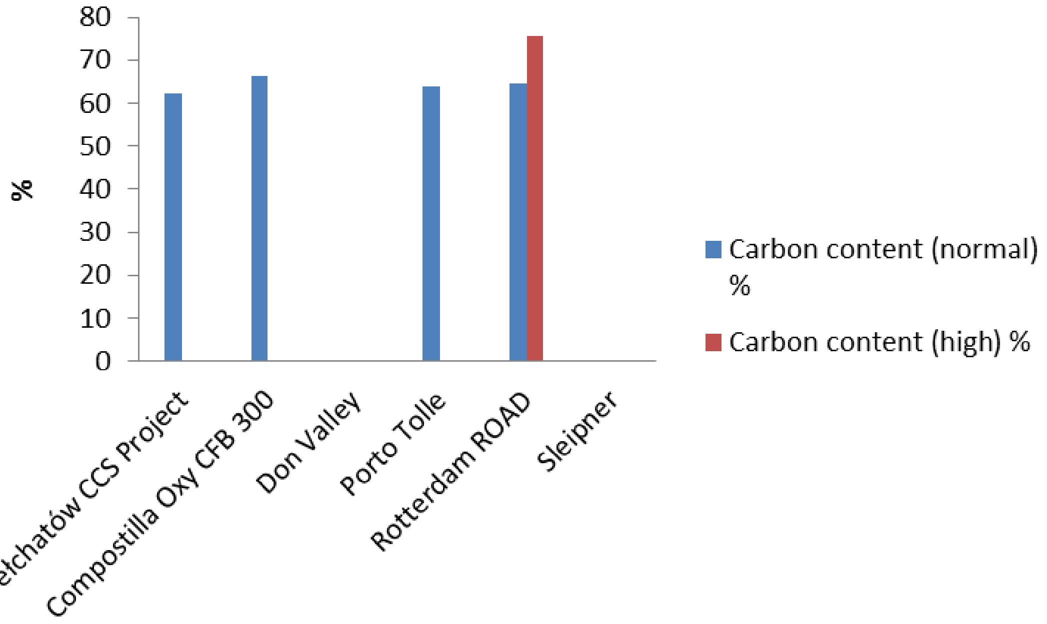


Figure 6 - Carbon content of the fuel used per project

[20] The current set of data should be interpreted with care. For example, whereas Compostilla combines oxy-coal combustion technology and a fluidised-bed furnace, Bełchatów, Porto Tolle and Road apply post-combustion flue gas cleaning of slip streams diverted from the exhaust gas duct. Due to the differences in slip stream and plant size of these projects, it is hard to compare the operational data and to characterise their 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).

Bełchatów power plants burn lignite and the remaining three projects receive, or will receive, bituminous or sub-bituminous coal. Two projects, Porto Tolle and ROAD, offer the option for co-firing with biomass (plant material) with 5% and up to 20% respectively. ROAD also offers extended fuel flexibility, as it may burn coal with carbon content up to 75.6% (Figure 5).

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

Capture technology progress in the Network.

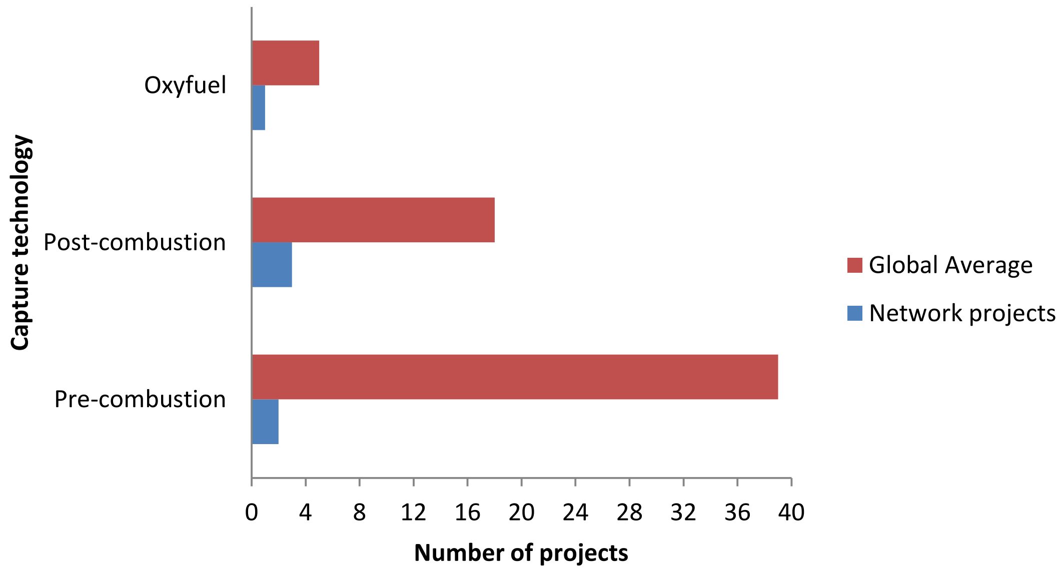


Figure 7 Number of projects using each capture technology compared to the global number of projects in operation or development.

Summary per project

Although only one project is currently capturing CO_2 (Sleipner) other projects have made progress towards an operational capture plant and all projects expect the rate of capture from the flue gas to be above 90%. The total energy demand for capturing CO_2 for the power sector is estimated by the projects to be between 0.08 and 0.4MWh/tCO_2 (though note that capture techniques, the assumptions, and the elements reported varies per project).

The **Bełchatów** project was planning to use Alstom's advanced amines capture technology, with the post-combustion flue gas cleaning of slip streams diverted from the exhaust gas duct. The flue gas was to be extracted after the environmental control systems (flue gas desulfurisation (FGD) and de-SOx), typical of conventional coal-fired power stations. The project had already obtained capture ready status and completed its Front End Engineering Design (FEED) documents for the capture plant.

The **Compostilla** project is using Flexi-Burn (a flexible air/oxygen) circulating fluidised bed (CFB) technology. This year the academic partner in the project (Ciuden) successfully commissioned a 30MWth boiler and testing so far has yielded promising results.

The **Don Valley** project has contracted the company BOC and its parent company Linde to supply the carbon capture technology and air separation units (ASUs) for the CCS plant. The FEED study for the plant is on-going.

The **Porto-Tolle** project has completed four FEED studies after a pre-selection of the licensors' technology. The suppliers to be admitted to License Agreement negotiation have been identified. The project will use amines 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 10,000Nm3/h of flue gases for the separation of 2.5 t/h of CO_2.

The **ROAD** project has completed the design of the capture unit and will be using primary amines in post-combustion.

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).

Costs

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

All of the projects report a full load capture rate of around 90%. The high efficiency quoted by Bełchatów, Porto Tolle and ROAD for the plant operating with CCS, is a reflection of the ambiguity in the current set of questions that are asked. These projects have, respectively, an efficiency penalty of 20.6%, 5.8% and 2.4% point. This is a reflection of these post-combustion systems operating on a limited slip stream of their operating base production units of varying size. The information below is therefore only a reflection of the penalty at a demonstration scale.

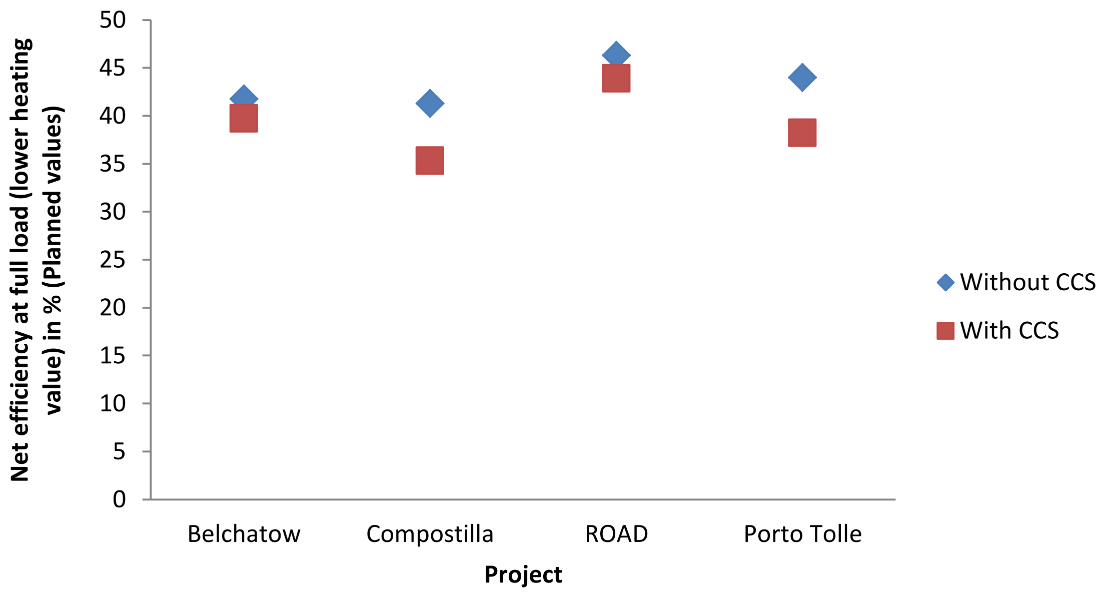


Figure 8 - Net efficiency at full load (lower heating value) in %. Figures are shown without and with CCS. (All available data displayed).

Solvent requirement and degradation

Three of the projects using amines reported a potential annual solvent requirement of between 950m[3] and 1500m[3]. ROAD expects the lowest solvent requirement per year ($950m_3$). (Figure 9 Solvent requirement and CO_2 captured per year for ROAD, Porto Tolle and Bełchatów.).

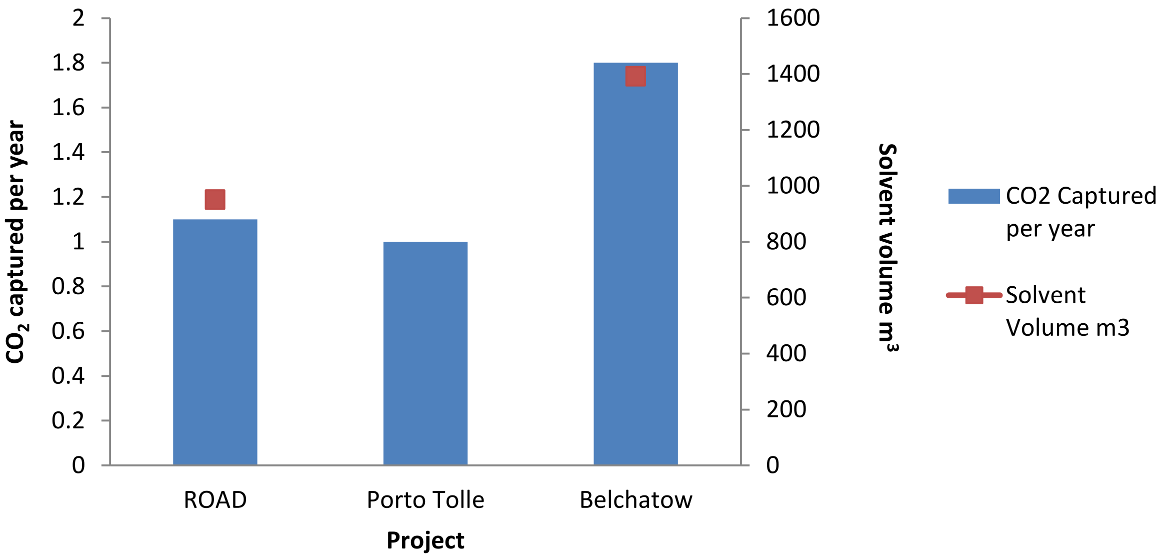


Figure 9 Solvent requirement and CO_2 captured per year for ROAD, Porto Tolle and Bełchatów. (Note that the solvents operate at different temperatures and CO_2 exposure levels.)

Airborne emissions

The following gaseous 'stack' emissions are expected from the production plants contained within the Network, on a variety of different process streams, after the CO_2 has been captured.

SO_x	NO_X	O_2	H_2O	MEA
HCl	HF	C_xH_y	Dust	NH_3

Transport

Photo: Apache II, will be used to lay additional offshore CO_2 pipeline at Snøhvit © Technip

Transport

Situation Vitals	
1	All Network projects will use pipeline to deliver CO_2 to the storage site.
2	Four Projects will use offshore pipelines.
3	The longest planned pipeline is Don Valley's EOR pipeline.

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 the deployment of CCS.[21] It can be transported as a solid, liquid, gas, or a dense-phase liquid by a variety of means, including by ship and truck. 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 to a dense phase, (where it has the density of a liquid, but the viscosity of a gas), as this is the most efficient state for pipeline transport. This compression also greatly reduces the volume of CO_2, allowing smaller pipes to be used.

In the US over 6,000 km of dedicated CO_2 pipelines currently transport over 45 $MtCO_2$ per year from natural and anthropogenic sources, and have been operating since the 1970s.[22] There is only one offshore pipeline for transporting CO_2. This is a 153 km, 8", 200bar, pipeline running along the seabed, taking the CO_2 captured from a gas processing plant in northern Norway back to the Snøhvit field under the Barents Sea, since 2008. These all provide valuable experiences, but there are three specific issues that the Network, and most other CCS projects, will need to address. Regulations and standards for CO_2 pipelines and third party access still need to be introduced in certain countries (in particular a number of Member States still need to ratify the London Protocol amendments in order to enable cross-border CO_2 transport, and certain countries will still need to ratify the OSPAR protocol to enable offshore storage). The economics of pipelines, particularly regarding oversizing to meet future demand and better unit costs, combined with high upfront cost, can be complex. Lastly, and the focus of the following section, will be the different design and management considerations for most of the Network's projects compared to existing pipelines.

The existing pipelines primarily transport CO_2 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, with particular consideration of liquid water, nitrogen and hydrogen. This situation may be even more complicated for 'shared' pipelines that have different

[21] Intergovernmental Panel on Climate Change: *Special Report on Carbon Dioxide Capture and Storage* (2005), Chapter 4, p 181

[22] Hill et al., *Geologic carbon storage through enhanced oil recovery*, 2012,

capture sources. In addition, varying capture and storage operating requirements also impacts design decisions.[23]

Network summary

Transport distances and methods and flow rates

All of the Network's projects will be using pipelines to deliver the CO_2 to the storage site. Collectively a variety of different volumes and contexts will be investigated by the Network projects. Don Valley, Porto Tolle, ROAD will all require offshore, subsea pipelines to reach the storage location (with varying onshore pipeline components – Don Valley having around 80 km of onshore pipeline before reaching the sea). Sleipner is already using an extremely short subsea pipeline. In contrast the Bełchatów and Compostilla projects have been planned with fully onshore pipelines. All projects, with the exception of Don Valley's EOR option will use a pipeline under 200km in length (Figure 10).

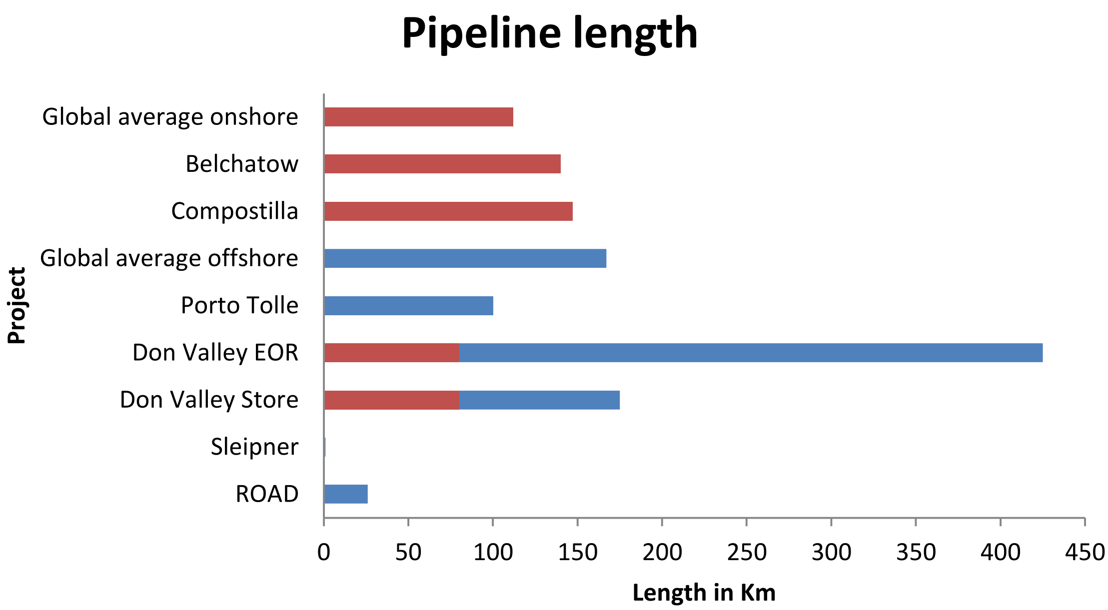


Figure 10 Pipeline lengths of the projects compared with the global average pipeline length per CCS project. Red indicates onshore pipelines. Blue indicates offshore pipelines.[24]

In order to transport the Network's 11 Mt CO_2 per annum, it is expected that the projects will experience a flow rate range of between 47kg/sec and 194kg/sec.

Compression and inlet conditions

As mentioned, in order to transport the CO_2 along such lengths of pipeline in the quantities required, the CO_2 needs to be compressed.

The Network's average pipeline inlet pressure and the average maximum pipeline temperature are also shown in Figure 11. In order to compress the CO_2 to achieve the expected average pressure and temperature conditions of 155 bara and 49 $^{\circ}$C,

[23] Network, *Lessons learned from the Jänschwalde project, Summary Report*, 2012

[24] Average numbers from the Global CCS Institute. 2012 data regarding all large-scale projects in operation or development.

the projects anticipate an average energy requirement of 88kWh per tonne of CO_2. 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. 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.

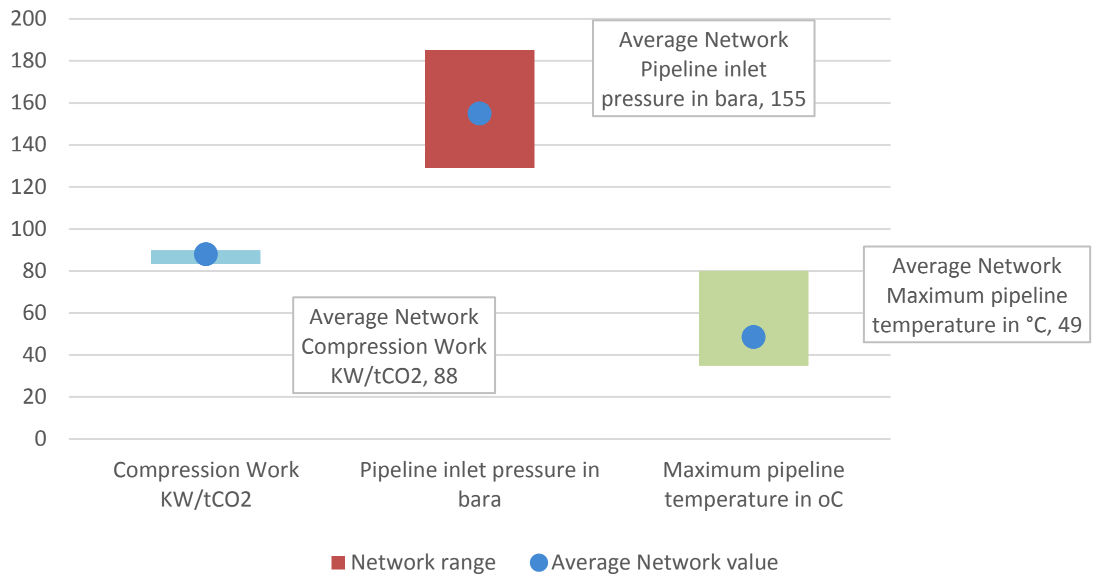


Figure 11 The compression work (kWh/tCO_2), the average maximum pipeline inlet pressure (bara) and the average maximum pipeline inlet temperature (^{o}C) for the projects.

The above information illustrates the currently expected maximum conditions for the Network's projects. For all of the projects the conditions of the CO_2 will change, particularly over long pipeline distances and terrain. For example, a high inlet temperature of 80°C will have no bearing on the subsea pipeline, as the temperature of the CO_2 will quickly drop to approach the temperature of the surrounding sea water at the seabed.

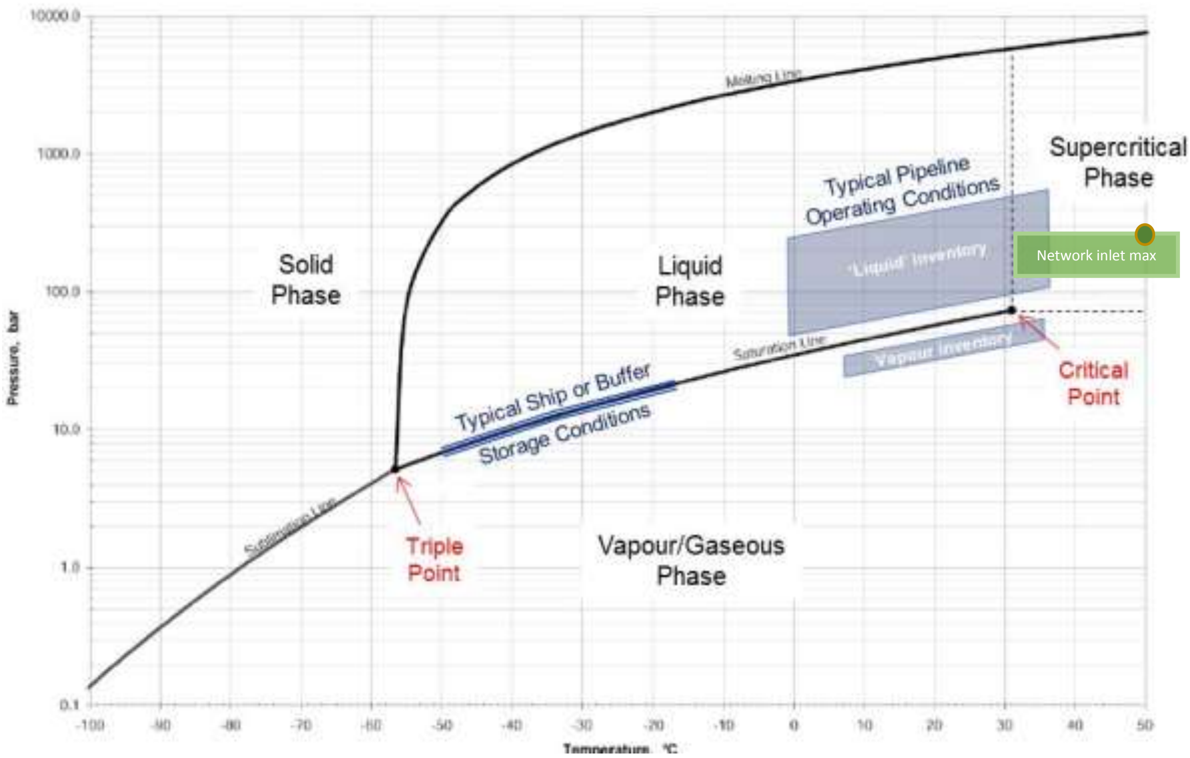


Figure 12 CO_2 phase diagram (DNV, CO2RISKMAN, 2013). The green box shows the Network projects' range of maximum inlet pressures and temperatures.

Impurities, their impact, managing them, and Network concentrations

In order for the Network's pipelines to transport the CO_2 over such distances, in the quantities required, all of the project designs have required a careful consideration of the CO_2 stream composition. As mentioned above the majority of the Network's CO_2 will come from production and capture systems that will intrinsically add small quantities of by-products or impurities to the CO_2 as it is anthropogenic. There are a number of consequences to such additions.

These impurities can have a profound influence on the thermodynamic properties and behaviour of the CO_2 stream, creating variations to the equations of state of the CO_2, resulting to changes to the flow rate (both in terms of mass and volume) of the CO_2 stream and its phase. Two-phase flow in a pipeline may present problems for compressors and transport equipment, due to slugging and fatigue, and this form of transportation is also inefficient. The interaction of certain impurities (particularly free water) in the CO_2 stream may result in equipment and pipeline corrosion, increased failure rates and propagation, damage and clogging (due to hydrate formation). Impurities can also have an impact on the storage aspects of the project (see the storage section below).

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. The injection and storage elements may require further cleaning steps, compression, heating, more injection wells, chemical additives, filters etc.

In the table below the individual projects have reported their expected CO_2 stream composition upon entering the transport system. Again, with different capture plant and operating contexts, the impurities, and how they are managed, varies considerably per project. This will be the subject of two expert workshops during 2013, with the projects discussing these ‘acceptable’ levels of additional components in the CO_2 stream. Early expected ‘generic’ results have been provided for comparative purposes.

	Bełchatów	ROAD	Porto Tolle	Jänschwalde Post combustion	Jänschwalde Oxyfuel	Compostilla	Don Valley	Post combustion (expected)	Oxyfuel combustion (expected)	Pre-Combustion (expected)
CO_2	99.70%	99.90%	>95.6%	>95.5%	>95%	>96%	up to 100% vol%	>99%	>90%	>95.6%
O_2	28mg/Nm3	50 ppmv	<0.4	<200 ppm	<0.8 vol%	< 4 vol%	<10 ppm	<0.01%	<3%	trace
H_2O	<483mg/Nm3	50 ppmv	<100 ppm	< 50 ppm	< 25 ppm	<10 ppmv	< 500 ppmv	0.14%	0.14%	0.14%
H_2						< 4 vol%	< 2vol%	trace	<trace	<3%
H_2S						< 200 ppm	< 250 ppm	trace	trace	<3.4%
CH_4						< 4 vol%	Total for all non-condensable gases and hydrocarbons is limited in the dense phase by the saturation pressure of 80 barg in the dense phase or to 4 mol.% total, whichever is the lower	<0.01%	-	<0.035%
N_2	314mg/Nm3		<0.4 vol %			< 4 vol%				
Ar			<0.4 vol %			< 4 vol%		trace	<5%	<0.05%
H_2						< 4 vol%		<0.17%	<7%	<0.6%
SO_x			50 ppm			< 75 ppm		<0.001%	<0.25%	-
SO_2				<1 ppm	<25 ppm					
SO_3				<1 ppm	<10 ppm					
NO_x			<20 ppm	<5 ppm	<50 ppm	< 40 ppm		<0.005%	<0.25%	-
Total Incondensables (Methane, H_2, Nitrogen, Carbon Monoxide, Argon etc.)		balance (N2 and Ar)	<0.4%	(N2 and Ar) < 500 ppm	(N2 and Ar) < 4.2 vol%		See above			

Table 2 Components in the CO_2 stream prior to entering the transport pipeline

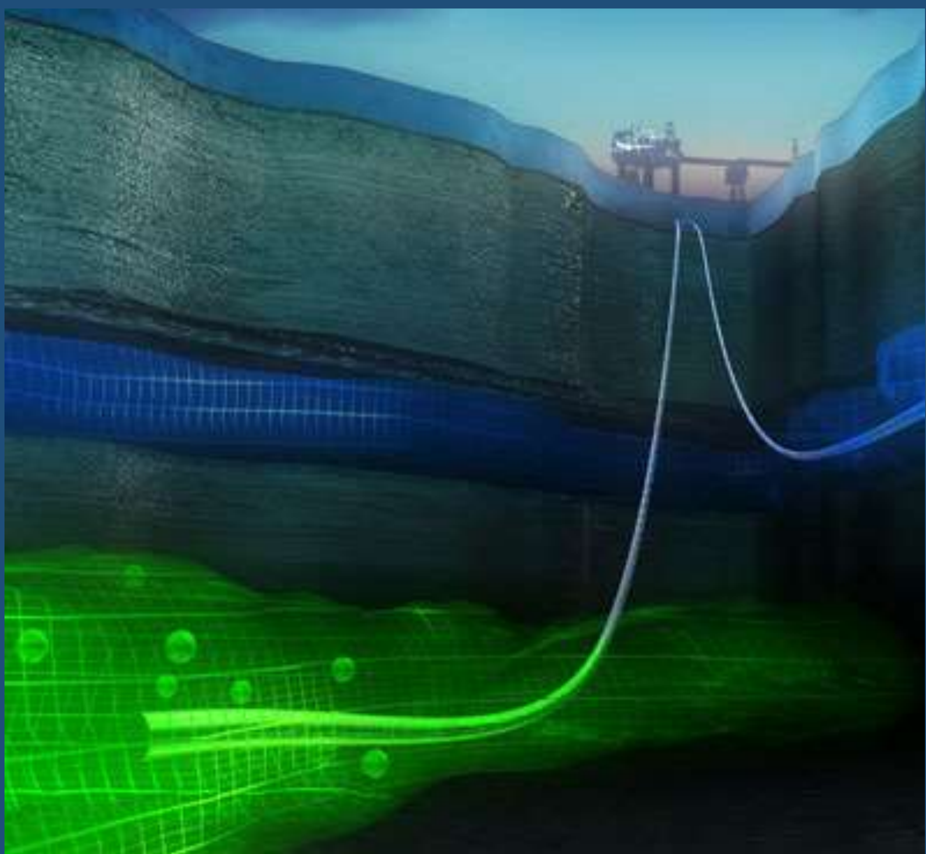
Operational impacts to pipeline design and flow rates

In addition to the design and engineering impacts of impurities, the transport design can be impacted by the availability of both the capture and storage elements. For some of the Network's projects, the supply of CO_2 into the pipelines is expected to vary considerably – following the output of the production process as well as shut downs and maintenance outages. The availability of the storage site may also vary. This dynamic flow over irregular periods will require both design and operating consideration, primarily to avoid or minimise excessive phase changes to the CO_2 stream or two-phase flow, which may over time impact the integrity of the system. Given that the Network's average range of pipeline flow is expected to be between 47kg/sec and 194kg/sec, variations may be considerable. The projects are taking a number of different and complementary approaches to this, including pipeline insulation, back up injector wells, additional pumps (and at varying capacity), etc.

Flow rates are a particular consideration for point-to-point small projects that may have to operate under quite flexible load profiles. For example, for Jänschwalde, the high flexibility demanded by the power plant created a power range of 13-100%. Such load conditions have a significant impact on the design of the total system, and was the main technical issue being faced by Vattenfall.[25]

[25] Further information is available from the Transport Concept document. This FEED study provides the main parameters of the proposed 52km long pipeline. (In English) http://www.ccsnetwork.eu/assets/publications/Feed_study_pipeline.pdf

Storage



Storage

Situation Vitals

1. All projects have completed their screening and selected, or are about to select, their storage sites.

2. The projected bottomhole pressures for Compostilla, Don Valley and Sleipner range from 80 to 248 bara, and injection rates varying between 30-70 kg/second.

3. Storage capacity and injectivity values are highly site specific, with Bełchatów having the greatest storage (800 Mt) capacity and Sleipner having the lowest bottom hole pressure (80 bara).
4. The CO_2 plume, groundwater and soil gas are the most subject to monitoring

5. Repeat 3D seismic survey is the preferred characterisation and monitoring technology used by the projects in the Network.

Summary

The safe and permanent storage of CO_2 is part of the most important factors in ensuring CCS can achieve its potential as a key climate change mitigating technology. As such the Network projects have to undertake extensive subsurface site selection, characterisation, monitoring and assurance processes, more than has ever been required from subsurface users (except for nuclear waste repositories).

Since each geological site is unique, and the legal and regulatory frameworks that are delivering the required licences and permits are still under development in several cases, it takes these early-mover projects several years before a decision can be made to proceed with a commercial project. This is particularly true for the sites where little or no data exist from previous oil and gas exploration and production. In all cases, storage site identification and characterisation is a lengthy process and therefore needs to be undertaken very early in the project development.

The Network's projects during 2012 have shown that storage site characterisation work is ongoing, but faces a slow-down in activities due to postponed Financial Investment Decisions (FID) tied to funding prospects and delays in permitting.

Despite regulatory and financial uncertainties, all projects of the Network have made progress in 2012. These "Early movers" projects play an essential role in identifying barriers and establishing a more streamlined process to deploy commercial CCS.

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 (as of October 2012):

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

O not started ☐ in progress ✓ complete

Table 3 Project Storage status table (October 2012).

As can be noted in this table, all projects have completed their screening and selected, or are about to select, their storage sites.

It is interesting to note that each project follows a different programme for its site selection and characterisation. For example while Compostilla considers they have not finalised their site selection, seismic surveys have been performed at two pre-selected sites, appraisal wells are in progress and significant baseline data have been acquired. 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.

Project activity highlights

Bełchatów: Of the 3 structures investigated, the Wojszyce structure (Permian –Mezozoic basin of the Mid-Polish Trough, Central Poland) was selected for further characterisation before the project was cancelled in early 2013. It is an onshore deep saline aquifer.

- A tender released in March 2012 to select a coordinator for the second phase of the project where data acquisition for characterisation was to be initiated.
- On July 10th the tender was cancelled and a new one was launched on July 20th.
- The offer submitted within the second round was being evaluated at the time of the project's cancellation.

Compostilla: Two sites have been selected for further assessment, one in the basin of the Duero River, region of Sahagun (province of Leon), referred to as the "Duero Site(s)" and one in the basin of the Ebro River, province of Aragon, referred to as the “Andorra site(s)” (Mesozoic formations of the geologic periods: Triassic, Jurassic and Cretaceous). Both sites are onshore deep saline aquifers.

- Duero: 5 wells were drilled (including logging and coring) to approximately 2200m depth average, showing a wide average permeability range in the Utrillas reservoir formation (300 to 1000 mD). The reservoir characterisation studies indicate good reservoir conditions with a 200m thick reservoir (braided system) with high porosities and permeabilities ranging from 0.3 to 1.4 Darcies. Coring is difficult and requires special equipment in these unconsolidated reservoirs.
- Andorra: The injection is planned into an open system, in the Utrilla formation, on the flank of a dipping monocline. A 7km x 13km plume has been modelled. A regional seal consisting of 300m of unfractured shales is present.

The Compostilla project is also carrying out a research pilot devoted to real scale experiments at **Hontomín** in the North of Spain (onshore storage in lower Jurassic carbonates with marl and anhydrite seals), investigating cost-effective operations such as slim drilling technologies, testing of various injection strategies, and deployment of a large set of monitoring technologies at depth and at the surface.

- The project is currently building the infrastructures at the Hontomín injection and storage test site which is expected to be operative in Sept/Oct 2013.
- The tendering processes have been launched for the drilling and well services.
- 3 shallow boreholes were drilled this year for the hydrogeological study and the initial results conform to those obtained from the existing wells in the area (500m depth boreholes in the Cretaceous).
- The current plan is to store approximately 20,000 t of CO_2.

Don Valley: deep saline formation: The reservoir consists of sandstones located on a closed structure in the Southern North Sea (Bunter formation). It is an offshore deep saline aquifer.

- Milestone decision in favour of saline storage site known as 5/42 with drilling appraisal scheduled and subsequently undertaken in summer 2013.
- Award of storage licence by DECC and signature of Agreement For Lease with The Crown Estate.
- Contractual terms have been agreed with a laboratory to undertake Special Core Analysis on 5 of the 42 formation water and core samples.
- The seabed survey was completed in April 2012. It resulted in better outcrop definition data for modelling and monitoring. The area is well known due to historical data including 3D seismic and core samples. New seismic has been shot. Capacity estimates are ongoing.
- Current studies including reports into Formation Damage; Sanding; Chemical Compatibility; and Generalised Equation-of-state Modelling (GEM).
- Facilities Conceptual Design is in progress.

Don Valley: CO_2 EOR: Two central North Sea oil fields were considered for CO_2 EOR storage options. The structure is a faulted dip closure with steep flanks and a very thick top seal. It is anticipated that the project can produce oil for 25 years or more. The project plans for there to be a continuous injection, with producers on the flank and injectors at the top (gravity drainage). No 'water-alternating-gas' (WAG) injection is needed in this case because of the availability of CO_2. The largest field has a 180 Mt capacity, the smaller 40 Mt.

- An Extended Feasibility Study, with increased budget for additional reservoir modelling and facilities studies.
- Extensive laboratory programme with results on pressure, volume, temperature (PVT), formation damage and CO_2 chemistry.
- Full field reservoir simulation models for two fields with > 95 Mt and >40 Mt storage.
- Optimising well designs and facilities.
- 40 wells have already been drilled in this field (25 years of production history) and 8 new wells are planned during the EOR operation.

Porto Tolle: north Adriatic Sea, offshore deep saline formation. The documentation for the request of an Exploration permit, including the drilling of an appraisal well that can later be re-used as an injection well, was arranged as well as the Environmental Assessment. Although the technical decrees of the Storage Regulation are still not implemented, from a technical point of view the project is ready to submit storage operations permit.

ROAD: North Sea. Offshore depleting gas field P18, approximately 20 kilometres off the coast. The gas reservoirs are at a depth of around 3,500 meters. The P18 field consists of three reservoir blocks, the P18-2, P18-4 and P18-6 blocks. P18-4 is the reservoir targeted by the project.

- The P18-4 reservoir block contains only one well, the P18-4/A2 well. A number of modifications are planned on the platform.
- Execution of the Front End Engineering Design (FEED) for the platform is expected to be finished in 2013. The project will only start to inject CO_2 in additional reservoir compartments once the gas exploitation is terminated.

Sleipner: North Sea. Offshore deep saline aquifer in unconsolidated sands of the Miocene-Pliocene Utsira Formation, which is overlain by thick Pliocene shales.

- The highly porous (35%–40%) and extremely permeable (approximately 2 D) Utsira sands are used to inject CO_2 since 1996.
- In terms of characterisation the project is preparing the next phase, to start injection of CO_2 from the Gudrun field from 2014.
- Sleipner continues to acquire 3D seismic surveys on a regular basis to obtain 'time-lapse' imaging of the CO_2 plume.

Storage Site Characterisation Overview

In fully complying with each Member State's transposition of the CCS Directive, each project proponent needs to carry out a characterisation and assessment of the potential storage complex and surrounding area in order to prepare for the development and submission of storage permit application for approval by the Competent Authorities, ensuring that the captured CO_2 will be permanently and safely storage.

Pre-operational storage site characterisation can be subdivided into two broad topics that will be examined per Network project (see also the regulatory chapter of this report):

- Applied geosciences,
- Wells and engineering.

Applied Geosciences

Characterization methods

In order to perform the pre-operational characterisation of the storage sites, all of the Network projects have been reviewing a number of non-invasive surface geophysical methods as well as borehole or well-based methods. The following sections provide an overview of some of the main techniques, and the main lessons learnt by the projects.

Surface methods

Seismic surveying in 2 Dimensions (2D) and in 3 Dimensions (3D) is a preferred method for site characterisation for onshore and offshore storage sites. These range from regional geology mapping, targeted reservoir and overlaying formations imaging, to high resolution imaging to measure or detect specific features or formation's content. They are also very useful in establishing a pre-injection reference, also called a 'baseline'. Seismic surveys when repeated are also recognised as one of the best monitoring tools (the so called 'time-lapse' or 4D seismic data acquisitions).

The **Sleipner** project acquired 3D seismic data in 1994 prior to starting injection in 1996; since then 8 repeat surveys were completed between 1999 and 2013 to track the CO_2 plume in the subsurface.

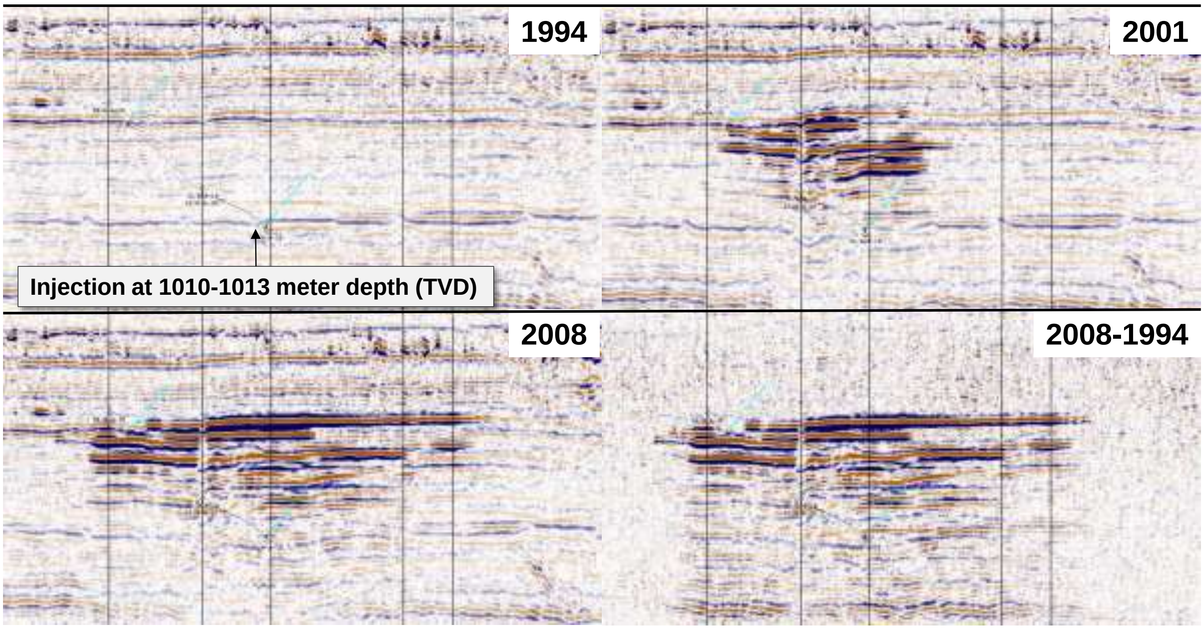


Figure 13 Sleipner CO_2 Time-lapse Seismic Data.

The **Don Valley** and **Porto Tolle** project launched comprehensive 'Survey evaluation and design' studies, investigating various offshore techniques with the intent to repeat them in the future for monitoring purposes. The study looked at offshore seismic data acquisition using surface towed streamer (the most conventional method), Ocean Bottom Cable (OBC), or Ocean Bottom

Seismometers technology (OBS).[26] It is intended to use this technology for the acquisition of characterisation, baseline and monitoring data. Each technology had its advantages and disadvantages in terms of reliability and quality, facility to deploy, repeatability, as well as costs.

Other onshore projects like the **Compostilla** project, both at the Duero site and at its pilot site, have acquired 2D and 3D seismic data at various resolutions. These surveys have been combined with audio magnetotelluric (AMT) surveys and with gravimetry at Hontomín. It should be noted that onshore, seismic surveys used beyond the initial characterisation and baseline dataset acquisitions can be challenging to deploy for monitoring (4D) because of both permitting (recurrent access to landowner's properties to record the data) and cost.

While more for the purpose of establishing a baseline and research, than reservoir and overburden characterisation, **Sleipner** also acquired a number of controlled source electromagnetic (CSEM) and gravity surveys. These may be possible alternatives to repeated seismic surveys. Whereas CSEM has been found to be less effective for characterisation work, due to limitations in the structural resolution, it could be a cost-effective way of mapping large-scale resistivity structures and monitoring the CO_2.

Not all methods investigated or tested by the projects to characterise and establish a baseline can be described here but these are the most broadly used or most promising methods. Besides surface geophysics, Interferometric Synthetic Aperture Radar (InSAR) and DInSAR (Displacement InSAR) using satellite and terrestrial SAR (GB-SAR) are used for baselines and future monitoring.

Exploration wells and engineering

All projects have conducted an inventory and checked the integrity of the wells existing in the zone impacted by the storage. Existing well completion reports were re-evaluated. Where integrity concerns existed, logging was performed using tools such as cement bond logging (CBL), with variable density log (VDL) or ultrasonic Isolation Scanner imaging tools for Imaging Behind Casing (IBC).

Exploration wells for appraisal being planned for by all of the projects in developments – except at ROAD and Don Valley CO_2-EOR site – but have not yet been implemented. Compostilla was drilling its exploration wells end of 2012 and results should be available in 2013.

In 2012, the projects performed core analysis using pre-existing data. Don Valley CO_2-EOR conducted an extensive laboratory programme, including formation damage tests on cores from two fields in the vicinity of the storage site, which showed very similar properties to the ones expected at the storage site. These formation damage tests on cores showed no detectable rock-fluid interaction. The CO_2-brine interfacial tension at reservoir temperatures and pressures were in the expected range. A number of other experiments were still on-going. Most projects plan to core the appraisal wells to perform additional tests with in-situ reservoir and caprock formations. The formation damage test will evaluate potential impact of CO_2 injection on the well injectivity.

[26] OBC uses a seismic cable placed on the seabed and can be equipped with hydrophones or multi component sensors to record converted waves. OBS has the advantage of presenting a denser number of sensors, allowing a conventional processing of the S waves.

Figure 14 Compostilla's appraisal well.

Injection performance

There are several factors pertaining to the performance of a carbon dioxide storage site which need to be considered. These include injection and injection back up options. Regarding the injection operations of a storage site, a number of elements need to be understood in both the planning and operational phases of a project.

In particular CO_2 injectivity is extremely site-specific and will vary with injection flow rates, pressure, absolute and relative permeability, and the nature of the injected fluid. One of the key elements influencing a well's injectivity is the bottom hole pressure. This is essentially the sum of the well head and hydrostatic pressures minus the frictional losses. The measurement and control of this pressure is important. If the pressure is too high, or too low, for the specific well there can be impacts on the injectivity rate and integrity of the site.

The variety in storage and injectivity conditions that may be experienced with CO_2 storage is well illustrated by the Network's projects. The projected bottom hole pressures for Compostilla, Don Valley and Sleipner range from 80 to 248 bara. 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]

[27] Shell Canada, *Quest Carbon Capture and Storage Project: Update to Directive 65: Application for a CO2 Acid Gas Storage Scheme*, 2011

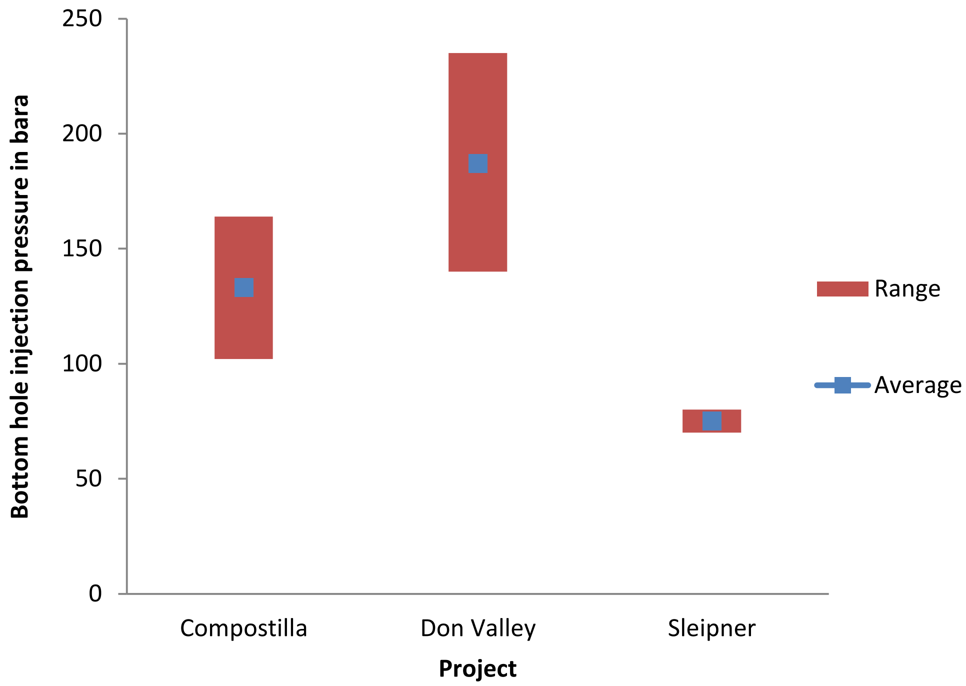


Figure 15 Range and average bottom hole injection pressure in bara.

The injectivity rate is the injection rate at a specified pressure, lower than the fracture pressure that permits the injection of CO_2 into a given reservoir and that allows the CO_2 plume to migrate away from the injection well. Don Valley has the highest injection rate from the projects which provided this data; Sleipner has the lowest, along with the lowest bottom hole pressure. Please note this data is not necessarily an indication of the injection rate per well.

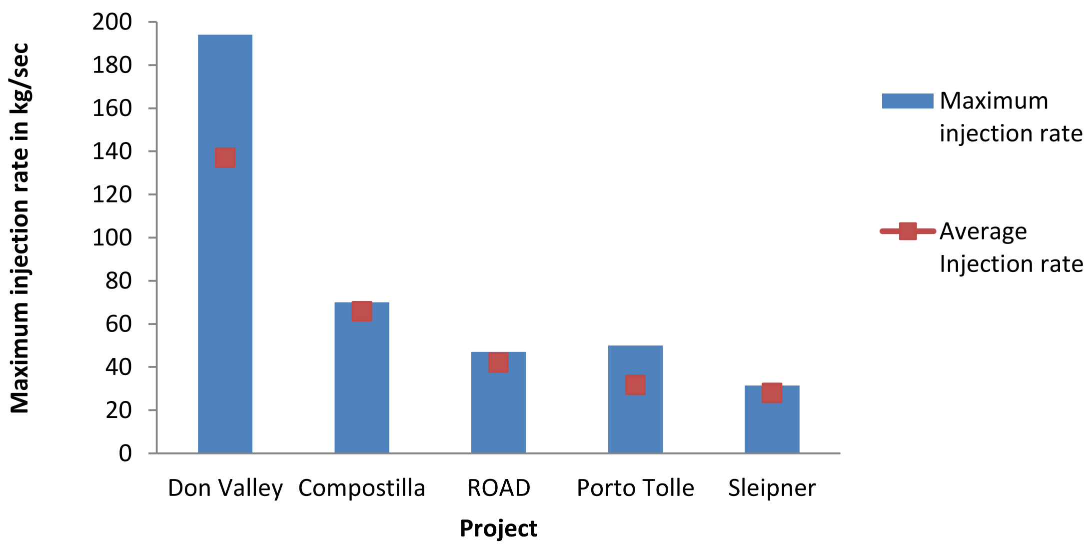


Figure 16 Maximum and average injection rate at each project. (All available data displayed).

From the data received from the projects, during the lifetime of injection operations the reservoir pressure may increase. The largest reservoir pressure increase is expected at the Compostilla project.

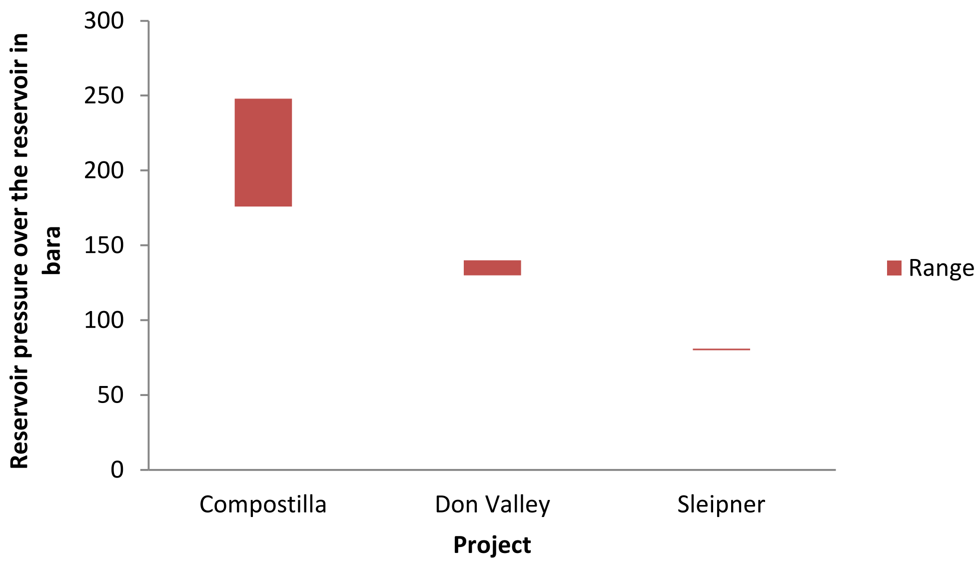


Figure 17 Reservoir pressure (estimated and actual) over the reservoir in bara.

Modelling

All projects have built a series of models from conceptual models to static and dynamic fluid flow simulation models and geomechanical models.

Modelling Capacity

Each project has to model the storage capacity of the intended reservoir. ROAD is planning to use the smallest reservoir and Bełchatów would have had the largest capacity (Figures 18). The projects have used a variety of modelling programs to complete the model of the storage capacity.

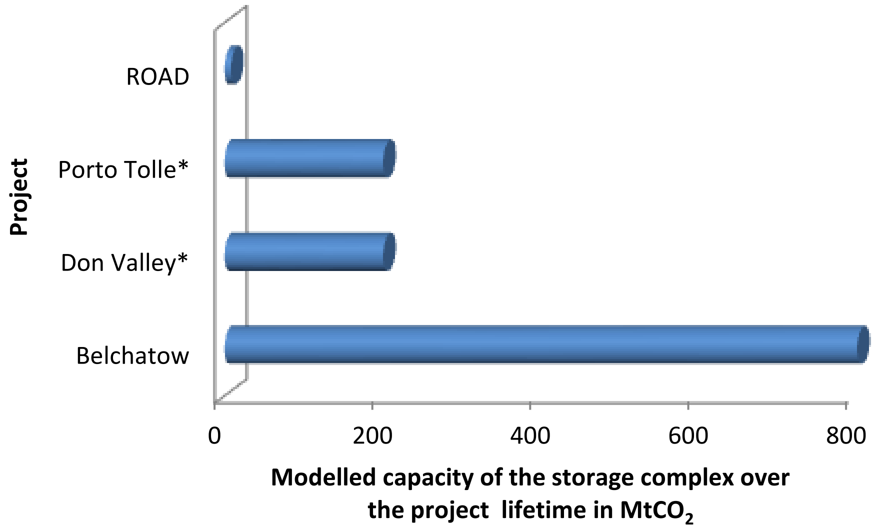


Figure 18 The modelled capacity of the storage complex over the project lifetime in $MtCO_2$. * chosen Don Valley Saline storage solution, and indicates the dynamic capacity. Other projects have not specified if the capacity is dynamic or static.

Hydrogeology of the aquifers in the overburden

The surface and borehole methods used to characterise the reservoir are also used to characterise the caprock and overburden, in particular any aquifer overlaying the targeted storage formations. Where possible projects have undertaken some tests in existing shallow wells and collected groundwater samples. This data is used to establish baselines prior to the injection of CO_2. For example, Hontomín has designed an extensive suite of hydrogeological tests to be performed in the injection well that will be drilled in 2013 (a detailed description of the tests will be given in the Storage Knowledge Sharing report of May 2013).

Just as for the targeted reservoirs, where geochemical analysis will evaluate the compatibility of the injected CO_2 into the saline water of the reservoirs and mineral assemblage, geochemical analysis of the groundwater in the overlying aquifers is analysed and impacts of any CO_2 or brine leakage as well as impact of a change in pressure are being evaluated.

Impurities, and the impact on storage

As noted in the Transport section, impurities can have a significant effect on the injection and storage of CO_2. The possible impacts of impurities are reservoir-specific and depend on the mineralogical composition of the rocks, 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.

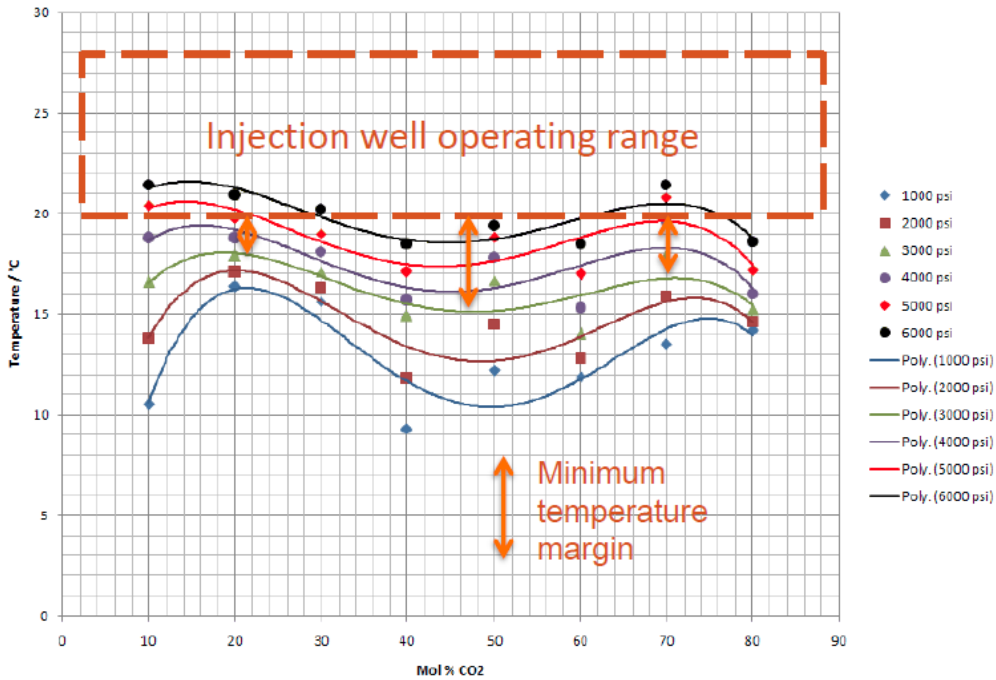


Figure 19 Don Valley's results from experiment regarding hydrate formation temperatures and pressures in CO_2-CH_4 mixtures saturated with H_2O.

In some cases it is possible for impurities to have a positive effect on a storage site. Impurities can modify permeability through mineral reactions which may actually aid the migration of CO_2 through the injection zone. In certain cases they can also increase the speed at which long term mineral trapping occurs.[28]

The EU CCS Directive does not stipulate the exact limit of impurities allowed in a storage site and simply states: 'A CO_2 stream shall consist overwhelmingly of CO_2. To this end, no waste or other matter may be added for the purpose of disposing of that waste or other matter.'[29]

Monitoring

Although the monitoring of CO_2 only begins once injection begins, monitoring tools and deciding on monitoring plans and strategies is an activity that must occur early in the project's process (particularly for obtaining licences). The Sleipner project, which has been in operation since 1996, has collected a wide range of monitoring data and helps provide an illustration of potential benefits of monitoring data to other projects currently in the planning stages. Consequently it was deemed to be of great importance for the Network and identified as a topic for knowledge sharing in 2012. The Network has a unique onshore-offshore mix and has the opportunity to highlight the differences and complementary methods that can be employed in the projects' monitoring activities. A number of shared learnings have been made.

- Some techniques are becoming 'standard', particularly downhole P&T sensors. Others, such as seismic, surveys discussed above, if it can be appropriately used.
- Clear and agreed definitions for monitoring objectives are needed.

[28] Garcia, S., et al. *Sequestration of non-pure carbon dioxide streams in iron oxyhydroxide-containing saline repositories*, 2012

[29] European Parliament and Council, *Directive 2009/31/EC on the geological storage of carbon dioxide*, 2009

- Characterisation of the local rock/fluid/stress system is important.
- Reservoirs will always cause surprises.
- Appropriate baseline measurements are critical.

Figure 20 Porto Tolle's deep laboratory station.

Storage sites vary greatly, and monitoring tools, techniques and plans should reflect the specific circumstances of the area. It is important to take into account local conditions such as the geology, regulations and public concerns. As monitoring plans always aim to ensure the safe and permanent storage of CO_2, detailed analysis of the benefits of each technique should be considered.

For example, repeated seismic surveys may not always be useful or feasible in certain offshore and onshore locations (obtaining permitting permission for repeated acquisitions onshore may be problematic; or the geology may not allow useful results to be obtained. Using a specific example, while 4D seismic is very useful in the case of Sleipner, it is considered of little benefit in the case of ROAD).

While there are a set of minimum monitoring requirements common to all sites, and these must be in place (usually as the result of regulation), it is possible to demonstrate that monitoring is a valuable investment in the lifetime of a project and will save the operator money and time in the long term. In particular, monitoring is important for a better scientific understanding of the overall system and its management (historic data matching).

Good and appropriate baselines and appropriate monitoring techniques are essential in order to build good models that will aid operations, but can provide tangible evidence to regulators, stakeholders and the public that storage of CO_2 is safe and permanent. However, it should be noted that baseline surveys acquired during the pre-injection/characterisation phase and monitoring during injection and closure phases do not have the same objectives. The baselines need to anticipate future problems which is challenging. As well, projects needs to anticipate the technology that will be available in 10 years from now. Monitoring plans should therefore be designed based on the project's performance management and risk control process. More information regarding the monitoring plans of the projects can be found within the Network's Monitoring report.[30]

Monitoring was also the theme of an international knowledge sharing event held in Alabama and attended by projects from North America and Europe. A range of monitoring techniques was discussed at the event and projects shared some key techniques used. Table 4 compares some of the key technologies used by the listed projects. Although this list is not exhaustive, among the techniques discussed, groundwater and soil gas monitoring and 3Ds were favoured by

[30] European CCS Demonstration Network, *Monitoring session (Storage)*, May 2012

most of the projects. A full report containing details of all of the projects involved in this international event can be found on the Network's website.[31]

Type of tool	Illinois Basin - Decator Project	Bell Creek	Cranfield	Shell Quest	Fort Nelson	Weyburn	Aquistore	Porto Tolle	Hontomin	Sleipner	Secarb (Plant Barry)
Atmospheric / Eddy covariance	Y			Y					Y		
Soil flux monitors	110	Y	Y	Y		Y	Y	Y	Y		Y
InSar	Y			Y		N	Y		Y		
Multibeam / sonar								Y		Y	
Sediment								Y			
Benthos								Y			
Oceanographic								Y		Y	
Ground water	17	Y		3	Y	Y	Y	Y	Y		Y
Lidar		Y							Y		
3D s	Y	Y	Y	Y		Y	Y		Y	Y	
Gravity						N	Y		Y	Y	
Wells	3	147	~55	12	4	500+	2		3	1	10
P&A		44		~5			1				
Injection	1	93	~46	~5					1	1	2
Observation / monitoring wells	2	10	~9	7	Y		1		2		8
VSP	Y	Y	Y	Y			Y		Y		Y
Microseismic	Y		Y	Y		Y		Y	Y		
ERT			Y				Y		Y	Y	
Reservoir Saturation Tool / pulsed neutron	Y	Y									Y
Tracers			Y	Y					Y		Y
High res noise interferometry									Y		

Table 4 Indicates only discussed (simplified) techniques per project during the conference. (The table does not reflect all of the tools that a project is currently using /will be using).

Key learnings

In conclusion there are a number of broad and specific learnings that have been made by the Network during 2012. There are three major points that can be drawn from the workshops held. It is important to address and focus on project "stoppers" and "delayers". Updates given by each of the projects within the Network showed that storage site characterisation work is ongoing but faces a slow-down in activities due to postponed Financial Investment Decisions (FID) tied to funding prospects and delays in permitting.

It is recognised that the "Early movers" projects play an essential role in identifying barriers and establishing a more streamlined process to deploy commercial CCS. However, each geological site is unique, with the Network projects alone illustrating that capacity and injectivity values are highly

[31] European CCS Demonstration Network, *Knowledge Sharing in MVA / MMV in CCS Demonstration Projects and Large scale CO_2 Injection Tests: Workshop summary*, 2012

site specific. As a result extensive screening and characterisation activity must be undertaken, often taking years before a decision can be made to proceed with a commercial project. It is therefore crucial that project proponents anticipate the importance of storage and treat it as a priority.

Communication and Engagement

Yorkshire pipeline to lead world in green energy

Ambitious scheme set to bury carbon in North Sea

EXCLUSIVE

Jack Blanchard

National Grid picks route for emissions clean-up

Pipeline to run below ground for 50 miles

Jack Blanchard

Campaigners: we welcome pipeline

E YORKS: Countryside group 'has no problem' with plans

by Jon Townend

Jobs hope in carbon capture pipeline project

Underground link could help slash gas emissions

Communication and Engagement

Situation Vitals

1. Public engagement activities have been progressing well for all of the projects throughout 2012.

2. Direct engagement has been the best method for public interaction.

3. Public engagement best practices have been demonstrated practically by the projects.

4. Projects continue to report on the importance of consistent messaging to the public, and in 2012 /13 the need for better articulation of the value proposition for CCS was brought into sharp focus. It is vital that a demonstration project becomes operational as soon as possible to act as a beacon in the context of future communication.

Context

Public engagement is of fundamental importance to new technologies and projects. The public's perception can result in either the success or failure of a project - which is why it is so important to ensure that communication and engagement are carried out from the start of a project and that the public is sufficiently engaged. This ensures that the public can make an informed decision on a project and any questions or concerns can be addressed by the relevant parties.

A CCS project, although not unique in the requirement for public engagement, faces some specific communication challenges due to the complexity of working with a suite of technologies and the multi-disciplinary teams associated with them. CCS projects also face difficulties with the general lack of public understanding around issues of energy and climate change – fundamental contexts for understanding the importance of CCS.

Network summary

Despite some delays and problems with financing for many of the projects, public engagement activities progressed well for all of the projects throughout 2012. Direct engagement with the public through meetings and bespoke engagement has produced successful results for the projects, leading them to believe that this is the best method for engagement with the local community.

Bełchatów held two significant sets of face-to-face meetings with their local communities during 2012, in March and then from July through to November. These included discussions with local authority representatives, councils, and the European Commission, to update them on progress on the storage component of the project and the plans for the preparatory works for CO_2 transportation pipeline. Most of the participants had a positive attitude to PGE's investment plans.

Compostilla is continuing to participate in local fairs and organise information sessions in local town-halls. A specific section on the webpage, dedicated to Sagún social acceptance campaign, is still active on the project webpage www.compostillaproject.eu. Four public engagement studies were carried out.[32] The Compostilla Project's Communication and Engagement specialist was interviewed for the Global CCS Institute's communication and public engagement case study report.[33]

Don Valley wrote to some 77,000 local residents and landowners to invite them to discuss the various options for the CO_2 pipeline corridor. A preferred pipeline corridor had been identified based on feedback from a series of public consultation events held in 2011. Subsequently, in the summer of 2012 stakeholders were also consulted on the possible locations for above ground structures such as the compressor site, intermediate block valves and pumping station. The transport solution for the Don Valley project is a shared user pipeline with capacity to support additional capture projects within the wider Humber Cluster area. www.ccshumber.co.uk

Porto Tolle has suffered a significant setback with the permits for the project's main power plant (not the CCS project itself). As a result, the project engagement activities have been scaled back and will remain high level until there is clarity on the timescales for development of the project.

ROAD's final investment decision has been re-scheduled to 2013. The project has been conveying to all stakeholders that the structural, low CO_2 price levels are giving insufficient economic incentives to investments in capital intensive 'low carbon' technologies like CCS. In close co-operation with its stakeholders, ROAD is actively working on finding a solution to close the financial gap caused by these low CO_2 prices. The project stressed that even when progression is slow communication is important, and the benefits of CCS will improve once a project commences operation in Europe. The ROAD Stakeholder Manager also contributed to the Global CCS Institute's case study report.

Network approach and lessons learnt

A number of topics were addressed during the2012 public engagement knowledge sharing workshops. These included:

- The key concerns and perceived risks raised by the public to the Network's projects
- The identification and management of key stakeholders
- An examination of the best communication tools

The thematic group of experts within the Network also identified a number of best practice guidelines for social site characterisation, messages and messengers. These guidelines fit closely with the most recent research conclusions and recommendations on best practice[34] for CCS communication and engagement. This helps validate the approaches taken by the project proponents and illustrates the practical application of public engagement best practice, in the pre-operation phase, as outlined and recommended by the research community.

[32] European CCS Demonstration Network, *Thematic Report: Public Engagement Session*, May 2012. These include a Social perception qualitative study; a public perception study; a CO_2 storage technologies social acceptance study and a psychosocial study.

[33] Global CCS Institute, *Communications for carbon capture and storage: Identifying the benefits, managing risk and maintaining the trust of stakeholders*, 2013

[34] World Resources Institute, *CCS and Community Engagement*, 2010,, and the case studies within CSIRO, *Communication, project planning and management for carbon capture and storage projects: An international comparison,* 2010 , See also the Global CCS Institute's Status Report 2012 for a good summary of the management approaches.

Some of the key project management and communication learning points resulting from the workshops are listed below in order to help other projects in their efforts to successfully engage with their public stakeholders

Stakeholders

The Network Projects agreed that one of the most important activities undertaken by the projects is the identification of stakeholders. All projects in the Network have detailed stakeholder maps which include national and local governments, NGOs, landowners and the general public. The Projects spent substantial time defining stakeholders in order to understand the people and organisations that are interested, influential or impacted by the project proposals. For each stakeholder, projects are determining their levels of interest, and trying to understand their needs and concerns. The projects recommend that there is a best practice guide associated with each stakeholder, allowing there to be an appropriate response to their needs. Undertaking this stakeholder mapping activity allows the project to effectively address any issues that may arise, and in some instances can shape the project's development and management decisions.

Timing is also very important. One of the best lessons learned by the Compostilla project was the need to "first inform, then perform". With an onshore 3D seismic campaign at the storage site, it was clear that the local community was deeply concerned by the equipment being used. It took concerted effort and direct engagement with the project to reassure the local public over what was being done and why. It was only by undertaking open and clear communication activity that the project was allowed to proceed – with the locals actually supporting the activity.

Communications

All projects have to carefully consider the kind of language and the kind of communication tools they use to discuss their project. During the course of the Network's discussions, it has been of interest to note that the communication tools and messages are not universally applicable. The success of a tool or message depends heavily on the local context and culture, with significant variances between countries. Socio-economic factors and the regional economy appear to influence public perception of a project, with areas experiencing higher unemployment rates and/or lower incomes tending to accept the benefits of CCS projects once all the information was properly explained and disseminated, contrasting to affluent areas that tend to react more negatively due to a lack of interest in new investments in the area. Nevertheless, the Network projects also highlighted a number of shared considerations that should be taken into account during the preparation of all communication tools:

- A project must be transparent and honest. Site visits to the power plant and capture unit are recommended.
- Projects have been criticised for fancy advertisement campaigns and glossy brochures – it is far more important to engage face to face with the local public.
- The process for communicating is extremely important. Engaging in dialogue and listening is far more important than focusing on technicalities and process.

- Having something tangible to show, such as a pilot plant or 'like-for-like' project is extremely helpful. Once the first demonstration project is operational, communication will be easier across Europe.

- Prepare a common language and shared messaging for the entire team. Some scientific or technical words can be unhelpful.

- All projects agree that videos and animations can be very helpful.

Figure 21 Porto Tolle's online tour - www.portotolleproject.com/visita_centrali/visita_centrale_portotolle

Messengers

The projects also highlighted the importance of using expert staff for communicating and delivering messages about the project in order to build trust and credibility with stakeholders. The projects within the Network use a variety of approaches when undertaking communication and public engagement, using both corporate and project specific teams. In both cases, having dedicated resource(s) to disseminate information about the project was always found to be beneficial. Some of the lessons learnt from the Network regarding messengers in the project team include:

- Project staff and engineers have greater credibility than public relations staff, but they require support to adapt their communication styles and engagement activities to meet stakeholder needs. Specific briefings and training on how to communicate with the public is beneficial, combined with a shared set of messaging.

- The Network's projects have found partnering with academic institutions extremely beneficial. These partnerships have been most successful when respected academic staff have undertaken communication activities, but with the support of communication experts to 'translate' the scientific language into something that can be easily understood.

Project organisation

Most projects have a dedicated communications team which works as part of the project management team and is fully integrated into the project. This has proven beneficial because the communications team can work directly with the other project team members to ensure that all project messages are synchronised. Most projects have quite a small team at this time with only 2-4 members carrying out public engagement activities.

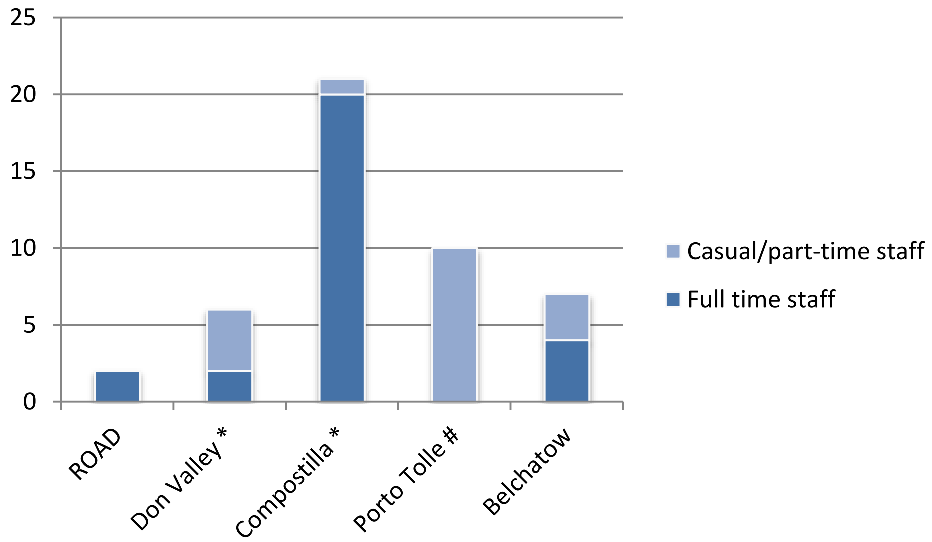


Figure 22 Members of staff involved in public engagement. *numbers of casual staff are approximate. # All staff work for the operator's wider communications team and dedicate a percentage of their time to CCS, number of staff is approximate. (All available data displayed).

The Network, as a group, has felt that it is extremely important that any public engagement activity is 'led' by the project manager, and is a central part of the management structure from the very beginning. This close integration of stakeholder engagement, communication and project management allows the project to quickly and successfully address key issues as they arise.

Recent developments

Significantly, in 2012, the first round of the NER 300 funding programme resulted in no CCS projects being funded under the EU scheme. Although this is a negative message for CCS on a European level, the projects have not reported any significant negative impact at a local level. All of the projects are continuing to work hard to engage the public, explain the requirements and the technical details of CCS. However, the lack of political support and delays send a confusing message, causing some to doubt the technology's safety and necessity. This situation has been exacerbated by a decline in interest from the media, making engagement more difficult. The projects agree that it is vital a demonstration project becomes operational as soon as possible to act as a beacon in the context of future conversation and communication.

Policy and Regulations

Policy and Regulatory Update

Situation Vitals

1. All countries represented by the projects in the Network are reported as being on track for transposing the CCS Directive regarding CO_2 storage, although some are doing it in a draft form, and there remain key gaps regarding the regulation of CO_2 transportation in Spain.

2. The European Commission, under the CCS Directive, adopted its very first Opinion on a draft national draft storage permit – successfully reviewing the permit for the ROAD project. (A second opinion will be given prior to injection).

3. The Bełchatów, Compostilla and Porto Tolle projects have suffered permitting delays. (Bełchatów was cancelled in early 2013).

4. The Jänschwalde project was cancelled due to the prolonged impasse in the adoption of a suitable German CCS law.

5. The Sleipner project is regulated under the Norwegian Act relating to Petroleum Activities (under the Ministry of Petroleum and Energy) and the Pollution Control Act (under the Ministry of Environment).

Policy and regulation development are key factors in the deployment of CCS. There is a wide range of policy, legislation, and regulation that is relevant to CCS, from international climate change agreements, through national climate and energy policy, to project-specific legislation and regulation.[35] The European Commission has supported and encouraged CCS with a number of policy instruments. The most important policy from the EU is the Storage Directive (Directive 2009/31/EC), the so-called 'CCS Directive' which is globally one of the most comprehensive examples of CCS-specific legislation.

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 (although civil liability is explicitly excluded), responsibility and sets a range of obligations for storage; including site selection, operating, closure and monitoring activities, and for the process regarding the site transfer to the relevant competent authority. The EU emissions trading system (EU ETS) was amended to allow captured and stored CO_2 to be treated as 'not emitted', providing a potential future incentive for CCS operations.

This Directive now needs to be transposed into national laws in Member States, and while all of the countries represented by the projects in the Network have, or are transposing the Directive some are only doing so in draft or limited form. In addition there is concern among the project

[35] Global CCS Institute status report 2012

members that the current manner of implementation of the Directive presents a significant financial hurdle for attaining a feasible project. Building on these Network discussions and within the case study that follows, the ROAD project highlights some of the main issues that they faced, and some of the main questions other projects should be aware of in their various jurisdictions.

Project regulatory updates

A number of the projects in the Network have faced difficulties with the resulting regulations and permits. The **Compostilla** project has been delayed significantly by the lack of progress in the implementation of suitable CO_2 storage regulations. The main reason for the delays is that the new legislation in Spain was transposed (Act 40/2010, of 29 December 2010) before the four guidance documents were released in March 2011. While the project obtained exploration permits for both the Duero and the Andorra storage site, the existing exploration permit was granted under the mining law prior to the transposition, and a re-application was necessary. At present, the regulations have not been sufficiently finalised to allow application for a storage licence. In addition, CO_2 transportation is not covered by this new legislation, rendering the permitting of transport of CO_2 impossible at this time. Due to these problems in the administration process the envisaged start date for the FID process has been moved to 2013.

The **Bełchatów** project (eventually cancelled in early 2013) changed the capture technology it intended to use, and had to apply for a new permit, resulting in several months of delay. In Poland the Ministry of the Environment is responsible for the transposition of the CCS Directive into Polish Law and for the permitting of CO_2 storage. A Draft Act to transpose the CCS Directive and amend existing laws has been created by the Ministry of the Environment called the “Assumptions for the Draft Act”, which has been accepted by the Council of Ministers in 03/2011. In August 2013 Polish parliament passed the CCS bill covering CO_2 storage in geological formations and laying down requirements covering the entire lifetime of a storage site. One of the main limitations of the Polish CCS bill is that it only allows for demonstration projects.

The **Porto Tolle** project produced the documentation for the request of an Exploration permit, including the drilling of an appraisal well that can later be re-used as an injection well, as well as the Environmental Impact Assessment. The technical decrees of the Storage Regulation are not yet implemented and the documentation has not been submitted.

More problematically the project has been severely delayed because of the decision from the State Council to void the first environmental impact assessment (EIA), requiring a new EIA to be produced for the change in use of the base plant (from oil to coal combustion). This is not in any way a reflection of the CCS component, but the CCS project is directly impacted by the delay.

The **Jänschwalde** project was cancelled, withdrawing from the Network, in early 2012 due to the prolonged impasse in the adoption of a suitable German CCS law. A compromise was finally reached in June 2012 between the Bundestag and Bundesrat, resulting in the CO_2 Storage Act of August 2012. The Act has a number of specific clauses limiting deployment. The maximum yearly storage capacity of a CO_2 storage-site is limited to 1.3 million tonnes of CO_2; the combined yearly storage capacity in Germany is limited to 4 million tonnes of CO_2; operators retain responsibility for a CO_2 storage site up to 40 years after its closure; individual Länder can block CO_2 storage operations.

The **Don Valley** project is re-assessing aspects of the project after the decision from the UK government not to provide funds from the UK's CCS Commercialisation competition, but the project expects that the UK's new energy bill and the structure and design of the Contracts for Difference (CfD) should cover the project's balance sheet. The project's transport EIA is being undertaken. Following the award of a carbon storage appraisal licence by the UK's Department of Energy and Climate Change (DECC) and the award by the Crown Estate of a CO_2 Storage Lease, National Grid undertook a successful intrusive exploration drilling of the chosen saline storage site in summer 2013.

The ROAD project achieved a considerable milestone when its storage permit was successfully reviewed by the European Commission, giving its first opinion of a permit submitted under the CCS Directive (a second opinion will be given prior to injection). Further information is provided below and a separate special report. 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 relating to Petroleum Activities (under the Ministry of Petroleum and Energy) and the Pollution Control Act (under the Ministry of Environment).[36] 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. All data and reports are disseminated to the Norwegian environmental monitoring database (MOD, 2002), overseen by the Norwegian environmental agency (KLIF).

Case Study of a storage permit

There are several important requirements of the European Union's Directive 2009/31/EC on the geological storage of CO_2, which require some degree of interpretation by Member States. Discussions at the CCS Network meeting in May 2012 led to the production of a case study of the storage permitting process of the ROAD project. The Network members identified several key issues of the storage permitting process which will be addressed in this case study report. It is hoped that the findings will be of interest and help to other project proponents and regulators.[37]

The case study has been organised into two main sections. Firstly, it gives an overview of the internal ROAD organisation, as the way in which the project was internally structured was very relevant for the storage permitting application. The report gives an overview of the key stakeholders and describes how the project kept in touch with them.

Secondly, the report goes into a brief description of the process, including detailed project timelines. It gives insights into how long the storage permitting process takes in the Netherlands, what

[36] http://www.npd.no/en/Regulations/Acts/
[37] ROAD, *Case study of the ROAD storage permit*, 2013.

the important milestones are, and which aspects of the permitting process can cause delays or time advantages. The study then covers some key details of the storage permit, and several important aspects of the Directive are discussed in detail. These aspects are crucial for developing any CCS project in Europe. The case study describes how the ROAD project interpreted the outstanding issues and was able to agree solutions with the competent authorities. More information regarding the solutions and steps taken can be found in the 2013 special case study report.[38]

Finally, it must be noted that the storage permit application was filed by TAQA. TAQA already holds the current gas production permit, submitted the application, and will be the storage permit holder and storage operator. As this case study is drafted to inform the other projects, ROAD uses it to describe their view of the process from a full chain project view. This case study is drafted by the ROAD project; it only represents the views and opinions of the ROAD joint-venture parties.

The authors hope that this case study can assist other European CCS demonstration projects with their storage permitting processes.

ROAD permitting case study

Getting a CCS project permitted is a long and difficult process, especially because of the storage permitting obligations. The regulations on a storage permit (the CCS Directive, Guidance Documents) are new and some key details can be interpreted in a variety of ways. In total the storage permitting process took almost two years for the ROAD project. ROAD was fortunate to have the Dutch competent authorities fully support the demonstration project. While this may not be the case for other projects, hopefully this report gives some lessons learnt and concrete examples on how to approach some of the key issues arising from the CCS Directive.

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 why an organisation would stop its involvement in a project.

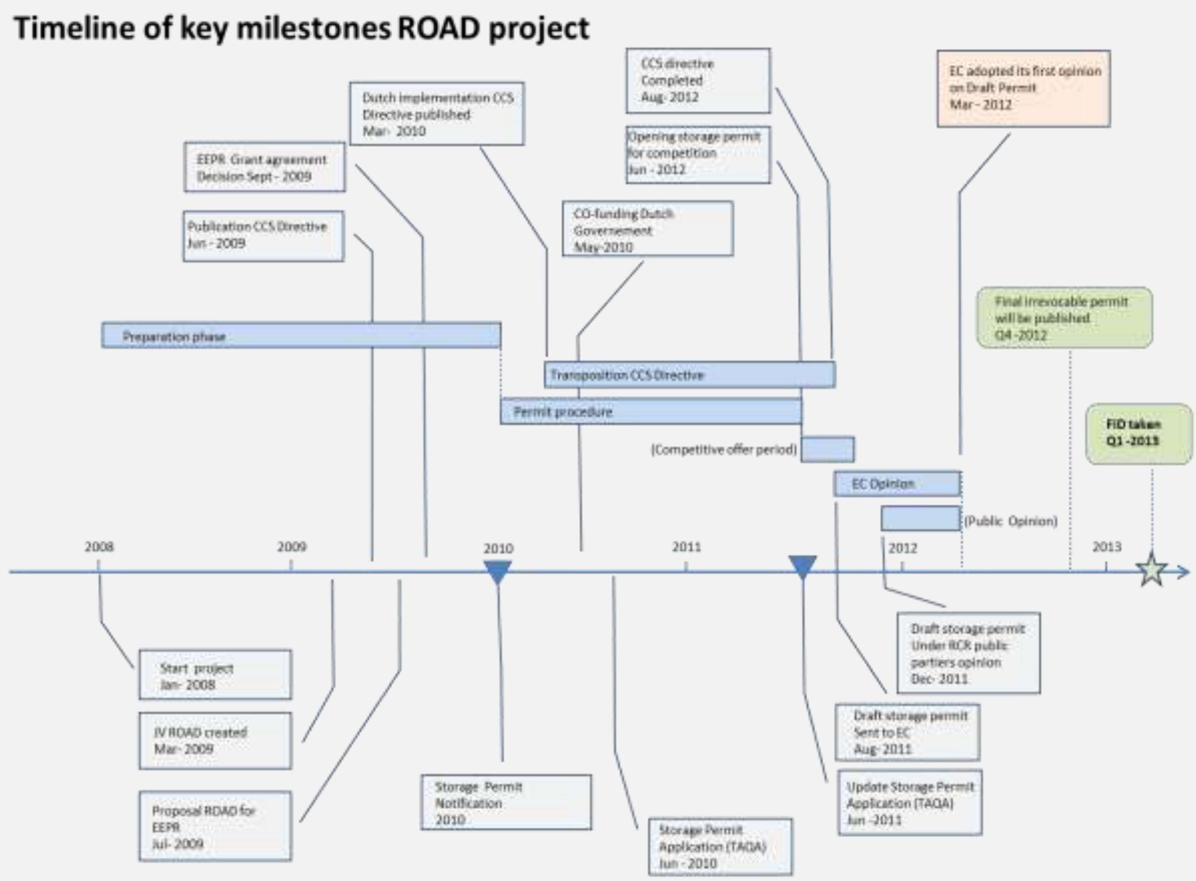
Internal organization and stakeholder management

In ROAD's experience, several different sets of expertise need to be brought together with a view to successfully obtaining the storage permitting. These include: technical, legal, communication, regulatory, and commercial negotiations. Organising a project should take into account the interactions and relations between all of these different experts. Structured weekly meetings during the permitting process (especially to line up with the external advisors) have been crucial, these included: technical experts meetings, and monthly meetings with the competent authorities. Communication to stakeholders or other third parties was centralised, and only a key team would undertake communications. This was highly appreciated by the competent authorities. ROAD experienced the same with the competent authorities, as they also appointed one general CCS manager. This single point of contact for both the project and authority proved to be a very effective and efficient method of discussing every aspect of the storage permitting process.

[38] ROAD, *Case study of the ROAD storage* permit, 2012.

Storage permit

The storage permitting process has taken almost two years, as characterised in the timeline below.



The CCS Directive gives a general regulatory framework to ensure permanent containment of CO_2 and, where this is not possible, eliminate possible negative effects and any risk to the environment and human health.[39] The Directive also introduces several key elements such as a monitoring plan, financial security provisions, provisions for the handover of responsibility and the financial mechanism. However, it only gives a high-level description of these elements and the interpretation of these elements is left to the Member States.

The Dutch Minister of Agriculture, Economic Affairs and Innovation decided to implement the Directive in its entirety, with no additional national provisions or any further interpretation of the key elements (monitoring plan etc.). ROAD fully endorsed this approach since each CCS project has its own specific characteristics, and in order to have a proper assessment of a project proposal a tailor-made approach is essential. Most other stakeholders agreed with this open and flexible legislation. The requirements for the storage of CO_2, set by the Government, are based upon the specific characteristics of each storage site. This means that the key elements of the CCS Directive are addressed in the storage permit.

Four key elements have been identified:

[39] Article 1(2) of the European Parliament and Council, *Directive 2009/31/EC on the geological storage of carbon dioxide*, 2009.

1. **Storage complex and storage site.** Following the information given in the CCS Directive, definitions are made regarding the storage site and for the storage complex. These definitions are not that easy to apply to a reservoir or deep saline formation. These definitions are also relevant regarding surrender of EUAs. No EUAs need to be purchased in case where the CO_2 leaks out of the storage complex, but remains trapped under the ground.
2. **Financial Security.** The CCS Directive requires that the storage operator must present proof that adequate Financial Security will be valid and effective before commencement of the injection. However, the CCS Directive does not require that the Financial Security be valid and effective at the time the permit application is submitted, only that it must be valid and effective before commencement of injection. The question which then was posed by ROAD was to what extent the applicant needs to provide proof in the permit application that the financial security will be "valid and effective" in time. ROAD faced the incongruity between the requirements of the CCS Directive and the “normal” practice for a demonstration project. Other essential questions included: (1) what are the obligations of the Financial Security and which activities must be included in the financial security? (2) What is an adequate calculation method for the amount of security which results in a good estimated amount of Financial Security? And (3) which instrument(s) would be acceptable for the Competent Authority?
3. **Financial Mechanism.** The CCS Directive states that Member States shall ensure that the operator makes a financial contribution available to the competent authority before the transfer of responsibilities to the competent authority takes place. The contribution should cover at least the anticipated cost of monitoring for a period of 30 years, but it also “may be used to cover the costs borne by the competent authority after the transfer of responsibility to ensure that the CO_2 is completely and permanently contained in geological storage sites after the transfer of responsibility”. In theory, this means that the competent authority can demand a financial contribution that is almost unlimited, while the competent authority will be forever responsible after the handover.
4. **Transfer of responsibilities.** After the storage site has been closed, the responsibility for all legal obligations can be transferred to the competent authority of the Member State, subject to several conditions. In ROAD’s opinion, clarity on the transfer of the responsibilities to the competent authority is one of the crucial issues that at this moment still has not solved. The main concern of the ROAD project is in which way and under which conditions the minimum period of 20 years can be reduced. The key questions that ROAD still has, include: (1) Which evidence is taken into account? (2) What if the competent authority is not convinced, although all available evidence indicates that the stored CO_2 will be completely and permanently contained? And (3) Who is going to assess this evidence?

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.

The first three regimes are also applicable on capture and transport, but this case study only addresses the storage permit, therefore only the liabilities for storing CO_2 are addressed in this case study. ROAD concludes that the liabilities arising from the EU ETS Directive are the main concern.

The business case for CCS

Photo: Bełchatów.

The business case for CCS

Summary of costs and risks

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 (responding to a changing regulatory or operating environment, and seeking future market leadership - in which case the project proponent is willing to make less of a return on the investment than normal) or commercial operation (where a certain rate of return is expected for the investment).

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 (see the box ‘CCS in context’ below). Such projects have very large up-front capital costs. For the Don Valley project, requires a capital expenditure (capex) of €5.8bn for the full chain – providing over 6,000GWh of clean electricity (650MW net generation capacity) and storing 5million tonnes of CO_2 emissions per year.

Estimated total project costs (excluding financing fees)	
Component	**Share (%)**
Power plant	68%
Transport (2Co share)	0%
Storage	26%
Sub-total	**94%**
Financing costs*	6%
Total	**100%**

Estimated power plant cost breakdown	
Component	**Share (%)**
CCS	59%
Non-CCS	26%
Other	7%
Sub-total	**91%**
Financing costs*	9%
Total	**100%**

** Financing costs comprise fees and interest accrued during construction*

Figure 23 Don Valley's capital cost details.

The majority of the costs are associated with the capture unit, a situation shared with the majority of the other projects in the Network. It should be noted that the Network projects in particular vary considerably in design and technology. Don Valley is a large new build IGCC, specifically designed for carbon capture. For smaller post-combustion projects, which only capture a fraction of the whole power plant’s emissions, the percentage share of the overall power plant’s cost are much smaller.

In addition, there are often quite high operational expenses (opex) for a CCS project. Usually, the greatest of these operational costs relate to the energy requirements for the capture and compression units. Such costs vary, with Don Valley’s costs including an air separation unit (ASU) needed for the gasification component of the IGCC, while for post-combustion capture solvents represent other additional costs.

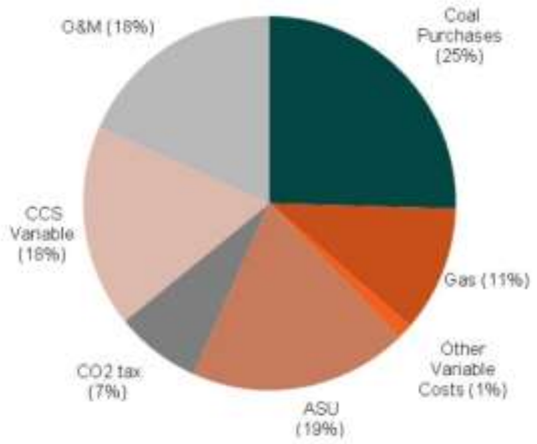


Figure 24 Don Valley's operating costs by share.

While not a comparable range for the points noted, the total energy demand for capturing CO_2 alone for the power sector is estimated by the projects within the Network to be between 0.08 and 0.4MWh/tCO_2, as shown within Table 5 (though note that the capture techniques, assumptions and elements reported varies per project).

Project	Energy requirement for each section of the chain in MWh/tCO_2		
	Capture	Compression / transport	Storage
Bełchatów	0.08	0.09	
Compostilla	0.402	0.0835	
ROAD	0.25	0.09 -0.15	0.00003
Porto Tolle		0.1	
Don Valley	tbc	0.0339	0.0004 (0.0002 to 0.002)

Table 5 The expected energy requirement for each technology in the chain. In the case where the figure has not been calculated, the box has been left blank. (All available data displayed).

The ROAD project provided the energy requirement for each technology in the CCS chain and the percentage energy requirement for the project is in Figure 25. It is important to note when considering this data that the ROAD project has a very short pipeline of just 26km.

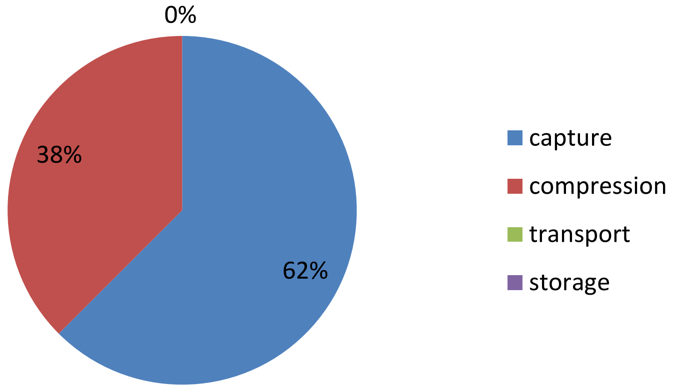


Figure 25 - The expected percentage of energy requirement for the ROAD project.

The operating costs for transporting and storing the CO_2 may be low, but the capital costs can be considerable. Two of the Network's early mover projects are actually taking on many of the costs, time and effort required to develop suitably scaled infrastructure that anticipates the large future demand for safe and viable storage of carbon dioxide – which will be vital in enabling the larger and longer term deployment of CCS, but they have few incentives for doing so while facing increased risk and upfront investment costs.

As noted in section relating to the timelines and project management, the time taken to develop a project of such a scale can be as long as 10 years – largely time taken to understand, minimise and reduce the risks associated with these costs. Doing so also helps reduce the cost of financing (internal, public, international, and private), which can become rather high for early mover projects of a new technology – even if CCS projects can individually produce clean low-carbon electricity, steel, gas, chemicals, etc. in quantities that are far greater, and more efficiently, than any other form of production. Such finance costs are another barrier to successful deployment of a project. [40]

[40] The CCSA have discussed the initial outcomes from the UK's CCS Cost Reduction Task Force.

Funding and incentives

Building a suitable business case for a CCS project is a key barrier to deployment, primarily due to the lack of income. The financing required per project is both significant and challenging in the current economic conditions, and because emissions are not properly levied. While this is a problem facing all such large infrastructure projects, because CCS projects are solely operating for environmental good – and function at such a large scale, and large resulting cost – the financial risks for early proponents can be quite large if there is not sufficient political backing and incentive to operate. Such risks need to be overcome in order for investors to be confident enough to take a final investment decision. The lack of an appropriate income is the main reason for delays in the deployment of projects within Europe and in the Network.

While there are multiple types of support that can be given to a project, including capital grants, operational incentives, debt finance, power price premiums, tax incentives etc. the following section will simply provide a brief overview of the global investment climate, followed by European and country specific funding and incentive schemes that apply to the Network members.

Investments globally

In order to provide some context to the levels and the state of assistance that has been given to European CCS projects, globally in 2011 renewable subsidies increased to $88billion with global investment reaching $257billion (primarily solar and wind, and excluding large hydropower). Together, these renewable energy sources are extremely important, and are expected to contribute 15% of the CO_2 abatement needs by 2020. By comparison CCS had been expected to contribute 4% of the CO_2 abatement needs by 2020, but received only $3billion of global investment in 2011.[41]

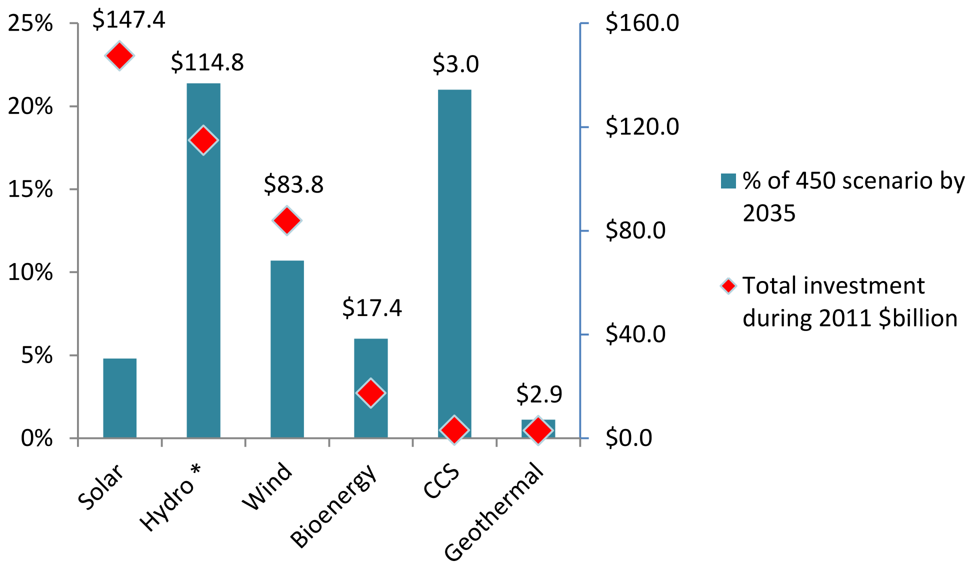


Figure 26 - Total investment in 2011 in clean technologies, Bloomberg New Energy Finance, compared to anticipated contribution to the IEA's WEO 2012's 450 scenario (derived data).

[41] UNEP (2012) and Bloomberg New Energy Finance data (Jan 2013).

CCS in context. A comparison with other low-carbon options

It is first prudent to note two points about the above and following figures. Unlike the power sector, where renewables can provide an alternative forms 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. Other electricity generation technologies can, and should, be used - but CCS in the power sector allows great quantities of electricity to be cleanly generated at scale. 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%. The reasons for this, using the Network projects as a comparative example (and these projects are only at demonstration scale), is illustrated below.

Wind

The projects in the Network will produce a total of 1710 MW of clean power. The projects average capacity factor is 75%. Based on these figures the Network will provide 11.2 million MWh/year of electricity. An equivalent 1710 MW wind farm[42], based on a capacity factor of 26% would only produce 3.9 million MWh/year of electricity, using 743 wind turbines and 291.5km^2 of land. A wind farm would require 4,932.7 MW installed capacity to produce an equivalent amount of electricity, requiring 2,143[43] turbines and 839.5km^2.

Solar

A 1710MW solar farm[44] based on a capacity factor of 19% would produce 2.8 million MWh/year of electricity using 1.6 million photovoltaic modules and 16km^2 of land. In order for a solar farm to produce an equivalent amount of electricity to the Network, it would require 6750MW installed capacity, requiring 5.85 million photovoltaic modules and 62.4km^2 of land.

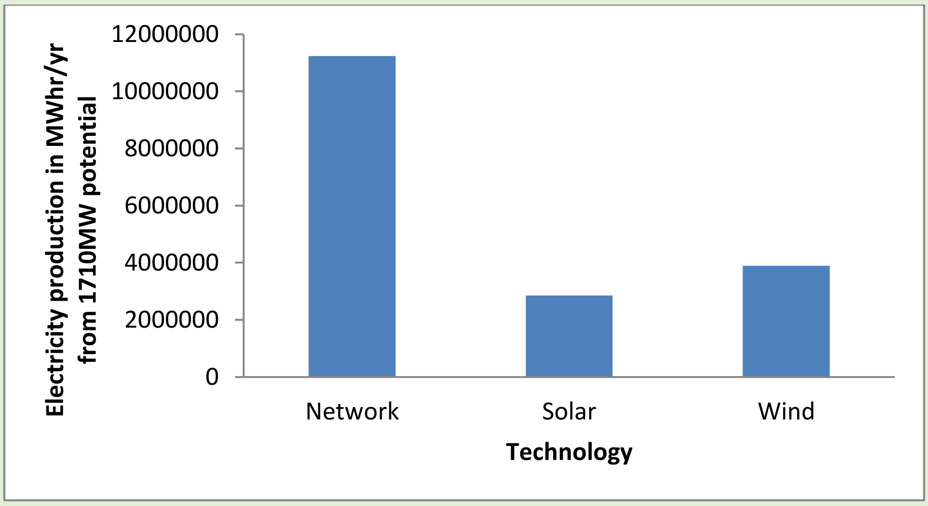


Figure 27 The projected electricity production from 1710MW installed capacity for each technology per year.

[42] Figures from the Whitelee wind farm in Glasgow have been used.

[43] Figure assumes no loss in capacity factor due to scale up.

[44] Figures based on the Montalto di Castro farm in Italy.

Funding for CCS in Europe

As noted within Figure 3 Map of the European CCS Demonstration Project Network 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. In 2008 The European Council called upon the Commission to bring forward a mechanism to incentivise Member State and private sector investments to ensure the construction and operation by 2015 of up to 12 CCS demonstration plants.

Within Europe a number of funding schemes have been established to aid the development of CCS, and these will be briefly outlined below. It should be noted that many of the issues identified within the following sections are currently being raised and addressed under the European Commission's *Green Paper: A 2030 Framework for Climate and Energy Policies* and the *Consultative Communication on the Future of CCS in Europe*.[45]

EEPR

European Energy Programme for Recovery (EEPR) was set up to co-finance projects designed to make energy supplies more reliable and help reduce greenhouse emissions, while simultaneously boosting Europe's economic recovery following the global economic crisis. The Commission launched a call to fund a portfolio of CCS projects in May 2009, received 12 proposals in July, assessed and awarded 6 grant agreements by early 2010. The Network's founder member projects were all awarded funding, ranging from €100-180m. This was shown to be fast, and effective method of providing funding to projects. This stimulus package contains a portfolio of capture technologies, and a full variety of transport and storage options at industrial scale. It should be noted that this is a limited funding stream, and cannot fully finance or support a CCS project.

NER300

The revised ETS Directive set aside 300 million EU allowances (EUAs) for the co-funding of CCS and innovative renewable projects. It was anticipated that 12 projects would be funded from this New Entrants Reserve (NER300). It was expected that the NER would raise €4.5bn, based on November 2010 prices when the first call was launched.

On the 18th of December 2012, the European Commission announced its award decision under the first call for proposals of the NER300 funding programme. Unfortunately no CCS projects were selected for the funding, and more than €1.2 billion (US$1.6 billion) has been awarded to 23 innovative renewable energy demonstration projects.

CCS projects were not selected during this round of funding primarily because of a lack of commitment from the member states to support their domestic project. The majority of projects were withdrawn citing "funding gaps" as the primary reason, largely a reflection of the capital requirements of such large scale infrastructure projects, and the wider economic environment within Europe. There was an exception, where the ULCOS Blast Furnace project (a CCS steel production plant) was given confirmed support by its Member State, but was then subsequently withdrawn from the process.

[45] See the Network's response to the Communication on the website.

The sale of the remaining 100 million allowances will be used to fund this second call, and the unused funds from the first call will be added to it.

The last phase of this funding programme was launched during the first quarter of 2013, with the objective of completing it by early 2014. The fact that no CCS projects were provided financing, despite 11 CCS projects passing extensive technical and financial due diligence assessments, is a reflection of a number of issues with the programme.

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. On the 30th of October 2012, the UK Department of Energy and Climate Change (DECC) announced its shortlist of projects to compete for the funding and in March 2013 DECC announced that the two projects taken through to Front End Engineering Design (FEED) are White Rose (Yorkshire, England) and Peterhead (Aberdeen, Scotland). The transport and saline storage solution for the White Rose project is the same shared user infrastructure that is being developed by National Grid with Don Valley. Under the Programme projects are also able to benefit from the reforms being made 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

In addition to the direct funding situation, European Member States are not providing operational support nor subsidies to CCS on a par with comparable clean technologies. Nevertheless certain key long-term steps have been taken.

Emission allowances

For the majority of projects being planned within the EU the main benefit for operating a CCS plant is that under the amended Emissions Trading System (EU ETS), each tonne of CO_2 that has been successfully captured and stored will be viewed as 'not emitted', therefore removing any obligation by the company operating a plant to purchase an emission allowance.[46] <u>This has been the single most important step in providing a long-term incentive for CCS operations.</u>

While this is a hugely important step for CCS, it faces a number of problems. Such a market based mechanism intrinsically promotes the use of established, lowest cost technologies, and is not suited to supporting new low-carbon technologies, such as CCS, alone. This situation has been exacerbated due to an over allocation of allowances, and other factors, resulting in EUAs being trading at around €4.50 (December 2012), proving little incentive to invest.

It is worth noting that the Directive foresees Member States using at least 50% of their auctioning revenues to finance 'the fight against climate change', including CCS.

[46] Directive 2009/29/EC of the European Parliament and of the Council amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community

UK

One exception is the UK, where a Carbon Price Floor (CPF) was introduced in April 2013 (at £16 per tonne of CO_2 and is designed to reach £30 by 2020 and £70 by 2030 in real terms); a Feed-in Tariff supported though technology-specific 'contract for differences' (CfD) for low-carbon energy; and an Emissions Performance Standard (EPS). The CfDs will probably have the greatest impact on CCS, providing a stable revenue stream by removing a power plant's exposure to price volatility, thereby granting investment certainty.[47]

Norway

The simplest incentive mechanism is in Norway, where a CO_2 tax was introduced in 1991. This has resulted in two large scale CCS projects, Sleipner and Snøhvit, with Sleipner operating since 1996 and storing the largest amount of CO_2 to date (for emission mitigation purposes alone). Facilities affected by the tax are also liable to cancel EUA allowances for their CO_2 emissions, therefore the carbon tax is adjusted periodically based on expected future ETS EUA prices. In January 2013 this carbon tax increased to NOK410 per tonne of CO_2 (€55).

Making the business case

In summary, while many steps are being taken, some of which may allow a project to take a positive financial investment decision, more needs to be done. Unlike many forms of renewables, which are 'commercially available', there has been a lack of similar or appropriate incentives and support from Member States for CCS as a low-carbon technology.

As previously mentioned, two of the Network's projects will not be proceeding – Jänschwalde and Bełchatów. Both were well developed and very credible projects, situated within two countries that have a great reliance on fossil fuel generated electricity and industries – ideally placed to profit from the environmental, economic, and energy security benefits that CCS provides. Both have been cancelled largely due to a lack of policy commitment and certainty. This clearly shows the necessity for political support to CCS on all levels of jurisdiction and how important this risk is for project deployment. Other risks include regulatory conditions, capital costs, delays in commissioning, and decommissioning challenges.

For more detailed information about making the business case for an individual Network projects, considering the income, risks and costs, see the report from the Don Valley project, '*Making the Business case for CCS*'.

[47] See also 2CO, *Making the Business case for CCS*, 2012.

Knowledge sharing

Outreach and Global Knowledge Sharing

The European CCS Demonstration Project Network is the world's foremost project knowledge sharing body. It functions by bringing together the experts on specific topics from each project on a regular basis to discuss specific topics for mutual benefit. Such meetings are often private and peer-based to ensure that a free dialogue is held – with as many of the learnings as possible from each workshop being made public by the Secretariat on a regular basis. External participants are invited to almost every meeting, ranging from other projects proponents, NGOs, technical experts, to researchers and developers. All publically available outputs are accessible through the Network's website www.ccsnetwork.eu.

It is widely acknowledged that knowledge sharing on a global basis will be critical in facilitating the widespread deployment of carbon capture and storage as a climate change mitigation technology. The need for inter-project knowledge sharing is even more crucial in the current economic environment, which has resulted in fewer large scale CCS projects in operation than originally anticipated.

The European CCS Demonstration Project Network has built up a considerable track record in peer-based project knowledge sharing. During 2012 the Network has engaged in a number of international knowledge sharing events including the international knowledge sharing event held in Alabama focusing on CO_2 monitoring techniques, organised by The Southeast Regional Carbon Sequestration Partnership (SECARB), the Southern States Energy Board, the Global CCS Institute, Natural Resources Canada, the European CCS Demonstration Project Network and the U.S. Department of Energy. Network members also engaged in the Platts conference, the opening of TCM Mongstad and IEAGHG 11. In addition to these events the Network has invited a number of external speakers to the knowledge sharing events, including a training workshop with the CO2ReMoVe project, engagement with the ECO2 project, and held its own dissemination event. The dissemination event provided the opportunity for the Network's projects to present on progress made this year and to hear from the Getica project and the Green Hydrogen project.

The Network is currently working with the Global CCS Institute to produce a structured plan for future global knowledge sharing.

Proposed topics for further investigation by the research and development community

Introduction

The purpose of this section is to provide the research and development (R&D) community with a perspective on the major issues identified by the projects within the European CCS Demonstration Project Network.

It collates the identified topics that the projects feel that further work is required, captured in the 2012 knowledge sharing events and six monthly survey of the projects.

While producing such a report to the R&D community is a new action by the Network, and may not be at the appropriate level, efforts will be made to reach out to specific areas of the community as appropriate. For further information, please contact the Network Secretariat.

It is hoped that the following items will be of interest. For more detail regarding the activities of the projects, particularly regarding their own research, see the thematic reports produced every six months by the Network. These can be found on the website www.ccsnetwork.eu.

Suggested topical areas

General comments

- The primary technological issue facing projects 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.

- While combining co-firing biomass with CCS can create negative emissions – the only technology to do so at scale, and will become an increasingly important topic – there is a view that co-firing biomass is actually competing with CCS at the moment as a separate 'industry'. This will need to be addressed as the two need to work together, and the need to review the incentives for biomass firing with CCS is explicitly referred to under the CCS Directive. Investigations into the net negative emissions balances, sustainability and methods for inclusion under the ETS all warrant further attention.

- A specific topic that the R&D community could urgently contribute to is investigation of the role of residual components in controlling phase behaviour of CO_2 in the transport and storage systems.

Capture

One of the largest areas of cost and concern is the capture element of the project.

- While a very wide topic, energy efficiency improvements will help drastically with the costs. This applies to all elements of the systems being investigated by the projects (liquid solvents, solid sorbents, membranes, WSG catalysts, compressors etc.)

- Materials selection 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 WSG integration, ASU optimisation, reduced steam requirements).

Transport

The transport of CO_2 by pipeline is primarily a topic that is facing regulatory issues, rather than technical problems (for example the lack of appropriate regulations in Spain), there are a number of aspects to be looked at. (See question regarding CO_2 purity above). During 2013 this topic will be discussed for the first time by the Network, and it is expected that more tangible needs will be defined.

- Parameter assurance is a topic that has been raised by the projects for further investigation.

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 area that would benefit from elaboration is the adaptation, application and reliability of CO_2 monitoring systems.

Conclusions

Photo: The Sleipner A Platform, as seen from the Sleipner T carbon dioxide treatment platform

Conclusions

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

During 2012 a large number of expert knowledge sharing workshops were held – often with other large scale projects both within Europe and internationally, and a number of research projects – covering a wide range of topics. These workshops included discussions covering CO_2 monitoring techniques, public engagement activities, regulatory and permitting developments, and storage characterisation.

Collectively the Network has stored 1 million tonnes of carbon dioxide during 2012. The projects within the Network working toward operational status continue to be developed, despite adverse delays due to permits and the unfavourable conditions for making final investment decisions.

During 2012 the Network was comprised of 3 post-combustion power projects, a gas processing project, one oxy-fuel power project, and one IGCC power project. Sleipner is the only project currently in operation. Each and every project will capture over 1 million tonnes of CO_2 per annum, at a capture rate of over 90%. The energy demand for capturing CO_2 for the power sector incurs the largest cost. SOx and NOx are quoted by the projects as the most common expected impurities in the slip stream gas.

Four projects (Don Valley, Porto Tolle, 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 between 30 and 80 ^{o}C.

For storage, a range of storage sites are being used or have been investigated, ranging from onshore saline formations, to offshore depleted gas reservoirs and EOR operations. Projected bottomhole pressures for Compostilla, Don Valley and Sleipner range from 80 to 248 bara, and injection rates varying between 30-70kg/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.

In terms of permitting and regulatory development, the ROAD project's storage permit has been successfully reviewed by the European Commission, which has given its first opinion of a permit submitted under the CCS Directive (a second opinion will be given prior to injection). The Bełchatów and Compostilla project still require further finalisation and implementation of the transports and storage regulatory regimes by their respective authorities. The Porto Tolle project needs to re-submit the Environmental Impact Assessment for their base plant.

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 – often more than 10 years for early movers – 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 suit.

As previously mentioned, two of the Network's projects will not be proceeding – Jänschwalde and Bełchatów. Both were well developed and very credible projects, situated within two countries that have a great reliance on fossil fuel generated electricity and industries – ideally placed to benefit from the environmental benefits; economic benefits; and energy security benefits that CCS provides. Both have been cancelled largely due to a lack of investment and policy commitment and certainty.

Current deployment and incentive mechanisms 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. The ETS is a mechanism unsuited to supporting the deployment of new technologies such as CCS, and with the deterioration of ETS prices there are few signals to the market that encourage investment. First movers face significant risks and costs. Unlike many forms of renewables, which are commercially viable, there has been a lack of similar or appropriate incentives and support from Member States for this low-carbon technology.

Appendix 1 – Raw data from the Network

It should be noted that the current format of the Network's survey reporting was mainly formed to comply with conventional power cycles, particularly post-combustion schemes. For this reason, the questionnaire does not cope with the characteristics of differing schemes such as oxy-combustion and pre-combustion. Nor does it fit with industrial processes such as Sleipner. For this reason it has not been possible for projects to fully, or consistently, provide usable data.
A proposal is currently being made to amend the current questionnaire.[48]

IEG 2012 Public.xlsx

The use of the filters is recommended.

Appendix 2 - Glossary

Ar	Argon
BAT	Best Available Technology
BarA	Absolute pressure
BarG	Gauge Pressure
CAPEX	Capital expenditure
CBL	Cement bond logging
CCGT	Combined Cycle Gas Turbine
CCS	Carbon capture and storage
CCSA	Carbon Capture and Storage Association
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 Difference
CH4	Methane
CO	Carbon monoxide

[48] The current set of data should be interpreted with care. For example, whereas Compostilla combines oxy-coal combustion technology and a fluidised-bed furnace, Bełchatów, Porto Tolle and Road apply post-combustion flue gas cleaning of slip streams diverted from the exhaust gas duct. Due to the differences in slip stream and plant size of these projects, it is hard to compare the operational data and to characterise their 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).

CO_2	Carbon dioxide
CPS	Carbon Price Support
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
FGD	Flue Gas Desulfurisation
FID	Final investment decision
FIT	Feed-in tariff
FS	Financial Security
GCCSI	Global Carbon Capture and Storage Institute
GHG	Greenhouse gas
Gt	Gigatonne
H_2	Hydrogen
H_2S	Hydrogen sulphide
IEA	International Energy Agency
IGCC	Integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
ISO	International Standards Organization
Kg	Kilogram
km	Kilometre
kW	Kilowatt
kWh	Kilowatt hour
LCOE	Levelised cost of electricity
NH_3	Ammonia
MEA	Monoethanolamine
MMV	Monitoring, measurement and verification
Mt	Megatonne (one million metric tonnes)
MVA	Monitoring, verification and accounting
Mtpa	Million tonnes per annum; million tonnes a year
MW	Megawatt – a unit of power
MWe	Megawatts electrical capacity
MWh	Megawatt hour – a unit of energy
MW/h	Megawatt per hour (change of power per hour)
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
OEM	Original equipment manufacturer
OPEX	Operating expenses
PC	Pulverised coal
ppm	Parts per million
R&D	Research and Development
RD&D	Research, Development and Deployment
SO_2	Sulphur dioxide
SOx	Sulphur oxides
TWh	Terawatt hours
VDL	Variable density log

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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.

Network support provided by: