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European Carbon Capture and Storage Project Network: Overview of the status and developments

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Abstract

The European Carbon Capture and Storage (CCS) 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 integration, regulatory environment and financial structures. This paper aims to provide a review of some CCS experiences gained from developing the Network projects. Besides technology and project development, sharing knowledge and lessons learned on project-level basis, also gives valuable insights on how to create policies that would assist more effective deployment of technology and can enable development and implementation of regulatory frameworks. Hence, knowledge acquired in CCS aspects during the early development of this technology in Europe will be presented in this paper.

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Keywords: CCS; Large-Scale; Demonstration; Regulations; Knowledge Sharing

1. Introduction

1.1. The role of CCS

Climate scientists and parties to the UNFCCC concluded that global warming should be limited to below 2.0 °C relative to the pre-industrial level "to prevent dangerous anthropogenic interference with the climate system" [1]. Achieving this goal requires deep GHG emission cuts.

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Nomenclature/Abbreviations

CCS	Carbon Capture and Storage
CFB	Circulating Fluidised Bed
CfD	Contract for Difference
DCO	Development Consent Order
DECC	Department of Energy and Climate Change
EC	European Commission
EEPR	European Energy Program for Recovery
EIA	Environmental Impact Assessment
EOR	Enhanced Oil Recovery
ETS	Emissions Trading Scheme
EU	European Union
EUA	Emission Unit Allowance
FEED	Front End Engineering and Design
GHG	Greenhouse Gas
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LHV	Lower Heating Value
NER	New Entrants Reserve
UNFCCC	United Nations Framework Convention on Climate Change

Concurrently, the IEA points out in its World Energy Outlook 2012 that the 2°C target is becoming more difficult and costly with every year that passes [2]. The report also states that to achieve the 2°C limit, globally no more than one third of proven reserves of fossil fuels can be consumed before 2050, unless CCS is widely deployed. It also states the 2°C limit will not be achievable under existing and proposed policy commitments. The IEA states that to achieve the 2°C limit, 14% of the total accumulated emissions abatement needs to come from CCS through 2050.

The EC proposed several scenarios for achieving its 2050 emissions target of reducing emissions by 80-95% compared to 1990 levels [5]. Four out of five proposed decarbonisation scenarios require a significant contribution from CCS, up to 32% in power generation. The only scenario proposed without CCS relies on 97% of the electricity consumption being produced from renewables. That scenario requires substantial electricity storage, a technology that is still in a research phase and is not commercially available.

The Energy Roadmap solely focuses on power generation. In the industrial sector, CCS and CCUS are the only technologies that can reduce emissions from steel production, gas processing, oil refining, paper and pulp, cement etc. If CCS is used with biomass, CCS could be 'CO_2 negative' and extract CO_2 from the atmosphere – the only technology that can do this.

The IEA Technology Roadmap for CCS suggests that the costs to half emissions by 2050 rises by 70% in the electricity sector if CCS is not implemented [3]. The European Commission's Communication on the Future of Carbon Capture and Storage in Europe also acknowledged that capital costs in the power sector might increase as much as 40% without CCS to reach the greenhouse gas targets required for a maximum 2°C rise in global temperatures [4]. In the Roadmap for Moving to a Competitive Low-carbon Economy in 2050, the EC suggests that if investments in low-carbon technology are postponed the cost will rise, highlighting that CCS needs to be demonstrated and implemented without delay.

Moreover, the latest report released from the IPCC working group III highlights that the mitigation scenarios that reaching atmospheric concentrations of about 450ppm CO2eq by 2100, entails mitigation costs that can increase substantially if CCS is not considered [6].

In light of these findings it is clear that CCS is a game-changing technology for tackling climate change, while maintaining sustainable and flexible industrial activities. Finally, CCS applications are expected to form a market to be worth trillions in multiple industrial areas within Europe states a report published by SINTEF [7].

1.2. The European CCS Project Network

The European Commission established the European CCS Project Network in 2009. The Network consists of large scale demonstration projects share experiences on CCS project development. The Network:

- Facilitates knowledge-sharing discussions where project developers identify and exchange lessons learned on technology, regulation and project finance; and use those experiences to give policy advice on how to support project development
- Leverages experience gained from project development to build public confidence in feasibility and safety of CCS
- Providing a common EU identity to CCS projects in Europe and promotes the technology in Europe and globally

Collectively, the Network projects already have or will demonstrate different technologies and infrastructure elements that CCS as a clean technology encompasses:

- Capture – the Network projects cover all of the main capture approaches: (i) post-combustion flue gas scrubbing and (ii) natural gas processing, pre-combustion and (iii) novel oxy-fuel combustion
- Transport – a range of elements are covered, from short point-to-point pipelines, to concepts where the infrastructure may be appropriately designed to anticipate future demand
- Storage – both on-shore and off-shore solutions have been investigated, including deep saline formations, depleted gas reservoirs and the use of CO_2 for Enhanced Oil Recovery (EOR) in oil reservoirs

This variety of technology utilized in projects has allowed the Network to investigate differences and synergies on a variety of topics.

The efforts of the Network's early mover projects alone has the potential to make a substantive impact on CO_2 emissions. The Sleipner Project, operating since 1996, captures and stores around 1 million tonnes of CO_2 per annum from its light oil and gas field. If all of the other Network projects developed as originally anticipated, the installed clean generating capacity would be approximately 2,000 MWe. Assuming an average capacity factor of approximately 75%, more than 13,000 GWh per year could have been generated. The Network projects could permanently storing nearly 12 million tonnes of CO_2 per year in total.

The EU CCS Network is composed of four large scale integrated projects. Table 3 gives a quick reference guide to the current members.

Table 1: Network projects reference table

Member	**Country**	**Industry**	**Capture Type**	**Transport Type**	**Storage Type**
Compostilla Oxy CFB 300	Spain	Power generation (anthracite and pet coke)	Oxy-combustion capture	Pipeline (onshore)	Dedicated geological storage
Don Valley	United Kingdom	Power generation (coal)	Pre-combustion capture (gasification)	Pipeline (onshore to offshore)	Dedicated geological storage (with option for later offshore EOR)
ROAD	Netherlands	Power generation (bituminous coal and partial co-firing with biomass)	Post-combustion capture	Pipeline (onshore to offshore)	Dedicated geological storage (depleted offshore gas reservoir)
Sleipner CO_2 Injection	Norway	Natural Gas Processing	Absorption (no combustion)	No transport required (i.e. direct injection)	Dedicated geological Storage

The Network has undergone several changes since its inception. Originally, the Network consisted of the six projects that were awarded funding under the EEPR: Belchatow (Poland), Compostilla (Spain), Don Valley (UK), Jänschwalde (Germany), Porto Tolle (Italy) and ROAD (the Netherlands). Sleipner project joined the Network on 2012. Crown Estate participate in the Network as an associate member, i.e. having an advisory role since 2014.

Four of the founding Network projects were terminated. First Jänschwalde in 2012 with Belchatow, Compostilla and Porto Tolle following in 2013. Compostilla project remained a member of the Network. Each of the projects terminated due to several factors, as presented in Table 2.

Table 2: Original Network projects and main challenges

Project	**Challenges**
Belchatow	Regulatory/Finance
Compostilla	Regulatory/Finance/Market conditions
Jänschwalde	Regulatory/Public opposition
Porto Tolle	Regulatory

2. Base plants and capture

The projects of the European CCS Network aim to demonstrate the full CCS chain by capturing and storing at least one million tonnes of CO_2 per year. Three out of four of the current Network projects are on coal power plants. ROAD project is also prepared for co-firing biomass (up to 30%). The Sleipner Project is the only one that demonstrates the CCS chain in natural gas processing.

The projects within the Network are considering different capture technologies. The development and deployment of those technologies is crucial to promote the viability and cost effectiveness of CCS. The capture technologies to be incorporated in the projects include post-, pre- and oxy-combustion. Fig. 1 demonstrates the capture technologies within the Network compared to other non-Network members projects in Europe and globally. Figures include projects in all stages of development, not only in power generation but also corresponding natural gas processing projects.

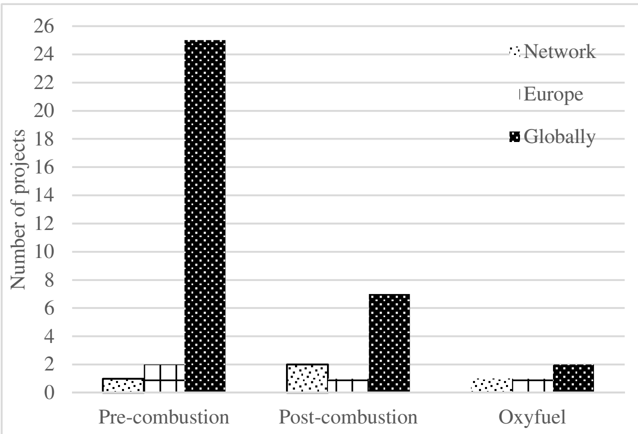

Fig. 1. Capture technologies within the Network, Europe and globally.

The three Network power projects have capacities ranging from 250 to 650 MWe. The projects will have a decrease in net efficiency in CCS mode - the expected net efficiencies reported by the power projects ranged from 35.4 to 43.9% (LHV). Projects have been reporting efficiencies by assuming the application of CCS only in various degrees of slip streams. The differences in CCS technology and volumes of slipstreams will reflect different effects of CCS on the net plant efficiency.

The application of CCS on larger or the total amount of flue gases produced by power plants is likely to have a greater impact on the overall net efficiencies. More specifically, it is anticipated that there will be further decrease in net efficiency when treating larger volumes of flue gas than when applying CCS on specific slip streams.

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 original Don Valley FEED study for the power plant was completed 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. The project has been looking to potentially introducing different technology. The ROAD project has finalised the design of the capture unit. The CO_2 capture technology will be using primary amines in post-combustion. Detailed engineering of the plant is completed. 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).

3. Transport

Transportation of CO_2 and other gases is a common practice around the world and is not expected to be a major barrier to CCS project development [9]. For most large-scale projects, pipelines are the favoured method of transporting CO_2 between the capture and storage sites.

All of the Network's projects are to use pipelines to deliver the captured CO_2 to the storage site. Don Valley, and ROAD would require offshore, subsea pipelines to reach the storage location. Sleipner is already using a subsea pipeline. All the projects are within the global average pipeline length ranges as estimated by data provided in the literature [10] both onshore and offshore (Fig. 2), with Sleipner project having the shortest pipeline (1km).

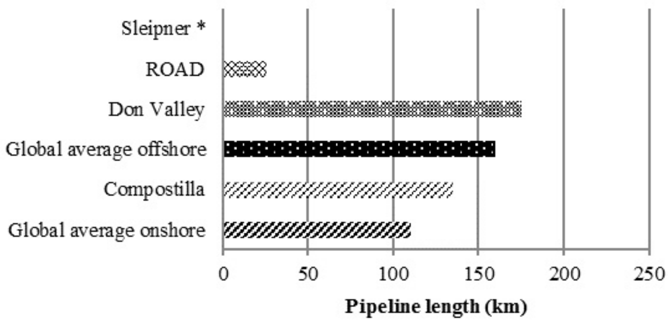

Fig. 2: Network projects pipeline length and global averages.

Network projects such as Compostilla, Don Valley and ROAD have conducted extensive flow assurance studies. Sleipner project has also significantly contributed with findings on this matter with its numerous years of operation [11].

In a study published in 2014 [12], 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 experiences, the thermophysical nature of CO_2 makes two-phase flow possible, especially during transient operations such as shut-down and restart of a pipeline, as reported in the literature [13]. The resulting dynamic behaviour of the two-phase flow, causing slugging, is still not fully understood and would require special attention in future developments.

Further Network project activities are focused on studies on CO_2 dispersion, crack arrest tests, behaviour of materials in terms of corrosion and other topics.

4. Storage

Projects have had a wide range of learnings regarding CO_2 storage. While operations are on standby at the Duero/Andorra sites due to regulatory and commercial issues, research activity continues at Hontomin site of Compostilla. Completion of injection and monitoring wells has been complemented with extensive characterization tests and injection of approximately 200 tonnes of CO_2. Compostilla's technical subsurface work has been also considered of significant importance to CO_2 storage activities.

The Don Valley Power Project investigated storage in a deep saline aquifer and have continued with characterization efforts including analysis of well test data. The data indicates significant storage capacity with no significant flow barriers in the reservoir. A storage development plan will be prepared based on revised modelling and will incorporate design of wells/operations and a Measurement, Modelling and Verification (MMV) program. While Don Valley conducted a feasibility study on the assessment of potential enhanced oil recovery (CO_2-EOR), there have been no further activities on the topic.

The storage permit for the ROAD project was issued in September 2013. However, operational plans are required and will need further studies to be undertaken prior to ministerial approval of a finalized permit.

Sleipner project started injecting additional CO_2 sourced from the Gudrun Field started during 2014. A second benchmark model will be released in 2015 to the research community.

The table below presents a summary of the current Network projects status except from Sleipner project which is already operational:

Table 3. Status summary the storage sites under development.

	Don Valley (saline)	**Don Valley (EOR)**	**Hontomin (Compostilla)**	**ROAD**
Site screen	✓	✓	✓	✓
Site select	✓	✓	✓	✓
Feasibility study	✓	✓	✓	✓
Appraisal drill and/or seismic	✓	n/a	✓	n/a
Baseline surveys	□	O	✓	n/a
FEED	✓	O	✓	O
Monitor plan	O	O	□	O
Storage License application	✓	O	n/a	✓
CO_2 Injectors	2-3	5-6	1	1
Injection back up	no	Yes	no	no

✓ Completed □ In progress O Not started

5. Public outreach

The Network experiences proved that public outreach is often a decisive component of a successful CCS project development. The scale of projects and their locations – different countries and communities – resulted in projects facing a variety of public acceptance challenges. From the Network experience perspective, these challenges can be determining for a project. For example, Vattenfall, the proponent of Jänschwalde project, finally quoted the cancellation of the project partly due to the large scale opposition from the public. Belchatow project faced similar issues, without however public opposition being the primary reason of the project being cancelled.

One of the major takeaways of the Network experiences is that commitment to proactive communication and engagement activities is essential for building and strengthening key stakeholder relations. Direct engagement with the public through face-to-face meetings and site visits was found to be the most effective engagement too.

The Network projects have all identified the levels of public engagement risk associated with the local communities impacted by their CCS project. Pooled knowledge of projects resulted in development of best practices for public engagement. The steps include surveying concerns and perceived risks raised by the public; identification and management of key stakeholders; followed by tailored messaging and communication tools.

Projects reported that the most frequent concerns of the public are over a continued use of fossil fuels and over the cost and actual benefits of CCS. Concerns regarding CO_2 transport and storage have been raised with the projects as well. For example, the Compostilla project initially identified low levels of public engagement risk associated with their project, but acknowledged that the levels were likely to increase when starting operations related to CO_2 Storage. This lead to development of an outstandingly successful public engagement project. CIUDEN, the project's academic partner, worked on outreach with Local Councils in Hontomin. CIUDEN have worked to translate and publish all of their existing education and outreach activities.

Don Valley project has also achieved a major milestone with the submission and subsequent acceptance by the UK Planning Inspectorate of National Grid's (CO_2 transport and storage proponent of the project) DCO application for the Yorkshire and Humber CCS Cross County Pipeline, a 'Shared User' pipeline. The project has evolved over a number of years through detailed engineering and environmental studies and by taking account views of local community and other stakeholders. Thus, the project introduced plans and held a series of consolations in the region on pipe routing, since 2011. Such interactive approach that includes community engagement is proved to be critical in gaining public support for projects.

It is expected that as large-scale CCS projects come online, new issues regarding public acceptance will arise. Lessons learned from demo projects will be vital in establishing a positive perception of CCS as a clean technology and an important part of an effective and efficient CO_2 emissions reduction solution [14].

6. Regulations and financing

6.1. Regulatory frameworks

On the EU level, capture and transport of CO_2 are regulated under amendments added to the EIA directive (85/337/EEC and 2008/1/EC). Storage is regulated under the directive on the geological storage of carbon dioxide (2009/31/EC)[1], commonly known as the CCS Directive. These directives were to be transposed by mid-2010 and included in the legislation on a member-state level, however, the transposition of these directives was in most cases significantly delayed – which was one of reasons why for example Belchatow project in Poland and in part Compostilla project in Spain did not move forward.

Having different legislation regulating different pieces of the CCS chain has proven to be a big challenge for this technology. In order to assess the adequacy of the existing Storage directive, the European Commission held a series of public consultations in October 2014. The conclusion of consultations was that while the directive created a lot of 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 [15].

On a national level, Network experiences have shown that for a project to progress, it is particularly important to have clear and efficient permitting process in place. For example, 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 didn't transpose the amendments from the EIA directive that was addressing CO_2 transportation legislation, and thus rendered CO_2 transportation.

[1] Amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006.

Bełchatów and Jänschwalde progress has also been challenged by the inadequate regulatory response on a 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.

In the UK, the challenge has not been the transposition of the CCS Directive, but the lack of coordination between financing schemes on national and European level. Namely, Don Valley project received funding from EEPR but was not selected by the UK government to receive funds from the UK competition. That made it impossible for the project to apply for money available from another fund on the EU level – NER 300, which was aiming to finance CCS projects. However, the Don Valley project has been in discussions with DECC to identify a route to access a CfD to support the plant's cost of power. The project continues to benefit from the EEPR grant that has now been amended and extended by two years through to the end of 2015. It has been amended to allow for the inclusion of an oxy-combustion option. The commitment from DECC to discuss potential access to a CfD is the next key milestone.

The Porto Tolle project also faced regulatory challenges, yet of a different nature. 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 EIA. 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 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. Significant learnings have resulted in from the project's experience in permitting process. More specifically, the ROAD project made a significant contribution to the CCS community by producing a comprehensive report highlighting their experience on obtaining all necessary permits [16].

6.2. Economic challenges

CCS projects have large up-front capital costs as well as high operational expenses and considerable funds are required to secure full deployment of this technology. Thus, projects face a number of challenges with financing. Experiences to-date prove that complementary measures for project finance are necessary for a project financial closure.

Much of the EU is still waiting on the necessary financial and regulatory incentive mechanisms to enable CCS. Fig. 3 presents a non-exhaustive list of the major funding schemes in Europe and the stage of CCS development they cover.

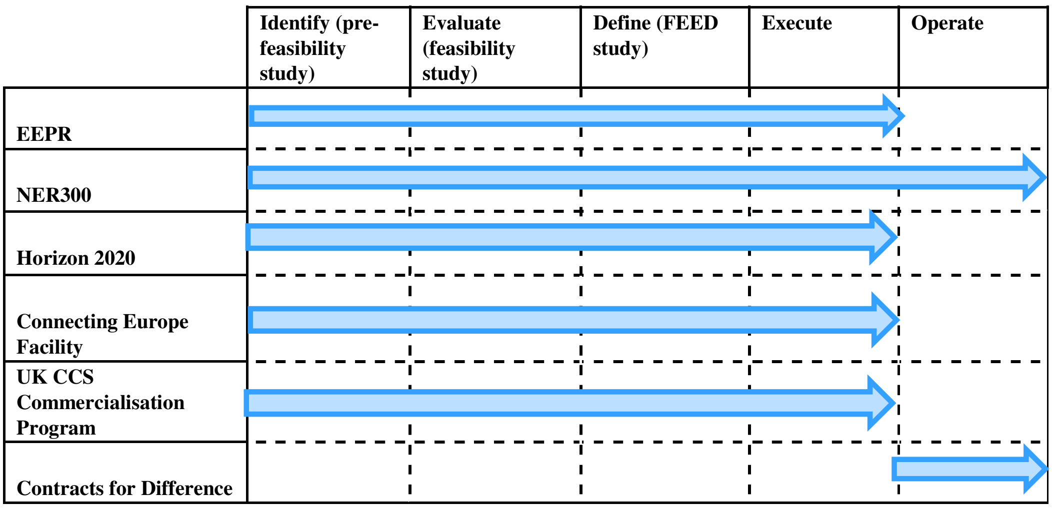

Fig. 3: Main EU funding schemes and applicability through CCS project development.

While a number of financial instruments have been established to support projects throughout different stages of development, the funding schemes are not well coordinated and connected and some application procedures and eligibility criteria have resulted in funds being inaccessible to CCS projects.

In 2009, The Network's founding member projects were all awarded eligible funding under the EEPR, ranging from €100 (Porto Tolle project) to €180 million (Belchatow, Compostilla, Don Valley, Jänschwalde and ROAD). The actual amounts awarded so far can be seen in Table 4. It is not expected that funds not used by cancelled projects will become available to active projects.

Table 4. Eligible and actual funds from EEPR [17].

Project	Eligible (€ million)	Paid (€ million)	Status
Belchatow	180.0	20.7	Cancelled
Compostilla	180.0	117.3	Cancelled
Don Valley	180.0	95.9	Active
Jänschwalde	180.0	15.2	Cancelled
Porto Tolle	100.0	34.7	Cancelled
ROAD	180.0	63.8	Active
TOTAL	1,000.0	347.4	

It was envisioned that this initial EEPR money would be followed by financing from the NER. Namely, in 2008 the EU agreed to set aside 300 million EUAs from the NER of the EU ETS. The NER 300 funds were to be used to finance demonstration of CCS and innovative renewable energy technologies.

Funds from NER300 can finance up to 50 percent of the eligible costs of a project. Hence, the relevant governments had to confirm that would be able to 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 got an award, as national governments were not able to confirm the level of co-funding they would provide. This was the case for the three of the Network's projects, Belchatow, Don Valley and Porto Tolle which applied for the first call of NER 300. In the case of the Belchatow CCS Project, Poland did draft the Domestic Financial Mechanism in 2012, but never got around introducing 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.

Another major issue with the current scheme is overreliance on CO_2 emission allowances price. The size of NER 300 has been directly exposed on price fluctuations under ETS – another policy that depends on series of variables. Therefore, any change on the carbon market directly influences the size of funds available. Thus the 2009 plummet of carbon prices significantly reduced the expected size of the fund and consequently money available to finance projects.

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 does not receive any other public support.

In the UK, under the Commercialisation Programme projects are 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). The CfD are expected to have a great impact on CCS by providing a stable revenue stream. Removing a power plant's exposure to price volatility would aid investment certainty. Don Valley Power project is currently under discussions with DECC on a CfD.

Conclusions

The Network members have faced various challenges in the process of project development. These initial projects provided the CCS community with important lessons learned when it comes to project engineering, permitting and public engagement. No significant concerns regarding technology have been reported and technology implementation is not 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, permitting processes are clear and efficient and that projects have timely and efficient public outreach campaigns. Finally, lack of consistent, reliable and long-lasting source of financial mechanisms both on the EU and on member state level remains the main reason for delays in CCS deployment.

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Disclaimer

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