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Highlights and Lessons from the EU CCS Demonstration Project Network

Zoe Kapetaki[a,]*, Jens Hetland[b], Thomas Le Guenan[c], Tom Mikunda[d], John Scowcroft[a]

[a]*Global CCS Institute, Place du Champ de Mars 5, 1050 Brussels, Belgium*
[b]*SINTEF Energy Research, Kolbjorn Hejesvei 1A, N-7465 Trondheim, Norway*
[c]*BRGM, 3 avenue Claude Guillemin BP36009, 45060 Orléans Cedex 2, France*
[d]*TNO, Princetonlaan 6, 3584 CB Utrecht, The Netherlands*

Abstract

The European Carbon Capture and Storage (CCS) Demonstration Project Network (the "Network") is currently composed of projects located in the Netherlands, Norway, Spain, and the UK. The goal of the Network is to accelerate deployment of CCS by sharing project development experiences about technology implementation, including transport and storage of CO_2, as well as regulatory environment and financial structures. This paper aims to provide an overview of some CCS insights gained from developing the Network projects. Besides technology and project development, sharing knowledge and lessons learned on project-level basis, have also given valuable insights on how policies can enable development and implementation of appropriate regulatory frameworks, and funding schemes towards effective deployment of CCS technology in power generation sector.

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1. Introduction

In December 2015, the Conference of the Parties (COP21) agreed on an ambitious target: To keep the increase of the global average temperature to well below 2°C, and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels. Making the target more stringent than the previous 2°C, strengthens the case for a need of deep-cut technologies such as carbon capture and storage (CCS). Deep reductions are needed not only in the power sector, but also in industry where the decarbonisation options are limited.

Nomenclature

CCS	Carbon Capture and Storage
CFB	Circulating Fluidised Bed

* Corresponding author. Tel.: +32 – 495 – 541 – 689.
E-mail address: zoe.kapetaki@globalccsinstitute.com

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CfD	Contract for Difference
DCO	Development Consent Order
DECC	Department of Energy and Climate Change
EC	European Commission
EEPR	European Energy Programme for Recovery
EIA	Environmental Impact Assessment
EOR	Enhanced Oil Recovery
ETS	Emissions Trading System
EU	European Union
EUA	Emission Unit Allowance
FEED	Front End Engineering and Design
FID	Final Investment Decision
GHG	Greenhouse Gas
MS	Member State
NER	New Entrants Reserve
PFBC	Pressurised Fluidised Bed Combustion

The EC, in its Energy Roadmap 2050 [1], proposed a number of different scenarios to meet the stringent 2050 emissions reduction targets. 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.

On this basis, six power projects were awarded funding under the European Energy Programme for Recovery in 2009, conditional on progression monitoring according to the agreed timeline, and proper knowledge sharing. This paper aims to provide information and key findings on obstacles and lessons learned by the projects since their inception.

1.1. The European CCS Demonstration Project Network

Successful operation of CCS demonstration projects is seen as crucial for enabling widespread commercial application of near zero emission power plants and industrial installations, to meet the European Union and global emission reduction goals.

In 2009, the European CCS Demonstration Project Network (the Network) was established by the European Commission to accelerate the deployment of commercially viable large-scale CCS projects across Europe. The Network was created to support knowledge and experience sharing among this community of European projects. Since 2009, knowledge and experience sharing has not been limited to technical progress – policy issues and regulatory development as well as public perception have also been a focus.

The Network provides added value to the European CCS projects by:

- Identifying good practices, lessons learnt and recommendations for large-scale project development,
- Providing a common EU identity to Network Members,
- Promoting CCS, EU leadership and cooperation potential to third parties/countries;
- Supporting the creation of a global network on CCS project development.

One of the goals of the Network is to create and facilitate a community of individual CCS demonstration projects that can share solutions aimed at accelerating project progress. All projects that apply for membership of the Network, inter alia, provide evidence about the maturity of the project, commit to knowledge sharing and actively participate in the Network organisation and procedures.

The Network is made of a unique collection of large-scale, early-mover CCS projects (Figure 1). The efforts of these early mover projects alone have had the potential to make a substantial impact on CO_2 emissions mitigation. The Sleipner Project captures and stores around 1 million tonnes of CO_2 per annum from its light oil and gas field.

However, the overall project development progress has been difficult for a number of reasons such as a lack of national CCS enabling policies, public support and of sound public financial support.

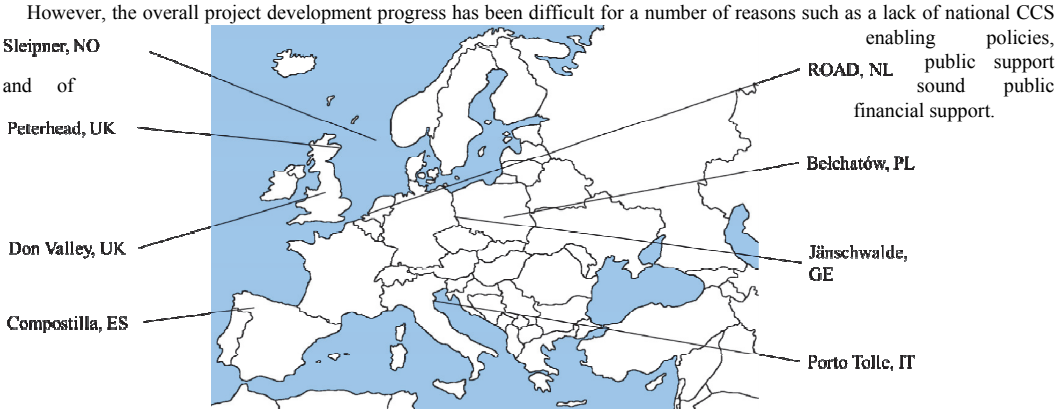

Fig. 1. Current and former Network projects by country.

1.2. Member's overview

The Network has undergone several changes since its inception. Originally, the Network comprised of the six projects that were awarded funding under the EEPR initiative: Bełchatów (Poland), Compostilla (Spain), Don Valley (UK), Jänschwalde (Germany), Porto Tolle (Italy) and ROAD (the Netherlands).

Four of the founding Network projects were suspended. First Jänschwalde in 2012, then Bełchatów, Compostilla and Porto Tolle in 2013.

The Norwegian Sleipner project joined the Network on 2012. The Peterhead CCS Project joined the Network in mid-November 2015. Nevertheless, following the UK Government spending review announcement of 25 November, the funding that the CCS commercialisation competition could have provided to the Peterhead project was withdrawn. Shell U.K. Limited, the project proponent, decided to honour its remaining commitment under the Front End Engineering and Design (FEED) contract it entered into with the UK Government in 2014, but it announced that the project would not proceed further.

Table 1. Current and former Network projects reference table.

Member	**Country**	**Industry**	**Capture Type**	**Transport Type**	**Primary Storage**	**Status**
Bełchatów	Poland	Power generation (coal)	Post combustion	Pipeline (onshore)	Onshore saline aquifer	Suspended (2012)
Compostilla Oxy CFB 300	Spain	Power generation (anthracite and pet coke)	Oxy combustion	Pipeline (onshore)	Onshore saline aquifer	Suspended (2013)
Don Valley	United Kingdom	Power generation (natural gas)	Initially pre-combustion (IGCC-CCS) turned into pressurised post-combustion (Sargas)	Pipeline (onshore to offshore)	Offshore saline aquifer (with later options for EOR)	Active. FID pending
Peterhead	UK	Power generation (natural gas)	Post combustion	Pipeline (onshore to offshore)	Offshore depleted gas reservoir	Suspended (2015)
Jänschwalde	Germany	Power generation (coal)	Oxy- and post-combustion	Pipeline (onshore)	Onshore saline aquifer / gas field	Suspended (2012)
Porto Tolle	Italy	Power generation (coal)	Post combustion	Pipeline (onshore to offshore)	Offshore saline aquifer	Suspended (2013)
ROAD	Netherlands	Power generation (coal with option of co-firing with biomass)	Post-combustion	Pipeline (onshore to offshore)	Offshore depleted gas reservoir	Active. FID pending
Sleipner CO_2 Injection	Norway	Offshore natural gas processing unit	Absorption at high pressure (no combustion)	No transport required (i.e. direct injection)	Dedicated offshore saline aquifer	Active. Operational since 1996

1.3. Network evolution through the years

The Jänschwalde project was one of the founding members of the Network and recipient of EEPR funding, however due to the ongoing impasse in the German CCS law, Vattenfall, the project operator, decided to halt plans for its CCS demonstration project in Jänschwalde, and consequently to resign from the Network.

The Bełchatów project in Poland was another founding member of the Network. In April 12, 2013, PGE, the project's proponent, announced that it had cancelled the Bełchatów because the company was unable to secure the necessary financing for the project.

The Porto Tolle project faced severe delays due to the annulation of the environmental permit for the Porto Tolle power plant, as well as difficulties in achieving closure for its financial structure. It was finally terminated in August 2013.

The Compostilla project completed its FEED study in 2013. The project did not proceed to full scale construction and operation. However, significantly advanced CO_2 capture and storage pilots have been developed through this project.

All of the projects experienced difficulties planning and following timelines. This was mainly due to commercial uncertainty and delays with reaching final investment decisions.

2. Project highlights

Bełchatów

- The project completed a comprehensive FEED study for the capture component.
- Capture ready status for the new-built 858 MW_e power plant where CCS would be integrated, has been obtained.
- Building permits were acquired for the capture plant but complications arose due to procurement rules.
- The storage site selection was completed and a feasibility study for transport was completed.
- The project operators carried out a public engagement campaign.

Compostilla

- Engineering design of a 330 MW oxy-combustion boiler with associated integration units was completed.
- Associated tests conducted yielded positive preliminary results.
- Pipe design and track of a 147 km pipeline with a fairly large height difference (350 m inlet-to-outlet, and with 600 m as maximum) was concluded.
- Preliminary characterisation of subsurface structures was well advanced.
- Economic and risk assessment finalised.
- The project proponents' FID, resulted in the cancellation of the full scale project in November 2013.
- The storage pilot developed within the project continues operations in the Hontomín Technology Development Plant, located in Northern Spain.

Don Valley

- Offshore storage feasibility study was completed.
- Project milestone decision taken to select the 5/42 (Endurance) site as the storage solution for the project.
- Successful appraisal drilling programme of the saline aquifer storage site (Endurance) completed, with the work receiving the award for innovation at the prestigious Gas Industry Awards 2014.
- Carbon dioxide captured from the (new build) Don Valley power plant in Stainforth (UK) would be transported to Bramston on the Yorkshire coast via a 'Shared User' pipeline to be constructed by National Grid Carbon (the Yorkshire and Humber CCS Cross Country Pipeline).
- The Development Consent Order (DCO) application to the UK Planning Inspectorate for the 'Shared User' pipeline, from the Camblesforth Multi-Junction site to the coast at Barmston, has been submitted and accepted by the Authority.
- Sargas Power acquired the Don Valley Power and CCS Project from 2Co Energy Limited in December 2014.
- The project shifted from pre-combustion with coal (IGCC-CCS) to post-combustion pressurised CO2 capture via potassium carbonate in a power cycle fuelled by natural gas.

Jänschwalde

- The proposed demonstration project would use two capture technologies, a rebuilt 250MW oxyfuel unit and a 50MW post-combustion capture unit.
- The oxy-combustion unit was to be built on technology developed by Vattenfall in a pilot at Schwarze Pumpe.
- Due to public opposition and political impasse in the German CCS law, Vattenfall – the project proponent – decided to terminate plans for its project plans.
- The project was cancelled in late 2011.

Peterhead

- In 2012 the UK Government selected Peterhead as one of four successful projects shortlisted to continue to the next stage of its £1 billion CCS Commercialisation Programme.
- In 2013 the Peterhead CCS Project was chosen as one of two preferred bidders eligible for capital funding available under the CCS Commercialisation Programme to undertake FEED studies over the following 18 months.
- The UK Government awarded Shell U.K. Limited with a 'multi-million pound' FEED contract for its Peterhead CCS Project in February 2014.
- Following the announcement by the UK Government, on November 25th 2015, of the withdrawal of funding for the CCS Commercialisation Competition, the project will not proceed to further stages.

Porto Tolle

- The Pilot in Brindisi has run for over 5,000 hrs, with promising results on the energy conversion and environmental aspects.
- The project completed its FEED for the capture unit.
- The project had been severely delayed because the Italian courts initially rejected giving Enel an operating license.
- Enel decided to re-apply for an Environmental Impact Assessment for the base plant.
- In 2013, the project was terminated.

ROAD

- Detailed engineering of the plant is completed.
- Permitting procedures finalised.
- Capture permits are definitive and irrevocable.
- Storage permits are definitive and irrevocable.
- Technical refinements are to be conducted before injection starts (in particular monitoring plan, corrective measures and financial security will be reviewed).
- The decline in the price of credits under the EU emission trading scheme led to foreseen financial gap in the business case, and delayed a final investment decision.
- In order to reduce the project's cost, the ROAD project has been looking at an alternative storage option, which is closer to the capture source and requires a shorter pipeline Q.

Sleipner

- Operational since 1996, capturing almost 1 Mtpa CO_2 from natural gas processed from the Sleipner East and the Sleipner West gas and condensate fields.
- Since 2014, CO_2 capture facilities at Sleipner T process an additional 100,000 to 200,000 tonnes per annum of CO_2 associated with gas production from the Gudrun field, which ties in to the facilities on Sleipner East.
- Apart from minor operational fluctuations, the main reason for annual changes in injection was found to be the gradually declining CO_2 content of the produced gas.
- An extensive program to monitor and model the distribution of injected CO_2 in the Utsira Formation is in place. This program includes a baseline 3D seismic survey and eight time lapse (4D) seismic surveys, three seabed microgravimetric surveys, one electromagnetics survey and two seabed imaging surveys.

3. Risks, challenges and lessons learned

3.1. Technology

The Bełchatów project was planning for a 260MWe post-combustion capture system integrated with the newly-built (2011) 858 MW unit at the 5,053 MW lignite-fired power plant. The CO_2 capture efficiency was expected to be >80% utilizing an advanced amine process.

Enel, Porto Tolle CCS project's proponent, tested a variety of different chemical solutions to capture CO_2 with the aim of finding the most effective one. The ROAD project has finalised the design of the CO_2 capture unit, which will be using primary amines in post-combustion. Sleipner's capture facility reduces 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).

The initial Don Valley FEED study for the power plant started in 2009 and work on an update and further definition, was halted when the project was de-selected from the UK competition in late 2012. After acquired by Sargas Power in 2014, the project has been looking at introducing different technology combining the advantage of the pressurised fluidised bed combustion technology (PFBC) with pressurised post-combustion carbon dioxide capture. The CO_2 capture unit employs a

chemical absorption technology, a thermally regenerated cyclical solvent process that uses activated hot potassium carbonate for removing CO_2.

The Jänschwalde project planned to add a 50MWe (gross) post combustion chilled ammonia capture process unit retrofitted to an existing 500 MW lignite block of the power station, and build a new 250MWe (gross) oxyfuel capture unit. Compostilla project was planning to use a Flexi-Burn CFB based on Foster Wheeler technology. The academic partner in the project (CIUDEN) successfully commissioned a 30MW boiler and testing yielded positive results.

The technical experience gained by the projects through their planning stages showed that there are *no significant concerns regarding technology and technology implementation is not considered a major reason for project progress delays.*

All of the Network's projects have been planning to use pipelines to deliver the captured CO_2 to the storage site. Don Valley, Porto Tolle and ROAD opted for offshore, subsea pipelines to reach the storage location. Sleipner is already using a subsea pipeline. Projects that were planning to use onshore pipelines, i.e. Bełchatów, Compostilla, Jänschwalde, are now suspended.

In a study published in 2014 [2], the projects concluded that CO_2 transport through pipelines is not a major hurdle because within certain operational limits CO_2 pipelines can be designed and operated efficiently. In project experience, the thermophysical nature of CO_2 makes two-phase flow possible, even during transient operations such as shut-down and restart of a pipeline at a very low back-pressure (less than 20 bar). The resulting dynamic behaviour of the two-phase flow, causing slugging, is still not fully understood and would require special attention in future developments.

With regards to CO_2 storage, the projects that decided to opt for onshore formations are now cancelled. Onshore transport and storage appeared to be challenging for project progress. In the case of Jänschwalde project, it can even be considered one of the reasons for cancellation due to public opposition on the initiative. While there have not been significant concerns regarding technology and technology implementation, a valuable lesson is that *public support proved to be essential for projects to progress with onshore activities.*

3.2. Regulatory Frameworks

Policy and regulatory development are key factors in the facilitation of CCS. There is a wide range of policy, legislation, and regulation relevant to CCS, from international climate change agreements, through national climate and energy policy, to project-specific legislation and regulation. The European Commission has supported and encouraged CCS with a number of policy instruments. The most important policy from the EU is the Carbon Dioxide Storage directive (Directive 2009/31/EC) – one of the most comprehensive examples of CCS-specific legislation.

The directive creates a framework, allowing the capture and transport of CO_2 to be regulated under existing legislation, and establishing foreseeable permitting procedures for the storage of CO_2. The directive establishes liability, responsibility and sets a range of obligations for storage; including site selection, operating, closure and monitoring activities, and the process regarding the site transfer to the relevant competent authority.

In order to assess the adequacy of the existing CCS directive, the European Commission held a series of public consultations in October 2014. The conclusion of consultations was that while the directive created challenges for the projects, opening the directive could result in an even higher set of unknowns, which might delay project development further. Thus, the recommendation was that the directive remained unchanged [3].

The directive was to be transposed by mid-2010 and included in the legislation on a member-state level. The transposition of the directive was in most cases significantly delayed – which was one out of several reasons why for example the Polish Bełchatów, the German Jänschwalde and in part Compostilla project in Spain not moving forward [4].

Bełchatów and Jänschwalde progress was challenged by the inadequate regulatory response at national level. Poland transposed the CCS Directive in April 2013 – about two years after the deadline. Germany transposed the Directive in August 2012. By that time, the proponents had already terminated the project (February 2012) partially because of the delays by the German authorities in transposing the EU directive on CCS.

At a national level, Network experience has shown that for a project to progress, it is particularly important to have a clear and efficient permitting process in place. For example, the Compostilla project faced serious delays due to the lack of CO_2 permitting regulation. Spain fully implemented the CCS directive by December 2010 (Ley 40/2010), however, it did not develop a system for storage licence application. It also did not transpose the amendments from the EIA directive that was addressing CO_2 transportation legislation. A valuable lesson from the projects' experience is that *timely transposition and alignment of legislation on the EU and national level is essential* to overcome delays and avoid project cancelations.

The Porto Tolle project also faced regulatory challenges – the project was aiming to finalise the permit in 2014 but was severely delayed because of the decision from the Italian State Council to annul the plant's initial Environmental Impact Assessment. The change from oil to coal combustion required a new EIA. The project was terminated in August 2013 at the request of the developer due to delays in project execution caused by these permitting issues.

The ROAD project achieved a considerable milestone when its storage permit for the P18-4 offshore field was successfully reviewed by the European Commission. In September 2013 the final storage permit became definitive. The basic design of the capture plant has been completed, and irrevocable capture plant permits have been obtained. These two substantially different project experiences demonstrate *it is important of having clear and comprehensive permitting procedures in place for projects to*

progress. In light of the alteration in the storage location for the project, from the P18-4 field to the closer by Q16-Maas field, regulatory activities for the project are still ongoing.

3.3. Funding and incentives

CCS projects have large up-front capital costs as well as substantial operational expenditure and considerable funds are required to secure full deployment of this technology. A number of financial instruments have been established to support projects throughout different stages of development.

The EU Emissions Trading System (ETS) was to be an important incentive mechanism for CCS in Europe. In 2008, the EU agreed to set aside 300 million European Union Allowances from the New Entrance Reserve (NER) of the EU ETS. The NER 300 funds were to be used to finance demonstration of CCS and innovative renewable energy technologies.

The European Commission is currently undertaking efforts to set up the details of the Innovation Fund – the successor of NER 300. Starting 2020, 400 million EU ETS allowances, subsequently increased to 450 million allowances, are to be invested in low-carbon innovation in industrial processes in addition to renewable and CCS demonstration projects.

In 2009, the Network's founding member projects were all awarded eligible funding under the EEPR, ranging from €100 million (Porto Tolle project) to €180 million (Bełchatów, Compostilla, Don Valley, Jänschwalde and ROAD). It is not expected that funds not used by cancelled projects will become available to active projects.

It was envisioned that the initial EEPR money would be followed by financing from the NER and successive schemes. Funds from NER300 could finance up to 50 percent of the eligible costs of a project. The relevant governments had to confirm they would provide co-financing for the remaining project costs. In the award decision of the first call of the NER 300 (December 2012), no CCS demonstration project obtained the required guarantees, as national governments were not able to confirm the level of co-funding they would provide. This was the case for three of the Network's projects, Bełchatów, Don Valley and Porto Tolle which applied under the first call of NER 300. In the case of the Bełchatów CCS Project, Poland did draft the domestic financial mechanism in 2012, but never introduced it into a law. Therefore, lack of support on the Member State (MS) level precluded the project applying for either of the two NER 300 calls [5]. These experiences demonstrate that *some application procedures and eligibility criteria have resulted in funds being inaccessible to CCS projects*.

An example of lack of coordination between financing schemes on national and European level has been the United Kingdom. The Don Valley project received funding from EEPR but was not selected by the UK government to receive funds from the UK CCS Commercialisation competition. That made it impossible for the project to apply for another fund at the EU level – the NER 300. Project experience has shown that *the funding schemes are not well coordinated and connected* and efforts towards addressing this issue are essential.

Norway and UK have been the only countries so far effectively introducing tools for incentivizing investment in CCS. In 1991, Norway adopted a simple and effective incentive mechanism: CO_2 tax. When the CO_2 tax rate was introduced in 1991, it ranged from 97 NOK (approximately €12) per tonne CO_2 for heavy fuel oil, and 259 NOK (approximately €32) per tonne CO_2 for petrol. Sleipner project was entirely incentivized by this tax and the EU ETS, and did not receive any other public support.

In the UK, under the Commercialisation Programme, projects were able to benefit from the reforms being made simultaneously to the electricity market to bring forward investment in low carbon electricity generation, including a CCS Feed-in-Tariff (based on a Contract for Difference). In November 2015, it was announced that "the £1bn ring-fenced capital budget for the Carbon Capture and Storage (CCS) Competition is no longer available". Shortly after, the Peterhead project suspended its activities. This experience reaffirmed the *need for a clear and stable policy environment when building long-term investor confidence in a technology*.

CfD, still available, aim to provide long-term price stabilisation to low carbon plants, allowing investment to come forward at a lower cost of capital and therefore at a lower cost to consumers [5]. The CfD is expected to have a great impact on CCS by providing a stable revenue stream. *Removing a project's exposure to price volatility would aid investment certainty.*

Regarding the ROAD project, the Dutch Ministry of Economic Affairs continues to support the project, with a grant of up to €150 million should the project proceed. The project is seen as important both to reduce national CO_2 emissions from coal-fired power production, but also in efforts to reduce the regional CO_2 emissions of the Rotterdam Harbour area. CCS is an important pillar of regional climate policy, the Rotterdam Climate Initiative (http://www.rotterdamclimateinitiative.nl/UK), and it is hoped that the ROAD project will act as a nucleus for further deployment of the technology throughout the port.

4. The way forward

The Network members have faced various challenges in the process of project development. These initial projects provided the CCS community with important lessons learned and knowledge-sharing among projects regarding issues pertaining to technology, permitting and public engagement. No significant concerns regarding technology have been reported and technology implementation is not deemed a major reason for project progress delays.

Experience to-date has shown that for CCS projects to progress, it is particularly important that member states provide adequate regulatory framework, with foreseeable and efficient permitting processes. In addition, projects must make the required provisions for timely and efficient public outreach campaigns.

On the way forward, consistent, streamlined, reliable, flexible and long-lasting financial mechanisms and support both on the EU and on member state level remains crucial in CCS deployment.

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