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Carbon capture and storage projects under the climate policy regime: The case of Halten CO_2

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Sammendrag: Rapporten diskuterer spørsmål knytt til institusjonar og instrumentbruk under det internasjonale og nasjonale klimapolitiske regimet ved bygging av eit planlagt gasskraftverk med karbonhandtering i Midt-Noreg.	**Abstract:** The report discusses institutional and policy issues associated with implementation of a planned carbon capture and storage plant in Mid-Norway under the international and national climate policy regime.
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Preface

The aim of this study is to assess institutional, political and legislative issues associated with the planned “CO_2 value chain from Tjeldbergodden to Draugen and Heidrun” industrial project. The Draugen and Heidrun oil reservoirs are two important components of the value chain and are situated on the Halten Bank off mid-Norway. For short we refer to the project as the “Halten CO_2 project”. This study is supplemented by an economic study and a study of legislative issues. The economic study is carried out by CICERO and focuses on the social value of the Tjeldbergodden industrial project. The legislative study focuses on environmental liability, discusses the relevant Norwegian legislation, and point out which adjustments Norwegian authorities should consider before CO_2 chains become operative in Norway. It is carried out by the Scandinavian Institute of Marine Law at University of Oslo (Berger, 2007a and 2007b).

The three studies are part of a wider study of the Halten CO_2 project, with the objective of evaluating the likely future conditions for CO_2 capture and storage projects in general and the Halten CO_2 project in particular. Other studies examine the Draugen and Heidrun reservoirs, CO_2 capture and transport, topside equipment, and financial aspects.

1 Introduction

There are a number of climate policy issues related to the Halten CO_2 project. This report considers institutional and policy matters at the national, European and international levels. We ask if the Halten CO_2 project will contribute to reaching existing climate policy targets in Norway and internationally, and to what extent existing and future climate policy instruments can contribute to the profitability of the project.

The Halten CO_2 project is a model for an early CO_2 value chain in Mid-Norway initiated by Shell and Statoil. It consists of four main components, where the first is a 860 MW gas-fired power plant linked to the methanol production facility at Tjeldbergodden. The power plant can also supply electricity offshore and contribute to regional electricity supply. The second component is facilities at Tjeldbergodden for capture of up to 2.25 Mt CO_2 annually associated with the power plant, transportation of the CO_2 to the Draugen and Heidrun oil reservoirs and injection of the gas at these sites. The third is Enhanced Oil Recovery (EOR) at the Draugen and Heidrun oil reservoirs, and possibly other sites, which after the end of the project can serve as final storage for the CO_2. The fourth and last component is an aquifer, likely close to the Heidrun reservoir, which can be used for final storage of captured CO_2 that is not permanently trapped in one of the oil reservoirs.

Capture will take place at Tjeldbergodden from both the power plant and from purification of gas for sale. Gas is transported by pipeline from Heidrun, the CO_2 content is reduced before sale, after which the CO_2 is transported back to the reservoir. The oil will be purified at the off-shore site. Draugen is only producing small amounts of gas, and all of the gas and CO_2 is re-injected into the reservoir. Gas from Draugen can be transported to Heidrun before injection at this site or at another site.

The investment decision for the Halten CO_2 project will be taken by end of 2008. The power plant and electrification of Draugen could start up in 2010-2011, whereas the first CO_2 supply for EOR at Draugen could take place about one year later. The Heidrun field can follow Draugen as a base for EOR activities.

At Draugen all CO_2 storage will be in the oil reservoir used for EOR. The duration of injection and recycling will be around 10 years. At the next stage the CO_2 will be used at the Heidrun field for another 10 years approximately. However, injection at Heidrun may start earlier if the injection capacity at Draugen is exceeded. The need for injection may exceed the injection capacity at some point in time. At Heidrun additional storage will probably be necessary in an aquifer some time in the period 2020-2030. However, the aquifer to be used for storage for CO_2 from Heidrun has not yet been identified. The exact share of storage in oil reservoirs compared to the aquifer is still subject to investigations. It can currently be assumed that 40 % is stored in the oil reservoirs as a result of the EOR operations.

The time horizon of our study is 2010 – 2030. In choosing the time horizon, the need for a sufficiently long period to invest in the Tjeldbergodden industrial project and operate the facilities must be balanced with the increased technology and climate policy uncertainties involved in a longer time horizon. The time period chosen means that the last three years of the Kyoto Protocol are covered, followed by a post-2012 regime. Many aspects of climate policy beyond 2012 is still unknown, but both Norway and the EU have stated that the target is to reduce its greenhouse gas emissions by 30% by 2020.[1] However, the government of Norway has stated that the targets partly will be met by investments in emission reduction measures in other countries.

The IPCC special report on Carbon Capture and Storage (CCS) (IPCC, 2005) is a main literature reference. In addition we are building on recent academic publications on CCS and climate policy, see e.g. Vajjhala et al. (2007) and Torvanger et al. (2005).

The next section of the study gives an overview of the climate policy framework for the period 2010-2030. Section three assesses how the Halten CO_2 project can be implemented in the light of international climate policy agreements and regulations, EU's climate policy, and Norwegian climate policy. Finally, section four provides an overall assessment of the implementation of the Halten CO_2 project, thereby summarizing the main findings of the study.

2 The climate policy framework

The global UNFCCC/Kyoto framework, EU legislation as well as national policies will affect the Halten CO_2 project. The following gives an overview of national and international climate-related regulations that may affect how the emissions reductions resulting from this project are credited in a climate policy context. Regulations related to environmental liability concerns are discussed in Berger (2007a and 2007b). Sections 2.1-2.3 focus on the period 2010-2012, which is the last three years of the Kyoto Protocol target period. Section 2.4 examines prospects for the post-2012 era until 2030.

2.1 International commitments

The fundament of the international climate regime is the UN Framework Convention on Climate Change (UNFCCC). Its purpose is to avoid "dangerous anthropogenic interference with the climate system". The Kyoto Protocol provides shorter-term, legally binding targets, and commits Norway to limit its net total average annual greenhouse gas emissions in the years 2008-2012 to 101% of its 1990 emissions. Allowances bought through the Kyoto mechanisms may be subtracted from the national emissions budget.

The UNFCCC and the Kyoto Protocol also commits Norway to monitor its emissions of greenhouse gases and to report regularly to the UNFCCC secretariat. The UNFCCC, the Kyoto Protocol and the Marrakech accord give no specific guidance or rules for CCS projects.[2] For several years, however, Norway has subtracted CO_2 captured from the Statoil-operated Sleipner field and stored in the Utsira formation (which is an aquifer) under the North Sea from its emissions inventories reported to the UNFCCC. In this way, the project contributes significantly to fulfilling Norway's Kyoto target. CO_2 permanently stored in oil reservoirs or other geological formations as part of the Halten CO_2 project could be treated in the same way. However, reporting and monitoring of captured and stored CO_2 will probably be subject to more detailed international rules in the future. In late 2005 COP11/MOP1 in Montreal initiated a process to consider CCS as a climate policy measure under the UNFCCC

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[1] The EU's 30% target is contingent on other countries taking on similar targets; otherwise the target will be 20%. EU has stated that 20% emission reduction is to take place within the region, not through buying emission allowances from other countries.

[2] The Marrakech accord is a 2001 agreement on the implementation of the Kyoto Protocol.

and the Kyoto Protocol. The recent IPCC Guidelines includes a framework for monitoring and reporting of CO_2 storage that is an important reference in this regard (IPCC, 2006).

2.2 The EU

EU legislation affects the incentives for a Norwegian CO_2 value chain in several ways: Through emission trading rules, state aid rules, EU funding for large-scale demonstration projects and more. EU policies in these areas are currently under rapid development. The following gives an overview of the current state of affairs in the EU.

The Commission recently outlined its views in a Communication on "Sustainable power generation from fossil fuels" (EU, 2007a). This followed extensive consultation and review processes under the Second European Climate Change Programme (ECCP II) and The European Technology Platform on Zero Emission Fossil Fuel Power Plants (ZEFFPP), and work in an "Ad Hoc Group of EU Experts on Monitoring and Reporting of CCS in the EU ETS" set up by the UK government (Dixon and Zakkour, 2006; ECCPII, 2006; ZEFFPP, 2006).

Emission Trading Scheme. From January 2008 the EU's emission trading directive will be implemented in Norway. Currently, only temporary provisions are in place for CCS in the EU ETS. The Commission foresees "development and adoption of guidelines on the monitoring and reporting of CO_2 capture and storage". In the meantime Member States may submit interim guidelines for the Commission's approval. After such interim guidelines are approved, captured and stored CO_2 "may be subtracted from the calculated level of emissions from installations" (Decision C(2004)130). A process has been established to establish such guidelines.

A large gas-fired power plant is clearly covered by the ETS, which includes all combustion plants with a capacity above 20MW. An "opt-in" clause allows governments to include more sources than the minimum list provided by the Directive.

Further incentives. It is widely recognized that emissions trading will probably offer insufficient incentives for most CCS projects in the near future. The European Commission has announced its intent to support the construction and operation for 10-12 large-scale demonstration facilities for "sustainable fossil fuel technologies" with an emphasis on CCS. Work on the design of a mechanism for such support is starting this year (EU, 2007a).

Liability. Long-term liability in case of leakage of CO_2 from storage sites is another issue that needs clarification. Existing legislation including the Environmental Liability Directive may have some relevance here (ECCPII, 2006; Berger, 2007a and 2007b).

2.3 Norway

On top of the target defined by the Kyoto Protocol, the current Norwegian government has announced its intention to reduce Norway's emissions with an additional 10% of its 1990 emissions by 2012. This implies that Norway should reduce its emissions to 91% of its 1990 emissions by 2008-2012. This target will be met through a combination of domestic measures and use of the Kyoto mechanisms. In its white paper on climate policy, the government says domestic measures shall constitute a "significant share" of the emissions reductions (MD, 2007).

Key climate policy instruments include the CO_2 tax for some sectors including offshore petroleum activity, emissions trading, and voluntary agreements with some industrial sectors.

The government also defines technical requirements for industrial facilities such as gas-fired power plants. Relevant regulations for the projects considered here cover emissions of greenhouse gases and other pollutants (e.g. emissions of NO_x and volatile organic compounds (NMVOC)), energy efficiency and use of CCS. Finally, the government offers funding for development and deployment of CCS technologies and relevant infrastructure.

CO_2 tax. For CO_2 sources that are covered by the Norwegian CO_2 tax, this may offer a positive incentive for CCS. Currently, these sources include well-stream CO_2 stripped from natural gas as well as combustion on offshore installations. The tax is not applicable to gas-fired power generation onshore.

Emission trading. From the second phase starting in January 2008, Norway's quota system will be fully integrated into the EU ETS and subject to the regulations in the emission trading directive. The Norwegian government will seek to "opt in" CCS facilities. The incentive effect of the emission trading system depends critically on the detailed rules for CCS and its linking to emissions trading, as outlined in section 3.2.2.

CCS as a technical requirement. In a recommendation to the Ministry of Environment regarding Statoil's proposed power plant at Tjeldbergodden, the Norwegian Pollution Control Authority has proposed that new power generation facilities fired by natural gas should be required to install CO_2 capture and storage (SFT, 2006). The Soria Moria political platform for the Labour, Socialist Left, and Centre parties' government also suggests that new concessions for gas-fired power should be "based on" CCS. In the recent agreement between Statoil and the government regarding the CHP plant at Mongstad, it was agreed that full-scale CCS should be installed by 2014, after four years of operation. At present it is unclear exactly what kind of CCS requirements that would apply to a gas-fired power plant at Tjeldbergodden.

Funding. The present government's political platform suggests that the government should offer financial incentives for companies to capture and store CO_2 from new gas-fired power plants. It also promises government investments in infrastructure required for a CO_2 value chain. In this regard clarification of the limits on government funding defined by EU state aid rules is crucial. The implementation of government funding policies is described in some more detail in section 3.2.3.

2.4 Climate policy beyond 2012

The future for international climate policy is presently very uncertain. The commitments in the Kyoto Protocol expire at the end of 2012, and talks about a successor agreement are at a very tentative stage. While some progress has taken place recently with regard to establishing dialogs between key actors, the challenge of committing the United States and major growth economies such as China or India to binding targets remain elusive.

Meanwhile, the EU, Norway and other countries have supported a maximum of 2ºC global warming as a long-term target to guide international climate policy, suggesting stringent emissions limitations over the decades to come. At the recent G8 summit in Germany, the EU as well as Japan and Canada supported halving global emissions by 2050.

The EU has announced a unilateral target of reducing its GHG emissions with 20% by 2020. Norway's government has proposed the following, unilateral long-term targets for Norway: contribute to reduce emissions by a magnitude of 30% of national emissions by 2020 compared with 1990 and becoming "carbon neutral" by 2030 by compensating for all remaining GHG emissions through use of the Kyoto mechanisms or similar arrangements in future agreements.

The balance between domestic emissions reductions and use of international mechanisms is controversial. Whereas EU favors a strict constraint on the use of Clean Development Mechanism (CDM) projects within its trading system, Norway is negotiating with EU to get an exemption from the emission trading directive on this point. In any case EU cannot interfere with the Norwegian government's right to decide the state's purchase of allowances and credits under the Kyoto Protocol. More generally the Norwegian government seeks to avoid setting absolute constraints on the use of emission allowances and credits from flexible mechanisms, since this could interfere with a least cost allocation of domestic and foreign abatement measures and projects. EU is more willing to limit import of emissions allowances to its emissions trading system from other industrialized countries and CDM credits under the Kyoto Protocol, apparently because they fear that free import could reduce the European allowance price so much that this will conflict with its long term climate policy target.

When it comes to policy instruments, the EU is preparing for a third phase of its Emission trading scheme to start from 2013, and considers further development of the system. Through the EEA agreement, Norway will be bound to follow the EU on emissions trading.

Since important uncertainties exist with regard to future climate policy environment and the cost of CCS relevant for industrial investment projects such as Halten CO_2, we examine the most important factors for the attractiveness of CCS for the time period 2013-2030. First, the stringency of climate policy is important. We simplify to the two cases of a strict policy, which gives rise to a high allowance price, and a weak policy, which gives rise to a low allowance price. Furthermore the future cost of CCS is uncertain. Simplifying to two cases, the cost can either be high or low. Table 1 illustrates the four different combinations of stringency of climate policy and CCS cost. In addition three more factors included in the table. These are constraints on the use of CCS, cost of alternative emission abatement measures and technologies, and CCS monitoring and verification costs. These three factors are included in the table such that they either support the most or least favorable CCS case. In Table 1 the upper left-hand cell represents the most favorable scenario for handling CO_2 emissions thorough CCS, whereas the lower right-hand cell, which has the darkest grey shade, represents the least favorable scenario. The two other cells with a lighter grey shade represent cases where CCS is medium favorable.

Climate policy scenario	**CCS cost scenario**	
	Low cost	**High cost**
Strong	*Most favorable for CCS* - High allowance price. - Low CCS cost. - No constraints on use. - High cost for alternatives. - Low monitoring/verification costs.	*Medium favorable for CCS* - High allowance price. - High CCS cost. - Some constraints on use. - Medium cost for alternatives. - Medium monitoring/verification costs.
Weak	*Medium favorable for CCS* - Low allowance price. - Low CCS cost. - Some constraints on use. - Medium cost for alternatives. - Medium monitoring/verification costs.	*Least favorable for CCS* - Low allowance price. - High CCS cost. - Strict constraints on use. - Low cost for alternatives. - High monitoring/verification costs.

Table 1. The attractiveness of CCS given climate policy and CCS cost scenarios.

Figure 1 shows another way of illustrating the long term attractiveness of CCS. A stricter climate policy will over time imply a rising value of CO_2 abatement, for instance reflected in the emission allowance price, shown as an upward–sloping line in the figure. Technological improvements will reduce the unit cost of CCS over time, seen as a downward-sloping line for CCS cost. If and when these lines intersect, shown as year a in the figure, CCS will become a highly interesting abatement measure. However, the cost of alternative abatement measures is also likely to fall over time, shown in the lowest downward-sloping line in the figure. In this example alternative measures have a lower cost than CCS and therefore become attractive earlier. In reality, of course, there are different alternative abatement measures carrying different costs, and also some variation in the unit cost of CCS. Therefore a mix of measures, possibly including the most attractive CCS cases, will at a given future time be the cost-effective combination to reach an abatement target. The important point is that the ranking of least expensive measures can change over time, both among CCS technologies and among alternative technologies, and across these two categories, as both CCS and alternative technologies improve over time.

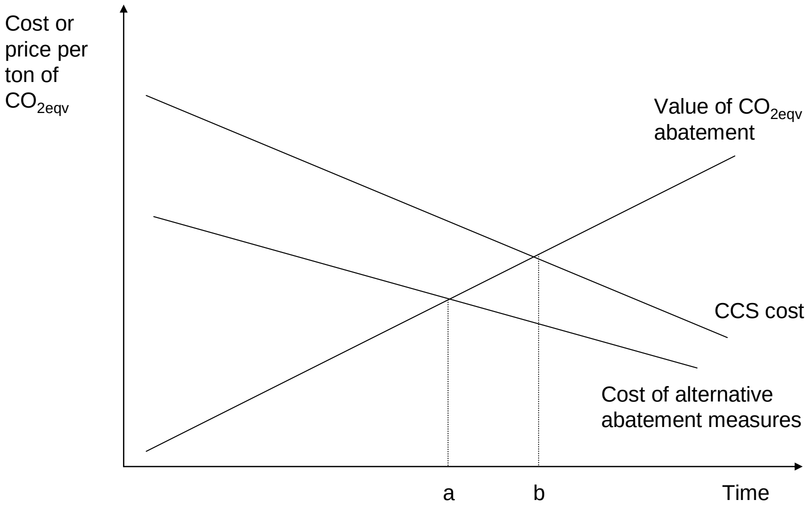

Figure 1. Attractiveness of CCS over time.

With 2030 as the time horizon our expectation is that the value of CCS will increase due to an increasingly stricter climate policy. We also expect that CCS will be more competitive as an abatement technology over time since it is relatively young. Thus there should be a large scope for improvements, not the least through learning by doing when we get experience from full scale demonstration facilities in Norway and EU. Still it is difficult to guess when the two lines in Figure 1 will intersect, but our expectation is that this could at least take one to two decades. It is also challenging to guess how much other abatement technologies can improve over time, and thus how their competitiveness compared to CCS will be.

3 Assessment of the Halten CO_2 project

In this section the opportunities and challenges to implementation of the Halten CO_2 project are examined in light of the climate policy commitments and regulatory framework outlined in the previous chapter. The discussion proceeds as follows: In section 3.1, the project's contribution to meeting Norway's climate policy commitments is discussed. In section 3.2, the applicable incentives and regulatory framework are outlined. Finally, section 3.3 takes a closer look at the rules for monitoring, verification and reporting, and associated costs to the project.

3.1 Compatibility with national and international climate policy targets

3.1.1 The Kyoto Protocol (2008-2012)

The power plant at Tjeldbergodden is expected to start operation during 2011 or 2012. It will therefore be operating at most for a small part of the Kyoto Protocol's first commitment period 2008-2012. Only the operation period that overlaps with the first commitment period will be relevant to Norway's compliance with the Protocol's existing provisions.

In case there is a time lag between opening of the power plant and installation of the CO_2 capture facility, CO_2 emissions from the power plant would be in the order of 2.5 Mt on an annual basis until capture is initiated. After the capture facility becomes operational, residual emissions from the power plant would still be a few hundred thousand tons.

The emissions from the power plant represent an increase in Norway's national emissions budget, which must be offset through use of the Kyoto mechanisms or reductions by other sources in Norway.

Provided that acceptable monitoring and verification procedures are followed (see section 3.3), CO_2 permanently stored under the seabed as part of the project can likely be subtracted from the Norwegian emissions budget reported to the Kyoto Protocol and the UNFCCC. In other words, CO_2 storage contributes to compliance with Norway's Kyoto target. If leakage of CO_2 from storage sites should occur this could represent a challenge for Norway's compliance with regard to the Kyoto Protocol or similar commitments (see section 3.3).

In case there is a lag between initiation of power production and CO_2 capture, and due to the fact that CO_2 capture will not be 100% effective, the Halten CO_2 project will add to the gap between Norway's Kyoto target and actual emissions, which must be filled by means of more reductions in other sectors or purchase through Kyoto mechanisms. If, however, the reference situation is e.g. gas-fired power production without CO_2 capture, the Halten CO_2 project clearly contributes to relatively lower emissions.

3.1.2 Longer term emissions and obligations (post 2012)

We organize the discussion of the Halten CO_2 project's relation to beyond 2012 climate targets at three levels. These relate to a) Norwegian emissions, b) emissions from industrialized countries that participate in some type of international agreement to limit their emissions beyond 2012 (possibly a second commitment period under the Kyoto Protocol), and c) global emissions.

a) Norwegian emissions. The overall effect of the total Halten CO_2 project on Norwegian compliance with its future commitments depends on the nature of these commitments (the future climate regime) as well as the kind of reference situation one compares the project with, similar to the situation under the Kyoto Protocol discussed above. Which reference situation is considered relevant depends on energy policy and energy market considerations. The potential contribution of the Halten CO_2 project to longer-term climate policy targets would be strengthened if the CO_2 infrastructure and storage sites are developed with an eye to possible future transport and storage of CO_2 from additional existing and new industrial sources in the region.

b) Emissions from parties to an international agreement. As long as the countries in Europe (and industrialized countries in other regions) are bound by international arrangements such as the Kyoto Protocol and the EU ETS, individual industrial projects should not affect total emissions in the short term. Introduction of a new emission source should in principle be counterweighed by reduced emissions elsewhere, while emissions reductions at one site would allow others to increase their emissions. However, emission targets are to be renegotiated regularly. One may argue that a successful development and dissemination of CCS technologies and related abatement cost reduction should make countries more willing to set ambitious climate policy targets.

Electricity supply to Draugen from the power plant at Tjeldbergodden is likely to reduce power-related CO_2 emissions since diesel aggregates and turbines at the platform are relatively inefficient. However, as long as there is a power supply shortage in the region (and Norway as a whole), the wider implications for emissions from the North European power grid is relevant. Thus, at least in the short term, some of the gains from reduced emissions at the platform will be lost to e.g. increased Danish emissions due to import of coal-fired power. In a scenario with sufficient supply of power from relatively clean sources this would not be the case.

c) Global emissions. A case can certainly be made that the Halten CO_2 project contributes positively to emissions reduction globally, but it would be a mistake to treat it as self-evident.

At least four aspects of the project influence global greenhouse gas emissions are important: Emissions from power generation, effects of enhanced oil recovery, technology/infrastructure development, and finally allocation of government subsidies for environmental projects.

All these aspects should be taken into account when considering the effects of the project on global emissions. In a long-term perspective, the most important effect of early CCS projects could be technology and infrastructure development. In a global and long-term perspective, the potential for technology development, learning benefits and infrastructure development are arguably more important criteria for assessing early CCS projects than directs effects on emissions from each project.

Gas-fired power with CCS technology has relatively low CO_2 emissions per electricity unit produced. The emissions are substantially lower than from conventional fossil power, but higher than renewable or nuclear energy. If the alternative for improving power supply in the Midt-Norge region is relying on new gas-fired power plants without CCS, or improving transfer capacity (allowing more imports from other parts of Northern Europe, likely to be covered at least in part by power generation from coal without CCS), the Halten CO_2 project will probably contribute to somewhat lower CO_2 emissions from Northern Europe.

While increased supply of fossil fuels due to enhanced oil recovery may improve the profitability of the Halten CO_2 project, it arguably represents a drawback in terms of induced additional CO_2 emissions. The content of fossil carbon in the additional oil recovered through CO_2-assisted EOR could in fact be almost as large or in some cases even larger than the carbon content of injected and stored CO_2 under some scenarios for CO_2-assisted EOR, depending on reservoir-specific circumstances. This does not represent a problem for compliance with Kyoto Protocol type agreements, because almost all the oil is exported and its related CO_2 emissions does not show up in Norway's emissions budget. But because most of the world economy is currently not bound by quantified commitments to limit emissions of greenhouse gases, increased supply of fossil fuels could potentially lead to increased global emissions. At best, the increased supply might be too small to influence the oil price and would then have no effect on global demand and thereby emissions. At worst (from a climate change mitigation perspective), additional supply from several CO_2-assisted EOR projects world wide could add up to lower oil prices slightly, and thereby this price-related CO_2 leakage would increase oil demand and global CO_2 emissions. To the extent that the project over its lifetime involves a significant share of storage of CO_2 that is *not* used for EOR, this would improve the balance between injected and extracted fossil carbon from a emission mitigation perspective.

Improving CCS technologies is an important element of the Norwegian government's long-term climate policy strategy, and the combination of CCS and EOR is seen as an important early step towards realization of CCS on a scale sufficient to significantly mitigate climate change. Full-scale industrial projects may help improve the technologies and could facilitate learning by doing that reduces costs. There should be a large potential for international collaboration on technology development and for transferal of improved technologies to other countries, in particular to countries with large coal reserves such as China, India and the USA. In this regard the government must consider that Norway's focus has been on gas power with CCS, whereas the large global potential is in coal-fired power production. On the capture side, the Norwegian government and energy industry are already involved in two large-scale projects involving post-combustion capture from gas-fired power stations with a 5-10-year time horizon (Mongstad and Kårstø). Given this, it is not obvious that it is critical from a technology development point of view to start an additional facility of similar type within the same time frame. The storage part of the project is perhaps more likely to involve large learning benefits. If realized, the Halten CO_2 project will be the first CO_2-assisted offshore EOR operation worldwide. Consequently, it will also be the first full-scale effort to inject and monitor CO_2 in an active offshore petroleum field with an eye to permanent storage of injected CO_2 in the field.

To the extent that the project requires government subsidies for capture, transport or storage another question becomes relevant: Could government support of other emissions-reducing (and energy-supply) projects give larger emissions reductions for the same amount of money? No-one knows the final answer to this question, but it seems safe to suggest that the government must find a sensible balance between a strategic investment in a mitigation technology where Norway likely has comparative advantages – such as CCS – and reducing the risk through spending money on a portfolio of technologies - such as off-shore wind, bio energy, fuel cells and solar cells - in addition to CCS.

3.2 Instruments and incentives

3.2.1 Tax

The Norwegian CO_2 tax is not applicable to gas-fired power plants onshore, only to oil and gas combusted at platforms in the North Sea.

3.2.2 Emissions trading

It is presently not clear which incentives the rules for emission trading will offer for CCS at Tjeldbergodden and other locations. There are two key issues in this respect: a) Rules for calculating emissions from an installation, and b) rules for allocation of allowances. Another interesting design feature of emission trading systems with regard to linkage to CCS value chains is the definition of installations. In the EU ETS installations are the basis for allocation of (free) allowances. These issues are discussed in turn below.

a) Calculating emissions. When installation owners surrender allowances (quotas) for greenhouse gas emissions to the authorities at the end of the year – will they need to surrender allowances corresponding to the entire amount of CO_2 generated at their installations, or may they subtract stored CO_2 from their calculated emissions? Only the second alternative gives a positive incentive for CCS projects.

For all or most of the time period covered by this report (2010-2030) stored CO_2 can probably be subtracted, subject to compliance with detailed monitoring and reporting rules (see section 3.3).

However, it may take some time to sort out the legal and procedural challenges that must be met before this can be realized. As they stand, the rules for the EU ETS suggest that a gas-fired power plant needs allowances for the entire amount of CO_2 generated, even if a large part of the CO_2 is in fact captured and stored. Eventually, common rules for monitoring and reporting of CCS will be agreed to within the EU, and companies will probably be allowed to subtract stored CO_2 from the calculated level of emissions from their installations.

In the mean time, member states and EEA states may be allowed to “opt in” CCS facilities. For the period 2008-2012, the Norwegian government will seek acceptance for such an “opt-in” of CCS facilities. Stored CO_2 may be subtracted from the calculated level of emissions at each installation provided that interim guidelines for monitoring and reporting are accepted (in Norway’s case by the ESA in consultation with the Commission). Approval of interim guidelines may take some time. However, the Ministry of Environment writes that they consider approval likely given the anticipated role of CCS in EU climate policies (“Energy policy for Europe 2007”). The Council of the European Union “urges Member States and the Commission to work towards strengthening R&D and developing the necessary technical, economical and regulatory frameworks to bring environmentally safe carbon capture and sequestration (CCS) to deployment with new fossil-fuel power plants, if possible by 2020”. (EU, 2007b)

b) Allocation of allowances. Allocation rules affect incentives for CCS. If all allowances were auctioned by the government, companies would have a clear-cut incentive to take measures to limit emissions (including through CCS if stored CO_2 can be subtracted from calculated emissions and if net costs per ton of CO_2 to the project owners are lower than the price of allowances). The Norwegian government has stated that its goal is that free allowances should be phased out after 2012 and that companies should prepare for a situation where they may have to pay for all the allowances they need. However, it is far from clear that the EU will in fact introduce a system where all allowances are auctioned.[3]

As long as installation owners receive some of the allowances they need free of charge from the government, based on past or expected future emissions, the specific allocation rules may heavily influence the incentive effects of the emissions trading system.

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[3] The main argument against free allowances is that it leads to inefficiencies through disincentives for emission abatement. If a company owner believes that he will be allocated fewer free allowances in the next period if he shows that his “need” for allowances is reduced, he will make relatively smaller efforts to reduce his emissions, since smaller present emissions reveals that his need is indeed smaller. In addition auctioning of allowances reduces the problem of large windfall profits for e.g. coal-based power producers.

The key question with respect to CCS is: Will free allowances for new gas-fired power plants be allocated based on expected *emissions to the atmosphere* or based on the total amount of CO_2 generated at their installations (i.e. including CO_2 which is stored)? In other words – will installations that practice CCS receive fewer allowances from the government than installations which do not (yet) practice CCS? The latter alternative would weaken incentives for CCS projects, and would lead to a negative incentive (that is, the emission trading system could in fact improve the relative profitability of fossil power plants without CCS compared with power plants with CCS). In addition power plants with CCS will have substantially higher capital and operation costs than similar power plants without CCS. Obviously government support is important to reduce this disincentive for CCS.

For 2008-2012 the Norwegian government has announced that it will set aside a special allowance reserve for new gas-fired power plants “based on CCS” as well as highly efficient combined heat and power (CHP) facilities. The term “based on” CCS is taken from the current coalition government’s platform, and may in some cases mean that CCS is to be introduced after several years of operation.

Norway’s National Allocation Plan (NAP) for 2008-2012 was presented in December 2007. The government has stated that allowances given free of charge to gas-fired power plants will be “in the interval 75-92% of expected emissions, depending on the facility’s environmental quality” (Ot.prp. nr 66, 2006-2007. Our translation from Norwegian).

Taken literally, the term “expected emissions” would seem to imply that the basis for allocating allowances for a plant with CCS would only be the residual emissions, which are emissions after CCS. In that case, a power plant with CCS would only receive allowances corresponding to a few percent of the total amount of CO_2 generated at the plant. If in such a case allowances must be surrendered for emitted CO_2 only, there will be a neutral effect on CCS from allocation of free allowances, see Table 2.

On the other hand, in the same bill the government emphasizes that the emission trading system should provide incentives to develop and commercialize technologies for CCS. This arguably suggests that all CO_2 generated at a plant (stored CO_2 + residual emissions) should be the basis for allocation, in order to provide a clear incentive for CCS. However, in this case there will only be positive incentives for CCS if only allowances for emitted CO_2 must be surrendered. If allowances for stored plus emitted CO_2 must be surrendered, the allocation effect on CCS is neutral.

If Norway is among the first countries seeking to include CCS under the EU ETS, Norwegian authorities could have the opportunity to influence EU decision making in this field at an early stage through its proposals.

CCS projects in Norway and elsewhere will likely be funded by the government to a large extent. As mentioned, clarification of EU state aid rules is crucial with respect to such government funding of CCS projects. One question that could possibly be raised by ESA and the Commission is whether incentives for CCS through allocation of free allowances is acceptable in cases where most of the costs for CCS are in fact carried by the state. However, a legal analysis of this question is beyond the scope of this report.

	Allocation based on stored + emitted CO_2	**Allocation based on emitted CO_2 only**
Allowances must be surrendered for stored + emitted CO_2	Neutral effect on CCS	Negative incentives for CCS (a highly unlikely scenario)
Allowances must be surrendered for emitted CO_2 only	**Positive incentives for CCS**	Neutral effect on CCS

Table 2. Options and generated incentives for CCS in the emission trading system.

CCS and installations in the EU ETS. The framework for the second phase of EU ETS (2008 - 2012) has already been formally adopted. Because part of a CCS chain – namely the power plant – already is included in the ETS, opt-in of a CCS facility must be adapted to the rest of the system. Work is underway to address how this might be done. However, beyond 2012 there will likely be a larger flexibility with respect to how CCS could be included. A key question in this respect is how to define a CCS installation as this is the unit to which emission allowances are allocated to.

The EU's emission trading directive (2003/87/EC) provides the following definition: "'installation' means a stationary technical unit where one or more activities listed in Annex I are carried out and any other directly associated activities which have a technical connection with the activities carried out on that site and which could have an effect on emissions and pollution". Furthermore, the directive defines what emission generating activities and greenhouse gases to be included. In other words not all emission generating activities within an installation may be included in the EU ETS. For example until 2012 fugitive emissions from methane will not be included.

There are three ways CCS could be defined with respect to installations:

a. Define the whole CCS chain as one installation (capture, transport and storage);
b. Define each element of the CCS chain (capture, transport and storage) as an installation; and
c. Define parts of the elements of the CCS chain as an installation.

Option a) will be challenging if there are different legal units involved in the chain and especially if more than one source is connected to the transport system and storage site. It has, however, an advantage with respect to its ability to link the responsibility for storage to the CO_2 emission source.

Option b) is challenging if parts of the chain are not included in the EU ETS (e.g. the transport system) and needs a set-up of system boundaries to ensure that the whole chain is consistently accounted for. Furthermore, a mechanism to link credits for capture at the source to safe storage is necessary.

Option c) would mean that potential emissions from parts of the chain are not included. This may, however, be the parts that are not very important in terms of emissions. However, setting the system boundaries will be even more important than for option b).

Without drawing any conclusions as to how CCS installations should be included in the ETS, it seems that all options have some practical, policy and legal challenges that need to be addressed. If the Halten CO_2 project is defined as one installation we note that this will constitute units with different ownership. If the project is defined as separate installations (e.g. the power plant, the land gas purification installation, transport system, the two EOR/storage sites at Heidrun and Draugen, and the aquifer at Heidrun) this would require proper agreements between the owners of the installations with respect to system boundaries, credits for storage and responsibilities for emissions.

3.2.3 Norwegian government funding

The companies behind the Halten CO_2 project have stated that government co-funding will be required to realize the project.

The current government's political platform suggests that any new concessions for gas-fired power plants should be based on CO_2 capture and storage, and that the government will use economic policy instruments and technology development to realize this. The government has committed itself to offer considerable economic support for CO_2 removal at Naturkraft's plant at Kårstø, and Statoils planned plant at Mongstad. Similar funding could possibly be available for CO_2 removal at Tjeldbergodden.

The government's platform further states that a state-owned company should be responsible for creating a value chain for transport and injection of CO_2, and that the state should contribute financially to this. In March 2007, the government announced its intent to establish a state-owned company that will plan and execute CCS projects (including capture as well as transport and storage activities) in collaboration with industrial partners (St.prp. nr. 49, 2006-2007). The availability of government funding for the Halten CO_2 project depends on two critical factors. First, funding is dependent on political decisions by the Norwegian government, and the outcome of negotiations between the project owners and the government. Second, funding is dependent on rulings by the EFTA Surveillance Authority (ESA) on the compatibility of such funding with EU state aid rules. Relevant guidelines for state aid are currently being discussed within the EU.

3.2.4 EU funding

Funding from the EU Commission represents an additional potential funding source for the project (see section 2.2).

3.3 Monitoring

Monitoring of CCS projects is essential for the purposes of crediting for the amount of CO_2 handled, confirmation of the quality of CCS projects, in particular the safety and permanency of storage in geological formations, and for public confidence in this emission mitigation technology. The requirements for monitoring will add a cost to the project. Credits for capture from a power plant will likely only be given if it can be demonstrated that the CO_2 is safely stored at a geological site. IPCC (2006) states that capture for other use (e.g. industrial use or use in greenhouses where CO_2 is released) should be counted as emission at the site. Also inclusion of CCS in the EU ETS will require development of monitoring guidelines. Below we present the current status of development of monitoring and guidelines and discuss the implications for implementation of the Halten CO_2 project. Monitoring costs will be determined by international requirements, national requirements as well as standards set by the company itself.

Monitoring techniques for deep sea storage include (DTI, 2005; IPCC, 2006)

- Seismic (2D and 3D)
- Gravimetry (complementary to seismic surveys)
- Electrical/electromagnetic (cheaper than seismic surveys)
- Geochemical (chemistry of fluid and gases to detect concentrations above background levels, pH)
- Ecosystems surveillance

3.3.1 Reporting and verification commitments

A Party to UNFCCC must submit a greenhouse gas inventory meeting certain quality standards as specified in adopted guidelines. Participation in emission trading for facilities, for example in the EU emissions trading scheme, will likewise require adequate reporting of emissions from these facilities. In both cases, the data on emissions and capture including underlying documentation will undergo a review to examine whether the guidelines have been adequately followed. If not, credits for CO_2 storage will not be given.

Implementation of CO_2 capture and storage (CCS) as a climate mitigation under a climate regime will require development of existing guidelines. Currently guidelines are under development, but there is yet no experience in implementing them at the national or facility level. Therefore it is uncertain what guidelines will be required for the Halten CO_2 project to be able to receive credits for captured CO_2. The discussion below is based on guidance documents that are under development. Risk assessment and monitoring techniques are also addressed by the IEA GHG R&D program. This has so far been at the level of exchange of information that can contribute to the development of standards. Also several international research projects have addressed issues related to monitoring and risk assessment.

Guidelines can be directed at a) monitoring and reporting of sites in operations and b) requirements for storage sites. It is expected that both types of guidelines are necessary for a good management framework. The latter has, however, not been developed to any extent.

IPCC Guidelines

The reporting of a greenhouse gas inventory under the first commitment period of the Kyoto Protocol is based on the IPCC 1996 Guidelines for greenhouse gas inventories and subsequent good practice guidance. There is no specific mentioning of CCS in these guidelines, but generally inventories are aiming at being complete with respect to all sources and sinks.

The 2006 guidelines for greenhouse gas inventories were adopted by IPCC in April 2006. CCS is an integral part of these guidelines. The Parties to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol are expected to adopt these guidelines at some point in time. In principle the 2006 Guidelines will apply to subsequent commitment periods of the Kyoto Protocol (post 2012). However, elements of it may be phased in earlier as agreed by the Parties, and Parties may already now choose using the methods for reporting. Since expected start-up of storage at Draugen will be 2011, it can be assumed that the value chain project will need to meet the requirements of the 2006 Guidelines.

The 2006 Guidelines integrate CCS into the inventory framework:

- Captured CO_2 can be subtracted from potential emissions at the source level if it is used for long term storage in appropriately monitored geological reservoirs

- Emissions from handling, transport, injection and storage of CO_2 are estimated when and where they occur
- Allocates responsibility for monitoring of stored CO_2 to the country injecting CO_2

The 2006 Guidelines provide methodologies for estimating emissions from all sources (from capture to storage) and monitoring storage sites (Volume 1, chapter 5). However, experience is very limited at present to recommend specific methods so the guidance is kept at a general level and no default estimation method is described for storage. Reflecting current experience it is assumed that apart from the capture system emissions are small. The 2006 Guidelines also addresses injection for EOR where part of the CO_2 injected is recycled. In this situation they recommend an assessment of emissions that is integrated with other fugitive losses (methane and other hydrocarbons).

EU Guidelines

The EU emission trading system does currently not include CCS. This means that at present CO_2 captured for geological storage from any source should be counted as emissions at the installation. However, the Commission Decision C(2004) 130 on "establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council" addresses CCS. It points out that ongoing research "will be important for the development and adoption of guidelines on the monitoring and reporting of CO_2 capture and storage". It also states that "such monitoring will take into account methodologies developed under the UNFCCC". Member states interested in the development of such guidelines are invited to submit their research findings to the Commission in order to promote the timely adoption of such guidelines. Member states are also invited to submit interim guidelines for the monitoring and reporting of the capture and storage of CO_2.

The UK's Department of Trade and Industry has initiated a process to develop draft guidelines for monitoring and reporting of CCS in the EU ETS, with inputs from a group of experts from across Europe as well as commissioned reports from ERM and Det Norske Veritas. More work will be needed to finalize such guidelines which are aiming at being consistent with both the current Monitoring and Reporting Guidelines used for the EU ETS as well as the IPCC guidelines (IPCC, 2006).

OSPAR/London Convention

The London Protocol has now been amended to permit storage of CO_2 in sub-seabed geological formations. Norway has proposed a similar amendment to the OSPAR convention. This amendment is supported by UK, France and the Netherlands and the amendment was approved by the OSPAR commission June 26 2007. The amendment will enter into force when 7 Parties have ratified it. The proposal covers CO_2 streams from carbon dioxide capture processes for storage, provided

i. disposal is into a sub-soil geological formation;

ii. the streams consist overwhelmingly of carbon dioxide. They may contain incidental associated substances derived from the source material and the capture, transport and storage processes used;

iii. no wastes and other matter are added for the purpose of disposing of those wastes or other matter;

iv. they are intended to be retained in these formations permanently and will not lead to significant adverse consequences for the marine environment, human health and other legitimate uses of the maritime area.

In parallel with this process it is developed guidelines under both conventions for site selection, reporting, risk assessment, risk management, permitting, monitoring, site-closure and mitigation and remediation options in case of leak. The guidelines, including a risk assessment framework, where adopted by the OSPAR commission 26 June 2007. The guidelines under the London Protocol was approved by the protocols Scientific Group 22 June 2007. The draft guidelines of the London and OSPAR protocols are focusing on how to avoid adverse effects on marine ecosystems and resources and not directly on climate. However, site selection, monitoring, risk assessment and management for these two purposes may largely overlap. Therefore the Guidelines contains elements similar as those under UNFCCC, although the OSPAR and LP guidelines goes further and include additional issues e.g. regarding risk and effects on the marine environment and other uses of the maritime area.

3.3.2 Experience from other projects

Below we review experience from the Canadian Weyburn project and the Norwegian Snøhvit and Sleipner projects.

Weyburn

The Canadian Weyburn project is like Heidrun/Draugen a combined EOR and CCS project, but it differs from the Norwegian projects in being an onshore project. The project started in 2000 and is planned to be in operation 25-30 years. At that time 20 mill tons of CO_2 are expected to be stored. The main purpose of injection is EOR (Weyburn oilfield) using CO_2 captured from a coal gasification plant.

The project has been monitored using soil gas concentrations and flux monitoring. These techniques would not be suitable for an offshore project like Draugen/Heidrun. Modeling is used to predict that storage will be safe for a large number of years (Zhou et al., 2004).

Sleipner

The Sleipner gas field (operated by Statoil) is the first full-scale CCS project designed specifically for CO_2 mitigation. CO_2 is separated from the produced gas and injected into the Utsira formation (which is a saline aquifer). Around 1 million tons have been injected annually since 1996 and this is expected to last for 20 years in total.

The CO2 plume at Sleipner has been monitored by time-lapse 3D (4D) seismic data in 1999, 2001 and 2002 and 2004. In addition gravimetric monitoring was performed in 2002 and 2005. Monitoring shows no leakage or other unexpected behavior of the CO2. This has been confirmed by reservoir simulations which match reasonably well the observations.

Snøhvit

The Snøhvit storage project has a similar purpose and structure as the Sleipner project (operated by Statoil) and is scheduled to start its routine production phase in 2007. The natural gas from the Snøhvit field contains five to eight per cent carbon dioxide. The greenhouse gas follows the well stream from the field to the land terminal, where the natural gas is liquefied ready for shipment. The carbon dioxide is then removed and piped back to the field. There it is stored in an aquifer (Tubåsen sandstone formation) 2,600 metres beneath the seabed at the edge of the reservoir and below the gas formation. A total of 700,000 tons CO_2

will be stored annually. A sealing formation which lies above the sandstone will ensure that the carbon dioxide does not leak out.

3D seismic is initially used to form the baseline for the storage project. The plan is to perform regular monitoring using 2D seismic. 3D will be used in case the 2D indicates any problems. Gravimetry may be used as a supplement to determine the horizontal extension of the CO_2. (Tore Torp, Statoil, personal communication.).

A problem with storage in smaller aquifers as used at Snøhvit (as opposed to the larger as used at Sleipner) is that pressure can build up following injection with danger of leakages. For this reason at Snøhvit pressure and temperature is surveyed at the bottom and the well-head.

Relevance of experience

Of the projects reviewed above only the Weyburn project is an EOR project. On the other hand it is not a deep sea storage project. Monitoring techniques, frequency and costs will be very different for deep sea sub-seabed projects compared to land based and shallow water sub-seabed projects. Although monitoring also will differ between oil reservoir and aquifer storage, similarities will be large. The same monitoring techniques can be used. Generally, storage in oil and gas reservoirs can be considered to be safer compared to aquifers, simply because oil and gas reservoirs have proven to be suitable for storage over a very long time period. Thus we will use the experience from the Norwegian off-shore aquifer storage projects as a starting point. Since experience is from pilot aquifer projects only, which typically imply relatively high monitoring costs, this may represent an upper bound of costs if storage behaves as expected – in the case of unexpected events costs may be higher.

3.3.3 Lack of final guidelines

The IPCC 2006 Guidelines will be the likely starting point of guidelines under the UNFCCC and EU ETS. It is unlikely that a regulation will require use of a particular monitoring technique as the chosen technique must be adapted to the particular project. Regulations may also require use of more than one technique. The London/OSPAR Conventions will for example have a larger focus on biological parameters.

Capture

According to IPCC (2006) the likely efficiency of capture and its monitoring cannot be expected to be 100 % effective. In the Halten CO_2 project capture will take place from the power plant and from the process removing CO_2 associated with the oil and gas.

Due to the political focus on capture from power plants and inclusion of power plants into the EU emission trading scheme it is certain that there will be requirements for monitoring of the emission estimates from the capture in line with Norwegian regulations and EU emission trading guidelines. These requirements will relate to the measurement as well as a third part verification. It can nevertheless be assumed that the costs of monitoring are small compared to the capture costs themselves.

Transport and storage

Experience from gas transport in the North Sea can be used to conclude that methane emissions from such transport are small. The IPCC default emission factor for transport of CO_2 by pipeline is 0.00014 Gg CO_2/year per km pipeline. This factor has been derived from experience in natural gas transport in general and emissions are expected to be smaller in a modern facility. Use of this emission factor shows that negligible emissions can be expected for pipeline transport for this project.

Major problems with CO_2 leakage with pipeline transport from Tjeldbergodden to Heidrun/Draugen should be detected using a mass balance (measuring gas in and out of the pipeline).

IPCC (2006) also addresses emissions from possible intermediate storage of CO_2 at the site prior to injection. The inventory must also consider evaporation to the atmosphere from CO_2 rich oil and gas being stored, transported or treated. Also fugitive losses of CO_2 and hydrocarbons from purification of crude oil on site must be considered. In this case both the hydrocarbon end CO_2 emissions must be counted as releases to the atmosphere (IPCC, 2006).

3.3.4 Injection/production phase

IPCC (2006) outlines the following procedure for geological storage:

1. Confirm that the geological storage site has been evaluated and that local and regional hydrogeology and leakage pathways have been identified.
2. Confirm that the potential for leakages has been evaluated through a combination of site characterization and realistic models that predict movement of CO_2 over time and locations where emissions might occur.
3. Ensure that an adequate monitoring plan is in place. The monitoring plan should identify potential leakage pathways, measure leakage and/or validate and update models as appropriate.
4. Report CO_2 injected and emissions from storage sites.

Points 1-3 will require a combination of modeling and monitoring and a proper documentation available for review. Modeling will give the initial prediction of the behavior and migration of CO_2 in the reservoir. Measurements are used to check that the CO_2 behaves as predicted and to calibrate the simulations.

The IPCC Guidelines suggest monitoring at least every 5 years, but this depends on the overall risk assessment, and governments may request more frequent monitoring. Furthermore, monitoring must be intensified in case of unpredicted behavior of the CO_2.

The total storage will be determined as a mass-balance equation:

Stored volume = Injected CO_2 *–* CO_2 *associated with products – leaked* CO_2

Consequently all these figures need to be measured accurately. Injected volumes can be metered accurately on a routine basis, such metering is necessary to be consistent with the IPCC (2006) Guidelines. CO_2 in the products will be measured on a routine basis for the purpose of determining their marked value. According to the equation the stored volume can only be found if leakage is zero or if leakage can be observed or at least estimated with sufficient accuracy.

The mass balance approach to determine the mass of stored CO_2 is more accurate than measuring of the mass stored. However, the stored CO_2 will need to be monitored with respect to horizontal and vertical migration.

3.3.5 Post-injection

There is evidently yet no experience with respect to what level of monitoring will be needed post-injection. It is likely that there will be regulations from the government that comply with the IPCC (2006) Guidelines and other guidelines as described before. See also the discussion of long-term liability in Berger (2007a and 2007b). The IPCC (2006) Guidelines prescribe that the monitoring plan should provide for monitoring of the site also post-injection. The monitoring plan should build on modeling forward in time and be appropriately directed in place and time based on these modeling results. When an agreement between modeling predictions and measurements is achieved, the frequency of measurements can be reduced. Monitoring may also be necessary after unexpected events, for example seismic events. Storage may also be affected by future oil and gas exploration or production at deeper layers not considered exploitable with present technologies.

After plugging a storage site, a 3D seismic survey should be performed to form a basis for future monitoring. Monitoring should be performed at least every five years the first 20 years, then with a reduced frequency if the site behaves as expected. Monitoring will need to be more frequent if the site does not behave as predicted.

How long would monitoring need to continue? Future regulations may request long-term monitoring and use of specified techniques. Monitoring may also continue using low cost techniques – or be stopped. Long term post-injection monitoring may be performed at a higher ambition level at pilot projects to gain experience.

3.3.6 Remedy actions

Regulations may require that plans for remedy in case of leakage are in place. Such remedy may depend on the cause of the leakage. Remedy actions have not been considered in this report.

3.3.7 Monitoring costs

There are few estimates of monitoring costs required for CCS. It is likely that such costs will vary a lot from project to project depending on site characteristics and suitable methods. Furthermore costs for routine projects are generally expected to be smaller than those of pilot projects because pilot projects were specifically used to demonstrate safe storage. Also project regulation standards will have consequences for monitoring costs.

DTI (2005) references one study that has estimated costs of monitoring during pre-injection, operation, closure and post-closure phases of a hypothetical storage project. Discounted costs were estimated at less than $ 0.10 per ton of CO_2 (undiscounted costs ranging from $ 0.15 to $ 0.30 per ton). These estimates assumed no monitoring was required in the post-closure phase. The study concludes that costs are unlikely to be a barrier to implementing a monitoring program.

It is also worth noting that it is likely that new techniques will be developed that can enable monitoring at lower costs than at present. For example experiments with high resolution seismic surveys have proven to be promising if the storage site is not situated in too deep layers (Tore Torp, Statoil, personal communication).

Since future regulation standards are not yet fixed, we will build on experience of monitoring costs from the Sleipner and Snøhvit projects, assuming that the Sleipner project monitoring activities broadly are in line with future guidelines. Thus for the whole Halten CO_2 value chain we have two oil/gas reservoir storage sites and one aquifer storage site.

A set-up of a simulation model for a storage site will cost 1 million NOK or more. The set-up will be at the start-up of the project, with updates after each seismic survey. The update is relatively inexpensive and costs are included in the costs of seismic surveys described below.

Monitoring costs

For the Sleipner project 3D seismic surveys have been used repeatedly. As previously described building on the experience of pilot projects routine monitoring can be done with 2D seismic surveys, gravimetric methods and more inexpensive methods may be developed.

A 3D seismic survey would cost at least 10-20 million NOK. The price depends on the area and both Draugen and Heidrun are large fields. Costs of a survey of a small aquifer could be less. It is worth noting that current prices of seismic surveys are high and they may decrease in the future depending on the situation of competition. A 2D seismic survey would amount to approximately 5 million NOK. Gravimetric surveys would amount to approximately 10 millions NOK. High resolution seismic surveys are not an option for Heidrun and Draugen because they are situated at large depths.

IPCC (2006) also recommends measurements of background fluxes of CO_2 around the storage site. For an offshore project this is best done analyzing ambient concentrations of CO_2 in sea water prior to injection and at regular intervals. It can be assumed that these costs are less than the ones described for seismic surveys described above.

OSPAR/London Guidelines may require monitoring of marine life around the storage site. Monitoring techniques for marine life is, however, yet at the research stage. At present most important is to determine what indicators are most relevant (bacteria, algae, foraminifera, fish, etc.). Direct monitoring of marine life at the depths and distance from shore as at Heidrun and Draugen can, however, be costly because it will require special sample equipment. Therefore it must be well planned. A cheaper (although not inexpensive) alternative could be to routinely monitor possible fall in pH around the site. Equipment for this could be permanently installed. (Jon Arthur Berge, NIVA, personal communication).

<u>An illustrative monitoring cost example.</u>

- We assume an initial 3D survey and use of a more inexpensive technique on 3-4 year basis in the period where injection is ongoing.
- Post-closure monitoring is assumed for 20 years (1 3D + 2D every five years). Although longer term monitoring may be necessary, it is assumed that lower cost techniques may be developed and no costs are estimated here. (For simplicity there is no discounting.)
- 2.25 mill tons CO_2 will be injected annually.
- 10 years injection is assumed at the Heidrun aquifer and in each of the EOR fields.[4]

The results are shown in tables 3 and 4. Annual costs are estimated to be 4.6 NOK per ton CO_2 injected. Costs are relatively high because there are three different storage sites and injection time in each is relatively short. The use of 3D surveys (which is an expensive method) is with present knowledge required twice for each storage site – before injection and just after the last injection.

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[4] All numbers in this paragraph are preliminary and subject to ongoing studies.

	Costs, million NOK
Draugen	
Set up of simulation model	1
Initial seismic survey	20
Two updates pre closure, cheaper technique (5 millions each)	10
3D at closure	20
Four updates pre closure cheaper technique (5 millions each)	20
Heidrun	
Set up of simulation model	1
Initial seismic survey	20
Two updates pre closure cheaper technique (5 millions each)	10
3D at closure	20
Four updates pre closure cheaper technique (5 millions each)	20
Heidrun- aquifer	
Set up of simulation model	1
Initial seismic survey	15
Two updates pre closure cheaper technique (5 millions each)	10
3D at closure	20
Four updates pre closure cheaper technique (5 millions each)	20
Total costs	**208**

Table 3. An illustrative monitoring cost example for Draugen and Heidrun.

		Unit
Injection, annually	2.25	Million tons CO_2
Injection years	20	Years
Total gas injected	45	Million tons CO_2
Costs per ton CO_2 injected	4.6	NOK per ton CO_2
Current CO_2 tax offshore	320	NOK per ton CO_2
CO_2 trading price, EU ETS, 2008	190	NOK per ton CO_2

Table 4. An illustrative monitoring cost example for Draugen and Heidrun. Cost per ton of CO_2.

Costs may be lower if low cost techniques are developed, the costs of seismic surveys are decreased, or if injection of the aquifer is extended. Costs may be higher in the case of unexpected events where 3D monitoring would be necessary at a higher frequency. Costs for biological monitoring have not been considered.

The tables show that our estimates indicate that the monitoring cost is likely to be small, e.g. in comparison to the current CO_2 tax at the Continental Shelf and the allowance price in EU's emissions trading system for deliverance December 2008. Compared to these price levels the monitoring costs are around 1-2%.

3.3.8 Conclusions

The Tjeldbergodden- Draugen/Heidrun project is more complex than the Sleipner and Snøhvit projects where Norway has experience. The increased complexity arises because of capture takes place on-shore and is transported off-shore, CO_2 rich gas due to the EOR which is transported from the site to the shore, and because three different storage sites will be applied over time. The increased complexity means that it will be necessary to closely monitor the mass balance of CO_2 as well as methane and other hydrocarbon emissions at several points of the value chain. On the other hand storage in depleted oil and gas fields can be considered safer than in aquifers, which may contribute to reduce post-closure monitoring costs. Furthermore, experience from the Sleipner project can be used to set up a more cost-effective monitoring plan. In our estimate total monitoring cost for the project is 4.6 NOK per ton CO_2. Storage at three different sites and relatively short injection time at each site drives up the cost. Development of lower cost monitoring techniques would be necessary to reduce the cost.

The need for long-term monitoring beyond post-closure is yet an open question. It is necessary to develop low cost techniques that can enable such monitoring. It is recommended that pioneering storage sites are well-monitored post-closure to gain experience, confidence in storage, and to enable testing of low-cost monitoring techniques.

4 Summary and overall assessment of implementation of the Halten CO_2 project

The Halten CO_2 project is an early CO_2 value chain in Mid-Norway initiated by Shell and Statoil. It consists of four main components, where the first is a gas-fired power plant linked to the methanol production facility at Tjeldbergodden. The power plant can also supply electricity offshore and contribute to regional electricity supply. The second component is facilities at Tjeldbergodden for capture of CO_2 associated with the power plant, transportation of the CO_2 to the Draugen and Heidrun oil reservoirs and injection of the gas at these sites. The third is Enhanced Oil Recovery (EOR) at the Draugen and Heidrun oil reservoirs. The fourth and last component is an aquifer which can be used for final storage of captured CO_2 that is not permanently trapped in one of the oil reservoirs.

In this report we have assessed institutional and policy issues associated with the implementation of the Halten CO_2 project under the international and national climate policy regimes.

The UNFCCC and Kyoto Protocol provide little guidance or rules for CCS projects, but IPCC has developed a framework for monitoring and reporting of CO_2 storage. However, there is an ongoing process for developing a regulatory framework for CCS under the

UNFCCC, within the EU, and in a number of other countries. The EU is aiming at linking CCS projects to their emissions trading system. In Norway planned CCS projects are exposed to the CO_2 tax, technical requirements, have an obligation to have enough emission allowances under the emissions trading system, but might also receive government support that is significant. The conditions for CCS projects beyond 2012 are very uncertain as long as the future international regime is as open as it is today. However, given recent signals from EU and increased awareness of the climate change problem it is likely that a more ambitious regime will be a reality in some years. A consequence will be a higher value of CO_2 storage, and when also the unit cost of CCS is likely to be significantly reduced this means that CCS will become increasingly competitive with other mitigation options over time.

For global efforts to mitigate climate change, the most important aspect of an early CCS project such as Halten CO_2 is the project's scope for contributing to reduced emissions in Europe and globally through spillover effects from technological development of CCS and related cost reduction. We believe that this potential is substantial. EOR-related projects such as Halten CO_2 may also contribute to development of infrastructure for future storage activities.

Residual emissions from the power plant at Tjeldbergodden after CO_2 capture will to some extent contribute to increased domestic Norwegian emissions under the Kyoto Protocol and any future agreement following similar principles. The Halten CO_2 project may still imply lower emissions than alternative scenarios. In assessing the project's effects on global emissions, the effect of increased oil recovery should also be addressed.

The incentive effects on the Halten CO_2 project from policy instruments much depend on the design of these instruments, in particular on how emissions are calculated and on allocation of allowances under the emissions trading system. Government support for technology development, investments in facilities and infrastructure, and possibly facility operation for some years, can be decisive due to the present gap between CO_2 storage value and CCS cost.

Monitoring in the operational phase of the project and in the post-injection phase is important for reasons of crediting, quality control and public confidence. Some guidelines for monitoring exist, but they will evolve over time. Monitoring implies a cost but this is likely to be small, e.g. compared to the value of CO_2 storage measured as the allowance price in EU's emissions trading system. Furthermore, it should be possible to reduce these costs through increased experience and technological improvements.

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