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Abstract

The ECCO project has developed a methodology and a supporting software tool for pre-feasibility studies of CO_2 Capture and Storage (CCS) value chains with and without Enhanced Oil or Gas Recovery (EOGR). Conclusions and recommendations for the realization of CCS value chains are presented in this report. The overall conclusion, based on the work conducted in ECCO, is that political willingness is crucial in order to make CCS happen on a scale that contributes to reaching the EU climate goals. If left to the market in the EU Emission Trading Scheme (ETS) context, investments in CCS technology development are likely to be insufficient, although using CO_2 for EOGR could improve the economics of a CCS value chain. It is also clear that economic incentives are necessary for overcoming issues such as long-term liability of CO_2 storage, third-party access to pipeline and storage and cross-border liability of storage integrity.

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1 EXECUTIVE SUMMARY

The ECCO project has been a three-year collaboration project under the EU 7th framework programme for research. The main objective of ECCO has been to facilitate strategic decision making regarding early and future implementation of CO_2 Capture and Storage (CCS) value chains. The ECCO project has developed a methodology and a supporting software tool for pre-feasibility studies of CCS value chains with and without Enhanced Oil or Gas Recovery (EOGR). Conclusions and recommendations for the realization of CCS value chains are presented in this report. The overall conclusion, based on the work conducted in ECCO, is that political willingness is crucial in order to make CCS happen on a scale that contributes to reaching the EU climate goals. It is also clear that economic incentives are necessary for overcoming issues such as long-term liability of CO_2 storage, third-party access to pipeline and storage and cross-border liability of storage integrity.

The main conclusions and recommendations from the ECCO project are listed below.

Financial Incentives:
ECCO conclusions: The required capital costs for establishing CCS value chains are too high for the stakeholders to make investments on balance sheet. Political incentives and external funding bodies are required to provide funding for infrastructure investments. Also, the long-term predictability of operational income streams for CCS value chains must be improved.

ECCO recommendations:

- A forward capacity market could be created to stimulate investments and give predictability to investors.
- Long-term predictability for a sufficient price of stored CO_2 could be created through bonus-malus schemes.
- The states or institutions considering granting support arrangements to CCS projects should recognize the need for contractual agreements around such projects to meet the fairly stringent requirements of private finance providers and to provide the support in a compatible, and hence bankable, form.
- Projects make use of EIB initiatives to lower their weighted average cost of capital funds where possible.
- Taxation on CO_2 emissions will promote CCS. This conclusion is not a specific ECCO conclusion[1].

Incentives for CO_2-based EOGR:
ECCO conclusions: EOGR may be a driver for the realization of early CCS value chains in Europe. With a carefully designed CCS value chain, where the captured and transported CO_2 is employed for EOGR purposes, it is not unlikely that good business cases can be developed. It is however crucial that the EU prioritises the barriers to entry for EOGR-based CCS projects.

[1] Norway and Australia will introduce a CO_2 tax of 23$/tonne from July 1st, 2012. Also the Emissions Trading System (ETS) is a form of CO_2 emissions taxation.

ECCO recommendations:

- Specific tax incentives for CO_2-based EOGR could be created, such as tax exemption/reduction for a kick-off period, shortened period of depreciation for CO_2 EOGR-related investments and modification of the tax basis. These recommendations on tax incentives are mainly based on similar incentive schemes in the US.
- Conditions could be set, when applicable, that suitable fields should be "CO_2 EOGR ready" in their plans for development and operation (PDO).
- The CO_2 EOGR facility should be licenced as a storage facility from the beginning of the activity.
- CO_2 EOGR should be promoted as the secondary recovery mechanism (the PDO process may be a tool for this) rather than tertiary recovery (i.e. replacing or complementing the water injection phase rather than following after end of water injection).

CCS Liability issues:
ECCO conclusions: The optimum CCS value chains will in most cases not be geographically restricted to one country, which means that there may be cross-border pipelines, storage sites and ship transport of CO_2. Countries should therefore be encouraged to engage in cross-border projects.

ECCO recommendations:

- Guidelines for allocations of risk between countries in cross-border projects should be defined.
- A trust fund should be established for mutualising the liabilities of storage operators.
- Ownership issues along the value chain should be carefully considered when establishing CCS projects as they may have a significant impact on contractual risk and project finance.

Organisation of the value chain:
ECCO conclusions: The initial investment cost for pipelines is in itself not a very significant part of the investment in CCS value chains, but commercial actors are likely to want to minimize their own investment in the establishment of early CCS value chains. Further, oversized pipelines are required in the establishment of a large-scale CO_2 infrastructure and such investments will require substantial funding from other bodies than the industrial stakeholders.

ECCO recommendations:

- Operation and ownership of a developed CO_2 infrastructure should be through the establishment of one or more independent transmission system operators (TSO) in order to manage capacity allocation and coordination of CO_2 flows.
- Member States should ensure transparency and non-discrimination in the access to CCS infrastructure.
- Clarification of access regulations to transport and storage networks is required.

Part I

About the ECCO project

2 INTRODUCTION

The CO_2-reduction targets, set by the EU[2] to contribute to limiting the global temperature increase to 2°C compared to pre-industrial levels, can only be reached through the use of a portfolio of technologies, one of which is Carbon Capture and Storage (CCS). Energy use accounts for roughly 80% of the greenhouse gas (GHG) emissions in the EU. The energy industry stands for 35% of the EU CO_2 emissions and other industry for 18%. CCS is the only technology that can capture at least 90% of CO_2 emissions from power plants and other carbon-intensive industries[3]. Although much of the required technology for capturing, transporting and storing CO_2 emissions is in place, the technical and economical viability of the CCS chains in the EU remains to be shown, and it is a challenge to define how the most efficient CCS infrastructure should be implemented. As a response to this need, the ECCO (European value Chain for CO_2) project was formulated and executed. The goal of this public report is to summarize the essentials of the work performed in the project and present the main strategic conclusions concerning the legal, financial, political and infrastructural requirements for the realization of CCS in Europe. The ECCO project builds on previous knowledge developed in other European Projects such as ENCAP, CASTOR, Dynamis and CO_2Europipe

2.1 ECCO objectives

The ECCO project has been a three-year collaboration project under the EU 7th framework programme for research. The main objective of ECCO has been to facilitate strategic decision making regarding early and future implementation of CO_2 value chains. This has meant seeking to give politicians and industrial leaders advice on how to establish and operate the most economically viable CCS infrastructure, hence contributing to an accelerated development of CCS, with the ultimate goal of combating global warming.

2.2 The ECCO methodology

The methodology employed to achieve the ECCO goals has been through answering the following key questions:

- What might be the future CO_2 world? (Scenario development)
- How to identify feasible CO_2 value chain options? (illustrative Case definitions)
- How to evaluate the CO_2 value chain options and choose the most promising solutions for CCS? (Tool development, application to Cases, analysis and conclusions of the simulations)

The ECCO project structure shown in Figure 1 clearly illustrates the key elements of the methodology, which were executed in the work packages 2.1, 2.2, 3.4 and 2.3. The basic approach with scenarios, case definitions, simulations and conclusions is very general and should be possible to apply for any evaluation of future large-scale infrastructure, although the supporting activities would be completely different in a study of, say, high-speed trains, natural gas transport or high-voltage transmission lines.

[2] 2020 objective: reduce GHG emissions by 20% compared to 1990 levels, rising to 30% providing that a satisfactory international agreement is reached. 2050 objective: reduce GHG emissions by 50%.
[3] European Technology Platform for Zero Emission Fossil Fuel Power Plants Strategic Deployment Document II – Moving forward with CO_2 capture and storage (CCS).

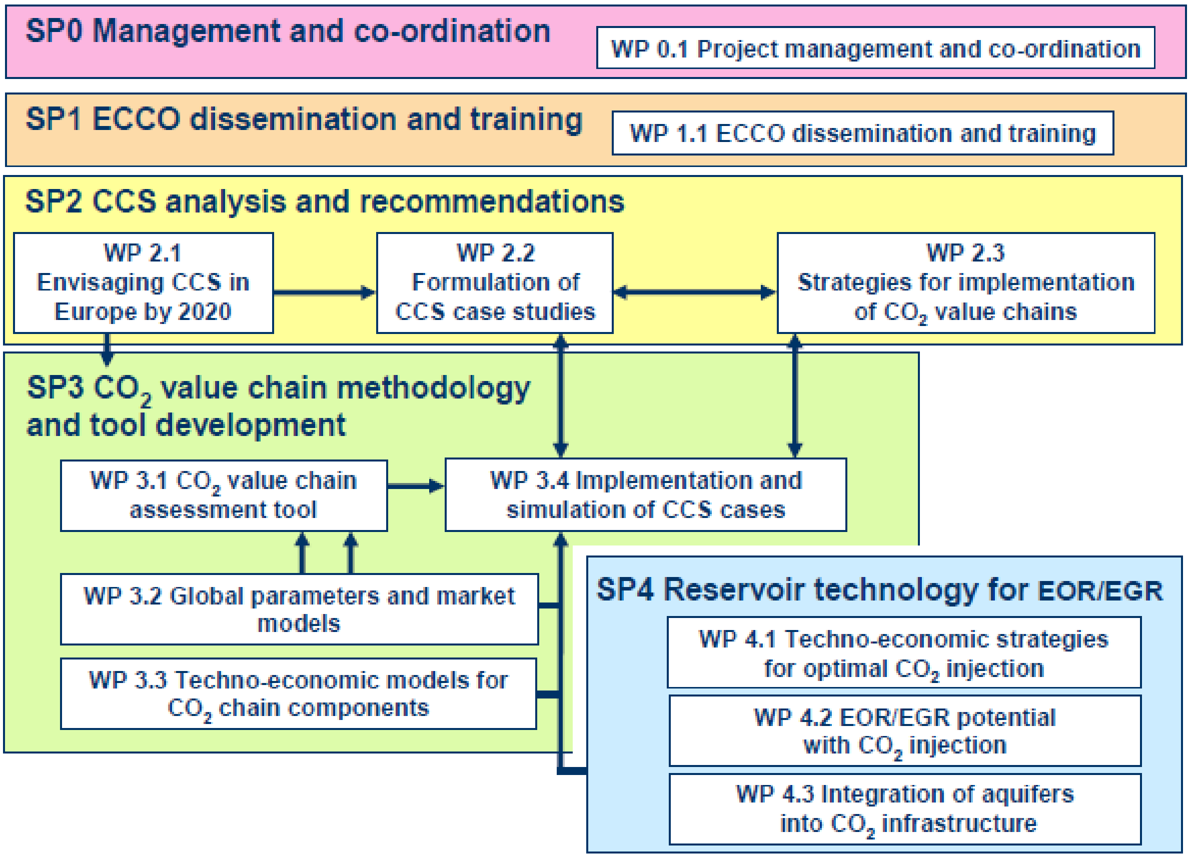


Figure 1: The structure of the ECCO project.

2.3 CCS value chains

The means of drawing conclusions in the ECCO project has been to design "CCS value chains" that consider the capture, transport and final use of CO_2 for EOGR, with focus on economic aspects. The choice to focus on EOGR in the ECCO project is justified by the fact that this use will give CO_2 an economic value, and hence may promote the early introduction of CCS. Further, there is in general a "Window of opportunity" for applying CO_2 for EOGR, which typically opens when the declining oil or gas production of a field reaches 20 or 10% of the earlier maximum production rate. This window typically closes when the oil/gas production is down to 4% or 2% of maximum production rate and marginal costs for maintaining any production become too high. For the North Sea, it should be noted that there is a significant number of fields where the window for the EOGR opportunity opens from now and onwards until 2020 or 2025, thereafter this opportunity appears to be declining. Hence, this window of opportunity has been a focus of the ECCO project.

A key activity for evaluating the CCS value chains has been the development of a value chain assessment tool (refer to WP3.1 in Figure 1 above). This tool (named the ECCOTool) has been developed within the project by several of the ECCO partners and its existence has been vital for obtaining the results that are the background for the conclusions and recommendations in the present report. The tool was designed for strategic decision support in an early analysis phase of CCS value chains, and is referred to in this report when necessary, without going into any detail on its design and functions.

In ECCO, many possible designs have been considered for the linking of CCS elements to form a CCS chain, which may eventually develop into an infrastructure. Generally these are built up from the very basic building blocks (capture, transport, storage) shown diagrammatically in Figure 2.

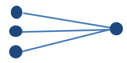
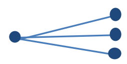
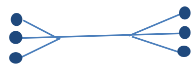
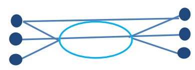
Arrangement	Illustration
One - One	
Many - Many	
Many - One	
One - Many	
Many – One - Many	
Many – Network - Many	

Figure 2. Types of basic CCS network.

The simplest arrangement is the direct link from a single capture plant to a single storage location which is not linked to anything else – this is known as a one-to-one connection. If a number of these connections are established independently of each other, then this is in effect a many-to-many type of infrastructure, but without any cross-links there is no possibility of capturing any benefits of scale or redundancy or any reliance from one to another and hence no complex infrastructure is created.

More diversity / redundancy is introduced in the storage options if a CO_2 source is connected to more than one storage location (one-to-many) or in the supply of the CO_2 if more than one source is connected to a storage site (many-to-one).

If the diversity of supply and storage are combined with a bulk transport connection for the main distance, this becomes a many-one-many type of connection. The merits of a bulk supply route like this are discussed below. Further diversity can be achieved by the creation of a network of more connections (many-network-many) which allows for CO_2 to be passed along more than one route to reach its final destination. This is an example of a mature infrastructure and is the potential end result of the initial infrastructures which ECCO has been exploring.

For the storage module in the ECCOTool, CO_2-EOGR potential and/or storage capacity of a CCS chain was determined in the ECCOTool through conceptual reservoir models representative of the North Sea and Hungary, where representative petrophysical fluid models and fluid compositions were added. Through the possibility to vary several input parameters, the characteristics of any known oil/gas reservoir or aquifer can be simulated.

3 SCENARIOS DEVELOPED FOR THE FUTURE CCS WORLD

Six European scenarios were developed as part of the study in ECCO to set the frames for and define the future CO_2 value chain options to be investigated in the case studies within the ECCO project. Scenarios are generally used as a tool to understand different ways that future events may unfold, and should not be regarded as forecasts. The scenarios were developed to reflect possible variations in the environment for European value chains for CO_2 in the next 30 years

The ECCO scenarios were defined along a set of 5 main drivers:

1) The degree of influence of the EU – the level of action set forth by the EU regarding regulations for combating climate change.
2) The degree of globalization – level of coordinated worldwide efforts to combat climate change.
3) Economic growth – energy intensity, fuel demand, technological advance
4) Fuel availability – a combined measure referring to high fuel consumption and low fuel price ("high" fuel availability means higher fuel consumption and/or low fuel prices; "low" fuel availability means lower fuel consumption and/or high fuel prices)
5) Degree of environmental changes - level of CO_2 emissions, weather changes, pollution and smog, etc.,

The particular combination of low or high degree of these impacts determines the overall scenario features. For each scenario the situation in 2040 and the development from 2010-2040 were described in relation to key issues shown in the Table 1.

Table 1*: Summary of the key issues for all ECCO scenarios*

	Scenario 1 "Happy planet"	**Scenario 2 "EU stands alone"**	**Scenario 3 "Weak EU"**	**Scenario 4: "We told you so"**	**Scenario 5 "Competition"**	**Scenario 6 "New Energy Policy"**
Environmental changes & public opinion	Public accepts CCS as a measure for CO_2 emission reduction Target emission reductions are reached	Europe has met most goals for emission reduction however the worldwide level of emissions continued to increase because of lack of coordination and technology dissemination	Due to high usage of fossil fuels without CCS the emission level has risen	EU has reduced its emissions but global emissions continued to rise	Public acceptance is sufficient Target emission has been exceeded There is urgent need to mitigate the climate changes	Public accepts CCS as a measure for CO_2 emission reduction Target emission reduction are reached
Political & regulatory	Tight regulations set in place and accepted internationally	EU focuses on keeping economic growth but minimizes emissions and uses ETS	EU's leadership has been weakened and there are no incentives accelerating realization of large scale international CCS projects	EU still stands strong and is determined to reduce the emissions but the rest of the world is not following	Political support for CCS is lacking, there are no common regulations, ETS has failed	EU is committed to reducing its overall emissions to at least 20% below 1990 levels by 2020, and is ready to scale up this reduction to as much as 30% under a new global climate change agreement when other developed countries make comparable efforts.
Global economy	Fuel prices are high, costs of capital are medium to high	Focus on economic growth Costs of capital are medium to high and there are high investment confidence and high investments	High economic growth and low energy price	The economic growth is not as high as it was around 2000 High price of energy and demand for fossil fuels leads to regional conflicts	Fossil fuels resources have been depleted, the price is high Investment confidence is good and costs of capital medium to high	Economic growth is assumed to be 2.2% on average up to 2030 and fuel prices are high.
Technology & infrastructure	Research was coordinated Commercial CCS became reality International network for CO_2 transport was established	Focused research and learning effect has reduced the price of CCS and made it relatively affordable	Research is driven by market forces and sponsored by industry; development of CCS technologies is limited due to lack of incentives	Energy efficiency was increased considerably Technologies for renewable energy were commercialize d and cover 50% of the consumption	Research is driven by private companies and no technology transfer takes place	Sufficient technologies to make substantial progress on energy efficiency in reaching energy and climate targets.

The scenarios served as the basis for work in WP3.2, Global Parameters and Market Models, where the descriptions of plausible future situations described in these scenarios were used to quantify the global parameters such as the oil and gas price, CO_2 price, electricity price, steel price, interest rate / (opportunity) cost of capital, economic lifetime, analysis period, rig rates, labour costs, manpower constraints, currency rates (if relevant) incorporating expert opinions and economic forecasting models. The quantified macroeconomic time series were then implemented in the ECCOTool.

4 CASE STUDIES IN ECCO

Cases to be studied with the ECCOTool were proposed by the ECCO partners. Use was made of the knowledge available from partners involved in all of the CCS chain components, particularly capture and storage, in selecting relevant and suitable components to include in each case. A set of questions were framed, by means of various workshops, covering the issues to be illuminated by the case studies. These covered not only practical areas including physical connections, volume and temporal compatibility/development, but also extended to issues such as economic viability, financial incentives, commercial arrangements and regulatory options. These questions were used to frame selection criteria for the proposed case studies.

Using the background analysis work, the scenarios and the selection criteria, discussions and decisions then took place to derive a set of recommended case studies. The selection took into account partner sponsorship to ensure that the cases were well grounded, collaboration with other bodies and projects to ensure consistency and diversity in order to illustrate a broad range of important issues relating to the economics and other barriers for early mover CCS chains. A summary of the six selected case studies in ECCO is given in Table 2.

Table 2. *Selected case studies in ECCO*

Case Name	Source(s)	Transport(s)	Buffer	Sink(s)
Baltic Basin	Mainly PCC around Baltic rim	Shipping Pipeline	Hub in Skagerrak & Danish Aquifer	EOR in Northern North Sea
Hungary	Refinery, CCGT PCC and Coal PCC	Pipelines onshore	None	Onshore storage & EOR
Denmark, Germany	Power and Industry in Denmark and North Germany	Pipelines via Dornum Hub	German Bunter Aquifer	Danish chalk EOR & Ekofisk
Holland	Various around Rotterdam	Pipelines	None	Dutch K/L sector & EOR extension
UK East Coast	Power and Industry NE England cluster	Pipelines	North Sea Aquifer	Central & Northern North Sea EOR
Norway	Mongstad CHP & Refinery	Pipeline	None	Norwegian Sea EOR

All defined cases except the Germany/Denmark case were implemented in the ECCOTool, meaning that five cases were implemented instead of the originally planned number of four. The results were thereafter used for deriving the conclusions summarized in part II of this report. The results obtained with the ECCOTool are of course dependent on the input provided and the assumptions made. Due to constraints of time and budget, all case studies for the final reports were run with the "Happy Planet" scenario, and it should be noted that the limited range of case studies and the sensitivity analyses that were performed are probably not sufficient to shed full light on all the complex issue of establishing CCS value chains in Europe. However, the work carried out made it possible to draw useful conclusions and further use could be made of the ECCOTool beyond the ECCO project to generate more case studies and more results that can help to broaden understanding.

Part II

ECCO conclusions and recommendations

5 OVERVIEW OF CONCLUSIONS AND RECOMMENDATIONS

In the ECCO project, the work on drawing strategic conclusions from the project and making recommendations for the implementation of CCS value chains was conducted in one dedicated work package, WP2.3 (refer to Figure 1). The work resulted in four final reports, listed in Table 3 below.

Table 3. *Overview of ECCO final reports.*

Deliverable No.	Title	Classification	Chapter in this public report
D2.3.2	Recommendations for improving the regulatory framework and optimizing the structure of the organization of the value chains	Public	6
D2.3.3	Recommendations for the facilitation, promotion and financing of the development of the infrastructure	Restricted	7
D2.3.4	Recommendations for the development of the infrastructure	Restricted	8
D2.3.5	Impact assessment of the deployment of CO2 value chains on the European policy goals	Restricted	9

This table illustrates that the conclusions and recommendations presented in the following four chapters are based on extensive concluding analysis work in the ECCO project.

6 RECOMMENDATIONS FOR IMPROVING THE REGULATORY FRAMEWORK AND OPTIMIZING THE STRUCTURE OF THE ORGANIZATION OF THE VALUE CHAINS

The report "Recommendations for improving the regulatory framework and optimizing the structure of the organization of the value chains" is the first in the series of four final reports from the ECCO project, and the only one to be publicly available[4]. The report provides recommendations for improving the regulatory framework that are necessary to facilitate the establishment of CO_2 value chains in the near term, with particular focus on CCS for CO_2-EOGR. The recommendations address financial incentives, liability issues, and organisation of the value chain. Recommendations are also made for an overall organization of the value chain in terms of access rights, trans-boundary transport and storage of CO_2 and rules for utilization/capacity allocation. The recommendations are summarized in Table 4.

[4] The report can be downloaded from the ECCO website, **http://www.sintef.no/ecco**

Table 4. Main recommendations for improving the regulatory framework and for optimizing the organization of the CCS value chain.

		Type	Description	Recommendations	Existing policies or new recommendations ?
Financial Incentives	**Current general incentive schemes applicable to all CCS project**	Emission Trading Scheme/ EU subsidies/ States subsidies	• EU - ETS • NER 300 • EERP • 50% of revenues from auctioning allowances to be used by MS for climate measures, including CCS • Direct subsidies at national level	• Insufficient incentives to encourage wide deployment of CCS. • Recommendation to establish incentive schemes common to all CCS projects, including EOGR projects, to encourage a wide portofolio of CCS projects. • If not politically feasible, specific incentives for CO_2 for EOGR to be considered as a fall-back for a given time (time to be clearly defined).	Existing policies (EU policy / National policies)
	Additional general incentives to be considered (example)	Capacity Market	Create a Forward Capacity Market to low carbon electricity generation for any sources not already supported by support schemes (such as feed in tariffs or green certificates)	Stimulates CCS investments and gives predictability to investors	ECCO proposal - Adaptation of traditional FCM
		Bonus Malus Schemes	Scheme directed towards CO_2 producers. Power plant emitting under a specific norm are rewarded (bonus). Power plant emitting above a specific norm are penalized (malus)	Creates long term predictability for a high price on CO_2 emission in the power sector	ECCO proposal - Suggested by the Netherlands' CCS task force recommendation
		Reward stored volume of CO_2 for permanent storage through delivered CO_2 price support	Directed toward storage operators		ECCO proposal

		Type	• Description	• Recommendations	Existing policies or new recommendations ?
Financial Incentives	Specific tax incentives for CO_2 for EOGR	Options to consider	• Tax exemption/tax reduction • Shorten depreciation time • Tax credit • Modification of the tax basis	• Applicable only for a kick-off period – until sufficient EOGR projects create a market for CO_2 storage. To be reviewed if more general CCS incentives are introduced. • Need to avoid accumulation of subsidies. • Verify compliance with State aid rules	ECCO proposals - Recommendations mainly based on similar tax incentive schemes in US
		Tax exemption/reduction	• Grant tax exemption or reduction for all oil produced through CO_2 for EOGR • Alternatively only for a specific volume of oil produced through CO_2 for EOGR	Consider risk that oil companies under-estimate their resources recoverable without CO_2 in order to maximize profits	
		Period of depreciation	Shorten depreciation time on investments directly tied to the use of CO_2 for EOGR	• Gives lower taxable income in the period from initial investment to full write down and consequently a lower up-front taxation	
		Tax credit	A tax credit could apply to all costs associated with installing the CO_2 flood, CO_2 purchase and CO_2 operating costs	With a tax credit of 15% granted, the remaining 85% of qualifying costs would be depreciated normally	
		Modification of the tax basis	Base taxation on the achieved oil price in the market place rather than on an averaged fixed price	Enables companies to hedge their production and reduce further risk by selling oil on forwards contracts without being taxed based on a potentially higher average fixed price assessment than actually achieved	
	Regulation for CO_2 for EOGR	Earmarked revenues	Earmark additional revenues to the State arising from the increase of oil produced through CO_2 for EOGR for further investments in CCS	Allows to finance the establishment of pipeline infrastructure, research, site selection etc	ECCO proposal
		• Plan for Development and Operation. • EOGR ready-EOGR retrofit	• Set as a condition in the PDO that CO_2 injection for EOGR has been assessed and considered. • Require, when applicable, a condition of "EOGR ready" for new fields and "EOGR retrofit" for existing fields.		ECCO proposal

		Type	• Description	• Recommendations	Existing policies or new recommendations ?
CCS - Liability issues		Cross border liabilities	Encourage countries to involve in cross border projects by giving certainties regarding the allocation of EUA in case of CO_2 migration and disturbances to storage integrity.	Define guidelines for allocation of risk between countries in cross border projects (cross border pipelines, cross border storage sites and ships transporting CO_2)	ECCO proposal
		Long term liability/transfer		• Favour the transfer of all liabilities, including liabilities to third parties • Define mechanism to avoid the unfair delay of transfer to the State	ECCO proposal
		Trust Fund	• To be established either at national of EU level and financed by operators by way of a fee per tonne of CO_2 injected. • Fund to be used to cover liabilities or expenses not already covered by the financial guarantee and any other liabilities that are excluded from the transfer	Establish a Trust Fund to mutualise responsibility of storage operators	ECCO proposal
		Financial guarantee/contribution		Clarify whether the constitution of a Financial Contribution and Financial guarantee are applicable for CO_2 for EOGR	ECCO proposal

		Type	Description	Recommendations	Existing policies or new recommendations ?
Organisation of the Value chain		Buffer location		• Clarify the regime of buffer location to avoid any significant risk of release of CO_2 to the atmosphere and environmental health risks • Clarify Third party access to buffer location	ECCO proposal
		Vertical integration versus independent TSO	• Need to avoid situation of ownership structure resulting in competition distortion • Independent TSO could manage capacity allocation and coordination of CO_2 flows.	• Assess the potential effects of vertical integration on competition. • Consider the establishment of independent TSO • MS to ensure transparency and non-discrimination in the access to infrastructure (information and condition of access to be published)	ECCO proposal
		Third party access	• Need for flexible mechanism as infrastructure not yet established. • The Norwegian petroleum concession system gives the competent authority the legal basis for stimulate third party access through injunction and prohibition when assessing the PDO	• Need to clarify the circle of those who are entitled to require access to transport and storage network • Clarify access to buffer location • Use the approach of EU gas legislation • Stimulate TPA through the assessment of the PDO	ECCO proposal
		Licencing	Ensures that the EOGR operator can enter into contracts with both CO_2 producer and transporters	License the CO_2 for EOGR facility as a storage facility from the beginning of the activity	ECCO proposal

7 RECOMMENDATIONS FOR THE FACILITATION, PROMOTION AND FINANCING OF THE DEVELOPMENT OF THE INFRASTRUCTURE

The second report in the series of four final reports from the ECCO project investigated the particular challenges associated with facilitating and financing a CCS chain, in particular one involving EOR. The results should be equally relevant for a value chain involving EGR, although EGR was not included in any of the ECCO case studies.

The amount of capital needed to invest in European CCS projects to make a realistic contribution to a reduction in anthropogenic CO_2 emissions is enormous. In the power industry, for instance, the capital requirement dwarfs the balance sheets of the main players involved. Hence it will be necessary to achieve the minimum conditions in these CCS projects that will allow them to attract external commercial finance. Also this finance may well need to come from sources which are less familiar with the relevant industrial sectors and so may demand quite stringent conditions.

A CCS chain could be considered to be broken down into three parts: (1) capture, (2) transport and (3) storage. Ownership of individual parts of the chain could play an important part in the viability to develop such a CCS chain and its operation because of risk management tax and financing issues.

There are a number of issues which lead to CCS projects incurring risks which are potentially of a nature to make them unfinanceable using conventional debt financing. Some of these are regulatory or are being dealt with through Member State / EC actions. The main requirement from a commercial point of view is that the developers can demonstrate an income stream to the project which is sufficiently firm to be bankable and of a size which meets the project hurdle rate.
In order that the income stream is adequate, and costs can be managed, the following sources of uncertainty / risk need to be tackled:

- the European emissions trading scheme (ETS) forward price does not have a sufficient track record to provide confidence in a bankable price level and it is also subject to political intervention risk;
- the degree to which the CO_2 price is reflected in the wholesale price of electricity in relevant Member States;
- storage qualification costs are uncertain because the requirements are not fixed;
- future financial risks associated with storage integrity of CO_2 are unbounded in time;
- demonstration project support is needed in a firm bankable form.

Some of these financing barriers have non-finance regulatory or legal solutions and are covered by the other ECCO reports. The following means are identified as full or partial solutions, some of which can be used in combination:

- incorporation of available European Investment Bank (EIB) finance initiatives to reduce the weighted average cost of capital funds (WACOC) to the project and hence the project hurdle rate;
- a support contract which is sufficiently firm to be bankable; this could be of the form of a firm price support or feed-in tariff, possibly as a tax relief or could be a capital grant / allowance. In whatever form, and possibly in combination with an ETS contract (see below), the value must be sufficient to allow projects to meet hurdle rates;

- an ETS contract of a form to make the forward ETS price bankable; a firm price swap may be ideal, but note that a contract for differences would not be suitable for new projects.

In summary the recommendations from the ECCO project concerning facilitation, promotion and financing of the infrastructure are that:

- those states or institutions considering granting support arrangements to CCS projects should recognize the need for contractual agreements around such projects to meet the fairly stringent requirements of private finance providers and to provide support in a compatible, and hence bankable, form.
- projects make use of EIB initiatives to lower their WACOC where possible.
- ownership issues along the chain should be considered carefully in establishing CCS projects as they may have a significant impact on contractual risk and project finance.

8 RECOMMENDATIONS FOR THE DEVELOPMENT OF THE INFRASTRUCTURE

The third report in the series of four final reports from the ECCO project investigated how one might recommend the most optimal form of the infrastructure that will facilitate and maximize the deployment of CO_2 value chains across Europe, in particular driven by the early opportunities for EOGR. Based on the development of different types of CCS chains in northern Europe and Hungary (refer to Table 2 in chapter 4), various alternatives that could provide a CCS chain solution were described and compared, and sensitivity analyses were made. Thereafter, some decision guidelines were defined and recommendations set out concerning optimal infrastructure design.

8.1 Decision guidelines

Some general guidelines from the analysis of example CCS chains were derived in ECCO, to assist in decisions relating to suitable CCS infrastructure for certain geographic areas. These guidelines are underpinned by the main factors which emerge as important to the infrastructure developer:

- technical / technological, including future expansion options
- economics
- legislation / regulation / public opinion

Basic connections
Most developers will fall into this category. If the absolute level of capital employed is the most important constraint then the most basic transport connection for CO_2 is the simplest solution. Depending on the location of the source and storage site, onshore and offshore solutions should be considered. If there is a choice of routing by land or sea, routing a pipeline onshore is likely to be cheaper but potentially liable to more delay or opposition due to planning issues. In EOGR value chains, higher oil prices have a direct linear impact on the distance that can be covered for a given level of support per tonne of CO_2, but the impact is rather limited in small-scale cases.

Grouping to bulk pipelines
If the CO_2 is to be transported over a considerable distance (greater than 50km, say) then it is worth considering collaboration with other sources of CO_2 to use a bulk pipeline for the majority of the distance rather than parallel separate streams (Many-One-Many). The benefit is that the initial capital cost is significantly reduced, provided that the sources come online at a similar time. Timing is extremely important however: a bulk pipeline requires early investment, while multiple separate source-sink connections allow for postponing part of the investment until a later date, if the sources do not come online at the same time.
A further issue for consideration is that the common carrier interlinks the risk profiles of the separate projects and also creates a potential common-mode failure.

Over-sizing
If the basic transport route runs from places with other potential sources of CO_2 and runs towards areas with other potential storage sites for CO_2 then over-sizing may be an interesting option if capital employed is not an absolute constraint. The level of risk that the pipeline will or may not be filled within a reasonable delay (e.g. 10 years) is the critical factor; hence as for the bulk pipeline option, timing of CO_2 sources coming online is crucial.

Buffer storage
One-way buffer storage (i.e. where the stored CO_2 cannot be recovered) can be introduced into a CO_2 infrastructure designed for EOGR at relatively low cost in favourable circumstances. A low-cost version can prove economic in a CCS chain, depending on the anticipated reliability of the other chain elements. More expensive platform-based buffers and two-way (partial recovery) stores seem unlikely to be economic. The purpose of the one-way buffer is to store the captured CO_2, so that it does not have to be vented, in cases where an EOGR site temporarily cannot receive it.

Long-distance extension to large EOGR fields
Extension of infrastructure to distant hydrocarbon fields with large EOGR potential can be economically attractive under the right conditions. If the capture activities have sufficient scale, the additional transport costs may be much smaller than the additional revenues from EOGR activities. This balance is also influenced by the outturn oil price (and tax regime) achieved for the EOGR and so project decisions for this kind of extension will be highly dependent on the forecast oil price.

Other network possibilities
Network interconnection is the next step in infrastructure complexity; this can lead to a higher reliability of revenues due to the introduction of alternative routes and the provision of spare capacity at lower costs due to the diversity of routes. It can also reduce the need for the inclusion of a buffer storage. The downside is interdependence of projects but there are plenty of precedents in existing network arrangements to deal with this issue for a more substantial network.

Continuity of CO_2 flow
The economics of a CCS chain rely heavily on the continuing flow of CO_2 along it, especially during the early years and especially if those early years attract additional subsidy. There may be some possibility to mitigate costs in the case of a shipping transport, but this will have a minimal overall impact on the overall chain economics.

8.2 Recommendations for infrastructure design

The underlying expectation in the design of CO_2 infrastructure, particularly in and around the North Sea is that it will grow in response to the need to store increasing amounts of CO_2. This leads to the requirement to look at the ways in which early infrastructure can be guided / encouraged to provide the best opportunities for future expansion. Examining the types of infrastructure in the examples studied that lend themselves to future expansion, it is clear that any "open architecture" relies on initial spare capacity being created in its main arterial routes. This may consist of oversizing of installed pipelines or possibly unused port capacities for shipping.

The alternative is that every new project builds its own infrastructure which may be efficient in delaying the incidence of capital spend for individual developments if these are well spaced in time, but will not encourage a swift take-up of CCS, nor will it limit the total cost of CCS infrastructure to meet EU CO_2 reduction targets.

Arterial routes can be defined as those pipelines linking additional economic CO_2 sources (i.e. those which will become the next set of capture targets as costs fall or prices rise) to the corresponding economic storage opportunities – those with economic capacity at a distance over which it is economic to transport the CO_2. One of the main potential economic drivers to new infrastructure or the take-up of spare capacity is the ability to supply CO_2 to EOGR projects, so the location of areas of significant potential EOGR should be factored into arterial infrastructure design.

A key issue is the question of how it can be economically sensible to build in expansion options into the first set of projects given that the prices will almost certainly reduce with time and these projects are the most difficult to finance? From the work in ECCO, an investment in oversizing pipeline infrastructure could be economic even if the delay in filling the spare capacity stretches to 10-15 years. So the issue boils down to the availability of capital for the project (initial projects will wish to minimise their capital to make them viable) and the risk of the additional CO_2 not arriving. This risk is a combination of pipeline location to catch future flows and confidence in the expanding requirement for CO_2 transport, but without a firm contract it may make the project unfinanceable.

The following table summarises the key barriers in the design and growth of a CO_2 infrastructure (from this and parallel reports as shown) and how each might be lowered or eliminated to encourage take-up together with the agent that could make this possible.

Barrier	**Possible Solution**	**Agent**
Transboundary legal issues	Legal agreements on waste transport and storage (see chapter 6)	MSs
Risk of lack of future CO_2 for oversizing	Underwriting of future flows	EC / MS
ETS not bankable against the risks involved in initial infrastructure	Contractual support and loan guarantees (see chapter 7)	EIB, MSs

9 IMPACT ASSESSMENT OF THE DEPLOYMENT OF CO_2 VALUE CHAINS ON THE EUROPEAN POLICY GOALS

The fourth in the series of final reports on recommendations and conclusions from the ECCO project is an "Impact Assessment" of the development and deployment of CO_2 value chains in Europe. An Impact Assessment is a well-defined procedure in European policy-making, for which clear guidelines exist[5]. Five different non-exclusive policy options arose from the reports summarized in chapters 5, 7 and 7, and the impact of these were assessed against the key objectives of the EU energy policy, which are sustainability, security of supply and competitiveness. The main conclusions regarding the investigated policy options and the business-as-usual reference case are:

- **Option 1: Business-as-usual:** As shown in the recent communication “A Roadmap for moving to a competitive low carbon economy in 2050” of the European Commission, a do-nothing scenario – which does not go beyond current policies – would result in only around 40% greenhouse gas emissions reduction by 2050 compared to the EU target of 80% domestic emissions reduction. If the societal choice is to mitigate climate change, this option is therefore not viable. In particular, if left to the market, investments in CCS technology development may be insufficient
- **Option 2: Promotion of EOGR-based versus non-EOGR based value chains:** An analysis of the impact of CCS value chains on sustainability, security of supply and competitiveness shows that EOGR-based and non-EOGR based value chains are similar in terms of sustainability, but that EOGR-based chains have the capacity to make significant impacts on both security of supply and competitiveness for the EU. Since EOGR-based chains also generally exhibit lower €/t costs, promotion of these chains is in principle adequately addressed by market forces, so there seems to be no economic rationale to specifically promote EOGR-based vs. non-EOGR based value chains. However, given the other potential advantages, such chains may be encouraged by the EU and MSs and it is encumbant on the EU to ensure that the addressing of barriers to entry for EOGR-based projects is prioritised.
- **Option 3: Investments in CO_2 transport infrastructure:** The assessment, based on ECCO case studies, shows that there may be a rationale for government investment at EU-level in oversized pipelines (provided additional flows are foreseen within a reasonable time, e.g. 10 years), although the exact economics depend on the specific circumstances of an individual case and would need further examination. On the other hand, it seems that investments in aquifer buffers as well as investments in bulk infrastructure extension to the Northern North Sea (NNS) for EOGR purposes, could be left to the market. However, the EU may have to support pioneering NNS infrastructure which is likely to overburden initial projects and any reliance on the market to deliver infrastructure is predicated on the EU ensuring that a sufficient overall greenhouse gas emissions reduction support scheme is in place. Finally, public awareness campaigns could help improve economics of CCS chains by enabling onshore activities
- **Option 4: Financial measures:** While EIB funds may provide some improvement to the capital cost, the bulk of funding will have to come from other EU or Member State funds. Various support instruments could accomplish the goal, provided they are sufficiently

[5] European Commission, 2009, Impact Assessment Guidelines, 15 January 2009, SEC(2009) 92.

firm to be bankable, e.g. firm price support or feed-in tariff, possibly as a tax relief, or a capital grant / allowance. Likewise, it would require an ETS contract of a form to make the forward ETS price bankable; a firm price swap is ideal. Regarding chain structure, regulation will need to strike a balance between allowing vertically integrated CCS chains in the short run in order to foster the deployment of early value chains, and regulating value chain organisation and third party access in the long run (potentially involving a neutral system operator) to enable long-term competitive growth of CCS.

– **Option 5: Improvement of regulatory framework:** Various regulatory improvements can be considered, such as active use of the Plan for Development and Operation; regulation for a requirement on "EOGR retrofit" condition in existing fields and "EOGR ready" condition in new fields; clear rules for cross-border projects; provision of certainties regarding the allocation of EUA in case of unsatisfactory storage integrity; characterisation of long term liability transfers; establishment of a trust fund; constitution of a financial contribution / guarantee; construction of a storage licensing scheme.

10 CONCLUDING REMARKS

The ECCO project has aimed at showing how early CO_2 value chains can be implemented, in order to play a significant role in meeting EU policy objectives for reducing GHG emissions. The hurdles (legal, financial, organizational) that must be overcome for the implementation to be possible have been studied and described in ECCO. In conclusion, the rationale for CCS is mainly policy-driven. If left to the EU-ETS market, with its current low CO_2 price, investments in CCS technology development are likely to be insufficient, although using CO_2 for enhanced oil or gas recovery (EOGR) may improve the economics of a CCS value chain.

An additional overview issue, not covered in the ECCO project, is how to ensure the most effective use of existing European geological reservoirs when designing European value chains for CCS. It is important to note here that any geographical location that is relevant for CCS would require substantial case-specific evaluation of different options for value chain configuration before any decision on infrastructure development could be made.

One of the key results from ECCO is the ECCOTool, which is a dedicated decision support software tool, designed and implemented for studies of CCS value chains. Based on the experience from the development and use of the ECCOTool within the project, it is stated by the ECCO partners that analyses conducted with the ECCOTool could provide much of the technical and economical support and guidelines that would be required when scoping future implementation of CCS value chains.

Further specific conclusions and recommendations can be found in the executive summary.

APPENDIX A: ECCO METRICS

Started 1 September 2008.
Duration: 3 years and 3 months.
Completed by November 2011.

Budget: 5.355 M€
~ 3.853 M€ in grant from the European Commission

Partners: 19 legal entities, of which
- 8 energy providers
- 2 engineering companies
- 1 NGO
- 8 highly ranked RTD providers

Coordinator: SINTEF Energi AS (SINTEF Energy Research)

List of partners:

SINTEF Energi AS
SINTEF Petroleumsforskning AS
Netherlands Organisation for Applied Scientific Research – TNO
Joint Research Center
IFP Energies nouvelles
Geological Survey of Denmark and Greenland
Norwegian University of Science and Technology
The Bellona Foundation
Progressive Energy Limited
STATOIL Petroleum AS
Vattenfall Research and Development AB
DONG Energy Power A/S
University of Zagreb
INA Oil Industry PLC
MOL Hungarian Oil and Gas Plc.
Project Invest AS
E.ON New Build & Technology Limited
RWE Npower

APPENDIX B: LIST OF ACRONYMS

CCGT	Combined Cycle Gas Turbine (power plant)
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power (plant)
CO_2	Carbon Di-oxide
DGF	Depleted Gas Field
EC	European Commission
ECCO	European value Chain for CO_2
EERP	EC CCS support programme: European Economic Recovery Plan
EGR	Enhanced Gas Recovery
EIB	European Investment Bank
EOGR	Enhanced Oil or Gas Recovery
EOR	Enhanced Oil Recovery
ETS	Emission Trading Scheme
EU	European Union
EUA	EU (emissions) Allowance
FCM	Forward Capacity Market
GHG	Greenhouse Gas
IGCC	Integrated Gasification Combined Cycle (power plant)
MS	Member State
NER 300	EC CCS support programme: New Entrants' Reserve
PCC	Post-Combustion Capture (power plant)
PDO	Plan for Development and Operation
SP	Sub-Project
TPA	Third Party Access
TSO	Transport Systems Operator
WACOC	Weighted Average Cost of Capital
WP	Work Package