Report 2007-087

European CO_2 Test Centre Mongstad – Valuation report

MEMBER OF THE PÖYRY GROUP

Econ-Report no. 2007-087, Project no. 54710 Restricted
ISSN: 0803-5113
EMA/ÅJE/VEI/BTE/KIB/KHO/mbh, ALO, 28. November 2007

European CO_2 Test Centre Mongstad – Valuation report

Commissioned by
Ministry of Petroleum
and Energy

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Abstract

This report presents an economic analysis of the Norwegian State's investment in the Test Centre Mongstad – a pilot plant for developing and testing carbon capture technology as part of a large programme to create an economically viable carbon capture and storage (CCS) scheme. The main conclusion is that the net present value (NPV) of the investment is positive in that the expected benefits for the Norwegian State's commercial interests in the oil and gas industry are clearly higher than the costs. The main driver for this result is an anticipation of a fairly restrictive climate change policy in the future, which makes CCS a central tool for safeguarding the market value of the state's oil and gas resources.

Background

The Norwegian State has entered into an agreement with Statoil (now StatoilHydro) to build a test facility for carbon capture at Mongstad in the county of Hordaland in western Norway, Test Centre Mongstad (TCM). At the outset, the Norwegian State will hold 80 per cent of TCM, while StatoilHydro will own the remaining 20 per cent.[1]

On 7 July 2007, the Norwegian Government submitted a notification to the EFTA Surveillance Authority regarding the investment in TCM. In the notification the Government argues primarily that the investment does not constitute state aid within the meaning of Article 61(1) EEA in that the Market Economy Investor Principle (MEIP) is fulfilled.

Mandate

With the purpose of estimating the NPV of the investment in Test Centre Mongstad, the Ministry of Petroleum and Energy (OED) has commissioned this report.

Using standard financial methods of valuation, we therefore analyse how the State may gain commercial benefits related to its various interests in the energy sector as direct and indirect consequences of the investment in TCM.

Conclusions and recommendations

The business case

The Norwegian State is a large resource owner and investor in oil and gas production and transportation on the Norwegian Continental Shelf (NCS). The NPV of the Norwegian State's part of the resource base is estimated by the Ministry of Finance[2] to NOK 3520 billion of which approximately fifty per cent is related to income generated from gas sales to Europe. Safeguarding the future value of these resources is of vital importance to the Norwegian State.

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[1] In June 2007 the Ministry of Petroleum and Energy, along with Statoil, entered into a cooperation agreement with four other companies: DONG, Vattenfall, Norske Shell, and Norsk Hydro Produksjon (the latter was merged with StatoilHydro on October 1 2007). The cooperation agreement applies to the planning phase preceding the decision to invest in TCM, and also entails an intention on the other partners' behalf to participate in the further development of TCM.

[2] St.meld. nr. 1 (2007-2008) "National Budget 2008", assuming a long term oil price of NOK 230 per barrel.

The value of the oil and gas in the ground is dependent on the future oil and gas prices and the costs of extracting and transporting the oil and gas to the market. Under future climate change regulations, the value could be unfavourably affected by the costs of reducing CO_2 emissions. Higher costs in producing, transporting, and utilizing oil and gas, resulting from high CO_2 emission costs, could significantly reduce the value of the Norwegian State's oil and gas resources.

An engagement in improving the sustainability of producing, transporting, and utilizing hydrocarbons will contribute to the long-term value of oil and gas. The future value of oil and gas will increasingly be dependent on the oil and gas industry's ability to develop technologies that minimize these resources' environmental impacts. The operators who demonstrate competence and know-how with regard to such technologies will gain strategic advantages. Thus, CCS is an instrument for safeguarding market values. As Norwegian gas will account for approximately 19 per cent of European consumption by 2015, there is little doubt that a strong business case can be made for the Norwegian State to engage in activities that protect the value of gas in Europe.

Significant learning effects from Test Centre Mongstad will reduce future costs of CCS

TCM is a test facility aimed at gaining access to the relevant technology components, developing these, and contributing to reducing the future CO_2 emission costs associated with producing, transporting and utilizing oil and gas resources. We find it realistic that TCM will give significant learning effects, which could benefit future investments in full-scale CO_2 capture plants, both in Norway and elsewhere.

The exact learning effect from a project which in many ways represents the very first step on the learning curve is uncertain. However, a reduction of 15–20 per cent in the overall investment cost of a future full-scale Mongstad CCS project, and even greater reductions in energy costs, is a conceivable ambition level.

Future climate policies may hit the petroleum sector hard

Any commercial benefits are conditional on expectations of existing and future climate policy demands. All commercial actors will need to evaluate the costs and opportunities associated with such policies and what measures are best suited to accommodate them.

The main driver for the profitability of TCM is the expected future CO_2 regulation in Europe. The EU has stated a goal of a 20 per cent reduction in EU CO_2 emissions by 2020, and CCS will be a significant factor in achieving that particular target. According to the European Commission's *An Energy Policy for Europe*, released in January 2007, "large-scale demonstrations of sustainable fossil fuels technologies in commercial power generation" should be constructed in order to "provide a clear perspective when coal- and gas-fired plants will need to install CO_2 capture and storage".

In general, the EU climate policy will have profound effects on the future position of fossil fuels in the energy market. The long-term European demand for gas could be affected by future climate change regulations. In a scenario where CCS for gas-fired power becomes mandatory, the willingness to pay for gas could be affected. Contributing to reducing the future costs of capturing CO_2 is a sound way to meet such potential development.

In a Norwegian context, CO_2 emissions are expected to increase in coming years from a level that is already 9 per cent above the country's Kyoto commitment. The Norwegian oil and gas sector counts for most of this increase in emissions. In a scenario where a larger part of the future energy need at offshore installations and the onshore petroleum facilities has to be covered by electricity produced onshore, or based on new renewable energy production systems offshore, carbon capture and storage in gas- and coal-fired power plants could represent an option for securing the power generation needed.

TCM is profitable for the Norwegian State

Given our expectation of fairly restrictive future climate policies, TCM is clearly profitable for the Norwegian State as a resource owner and investor on the Norwegian Continental Shelf (NCS).

The quantifiable costs and benefits included in this report are as follows:

Costs:

- *The cost of TCM.* Based on preliminary data, the cost figure for the Norwegian State's share of TCM used in this report (80 per cent) gives a cost estimate in terms of NPV in the range 1060–1900 million NOK.

Benefits:

- *The impact of lower CCS costs on the European gas prices.* Lower carbon capture costs of gas could impact the future gas price. In a situation where CCS for gas power becomes mandatory, lowered CCS costs will reduce the cost of power based on natural gas and thus increase the value of gas. This option value of TCM could be several times the investment in TCM. The break-even cost represents significantly less than one per cent of the SDFI portfolio. This cost can be considered as a moderate "insurance premium".
- *Cost savings at the full-scale carbon capture plant at Mongstad.* A major part of the cost of investing and operating the test centre will be paid back by the expected cost savings for the full-scale carbon capture plant at Mongstad. Some of these effects would likely appear before the test period at TCM is over. The NPV range is calculated to NOK 900–1810 million, which constitutes more than 90 per cent of the preliminary cost figure for the test centre.
- *Cost savings at other full-scale capture plants in which the Norwegian State may invest as part of developing petroleum resources.* In a scenario where CCS is required in land-based power plants supplying electricity to oil and gas producing fields on the NCS, the technological benefits of TCM could be further deployed in other full-scale capture plants. These benefits may then in turn contribute to lowering the future cost of producing and transporting oil and gas from the NCS. The NPV effect related to cost savings at one additional full-scale CCS plant (100 percent State ownership) is estimated at NOK 725–1450 million. The NPV effect is reduced to NOK 250–500 million if the state participation reflects the SDFI's part of the total remaining reserves on the Norwegian Continental Shelf.
- *CO_2 for EOR.* Reduced costs of carbon capture technologies resulting from TCM could be a catalyst for an early development of a CO_2 infrastructure offshore in North-Western Europe. This could in turn make CO_2 injection for EOR more likely. Today there are no official plans for utilizing CO_2 for EOR, and some oil fields could reach maturity before CO_2 will be accessible. Higher oil prices and a development of CO_2 infrastructure may, however, improve the prospects for EOR

investments in new field developments. The NPV of CO_2-based EOR projects in new fields may, given the right assumptions, amount to several NOK billions.

The results of the calculations underline that the distribution of benefits and costs is somewhat asymmetrical, which is typical of an innovative technology project such as TCM. In this perspective, TCM functions as an option for a private investor faced with huge uncertainties regarding policy, technology, and market conditions.

An additional positive indication of the project's economic viability is that TCM is not a unique venture. An international survey shows that other commercial actors are also engaged in similar technology projects with the purpose of developing CCS technology with a commercial motivation.

1 Introduction

1.1 Background

The Norwegian State has entered into an agreement with Statoil (now StatoilHydro) to build a test facility for Carbon Capture at Mongstad in the county of Hordaland in the Western part of Norway. The capture facility will be connected to the Energiverk Mongstad (EVM), a Combined Heat and Power Plant (CHP) under construction at the same site. The EVM is currently under construction by StatoilHydro, and will be operative from 2010.[3] Furthermore, it is the intention of the contracting parties to build a full-scale capture plant due to come into operation from 2014.

The test facility has been named Test Centre Mongstad (TCM), and the State's owner interest will be governed by the state enterprise Gassnova SF under the Ministry of Petroleum and Energy. At the outset, the Norwegian State will hold 80 per cent of TCM, while StatoilHydro will own the remaining 20 per cent. However, in June 2007 the Ministry of Petroleum and Energy, along with Statoil, entered into a cooperation agreement with four other companies, DONG, Vattenfall, Norske Shell, and Norsk Hydro Produksjon.[4] The cooperation agreement applies to the planning phase up to the decision to invest in TCM, and entails an intention on the other partners' behalf to participate in the further development of TCM.

1.2 Mandate

With the purpose of estimating the net present value (NPV) of the investment in Test Centre Mongstad, the Ministry of Petroleum and Energy (OED) has commissioned this report.

We are to consider the future value to the Norwegian State from its considerable oil and gas resources, and to which extent this value may be influenced by the State's investment in TCM. The value derives from the resource rent to the State from petroleum activities, and from its commercial interests in the SDFI (State Direct Financial Interest), which is managed by the wholly State-owned enterprise Petoro. In our evaluation, we apply the "Market Economy Investor Principle" (MEIP). If the NPV of the TCM investment for the State's commercial interests is neutral or positive, the MEIP is met.

Using standard financial methods of valuation, we therefore analyse how the State may gain commercial benefits related to its various interests in the energy sector as direct or indirect consequences of the investment in TCM.

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3 The Danish energy company DONG will be the formal owner and operator of EVM, but the financial risk and investment decision lies with StatoilHydro.

4 As of October 1, 2007, Norsk Hydro Produksjon is a part of StatoilHydro.

1.3 About this report

This report has been prepared for the Ministry of Petroleum and Energy as a part of the Ministry's notification to the EFTA Surveillance Authority regarding the State's investment in Test Centre Mongstad. We have had the opportunity to gather information and data from the Norwegian Petroleum Directorate, Gassnova, Petoro, and StatoilHydro. All analyses and conclusions reflected in this report remain the responsibility of Econ Pöyry, however.

The report is structured as follows:

- In chapter 2, we describe the potential benefits from investing in TCM from the State's commercial perspective.
- In chapter 3, we describe possible scenarios for future climate policies at a Norwegian and international level, and analyse the range of possible outcomes for the future price of CO_2 emission allowances faced by commercial investors in the Norwegian petroleum sector and the European energy sector in general.
- In chapter 4, we describe the TCM project and discuss the possible learning effects of a technology project such as TCM in light of economic theory and practical experiences from the energy sector.
- In chapter 5, we quantify the benefits and costs of TCM under different scenarios for future climate policy, oil prices, TCM investment costs, learning effects etc., and answer the question of the financial value of investing in TCM from the Norwegian State's commercial point of view.

2 Benefits of the TCM project

2.1 Introduction

As resource owner and direct investor in oil and gas production and transportation projects, the Norwegian State has a major commercial interest in Norwegian petroleum production.

The net present value of the Norwegian State's part of the resource rent is a function of future oil and gas production, the oil and gas price, and the future costs of producing and transporting the hydrocarbons to the market. Based on a conservative price assumption (long term oil price of 230 NOK/ barrel) the Ministry of Finance has estimated the NPV of the State's share of the resource rent to NOK 3520 billion[5] of which approximately fifty per cent is related to income generated from gas sales to Europe. Assuming an oil price more in line with the present future prices, the NPV of the Norwegian State's share of the resource rent could be twice as large.

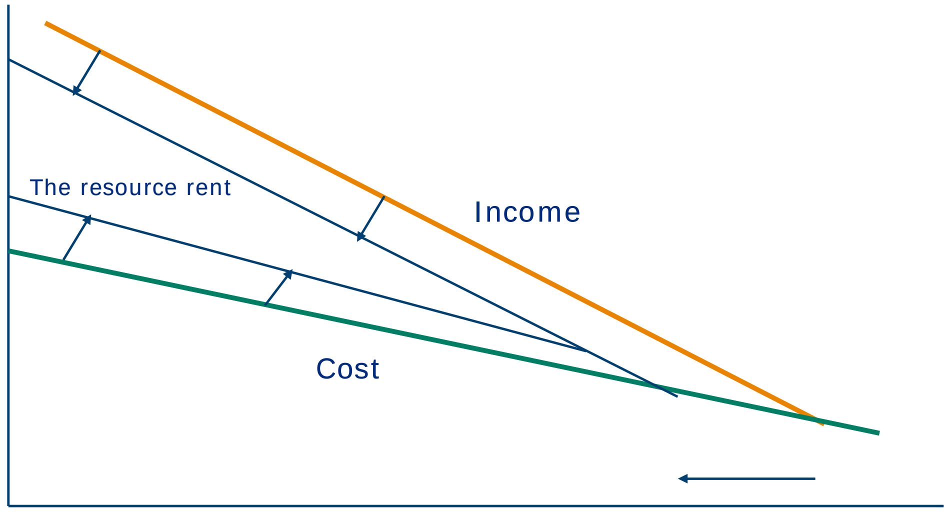
An engagement in improving the sustainability of producing, transporting, and utilizing hydrocarbons will contribute to the long-term value of oil and gas. The future value of oil and gas will increasingly be dependent on the oil and gas industry's ability to develop technologies that minimize the environmental impacts. The operators who demonstrate competence and know-how with regard to such technologies will gain strategic advantages. CCS is thus an instrument for safeguarding future market values. As Norwegian gas will account for approximately 19 per cent of European consumption in 2015, there is little doubt that a strong business case can be made for the Norwegian State to engage in activities that protect the value of gas in Europe.

The cost of reducing CO_2 emissions from various emission points through the value chains of oil and gas could reduce the size of the resource rent. This cost of reducing CO_2 emissions would most likely affect the demand for oil and gas, shifting the income curve down in the diagram. One specific example is reduced willingness to pay for gas in power production if CCS becomes mandatory.

Future CCS requirements could also increase the cost of producing oil and gas, as indicated by the shift upwards of the cost curve. Higher power prices due to higher generation costs in fossil power stations is one example of increased production costs.

[5] St.meld. nr. 1 (2007-2007)

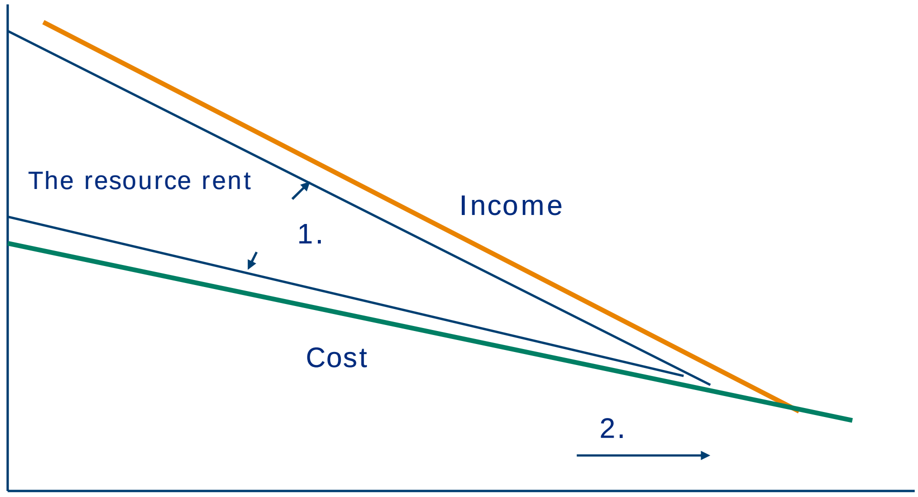
Figure 2.1 The resource rent before and after higher CO_2 costs



Source: Econ Pöyry

Test Centre Mongstad aims to develop CO_2-capture technology that will contribute to reducing the development costs and operating costs for future full-scale CCS plants. This could counterbalance some of the negative effects on the resource rent, as illustrated in the figure below. Reduced CCS costs would both increase the resource rent (arrows marked 1) and extend the life span of the resource base (arrow 2).

Figure 2.2 The impact of reducing CO_2 emission costs for the resource rent



Source: Econ Pöyry

Potential benefits will accrue to different parties, depending on their positions as investors in future CCS plants and as actors in other areas of a future CO_2 value chain in Europe and other regions. We will examine what benefits the State as commercial actor may realize.

As pointed out, future CCS projects may affect the State's commercial interest on both the revenue side and cost side:

- Gas is a substantial part of the future value of the Norwegian petroleum resource base. Moreover, gas-fired power plants are one of the main takers of gas and are expected to become more important. In a future scenario where CCS could become a requirement for producers of electricity by gas-fired power plants, this could substantially reduce their willingness to pay for gas. In such an event, the gas price and thus Norway's resource rent may be dramatically reduced. Reducing CCS costs could therefore be vital to safeguarding future income from the NCS.
- The reduced CCS costs will also apply to future CCS plants in which the Norwegian State may invest as a licensee. For instance, if it is assumed that Norwegian oil and gas is extracted using electricity generated onshore with CCS, it could contribute to building a perception in the market place of NCS energy resources as sustainable from a climate change point of view. This can be termed a 'green branding' effect, and further help safeguard future revenues from fossil energy sources.
- In a scenario where CCS facilities are built along the Norwegian coast, new prospects for enhanced oil recovery (EOR) by CO_2 injection could be created. The availability of CO_2 at a reasonable price and an infrastructure for CO_2 transport and storage (i.e., pipelines, platforms and other installations), may provide value to future EOR projects, thereby also deferring the time of abandonment for a number of years. This reduces the net present value of abandonment costs.

As the list above shows, any benefits are conditional on expectations of existing and future climate policy demands. All commercial actors will need to evaluate the costs and opportunities associated with future climate policies, and what measures are best suited to accommodate them. In the rest of this chapter, we describe the potential benefits further, from a general and primarily qualitative perspective. The assumptions and calculations are discussed further in chapter 5

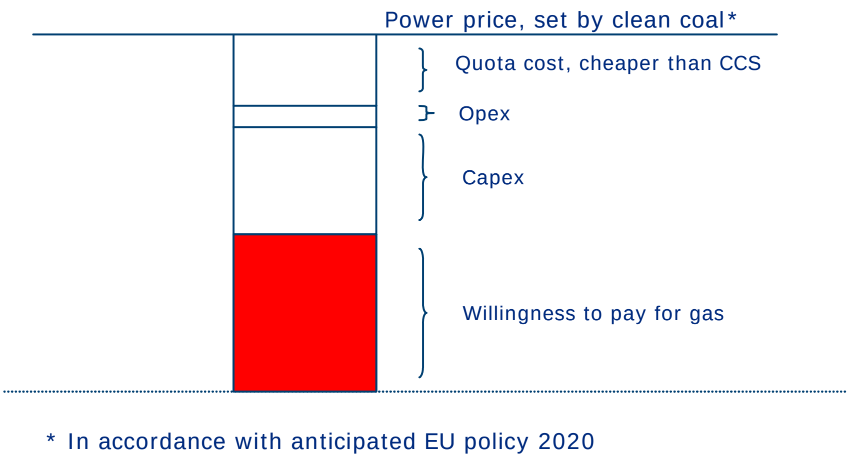
2.2 Impact on European gas prices

Gas-fired power plants are increasingly important off-takers of Norwegian gas. If CCS on gas-fired power generation becomes mandatory, the willingness of power producers to pay (willingness-to-pay, WTP) for gas, and thus the European gas price, may come under pressure. To the extent that TCM can contribute to reducing this pressure, the value implication could be large.

In this section, we will present a conceptual model for the relationship between the cost of CCS for gas power and the demand for gas expressed as willingness to pay for gas from a gas power investor.

In Figure 2.3, we anticipate CO_2 emission regulations through a quota system which is tight enough to give coal power producers incentives to invest in CCS. Initially, a gas power investor will choose to buy emission allowances (quotas), as long as that option is cheaper than building CCS. The willingness to pay for gas is then the difference between the power price, which is set by clean coal[6] and quota costs, operating costs, and capital costs.

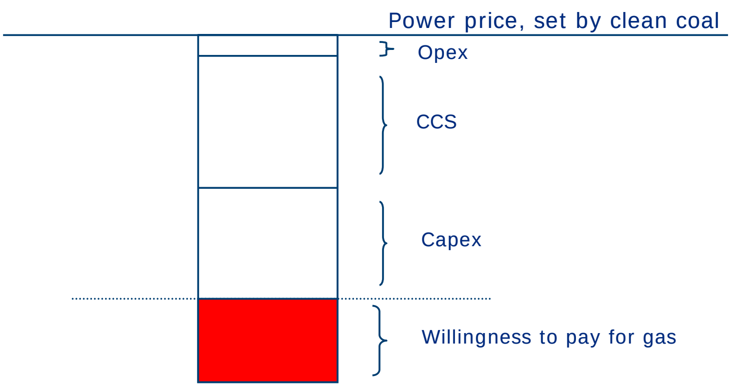
Figure 2.3 Willingness to pay for gas in gas power. Gas power must buy quotas



Source: Econ Pöyry

However, if a regulation to invest in CCS is imposed for gas producers, the willingness to pay for gas could drop significantly as indicated in Figure 2.4. The reason is that CCS costs replace the cost of buying emission quotas, which, at the outset, was higher than buying quotas.

Figure 2.4 Willingness to pay for gas in gas power. Mandatory CCS for gas



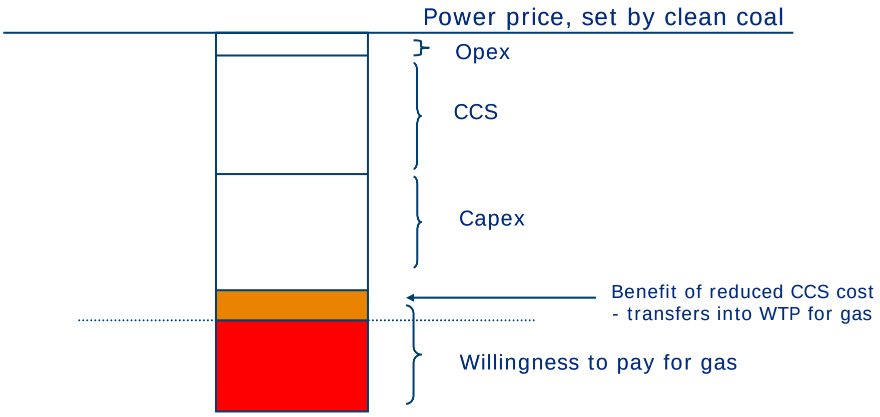
Source: Econ Pöyry

If, then, the cost of CCS is reduced by technological development projects such as TCM, the competitive position of gas will strengthened, giving a higher willingness to pay for gas, as indicated in Figure 2.5.

6 By *clean coal* we mean coal power stations with CCS.

Given the size of the Norwegian State's resource base and direct investments, even a marginal increase in this willingness to pay will have a large impact. As will be further analysed in chapter 5, the investment in TCM is small related to the value at stake for the Norwegian State as a resource owner and investor in oil and gas projects.

Figure 2.5 Willingness to pay for gas in gas power. Effect of reduced CCS cost for gas power on willingness to pay for gas



Source: Econ Pöyry

2.3 Benefits for the State as an investor in future capture plants

The most direct positive effect of the Test Centre will be that the costs of a full-scale capture plant decreases, first and foremost for the CCS plant planned for start-up at Mongstad in 2014. Full scale CCS at Mongstad is a direct consequence of political decisions and is based on the current Government's climate policy. Given this decision, any cost reduction connected to this plant will be of benefit to the State as an investor.

The experiences and technological innovation to which the Test Centre contributes, will also benefit the construction of any future CCS plants, both within and outside Norway. To the extent the State directly involves itself in future plants, the experience gained from the test plant will give competitive advantages. The strategic benefit is in other words connected to the position the State and its companies gain as commercial investors in future plants from the experience of building and running the Test Centre.

The value of the Test Centre for investments in full-scale plants will be dependent on the shadow price of CO_2 emissions in coming years, which, in turn, depends on future national and international climate policy. With a strong climate regime with high emission prices, the extent of abatement measures will increase and the profitability of investments in CCS plants improves. Consequently, more plants will be constructed.

The value of a position in the CO_2 value chain can be seen as an option value that can give potentially large rewards in a future marked by radical climate policies.

2.4 New prospects for CO_2 in Enhanced Oil Recovery (EOR)

Another effect of cheaper CO_2 capture could be that it may open new prospects for CO_2 injection as an EOR scheme. Enhanced Oil Recovery (EOR) is a generic term for techniques for increasing the amount of oil that can be extracted from an oil field. This improved extraction is achieved by either gas injection, thermal recovery, or chemical injection. Gas injection is the most commonly used EOR technique. Various gases can be used for this purpose, with natural gas a common option; CO_2, however, can also be used. Under certain conditions, CO_2 may even be a more effective injection gas than natural gas for such purposes. The gas is injected into a reservoir whereupon it expands and thereby pushes additional oil to a production wellbore. Moreover, it dissolves in the oil to lower its viscosity and improve the flow rate of the oil.

The gross revenues from an EOR project are determined by the production profile (incremental production of crude oil over a base profile without gas injection) and the price of oil. The cost of EOR is the increased energy consumption entailed by injecting gas, any additional capital expenditures related to the injection, and the opportunity cost of the gas injected. In the case of CO_2 injection, the opportunity cost of CO_2 equals the delivery cost at the platform. In addition, an EOR project would prolong the field's lifetime pushing the huge abandonment expenses further into the future, thereby realizing a considerable gain in NPV.

However, the potential for using CO_2 for EOR on the NCS is currently considered limited (see Gassco, 2006),[7] due to high delivery costs and the fact that potential demand for CO_2 from various fields is subject to many restrictions. One such restriction is that injection must take place in certain periods toward the tail-end of the production curves, complicating timing and supply.

Nonetheless, CO_2 injection could potentially become a future option for EOR on oil fields on the Norwegian Continental Shelf. In such case, a precondition is that CO_2 is available at the right time and at a cost at which the project is economically viable. The demand for CO_2 for EOR purposes – primarily in new fields – could therefore increase if, or when, an infrastructure for CO_2 is established and CO_2 can be delivered at a reasonable price.

Reduced costs as a result of the deployment of carbon capture technologies, i.a. through TCM, could turn out to be a catalyst for an early development of an infrastructure for CO_2 on the NCS, potentially making CO_2 a more realistic option for future EOR considerations. In addition to this increased accessibility, lower capture costs for CO_2 due to TCM could lead to lower delivery costs for CO_2, which may in turn increase the profitability of future EOR projects. In this scenario, TCM could contribute to an option that, under the right circumstances, may be of considerable value.

[7] "Innledende forhandlinger mellom de kommersielle aktørene i en CO_2 kjede", Gassco in co-operation with Petoro and Gassnova.

3 The pressure for decarbonisation

An important factor for the profitability of investing in carbon capture technology will be the future international price of CO_2. Other policy requirements may also have an impact on CCS investments. As Norway will adopt the EU climate change Directive and become a member of EU's Emissions Trading Scheme from 2008, the EU ETS allowance price (the EUA price) price will form a benchmark for the profitability of Norwegian abatement measures. This will apply to measures in the Norwegian energy sector also, including the petroleum sector and petroleum-related onshore activities.

3.1 The international price of CO_2

3.1.1 The international policy framework

The marginal cost of climate change caused by emissions of greenhouse gases (GHG) – of which CO_2 is the most significant by volume – is associated with the concentration of GHG in the atmosphere. Hence, one can argue that it makes sense to implement a policy target associated with total GHG volumes, rather than relative reductions. In accordance with this, both the Kyoto protocol and the EU Directive on climate change cap emissions of GHG from parties to the protocol and EU member states, respectively. Future CO_2 emission prices will thus reflect the marginal cost associated with meeting caps, and the value of reducing CO_2 emissions is linked to the cost of abatement measures.

The willingness to pay for CO_2-emission reducing measures and technologies, such as CCS, thus depends on the strictness of future climate policies and the cost of other abatement options and technologies. It is likely that the world will depend on energy produced by fossil fuels for many years to come. The gravity of climate change and the dependency on fossil fuels indicate that technologies which reduce or eliminate emissions of CO_2 from the burning of fossil fuels may be crucial in order to cap emissions at a necessary level in the future. This suggests that CCS technologies can have a significant market potential.

The Kyoto protocol caps emissions for the period 2008–12, and only for Annex B countries (industrialized countries that have ratified the protocol). The second trading period of the EU ETS coincides with the Kyoto period. Emission allowances for the ETS second phase, called EUAs, are currently traded at a price of 21.75 €/tonne for 2008 and 24 €/tonne for 2012 (NordPool, November 1, 2007). What is interesting for Test Centre Mongstad is how carbon prices develop after 2012. Although there are significant uncertainties on these issues, it is widely expected that international negotiations will lead to a new framework agreement for the post-2012 period. At the Montreal meeting of the parties in 2005, an important conclusion was to aim for a direct transition from the Kyoto period to the next global climate agreement, which means it is reasonable to expect that a global carbon market will exist beyond the Kyoto period.

Continuation of the EU ETS (Emission Trading Scheme) is even more likely. The EU Commission has stated in its Energy Policy Strategy, published in January 2007, that the EU ETS will be continued after 2012. According to this strategy, the EU will commit to reduce CO_2 emissions by 20 % until 2020, compared to 1990 levels. It was also stated that emissions would be cut by 30 % if other countries take on binding (and ambitious) targets. Hence, it is fair to assume that the EU ETS will be continued post 2012, but the ambitions of the scheme, i.e., the cap, and hence price developments, depend, to a large degree, on developments in international climate negotiations.

3.1.2 Future carbon prices – drivers and forecasts

Even though there is not one global market for emission allowances, markets are linked through the use of credits from the Kyoto mechanisms (CDM and JI, see below). The EU ETS is currently the largest institutionalized market for emission allowances, but other schemes are developing around the world, and international credits are increasingly traded as projects start producing them. For the future it is highly likely that markets will become increasingly integrated, and that prices will converge. The following discussion of ETS prices may therefore be interpreted as a discussion of future global prices as well.

There is currently no such thing as a consensus forecast for ETS prices post 2012. For the 2008–12 period, the consensus price forecast will be that provided by forward prices on the exchanges.

Although many of the crucial market drivers and regulatory framework conditions are still uncertain, price discovery in the ETS will largely be driven by the same factors post 2012 as in the second trading period. The drivers broadly fall into two categories:

- The cap on emissions – and the possibility of importing emission credits[8]
- The cost of abatement measures

Abatement measures broadly fall into three categories:

- Measures in the ETS sectors
- Measures in non-ETS sectors in countries that are party to the Kyoto protocol
- Emission reductions in projects under the Kyoto project based mechanisms, i.e., from CDM and JI projects[9].

An interesting feature of the market is the possibility of banking allowances from one trading period to the next. Currently there are no limits on the banking of Certified Emission Reductions (CERs). EUAs cannot be banked from the first trading period to the second, which explains why current first phase prices can be close to zero while 2008 prices are above 20 €/tonne. It is uncertain but very unlikely that EUAs can be banked from 2012 to 2013. The possibility to bank CERs provides some indication of price expectations for the post 2012 market. Given the current expected market balance in the EU ETS, market prices suggest that CERs will only be used for compliance to a

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[8] In ETS phase 2 the Commission has restricted the use of imported credits to between 10-20 % of total allowances (varies between Member States). This restriction should be related to the supplementary principle in the Kyoto protocol. The import restriction is not expected to be binding.

[9] CDM stands for Clean Development Mechanism. CDM projects are carried out in developing countries and produce Certified Emission Reductions. JI stands for Joint Implementation. JI projects are carried out in industrialized countries which are parties to the Kyoto protocol (Annex 1), but credits are transferred from the host country, where the project is carried out, to the country financing the project. JI projects produce Emission Reduction Units (ERUs). Both CERs and ERUs can be used for compliance by EU ETS installations. In terms of volumes CDM projects provide the main source of import credits.

small extent. This may be taken as an indication that the market expects higher prices post 2012 than in the second trading period.

Abatement costs in ETS industries, i.e. the marginal abatement cost given the cap set by the National Allocation Plans (NAPs), indicate a price level of between 20 and 25 €/tonne CO_2 in 2008–2012. Most of the abatement potential is found in the power sector.

As of 2007, it seems likely that the restriction on the import of CERs in the second phase ETS will not be binding. If CERs are not used for commitment, they can be banked and used for compliance in the next period. Hence, if prices post 2012 are expected to be higher than in 2008–2012, CERs will be banked to the extent possible.

Prices for the post-2012 period depend on the outcome of international negotiations, as well as the impact of other climate policy measures such as including renewables policies and energy efficiency measures. Despite these uncertainties, a few price projections for post-2012 have been published. Prices vary of course, but most forecasters expect climate policies and hence, caps, to become stricter in subsequent periods. A much quoted forecast from Deutsche Bank, is an average price of 35 €/tonne from 2013–2020. Another international bank, UBS, also forecast an increase in second phase EUA prices because of expectations of higher prices post-2012.

Although it is reasonable to expect tougher targets post-2012, there are also developments that could indicate lower prices, if not looser emission targets. The impact of the EU reaching the renewables targets would, for example, be lower demand for emission allowances from the European power sector. Lower baseline emissions would probably imply lower caps, but it is unlikely that such a response would fully offset the impact of a substantial increase in renewable electricity production. On the other hand, it is not regarded as likely that the EU will be able to reach such an ambitious renewables target in the proposed timeframe.

Based on these (uncertain) parameters, we propose a 'best guess' price range of 25–35 €/tonne for the 2012–2020 period.

This is not to say that prices could not rise higher. The development in political awareness and acceptance of climate change effects and the need for action seems to increase rapidly. The scientific consensus on climate change has also grown. The latest results and observations seem to indicate that the climate may change even more rapidly than what was expected only a few years back. It is fair to say that uncertainty still abounds when it comes to the degree and effects of climate change. As scientific and empirical evidence becomes clearer, it may well be revealed that climate change is a greater threat than previously anticipated and that more mitigation action is needed. In such a scenario, CCS may be necessary and CO_2 prices could be significantly higher than the best guess range.

3.1.3 EU policies on CCS

The value of CCS may, however, also be influenced by other measures than the carbon market price. The EU has stated a strong interest in the development of CCS technology and intends to set up 12 large-scale demonstration facilities by 2015 and have the technology ready for commercial operation by 2020. Currently, CCS is not part of the

ETS, but it is possible to apply for opt-in. CCS is part of the discussion regarding revision of the ETS Directive and could be included from 2013.

Current prices, including price expectations for the 2008-2012 period, are not likely to cover the costs of developing and implementing the CCS targets. However, EU policies on CCS should be viewed in a broader perspective than just the EUA price. The international climate policies and the EU ETS in particular should be perceived as a measure for achieving the long-term transition to a sustainable low-carbon economy. In this perspective, the EUA price is not necessarily an endogenous price formed in a market, but rather a policy tool which will be used along with other measures, such as stricter requirements for CCS and financial support for renewable energy sources. Specifically, the EU Commission's *An Energy Policy for Europe*, released in January 2007, set out a target to "design a mechanism to stimulate the construction and operation by 2015 of up to 12 large-scale demonstrations of sustainable fossil fuels technologies in commercial power generation in the EU25", and "provide a clear perspective when coal- and gas-fired plants will need to install CO_2 capture and storage. On the basis of existing information, the Commission believes that by 2020 all new coal-fired plants should to be fitted with CO_2 capture and storage and existing plants should then progressively follow the same approach."

3.2 Climate policy in Norway

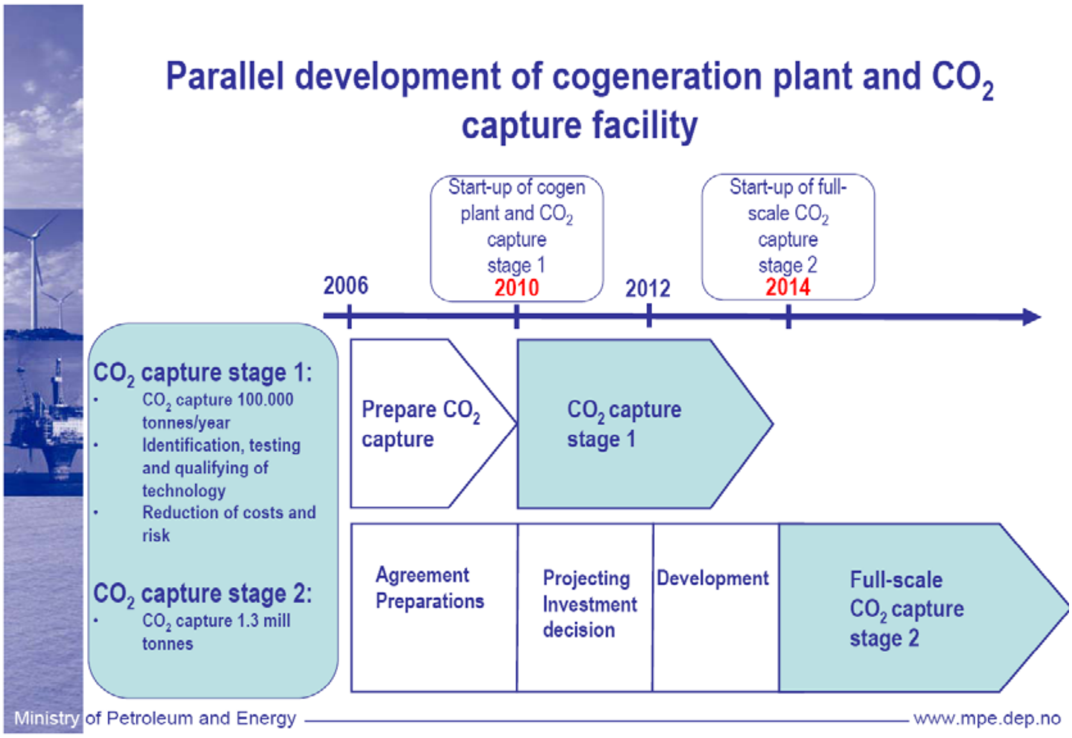
Norway has specific challenges in meeting the Kyoto targets because of the difficulties in reducing emissions from its power sector (100% hydropower in 1990). The Kyoto protocol limits the options to import credits (supplementary principle), and abatement opportunities in other sectors are limited and costly. In fact, the Norwegian government's White Paper on climate policy from June 2007[10] explicitly states that a given amount of emissions reductions must be met by domestic measures and not through quota purchases, CDM/JI or similar.

The exact action plan for meeting the domestic 2020 targets is not yet known, but the White Paper is currently being discussed in the parliamentary committee for Energy and the Environment, with a decision expected during the winter of 2007/2008. Of course, the plan is likely to be revised and updated as new information becomes available.

[10] St.meld. nr. 34 (2006-2007) (Report to the Storting).

4 TCM project and expected learning effects

Figure 4.1 Timeline for Mongstad development



Source: Ministry of Petroleum and Energy

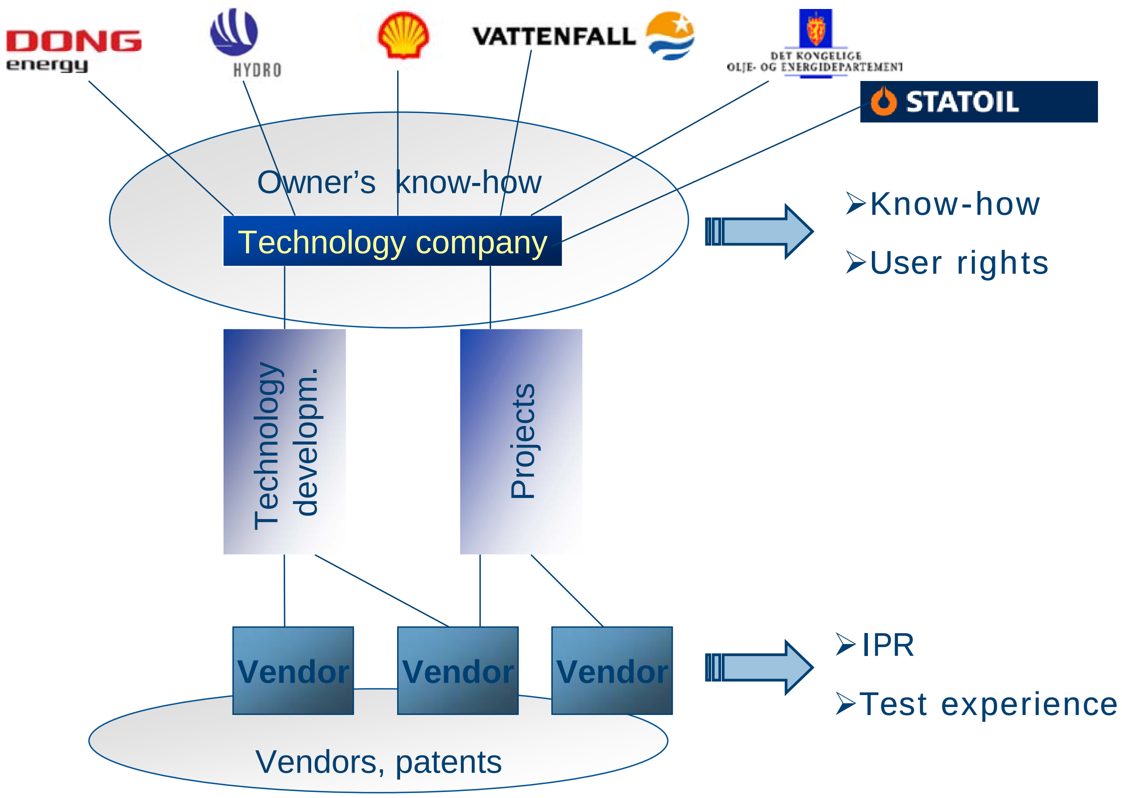
The emission permit for the Mongstad CHP and the agreement between the State and StatoilHydro stipulate that development of a full-scale CCS plant must proceed in parallel with construction of the cogeneration plant. In order to reduce technical and financial risk, the project will progress in two stages. The first stage will be in place when the cogeneration plant starts operation in 2010. The second stage, full-scale carbon capture, will be in place by the end of 2014.

4.1 Test Centre Mongstad – Technology development (CO_2 capture stage 1)

The main purpose of Test Centre Mongstad is to gain access to relevant technology components for the post-combustion carbon capture processes, test different technology solutions, reduce the uncertainty and to reduce costs related to for future investments in full-scale carbon capture plants. At this stage, the facility is required to capture at least 100 000 tonnes of CO_2 per year. The Test Centre Mongstad project represents a step forward from research and development projects towards actual use of technologies for CO_2 handling. This work will entail very valuable experience related to technology solutions for full-scale capture, at this cogeneration plant and other future gas-fired power plant projects.

The Test Centre project is to be operated by a so-called unlimited company with shared responsibility (DA) to be set up in early 2008. The State, StatoilHydro, and other potential owners participate on equal terms, providing competence and capital and gaining user rights to resultant technological innovations. Technology vendors' participation will be based on competition, and the vendors will retain intellectual property rights.

Figure 4.2 The TCM business model



For the joint venture partners, including the Norwegian State, the objective will be to contribute to the further development and promotion of CCS technologies, and thereby create a wider market for such technologies. The commercial motive is primarily to contribute to reducing the future costs of producing, transporting, and utilizing oil and gas and thereby safeguarding the future value of petroleum, not to earn money on the technologies as such. The know-how gained through technology projects such as TCM will also give partners credibility, thereby supporting their core business activities in the future, both in Norway and elsewhere.

For the vendor companies, which deliver the various technology components, the project will serve as a laboratory for testing and developing their technology solutions.

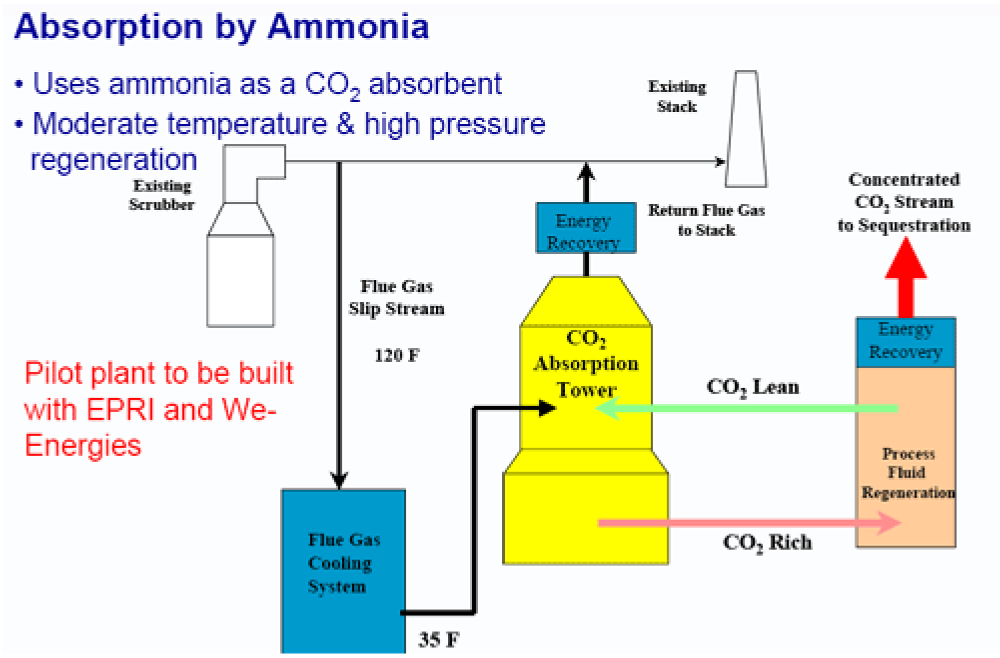
This set-up implies that the benefits of the innovations taking place as the result of TCM will be spread to other projects through improved know-how in the owner companies as well as in the vendor companies. The innovation process, which is enabled through this organisation, has several similarities with the innovation processes in other parts of the oil and gas industry, where technologies are developed through symbiotic interactions between the oil and gas companies and the technology providers.

An investment decision is to be taken concomitantly with the creation of the DA. According to estimates by Gassnova, the investment costs related to stage 1 technology development and construction of a capture facility for at least 100 000 tonnes of CO_2, will amount to some NOK 1000–2000 million, plus annual operating costs of around NOK 150 million. There are also costs related to planning and setting up of the technology company as well as operating costs related to the transport and storage of CO_2. The Test Centre will evaluate two alternative capture technologies, both based on post-combustion CO_2 capture, but with different chemical processes based on amine and ammonia as absorbents, respectively.

An amine-based post-combustion CCS process works by cooling down the flue gas from the power plant to 40–50 degrees Celsius and allowing it to rise through an amine-laced 'scrubber' in a 40 metre-high absorption tower. The CO_2 in the flue gas reacts with the amine to form a solution that runs down to the bottom of the tower, while 'clean' flue gas (containing 10–15% of original CO_2-concentration) escapes at the top. The CO_2 is then removed from the amine by heating it to approx. 120 degrees, allowing the amine to be reused.

In June 2007, Alstom and Statoil announced their agreement to develop an ammonia-based CO_2 capture and storage facility for TCM. Alstom has developed the so-called 'chilled ammonia' process, which may recover 90 per cent of CO_2 emissions at a lower energy input than comparable CCS processes.

Figure 4.3 Chilled Ammonia process



Source: Alstom

Ammonia is structurally similar to amines (amines being chemically derived from ammonia) and can be used to absorb CO_2 from flue gases in a similar fashion. This process has been tested previously, and the innovative aspect lies in the focus on chilling the ammonia. Ammonia is currently utilized commercially in SO_2 capture and storage from power plants. The system operates by allowing the cooled flue gas to flow upwards in counter current to the slurry containing a mix of dissolved and suspended ammonium carbonate and ammonium bicarbonate. More than 90 per cent of the CO_2 from the flue gas is captured in the absorber. The remaining low concentration of ammonia in the clean flue gas is captured by cold-water wash and returned to the absorber. The clean flue gas, which now contains mainly nitrogen, excess oxygen, and low concentration of CO_2, flows to the stack.

4.2 Learning effects in comparable developments

The main effect of TCM is to decrease costs for future investments and operation of full-scale carbon capture plants. In this section, we take a closer look at learning effects in comparable developments and give a survey of other demonstration and pilot plants in other countries.

4.2.1 Learning effects in comparable developments

For many new technologies, decreases in unit production costs as the technologies mature have been observed. These cost reductions are due to several factors, but one of the most important is the learning, or experience, gained through production. This learning effect can be described in the form of learning or experience curves. A learning curve states that a technology’s costs will decline as its production and utilization, and thereby the experience of using it, grows. The curve can be considered an empirical operationalization without any thorough theoretical foundation. The basic idea is that the more one engages in development, the more opportunities exist to reduce costs and improve the product. Experience curves, which are broadened learning curves that include all costs necessary to research, develop, produce and market a given product, were introduced in the 1970s by Boston Consulting Group (BCG, 1973). The main argument for introducing these curves is that learning-by-doing (LBD) does not only occur as an improvement in labour productivity, but also in associated R&D, overhead, advertizing and sales expenses. These efficiency gains can yield cost reductions that can be characterized by a curve with the same functional form as the learning curve. In this study we will not distinguish between learning and experience curves, but our interpretation will be closest to experience curves.

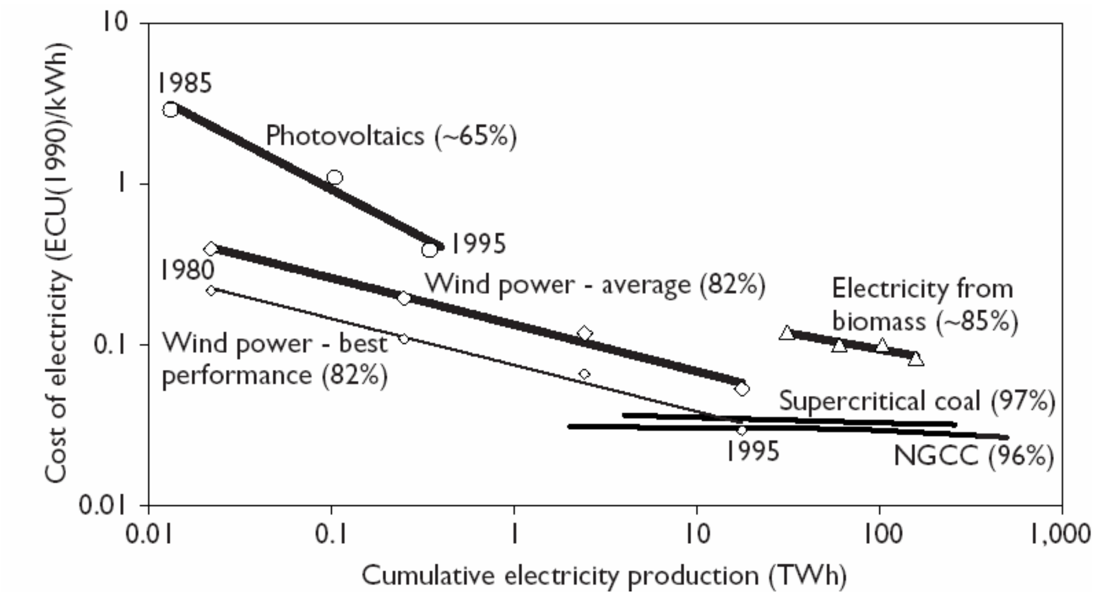
The rate for the decline in costs is measured by the progress ratio (PR). A PR equal to 0.8 (or 80 per cent) means that costs are reduced to 80 per cent of the previous level for each doubling of the cumulative experience or production.[11] The PR can also be expressed in form of a learning rate, which is equal to 100-PR, meaning that a PR of 0.8 (80 per cent) equals a learning rate of 20 per cent.

[11] Dutton et al. (1984) compiled over 100 firm-level studies, and found a mean progression rate of 0.8.

Experience curves can often be divided in different stages with different PRs. Ayres and Martinàs (1992), who studied integrated circuits, showed higher PR in early stages of development, and lower PR when the technology is more mature (i.e. has a bigger commercial market). This is consistent with the common assumption that market pressure allows for a high level of learning-by-doing.

The figure below shows experience curves for a selection of energy technologies. Clearly, the progression rate differs between technologies. The figure supports the assumption that the cost reductions are largest in the early stages.

Figure 4.4 Experience curves for energy technologies



Source: IEA (2000): Experience curves for energy technology policy

McDonald and Schrattenholzer (2001) analysed 26 estimated PRs for energy technologies, and found that the PR varied from 0.63 to 1.11, with a median of 0.84. A PR>1, meaning that the costs actually rises with accumulated production, are typically found for large energy plants. According to Neij (1997), possible explanations can be that the costs associated with changes in design and product development are larger than the cost reductions from standardization, economies of scale, specialization, and rationalization. Improved security and environmental performance can also drive the costs.

There has been several estimates of PR for wind power, amongst them Junginger (2000) who finds PR between 0.84 and 0.97, and Ibenholt (2002) who estimates a PR for Danish wind power equal to 0.92 for the period 1984–1999. Carbon Trust (2006) has estimated possible future PRs for wave and tidal power. Wave power is expected to have a PR between 0.85 and 0.9, while the prediction for tidal power is slightly higher, 0.9–0.95.

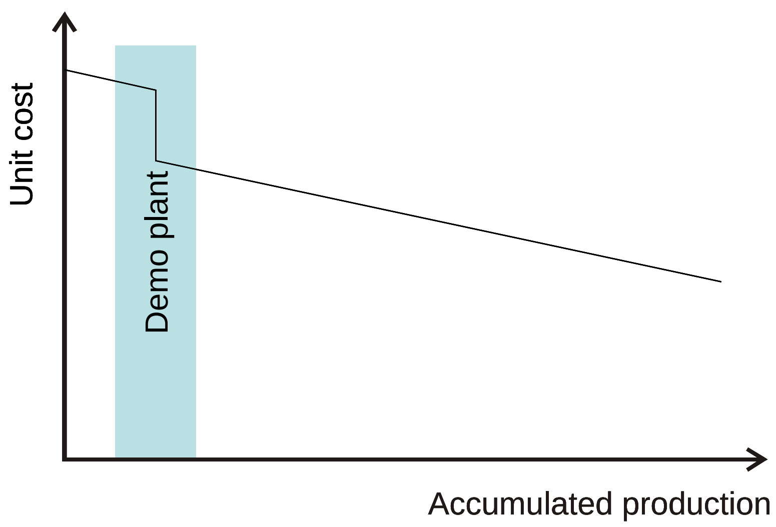
A learning curve states an empirical connection between costs and accumulated production, but it does not explain this connection. The mechanisms for learning-by-doing are numerous; for instance, experience gained by individuals, improved functioning of organizations, and economies of scale. Learning-by-doing is not the only means of reducing costs: improvements in down- or upstream technologies can also lower costs. Generally, cost reductions are driven by five factors: 1) technological progress; 2) input price changes; 3) internal efficiency improvements; 4) learning by doing; 5) economies of scale. However, except from factor 3 and 4, it is likely that any correlation with accumulated output will be at least partly spurious.

It is important to keep in mind that an experience or learning curve shows a long-term development, and that it cannot predict when and how the costs will fall. But it may be a useful tool when assessing the cost reductions necessary to make a technology commercially viable. It has been noted that "the experience curve is a long-range strategic rather than a short-term tactical concept. It represents the combined effects of a large number of factors (…) it cannot be used reliably for operating controls or short-term decision-making. But in the formulation of competitive strategy, the experience curve is a powerful instrument, indeed."[12]

4.2.2 Base line and ambitions for cost reductions in full scale capture plants

For TCM, an important question is how the Test Centre may appear in the experience curve. There are few, if any, empirical studies of how a demonstration plant affects production unit costs. It is possible that a demonstration plant leads to an important change in the content of the development process, revealing large cost savings. But the opposite may also occur, i.e. changes in the process design or alike actually increases the unit cost. Another aspect is the fact that a demonstration plant is limited in time and production volumes, thereby giving limited opportunities to "ride down the learning curve". If the demonstration plant reveals cost savings, this will probably appear as a shift in the learning curve, rather than a transition along the curve, see figure below.

Figure 4.5 Possible shift in the learning curve induced by a demonstration plant



12 See Bodde (1976).

When estimating the effects the Test Centre might have on unit costs it can be useful to distinguish between the various cost components and the Test Centre's ability to influence these. The cost components are:

- Investment costs
- Operational costs
- Energy use in order to extract CO_2
- Disposal of CO_2

TCM can most likely only affect the first three components, through improved chemicals that reduced the energy use, improved plant design (streams, pressure and heat) and/or improved components (like heat converters, pumps, boilers etc.). The largest improvements are likely to occur for investment costs, through improved plant design.

4.2.3 Other pilot and demonstration plants

There are several other existing or planned pilot or demonstration plants for CCS, and in Table 4.1 we have gathered information about these pilot plants.[13] The table shows that there are several industrial actors that have chosen to engage in pilot plants. Amongst these actors are both privately and state-owned companies like for instance Total, Vattenfall, American Electric Power (AEP) and E.ON.[14] Several of these companies have a long tradition for engaging in R&D in new energy technologies, and they regard CCS as an important part of a sustainable energy future.

As can be seen in Table 4.1 most of the pilot plants are based on coal, reflecting the fact that it is CCS from coal that has the largest potential for CO_2 reductions. The advantage of TCM in this perspective is that the process of capturing CO_2 from the refinery flue gas represents a flexible technology that may be converted to coal. The pilot plants already in operation, and some of the plants under construction, are very small compared to TCM, with annual capture targets of less than 10,000 tonnes. Larger pilot plants will most probably induce larger cost reductions per tonne CO_2, due to a positive scale effect. The existence of competition in technology development can also be a positive driver for cost reductions.

4.2.4 Summary – learning

For all new technologies, there are learning effects, meaning that the unit cost is reduced as a function of cumulative production. How large this effect will be for a specific technology, like CCS, is difficult (or even impossible) to predict. For energy technologies, an average learning effect of 20 per cent has been observed, but it is important to keep in mind that there are large variations between technologies and over time and development stage for the same technology.

A pilot or demonstration plant will most likely give the learning curve for the specific technology a significant downward shift, i.e. lower costs. TCM is likely to contribute

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13 For a more detailed description and more demonstration plants see www.zero.no.

14 At http://www.zero.no/fossil/co2/players a total of 42 actors engaged in CCS projects are listed.

most to reduced investment costs for a full-scale plant through improved plant design, but also lower energy costs.

Globally there are several private companies engaged in pilot plants for CCS, showing that there exists a commercial interest in these technologies.

Table 4.1 Existing and planned pilot plants for CCS technologies

Country	**Company**	**Technology**	**Tonnes CO_2**	**MW**	**Start-up**
Japan, Nanko Power station, Osaka	Mitsubishi (MHI)	Gas and syngas from coal, post-Combustion, amin	2 t/d		1991
Canada, Boundary Dam, Saskatchewan		Coal, post-combustion, diff. chemicals	4 t/d		1987/ 1999
Japan, Hiroshima	Mitsubishi (MHI)	Coal, post-combustion, amin	1 t/d		2002
Denmark, Esbjerg	CASTOR (EU-project), several companies	Coal, post-combustion, amin	8000 t/y		2006
Japan, Matsushima Nagasaki	Mitsubishi (MHI)	Coal, post-combustion, amin	10 t/d		2006
USA, Kimberlina	Clean Energy Systems (CES)	Gas and syngas from coal, Oxyfuel		20	2006
USA, Wisconsin	We Energy + appr. 20 other	Coal, post-combustion cooled ammonium		5	2007
USA, Ohio	Powerspan	Coal, post-combustion cooled ammonium	20 t/d	1	2007
France, Lacq	Total	Oxyfuel	150 000 t/y	30	2008
Germany, Schwartze Pumpe	Vattenfall	Coal, Oxyfuel		30	2008
USA, West Virgina	American Electric Power, Alstom	Coal, post-combustion cooled ammonium	100 000 t/y	30	2008
Sweden, Karlshamn	E.ON	Oil, post-combustion cooled ammonium	0.2 t/h	5?	2008
Norway, Risavika	ZENG, Lyse Energi a.o.	Gas, Oxyfuel		50	2009
Australia, Biloela, Queensland	CS Energy a.o.	Coal, Oxyfuel	150.000 t/y	30	2009
Norway, Mongstad	Statoil a.o.	Gas, post-combustion, 2 technologies	100 000 t/y		2010
Wales, Aberthaw	RWE npower	Coal, post-combustion		25	2010
Germany, Niederaussem	RWE, Linde, BASF	Coal, post-combustion			2010
Spain, several plants		Post-combustion, pre-combustion and oxyfuel		5-10	
Netherlands, Drachten	SEQ International and ONS Energy	Oxyfuel	200.000 t/y	50	
Netherlands, Limburg	NUON	Coal, gasification			

Source: www.zero.no

5 Valuation

5.1 Introduction

In this chapter, we present a valuation of costs and benefits of the Norwegian State's business case as it was presented in chapter 2. The State's share of these value elements will differ, but in general we will report its share according to SDFI ownership on the NCS and a share of 80 percent of total NPV, representing the total government take.

The calculations are based on a standard valuation method, i.e. calculating net present value before tax, using a real weighted average cost of capital before tax of 7 per cent.[15] Data are taken from publicly open sources, discussed with industry experts, and calibrated against our own experience. The cost estimates for TCM and for the full-scale capture plant at Mongstad are based on cost figures published by Gassnova SF. All numbers and figures are reported in real terms, while all NPVs are discounted and presented in 2007 NOK.

5.2 The cost of TCM

The size of capital expenditure (CAPEX) is still under evaluation in the TCM planning phase. Information received from Gassnova SF indicates a range for capital expenditures (OPEX) of NOK 1000–2000 million, while operating cost is estimated at NOK 150 million per year over five operating years. We assume a base case estimate in the middle of this range, but provide a sensitivity analysis at the end of this section.

Total capital expenditure for TCM in our base case is projected at NOK 1500 million, including necessary land acquisition, property and equipment. 75 percent of total capital expenditure is expected to be related to engineering, procurement, and construction (EPC), which is where we expect to see the main learning effects from TCM. The remaining 25 per cent of capital expenditure is related to external connections and administration with limited learning effects. For operating expenditures, the current estimate is NOK 150 million per year, including utilities and energy, man-hours, services and modifications, for yearly abatement volumes of up to 100 000 tonnes of CO_2. More specifically, energy costs are assumed to be NOK 75 million per year and other operating expenditures are set to NOK 75 million per year. The non-energy related operating costs of a full-scale plant today are assumed to be approximately 5 per cent of total capital expenditure, based on experience from similar processing and reports on the Kårstø CCS plant. In terms of learning effects, utilities and energy show the greatest potential for improvement.

[15] A Weighted Average Cost of Capital (WACC) of 7 per cent real before tax corresponds broadly to the risk level of an average project on the Norwegian stock exchange or slightly above, as discussed in for instance the Ministry of Finance's current guidelines for economic cost-benefit analysis (2005). Although the TCM carries great project-specific risks, primarily technology-related, these are primarily non-systematic by nature and should not be accounted for in the cost of capital. See also NOU 2000:18 for a consideration of the cost of capital on the Norwegian Continental Shelf, where it is concluded that the equity risk level of a typical NCS operator is below the stock market average. A 7 per cent real discount rate before tax has also been applied in valuations of the SDFI portfolio (see WoodMackenzie, 2005).

The estimates for the operating expenditure include all internal processing and operations, but no transportation and storage.[16] TCM is planned to be operational from 2010 to 2014 giving a total lifetime of 5 years. We will assume no terminal value of the TCM plant or equipment. This gives a total negative NPV of the Norwegian State's 80 per cent stake in the project of NOK 1480 million (2007 NOK).

Given the uncertainty at this stage of the planning phase, a sensitivity analysis on the overall cost figures is needed. If we design a more pessimistic case with capital and operating expenditure at NOK 2000 million and 175 million, respectively, the NPV would instead be a negative NOK 1900 million. On the other hand, an optimistic case with capital and operating expenditures in the lower part on indicating ranges, of NOK 1000 million and 125 million, give an NPV of NOK 1060 million.

The potential benefits will have to be weighed against this expected cost of TCM.

Table 5.1 Cost of TCM investment and operation

Value element (NOK million)	Low	Base	High
TCM investment and operation	-1 900	-1 480	-1 060

5.3 Value of reduced costs at other CCS plants

5.3.1 Mongstad Phase 2

The immediate effect of TCM is reduced capital and operating expenditures in the full-scale capture plant at Mongstad. The exact dimension of this plant is uncertain, however, as it is not yet decided whether one will capture CO_2 emissions from the cracker and other processing facilities in addition to the decided CHP plant. The CHP plant alone will emit an annual volume of 1.1 million tonnes of CO_2, while the cracker and the remaining facilities account for 0.8 million tonnes and 0.2 million tonnes of CO_2, respectively. The current goal is to capture the total volume so we assume a larger plant in our base case. Sensitivity analysis will be provided at the end of this section.

Starting with capital expenditure, the knowledge and experience from TCM will be expected to generate reductions in total investment of the full-scale capture plant at Mongstad in the range of 15 to 20 per cent. This stems mainly from an estimated 30 to 50 per cent reduction in equipment costs from technology improvements, which is related to the EPC part of the capital expenditure breakdown. The best estimate of capital expenditure for a full-scale plant is the report on the Kårstø capture plant, which indicates approximately NOK 3500 million (NVE, 2006). However, given the worldwide investment levels and associated price pressure, recent studies indicate a significant increase on previous estimates.[17] Moreover, the Kårstø plant is designed to capture an annual CO_2 volume of 1.1 million tonnes, while the volumes in question for the full-scale capture plant at Mongstad are in the range of 1.1 to 2.1 million tonnes. Still, a full scale-up, meaning a doubling of the costs from Kårstø would probably be an overestimate. Based on these factors, we currently estimate the full capital expenditures

[16] According to the agreement between Statoil (now StatoilHydro) and the Norwegian State, the responsibility for transporting and storing the CO2 from the TCM belongs with the State and is not a part of the TCM investment decision.

[17] Presentation by H.S. Andersen, Norsk Hydro, to the Marcus Evans Conference: "*Carbon Capture and Storage*", 13-14 September, 2007, Berlin.

for CCS Mongstad at approximately NOK 5000 million. Given the discussed learning effect, TCM has the potential to reduce total costs of the full-scale capture plant by NOK 1000 million. Moreover, the learning effects on capital expenditures should migrate to the CAPEX-related operating expenditures (see above for a description of the non-energy operating costs).

The greatest learning effects are expected in the remaining part, the energy part of the operating costs. The current aim is to reduce the 'power penalty' (i.e. loss of net plant electricity output because of the CCS plant) from 83 to 58 megawatt (MW) and thus increase the electrical efficiency from 46 to 50 per cent. This equates to an approximate 30 per cent decrease in energy costs, with a likely range of 20-40 per cent decrease. Moreover, it is expected that energy costs will be of an equal magnitude to non-energy operating costs, leading to an expected reduction in total operating costs for the full-scale plant of around 15 to 30 per cent. The baseline estimate for operating costs is NOK 500 million for an annual captured volume of approximately 2.1 million tonnes of CO_2, given a CAPEX of NOK 5000 million.[18] TCM may thus be credited an annual reduction of NOK 75 to 150 million in positive value. Recalling the discussion of learning effects in chapter 4, these calculations seem to be reasonable estimates.

We may now calculate the total value of the expected improvements for the full-scale capture plant at Mongstad generated by TCM. We assume a lifetime of 25 years (from 2014 to 2038) and no terminal value of the plant and equipments. For a base case consideration we will, moreover, assume learning effects of 15 per cent on CAPEX (and related non-energy OPEX) and 30 per cent on energy efficiency. Under the assumptions specified above, such a base case for the cost reduction attributable to TCM would have a value of NOK 1,360 million, only NOK 120 million short of the TCM costs.

A sensitivity analysis on a more pessimistic case, with a learning effect for CAPEX and energy costs of 10 per cent and 20 per cent, respectively, gives a value of NOK 900 million. Though smaller, it is still substantial. Moreover, a more positive case with 20 per cent and 40 per cent learning effects on CAPEX and energy costs, yields a total value of NOK 1810 million.

Thus, for the full-scale plant of Mongstad, the cost saving generated have a significant value, almost as large as the costs of TCM.

Table 5.2 Value of reductions at full-scale CCS Mongstad

Value element (NOK million)	Low	Base	High
Reductions at full-scale CCS Mongstad	900	1 360	1 810

5.3.2 Other CCS plants

Furthermore, in a scenario where the Norwegian State should be involved in other CCS plants in the future, lower costs stemming from TCM should be considered as a potential benefit.

For the sake of simplicity, we will assume that other future CCS plants in Norway are similar to the Kårstø plant. Kårstø represents more or less a standard CCGT plant with

[18] Given that the CCS facility will capture 1.1 million tonnes of CO_2 from the power plant, 0.8 million tonnes of CO_2 from the cracker and 0.2 million tonnes of CO_2 from other processing facilities.

moderate CO_2 emissions. With the base-case assumptions for learning effects outlined above, the corresponding cost savings due to TCM for a plant of this size would be approximately NOK 1080 million. For the pessimistic and optimistic case, the value would be NOK 725 million and 1450 million, respectively. These figures represent 100 per cent state ownership. If we assume that the state participation will correspond to the SDFI share of future gas reserves, the effect will decrease to one third.

The following table reports this share for all cases, while the full-share figures calculated above must be interpreted as a maximum value.

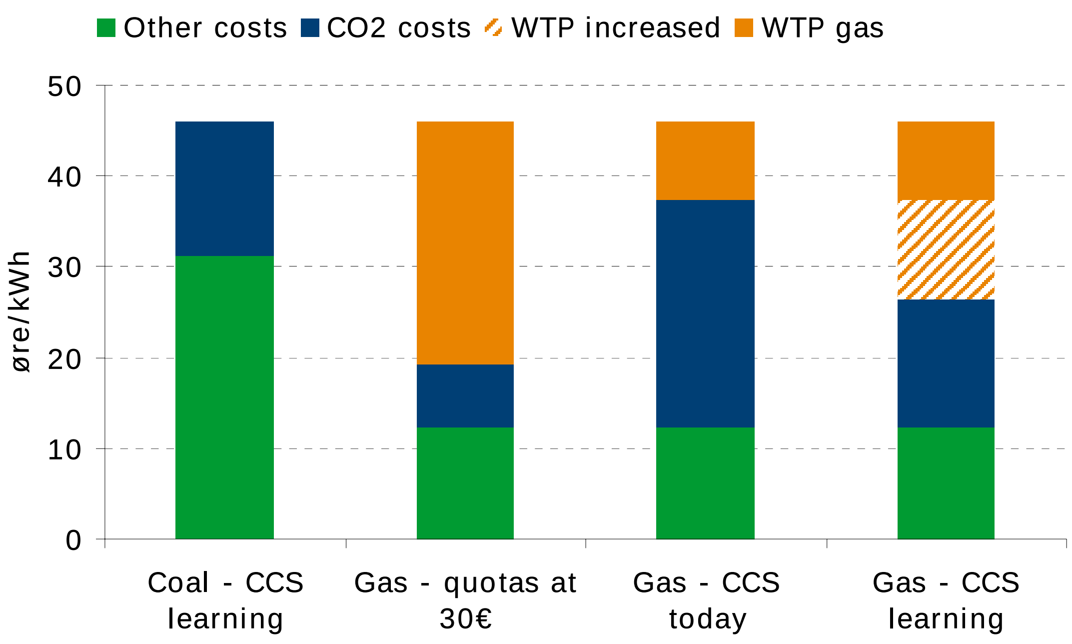
Table 5.3 Value of reductions at other CCS plants

Value element (NOK million)	Low	Base	High
SDFI - Other CCS plants	250	373	500
Max share - Other CCS plants	725	1 080	1 450

5.4 Sustained willingness-to-pay for Norwegian gas

Chapter 2 described a conceptual model for analysing how reduced costs of CCS on gas power could impact the European gas market. Figure 5.1 builds upon that model and shows gas power producers' willingness to pay for gas in 2020 under different assumptions.

Figure 5.1 Cost of electricity generated in 2020 with learning effects[19]



The point of departure for this model is that the EU is assumed to implement climate change regulations that are restrictive enough to stimulate coal with CCS. An implica-

[19] Source given by Gassnova: ZEP WG1 – Oct 2006. Some assumptions: Coal price 2.3€/GJ, Gas price 5.8€/GJ = 165 øre/Sm3, 8% WACC. Shown coal is hard coal.

tion of that assumption is that coal power with CCS sets both the power price and the quota price in the future.

The figures are taken from ZEP-WG1 (2006), and the first bar shows the total cost of electricity produced in coal power plants with CCS.

Without any other regulations than an obligation to buy quotas, investors in gas power plants will choose the quota option. This is represented by the second pillar, showing a willingness to pay for gas that stays fairly high.

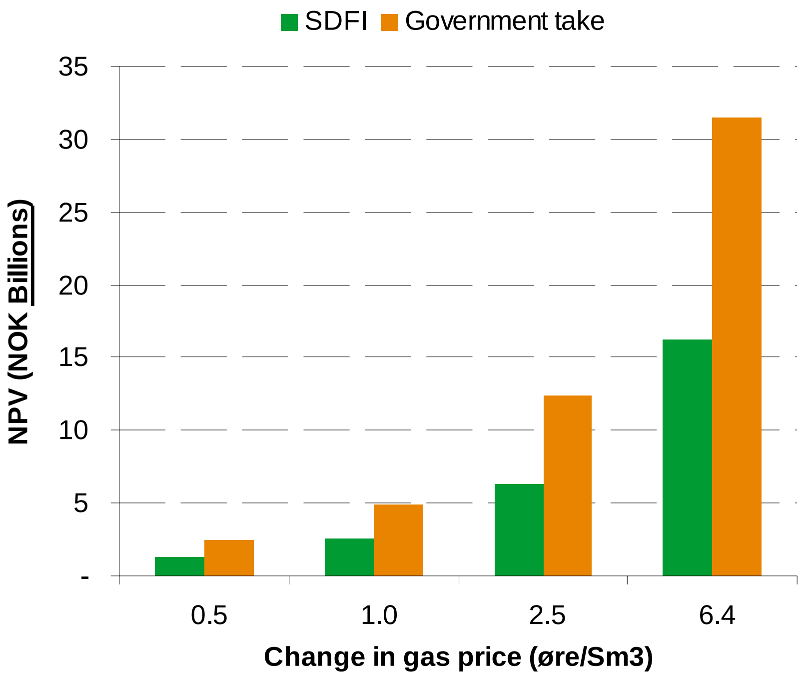
However, if CCS becomes mandatory for gas power producers the willingness to pay could drop dramatically, as the third bar shows. The third bar is based on the current CCS cost level for gas, i.e. absent any learning effects.

In the last bar, lower CCS costs for gas translates directly into increased willingness to pay for gas and illustrates how important is could be for a large gas producer to contribute to lowering the CCS costs for gas power production.

The increased willingness-to-pay shown in Figure 5.1 is equal to approximately 11 øre/kWh (equals 64 øre/Sm3 gas), and represents the total learning effects over a period of 12 years including those which stem from TCM.

How much of this increase (or rather, the reduced decrease) that can be attributed to TCM is highly uncertain, but even small price movements have large impacts on the value of the Norwegian State’s gas reserves. Figure 5.2 illustrates this effect by showing for different price movements the associated change in NPV for total government take and for the SDFI portfolio alone from 2020.

Figure 5.2 Impact of gas price movements on the NPV of the Norwegian resource base and SDFI



If we only consider the value of sustaining the willingness-to-pay, a price increase of 0.27 øre/Sm3 gas would make the value of the government take equal to the estimated costs of TCM. If we only consider the SDFI portfolio, an increase of 0.54 øre/Sm3 gas is necessary to cover the total cost of the TCM, which is less than 0.5 per cent of the current natural gas price.

The investment in TCM could then be seen as a moderate insurance premium or a hedge against a future market situation where climate change regulations put pressure on the natural gas price and where low CCS costs could be a sound way to prepare for defending the future value of gas in the market.

5.5 Value of Enhanced Oil Recovery and deferred abandonment

As discussed in Chapter 2, in a scenario where assumptions are made about the availability of CO_2 on the NCS, although initially for storage, future declining oil fields may be able to enhance their production through CO_2 injections and also defer their abandonment expenses.

The profitability of CO_2 injection projects is subject to many factors, including investors' oil price expectations, the availability of CO_2 at a reasonable price and expected planning and modification costs in existing fields. It is difficult to state exact numbers in this respect, but given the right assumptions, the option value of CO_2 for EOR could amount to several billion NOK.

5.6 The net benefit of TCM from the State's commercial perspective

Taking the Norwegian State's commercial perspective described in this report, the investment in TCM is profitable.

The conclusion is based on the following:

- Based on the preliminary cost figures, more than 90 per cent of the Norwegian State's share of the TCM costs would be paid back through the cost savings at the full scale carbon capture plant at Mongstad.
- Reducing CCS costs for gas, which is the main objective for TCM, could considerably limit the negative impact on the willingness to pay for gas in power production in a future with fairly restrictive climate change regulations. Looking at the SDFI portfolio, the break-even cost represents less than 0.5 per cent of the current gas price. TCM could therefore be considered as a moderate 'insurance premium', or a hedge against an unfavourable competitive situation for gas in the future.
- Other option values related to later investments in CCS and the potential for utilizing CO_2 for EOR could also be significant.

The results from the above calculations underline that the value of TCM is mostly related to the upside potential arising from a fairly restrictive climate policy and that in such a situation TCM may help safeguard the future income from the Norwegian resource base. In addition, there are possible commercial opportunities in the interface between CCS facilities and the existing infrastructure on the NCS.

The distribution of benefits and costs is somewhat asymmetrical, which is typical of an innovative technology project such as TCM. In this perspective, TCM functions as an option for a private investor faced with huge uncertainties regarding policy, technology, and market conditions.

List of References

Andersen, H.S., Norsk Hydro (2007): Presentation at the Marcus Evans Conference: "*Carbon Capture and Storage*", 13-14 September, 2007, Berlin.

Ayres and Martinàs (1992): "Experience and the life cycle: Some analytic implications", *Technovation*, 12:7, 465-485.

BCG (1973): "The Experience Curve Reviewed – II. History", *Perspectives*, no. 125.

Bodde, D.L. (1976): "Riding the Experience Curve", *Technology Review*, March/April 1976.

Carbon Trust (2006): *Future Marine Energy: Cost competitiviness and growth of wave and tidal stream energy*. Report nr CTC601.

Dutton, J.M., A. Thomas and J.E. Butler (1984): "The History of Progress Functions as a Managerial Technology", *Business History Review* 58(2), 204-233.

ECON (2007): *Shock Therapy. Electrification of the NCS.* Norwegian Continental Shelf Quarterly Report, volume 4 number 3. Published at www.econ.no.

EU (2007): *An Energy Policy for Europe.* Communication from the Commission to the European Council and the European Parliament. COM(2007) 1 Final. Brussels, 10.1.2007.

Gassco (2006): *Innledende forhandlinger mellom de kommersielle aktørene i en CO_2 kjede.* Joint report with Petoro and Gassnova (*Preliminary negotiations between the commercial actors in a CO_2 value chain.* In Norwegian.)

Ibenholt, K. (2002): "Explaining experience curves for wind power", *Energy Policy*, 30 (13), 1181-1189.

IEA (2000): *Experience curves for energy technology policy*. IEA/OECD, Paris.

Junginger, M. (2000): *Experience curves in the wind energy sector, use, analysis and recommendations.* Report nr NWS-I-2000-29, Utrecht University.

McDonald and Schrattenholzer (2001): "Learning rates for energy technologies", *Energy Policy* 29, 255-261.

Ministry of Finance (2005): *Veileder i samfunnsøkonomiske analyser*. (*Guidelines for economic cost-benefit analysis.* In Norwegian).

Ministry of Petroleum and Energy (2007): *The Skarv license lays the grounds for climate friendly technology*. Press Release, 9.11.2007.

Neij, L (1997): "Use of experience curves to analyse the prospects for diffusion and adaption of renewable energy technology", *Energy Policy* 23(13), 1099-1107.

NOU 2000:18: *Skattlegging av petroleumsvirksomhet.* The Ministry of Finance. (Norwegian Official Reports 2000:18: *Taxation of the petroleum sector.* In Norwegian).

NPD (2007): *Faktaheftet 2007.* Norwegian Petroleum Directorate and Ministry of Petroleum and Energy. (Fact Sheet. In Norwegian).

NVE (2004): *Kostnader ved produksjon av kraft og varme i 2002.* Handbook no. 2/2002, revised edition 2004. Norwegian Water Resources and Energy Directorate. (*Costs of generating electricity and heat in 2002.* In Norwegian).

NVE (2006): *CO_2-håndtering på Kårstø*, Pål Tore Svendsen (red), Norwegian Water Resources and Energy Directorate. (*Carbon Capture and Storage at Kårstø.* In Norwegian).

SFT (2007): *Reduksjon av klimagasser i Norge: En tiltaksanalyse for 2020*. Norwegian Pollution Control Authority. (*Reduction of greenhouse gas emissions in Norway: An abatement analysis for 2020.* In Norwegian).

SINTEF (2005): *Tjeldbergodden Power/Methanol – CO_2 reduction efforts, SP2: CO_2 capture and transport*, H.M.Kvamsdal and T.Mejdell et al.

St.meld. nr. 34 (2006-2007): *Norsk klimapolitikk.* The Ministry of the Environment. (Report to the Storting no. 34 (2006-2007): *Norwegian climate policy.* In Norwegian).

WoodMackenzie (2005): *Valuation of State Direct Financial Interest.* June 2005. Prepared for the Ministry of Petroleum and Energy.

ZEP WG1 (2006): *The final report from Working Group 1 - Power Plant and Carbon Dioxide Capture,* The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP).