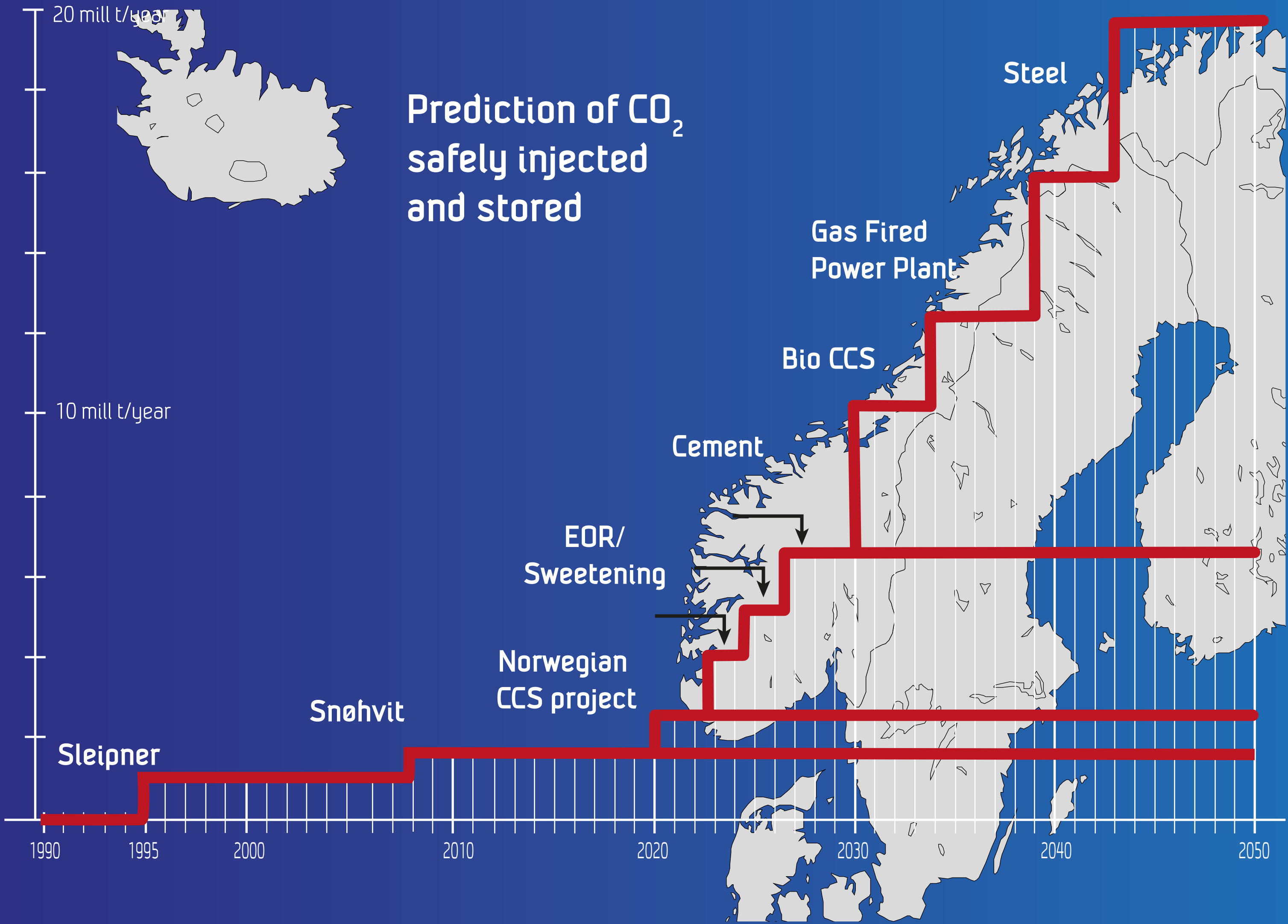
# Nordic CCS Roadmap

## - A vision for Carbon Capture and Storage towards 2050




Sleipner A Photo: Harald Pettersen - Statoil

Melkøya - Photo: HELGE HANSEN -Statoil

Photo: Store Norske Spitsbergen Kulkompani AS

Norcem Brevik - Norway - Photo: Norcem

Østrand pulp mill

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# Executive summary

- **Global, EU and Nordic climate targets cannot be met without CCS**

The facts are clear: 'business-as-usual' in the Nordic energy sector will not deliver the region's climate goals. Indeed, while electricity production is based to a large degree on renewable energy, industry is still very dependent on fossil fuels.

As Carbon Capture and Storage (CCS) is the only technology which can substantially reduce $CO_2$ emissions from fossil fuels, it means that 20-30 million (M) tonnes must be captured and stored annually by 2050 in the Nordic countries. In fact, in some industries, such as steel and cement, CCS is the only means of achieving deep emission cuts.

Bio-CCS is also the only large-scale technology that can remove $CO_2$ from the atmosphere to deliver 'carbon negative' solutions and is already being deployed at industrial scale in the US. The Nordic region is unique in that a large proportion of its $CO_2$ emissions are biogenic (i.e. derived from biomass) – particularly in Sweden and Finland – and Bio-CCS could be an effective and cost-efficient option for industries with no other means of reducing emissions.

There is no question that CCS can deliver: all elements of the value chain are proven and plants such as Sleipner and Snøhvit in Norway are already storing ~1.7 million tonnes of $CO_2$ a year. The next step is therefore to scale up to large, integrated demonstration projects, with the potential to drive costs down – from both technology improvements and economies of scale.

The NORDICCS project – a collaborative research project between leading CCS research institutions in the five Nordic countries – has therefore developed a Nordic CCS roadmap that outlines key strategies for reducing costs, achieving economies of scale – and accelerating wide deployment. This is based on economic analyses of 10 case studies deemed likely to be the most cost-efficient solutions for CCS deployment.

- **Maximising Nordic collaboration to achieve significant economies of scale**

There are great advantages to be gained from a Nordic collaboration on CCS. Firstly, there are large $CO_2$ point sources in Sweden and Finland, complemented by large storage capacity off the coasts of Norway and Denmark. The development of large-scale projects utilising joint $CO_2$ hubs and storage sites will therefore benefit from significant economies of scale.

Secondly, this vast storage capacity could store $CO_2$ not only from the Nordic region, but other European countries as well. The high number of producing oil fields also creates significant opportunities to kick-start early CCS deployment by combining with Enhanced Oil Recovery (EOR).

Finally, collaboration will accelerate the development of carbon negative solutions, e.g. a CCS bio-industry project with capture at a pulp or paper plant in Sweden or Finland, or a CCS bio-energy project.

- **Combining CCS with Enhanced Oil Recovery to kick-start deployment**

In the US, commercial-scale CCS projects have been profitable for nearly 30 years due to the use of $CO_2$ for enhanced oil recovery ($CO_2$-EOR). The Nordic region is now ideally placed to take the lead in EOR and offshore $CO_2$ storage in Europe, with large sources of $CO_2$ around the North Sea basin, large storage capacity and decades of industry experience.

Indeed, the combination of $CO_2$-EOR with permanent $CO_2$ storage in oil reservoirs is a critical, near-term solution for creating economically viable CCS projects, facilitating early CCS infrastructure – and kick-starting deployment. It represents a win-win situation as it combines $CO_2$ capture from industries that need CCS with the use of $CO_2$ injection to increase oil production, thus financing a significant element of the project.

The reason earlier EOR projects in Denmark and Norway did not materialise was mainly due to; insufficient amounts of $CO_2$ (at least 2-5 M tonnes per year); the high costs of retrofitting existing infrastructure with CCS, and most importantly the loss of creating revenues in the standstill period for retrofit. Urgent action is therefore needed to implement EOR while oil and gas developmens are still taking place.

- **Natural gas sweetening: the most economically viable option**

The roadmap analysis shows that natural gas sweetening (i.e. removing $CO_2$ from natural gas before it is exported) is the most economically viable case for CCS, which could also kick-start deployment in the Nordic region. It not only shows the lowest cost of $CO_2$ capture, but our reported costs will be reduced even further using a more optimised $CO_2$ capture proces, as opposed to the MEA process used in our calculations.

Work is therefore on-going in the NORDICCS project to accurately estimate the costs of natural gas sweetening using more advanced solvents. Preliminary data show that a significant reduction in cost is reasonable due to higher pressures which result in reduced absorber size and higher input pressure to the $CO_2$ compressor, significantly reducing both electricity consumption and investment costs. The costs of transport and storage have not been calculated for the sweetening plant as the exact location has not been determined, but it is reasonable to assume that it will be close to a storage site, resulting in low transportation costs.

Another significant benefit is that removing up to 2.5% $CO_2$ from natural gas will result in a 2.5% increase in the sales volume of the gas based on heating value and will therefore be more valuable per tonne. Gas exports to Europe in 2012 were worth 242 billion NOK (€30 billion), which translates into an additional ~1.7 billion NOK (€210 million) per year if the $CO_2$ is removed and replaced with pure natural gas. However the potential has to be assessed more carefully.

As natural gas sweetening projects will capture potentially larger volumes of $CO_2$-storing up to 3 Mt/year may be feasible. They will also provide a continuous source of $CO_2$ which is necessary to kick-start an EOR project. This will create a market for $CO_2$ in the Nordic region that the land-based industry can sell to thereby reducing their costs for CCS.

Finally, an interesting aspect is that $CO_2$-EOR can be a reason to open up gas fields that were previously considered uneconomical due to the high $CO_2$ content.

- **Industrial CCS: $CO_2$ clusters and joint storage sites will significantly reduce costs**

The roadmap analysis also shows cases from the cement, steel and petrochemical industries to be among the most economically viable cases, ranking second, third, fifth and seventh in terms of cost efficiency. Many of these are in the Skagerak industry cluster, a collection of Swedish, Danish and Norwegian large $CO_2$ point sources.

These point sources are not only located in close proximity, but within a short distance of a potentially joint storage site in the Gassum formation on the Danish continental shelf, or via easy ship transportation to the well-known Utsira formation off the Norwegian coast. The potentially large scale of this $CO_2$ cluster could also make it a candidate for $CO_2$-EOR projects in nearby oil fields, thus reducing costs even further.

- **New large natural gas plants with CCS: exporting low-carbon electricity to Europe**

Finally, the roadmap analysis shows that a large-scale (2,000 MW) onshore power plant built for supplying offshore oil fields, or Norwegian 'green' production of aluminium, is also highly economical. The size of the power plant is scaleable, and could consist of one to five combined cycle gas turbines with $CO_2$ emissions totalling up to 5 Mt/year. This will also allow the use of the

$CO_2$ for an EOR project in a nearby oil field, reducing costs even further, while the platform itself is electrified with zero $CO_2$ emissions. The low estimated costs of this CCS project are due to the economies of scale.

Finally, such a project will help advance CCS technology for gas-fired power plants, facilitating the Nordic industry in its bid to become a leading provider of this critical low-carbon technology.

- **Creating the framework conditions needed for CCS deployment**

The current EU Emission Trading System (ETS) is not proving effective in incentivizing CCS: the cost of carbon emission allowances is too low. However, it should be maintained as a long-term mechanism for driving CCS. Biogenic $CO_2$ emissions should be included as a matter of urgency as there is currently no incentive to capture and store them via CCS.

It is therefore essential that additional policy instruments are implemented in order to drive CCS demonstration and deployment:

**Government support**
As with any large complex project, CCS incurs significant financial risk, involving not only the cost of establishing the project (CAPEX), but also the additional operational costs over the lifetime of the project (40+ years). The issue of long-term financial reliability must therefore be urgently addressed. Government funding for CAPEX has been key to the implementation of large-scale CCS projects in US and Canada, which is reasonable since a 'first-of-a-kind' unit will always be more expensive than an 'nth-of-a-kind' unit. In the Nordic region, it may be important for governments to help fund the development of the first large-scale storage sites in the North Sea. This could take the form of a central storage site where all the Nordic countries could have rights to store $CO_2$ and all the Nordic governments could share in developing associated storage and transport hubs.

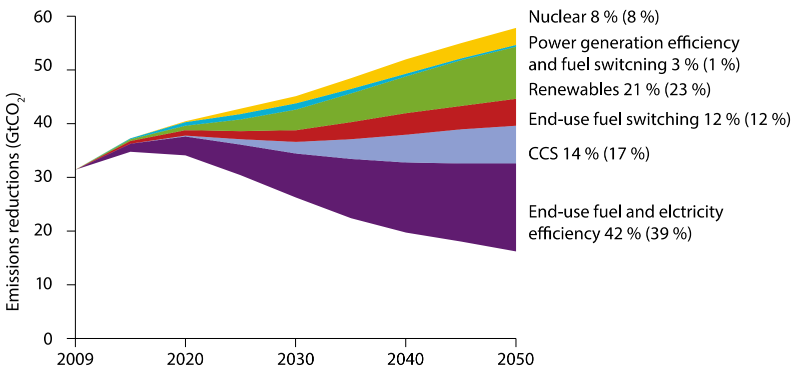
**CCS Certificates for fossil fuel suppliers**
Another potential policy change is a shift from 'emitter pays' to 'supplier pays'. A portfolio standard could be set up that demands that fossil fuel suppliers have a minimum share of low-carbon energy in their energy supply or produce certificates equivalents to this. For example, in order to sell one tonne of natural gas, a supplier would need to buy CCS Certificates  ofsetting the emission caused, which would be in the order of 2.3 tonnes of $CO_2$. The main advantage is that a specific binding target would be set for CCS deployment by policymakers, while the market sets the price for the certificates to fulfil the volume.

**Feed-in tariffs**
Feed-in tariffs (FiT) are long-term contracts based on the cost of generation for a particular technology. Some of the risks involved with FiT are over or under compensation, which is more difficult for CCS than for renewables as there will be fewer and larger projects and the implementation of capture technologies will depend on the right price level for the tariff. FiTs already exist for renewables in Finland – it is not unreasonable to establish a similar mechanism for CCS.

**Measurement Reporting Guideline (MRG) for shipping of $CO_2$**
One issue that must be resolved is that the transport of $CO_2$ by ship is currently not allowed under the ETS – only by pipeline. This is a problem, for instance in the Skagerak area, because Nordic CCS projects may require $CO_2$ to be shipped from sources in Sweden and Finland across national borders for offshore storage in Denmark and Norway. In order for shipping to be allowed under the ETS Directive, a MRG must therefore be established. the NORDICCS project has created a working group to develop a proposal.

# Nordic climate targets cannot be met without CCS

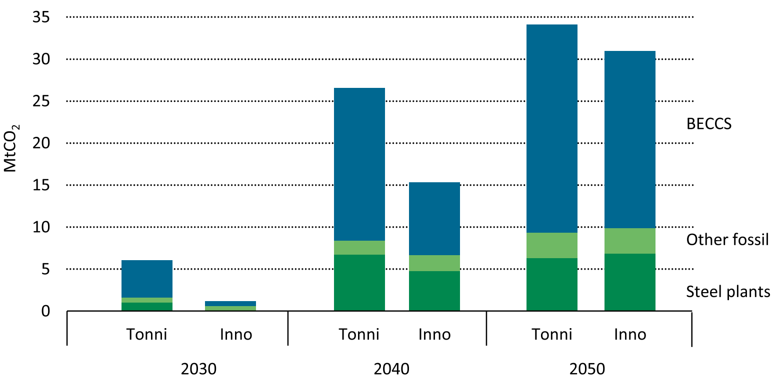
**20-30 Mt of $CO_2$ must be captured and stored annually by 2050**
It is generally accepted that the world's $CO_2$ emissions must be drastically reduced in order to limit the rise in average global temperature to 2 degrees Celsius – and avoid irreversible climate change.




Note: numbers in brackets are shares in 2050. For example, 14% is the share of CCS in cumulative emission reductions through 2050, and 17% is the share of CCS in emission reductions in 2050, compared with the 6DS.

**Emissions reduction goals for 2050 as analyzed by the IEA**

## Industrial CCS in the Nordic countries in the Tonni and Inno scenarios




Notes: Tg = teragrams = 1012 g = 106 tonnes. Includes CCS in Denmark, Finland, Norway and Sweden.

**Targets for $CO_2$ abatement via CCS by 2030, 2040 and 2050 for theTonni and Inno scenarios developed by VTT**

To this end, the United Nations, the IEA and the EU have set targets to reduce global emissions by 50-85% by 2050; and in the most recent analysis by the IEA, the most economical scenario is the application of CCS to 14% of the world's $CO_2$ emission sources (see the top figure from the July 2013 IEA CCS Roadmap).

Viewed as one region, the Nordic countries have aligned their ambitions with the Carbon-Neutral Scenario shown in the recent IEA report, "Nordic Energy Technology Perspectives (NETP)" in which GHG emissions must be reduced by 85% by 2050 (compared to 1990 levels), with carbon credits used to offset the remaining 15%.

A unique characteristic of the Nordic region is that its energy supply relies on an extensive amount of renewable hydro and nuclear power. Electricity generation is therefore characterized by relatively low $CO_2$ emissions of ~ approximately 100g $CO_2$ per kWh – considerably lower than the global average of 550 g/kWh and the EU average of 430 g/kWh.

Industry, on the other hand, is still very dependent on fossil fuels and in some sectors, such as steel and cement. CCS is the only means of achieving deep emission cuts. This means that a minimum of 20 Mt of $CO_2$/year must be captured and stored in the Nordic countries by 2050, according to IEA scenarios in NETP.

An analysis by VTT goes even further at 33 Mt $CO_2$/year by 2050, as can be seen from the bottom figure. VTT assumes two different scenarios: the Tonni scenario, where industrial production increases while still using current technology; and the Inno scenario, where rapid technology development is combined with greater urbanization. In both scenarios, CCS plays a vital role in emissions reductions, with a trend towards over 50% of the $CO_2$ captured derived from industrial sources and a significant amount from bio-energy.

# Unique opportunities for Nordic collaboration

## The potential to achieve significant economies of scale

There are significant advantages to be gained from a Nordic collaboration on CCS.

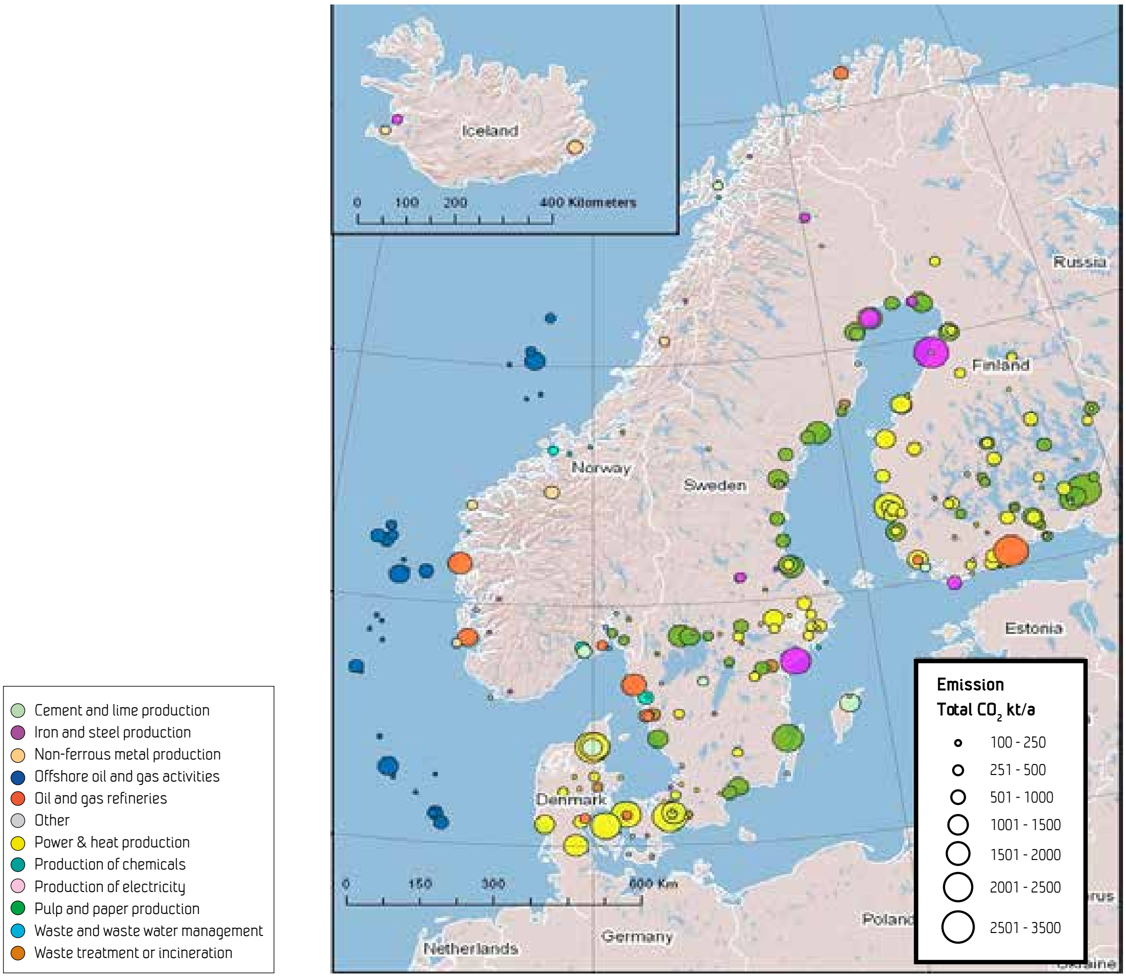
There are not only large $CO_2$ point sources in Sweden and Finland, but vast storage capacities off the coasts of Norway and Denmark which more than compensate for the lack of adequate storage capacity in Finland and Sweden. The development of joint hubs and storage sites will therefore result in economies of scale, significantly reducing the cost per tonne of $CO_2$ stored.

**Opportunity: Nordic synergies**

- Vast storage capacity off the coasts of Norway and Denmark
- Large emission sources in Sweden and Finland

⬇

- Joint CCS projects could allow scale up
- Reductions in cost due to economies of scale



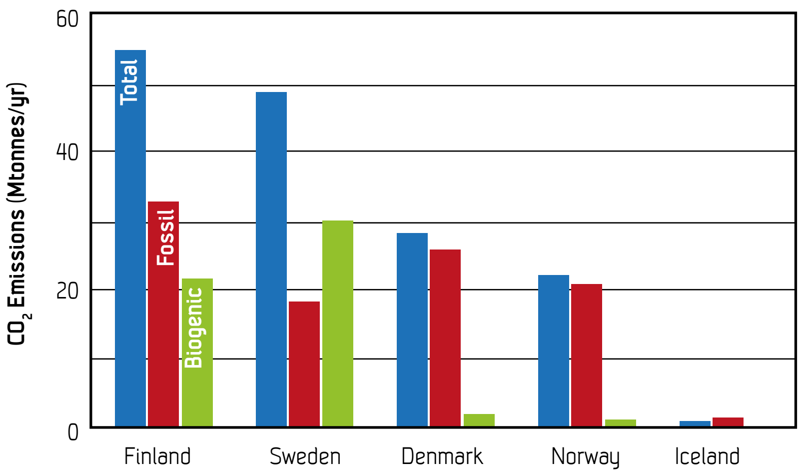

Industrial stationary point sources of $CO_2$ (>100 000 tonnes emitted/year)

## The importance of accelerating 'carbon negative' solutions

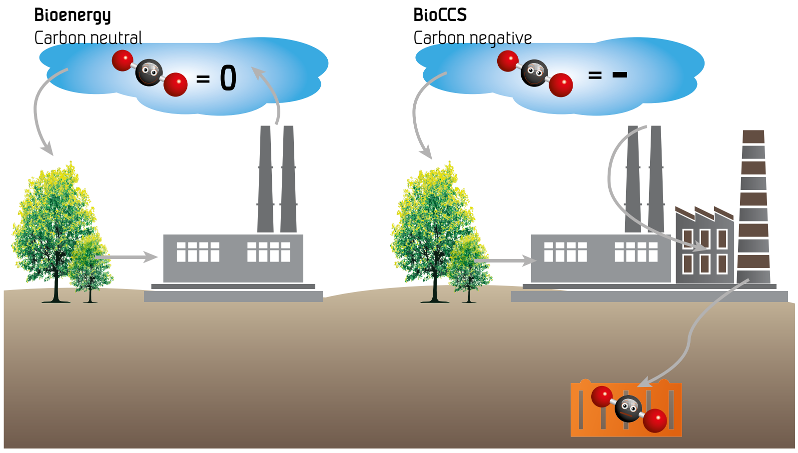
**Nordic synergies - biogenic emissions**

- Significant biomass energy sources in Sweden and Finland

- Potential for Bio-CCS projects that can go carbon negative!




**$CO_2$ emissions from stationary point sources with emissions › 100,000 tonnes (2009)**




The Nordic region is unique in that a high proportion of its $CO_2$ emissions are biogenic, as shown in the top figure. Sweden and Finland have a particularly high proportion of biofuels with around 60% and 40% of their $CO_2$ emissions of biogenic origin, respectively.

Biogenic emissions are carbon neutral as the biomass consumes $CO_2$ as it grows. Biomass conversion technologies, when combined with CCS, can therefore remove $CO_2$ from the atmosphere to achieve carbon negative solutions, as shown in the bottom graphic. Bio-CCS is now taking place on a commercial scale in the US, where the Archer Daniels Midland company leads a consortium that captures and stores $CO_2$ from a bioethanol plant in Decateur, Illinois using Alstom's amine technology for capture. During the first year of operation, 317,000 tonnes of $CO_2$ were stored in the Mount Simon Sandstone formation. A comprehensive monitoring program tracks the stored $CO_2$.

Bio-CCS can be a relatively effective and economic means of removing some of the $CO_2$ emissions that are already locked-in by existing industries with no other mitigation options available and there is potential for both bio-industry and bioenergy applications in the Nordic countries. By capturing and storing biogenic $CO_2$ offshore in Norway and Denmark, large-scale carbon negative projects are therefore feasible. Indeed, it may be a necessity in order to ensure 2050 goals are met.

# Combining CCS with EOR to kick-start deployment

## Creating economically viable CCS projects today

A key barrier to implementing CCS projects is the high cost. Yet it has been demonstrated to be profitable in commercial-scale applications for nearly 30 years in the US due to the use of $CO_2$ for EOR: in 2010, 56 Mt of $CO_2$ were injected into oil wells to increase oil production.


Generally, CCS projects large enough to store 1-5 Mt of $CO_2$/year require capital expenditure of €1-4 billion. The obvious solution to alleviate the cost is to investigate the possibility for EOR as a means of storage.

All five active CCS projects in the US are EOR projects: three are natural gas processing, one is a fertilizer plant and one is hydrogen production.  The largest single source of anthropogenic $CO_2$ used for EOR is the capture of 4 Mt of $CO_2$/year from the Shute Creek gas processing plant at the La Barge field in western Wyoming.

Another example of a successful EOR project is the Weyburn $CO_2$ flood in Canada operated by Cenovus Energy. The $CO_2$ originates from the Northern Great Plains gasification plant in Beulah, North Dakota and is transported via a 320 kilometer cross-border $CO_2$ pipeline to two EOR projects (Weyburn and Midale) in Saskatchewan, Canada. The $CO_2$ flood totals ~1 Mt of $CO_2$/yr and as of July 2010, 18 Mt have been injected. The implementation of the $CO_2$-EOR project, along with the continued infill well development program, has resulted in a 65% increase in oil production and extended the life of the Weyburn field by 25 years.

Six of the seven large-scale CCS projects currently being planned in the US and Canada are EOR projects, according to the European CCS Demonstration Project Network. This includes Boundary Dam, the world's first coal-based power plant with CCS, due to open in Canada in 2014.

While affordable pricing of $CO_2$ is important, the number one barrier to achieving higher levels of $CO_2$-EOR production, both in the US and worldwide, is lack of access to adequate and reliable supplies of $CO_2$.

## Urgent action is needed as the window of opportunity is limited

Natural Gas Pipeline
Photo: Shutterstock

Extensive offshore storage capacity off the coasts of Denmark and Norway, combined with an existing infrastructure of offshore oil and gas fields, provide the Nordic region with a unique opportunity to reduce the costs of CCS projects via $CO_2$-EOR.

There have already been attempts to start EOR projects on the Norwegian Continental Shelf. In 2009, Maersk Oil planned to use $CO_2$ from a Finnish power plant and ship it to the North Sea for injection into a depleted oil or gas field for the purposes of EOR/ EGR. However, this project was abandoned in 2011 as insufficient $CO_2$ was captured to fill the needs of the oil field, according to Maersk. Another example is Statoil's Gullfaks field, where a detailed EOR feasibility study was performed. However, this project was also deemed unfeasible due to the lack of a reliable supply of $CO_2$ (5 Mt/year).

Natural gas sweetening could 'sweeten the deal' for CCS by removing and storing more of the $CO_2$ present in Norway's natural gas which is exported to Europe: the processed export (or sales) gas contains up to 2.5% $CO_2$ (see page 14).

Several studies have come to the conclusion that without economic incentives, $CO_2$-EORmay not be economical in the North Sea. However, a recent study by Durham University concluded that using $CO_2$-EOR in existing North Sea oil fields could yield an additional three billion barrels of oil over the next 20 years, value of at € 175 billion – but only if the current infrastructure is enhanced now. Early results from a study using $CO_2$ foam for EOR by University of Bergen suggests that up to 95% of the oil may be recovered from offshore wells via $CO_2$-EOR.

It is therefore essential to take immediate action in order to make the best use of the remaining oil reserves in Norway, Denmark and the UK. If not, vital infrastructure for CCS will be lost as oil fields decline and are abandoned.

Sleipner A - Photo Harald Pettersen - Statoil

# Case studies

## Determining the most cost-efficient solutions for CCS deployment

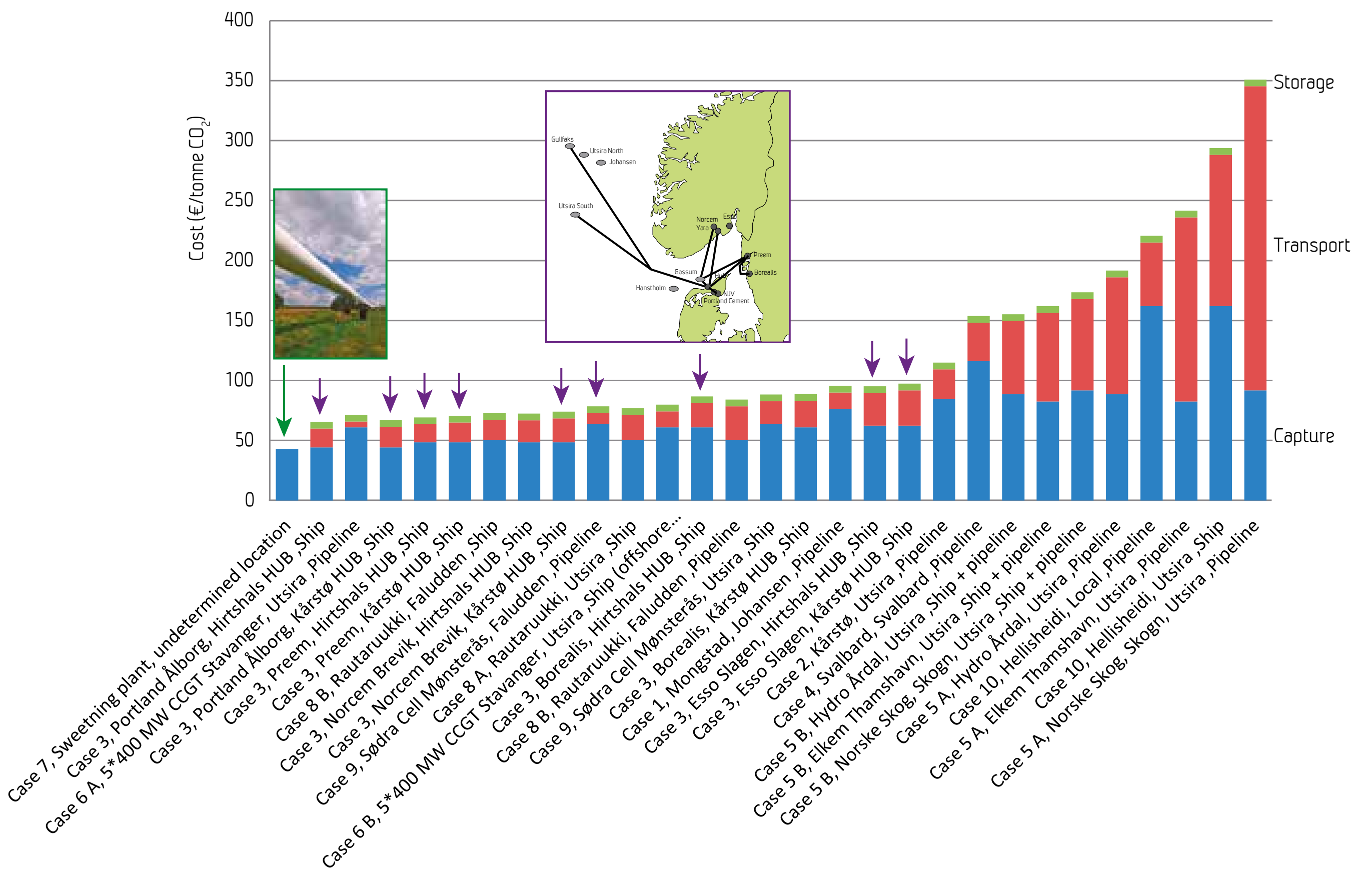
In order to determine the most cost-efficient solutions for CCS deployment in the Nordic region, economic analyses were performed for 10 cases which satisfied the following criteria:

- Projects are large-scale, where economies of scale reduce the cost per tonne of $CO_2$ stored
- Potential exists to benefit from EOR in order to reduce costs
- CCS is applied to industries where $CO_2$ is a by-product of the manufacturing process and no other mitigation option is available (e.g. steel and cement).

Capture, transport and storage costs were calculated using a 2012 cost level in euros. Escalation is Consumer Price Index (CPI) in Eurostat. Rate of return is set to 8% and project lifetime to 25 years. The detailed methodology used for the economic analyses of CCS case studies is given in Appendix 1.

Estimated costs for capturing and storing $CO_2$ for selected Nordic cases are shown in the figure below, divided into capture, transport and storage. The capture costs assume the use of the generic Tel-Tek MEA process. It is important to note that in the calculation of capital expenditure (CAPEX), it is assumed that the plant is nth-of-a-kind. The first plants will therefore be more expensive than the costs given here. However it is necessary to perform the comparison between these cases on a nth of a kind basis in order to determine what is most economical long-term.

**Cost estimates for Nordic CCS cases**



## Natural gas sweetening: the most economically viable option


Natural Gas Pipeline
Photo: Shutterstock

The roadmap analysis shows that natural gas sweetening (i.e. removing more $CO_2$ from natural gas before it is exported) is the most economically viable case for CCS. The capture costs are the lowest, as shown in the figure on page 13. These costs will be reduced even further using the less costly capture process, MDEA (as opposed to the MEA process used in our calculations). The costs of natural gas sweetening using MDEA is currently being analysed accurately in the NORDICCS project. Preliminary data show that a significant reduction in cost is reasonable due to higher pressures which result in reduced absorber size and higher input pressure to the $CO_2$ compressor, significantly reducing both electricity consumption and investment costs. The costs of transport and storage have not been calculated for the sweetening plant as it is a new project, but it is reasonable to assume that it will be close to a storage site, resulting in minimal transportation costs.

The results also show that capture costs reduce significantly with increasing volume and projects storing 2-3 Mt of $CO_2$/year are not unrealistic. For example, capture costs using the MEA process for an nth-of-a-kind plant are reduced from 45 to close to €40/tonne of $CO_2$ when the volume increases to 3 Mt/year. Capture and storage sites also have the potential to be in very close proximity, thus reducing transportation costs considerably. Due to this, the transportation and storage costs for the gas sweetening project are likely to be among the lowest of the cases, i. e. as low as Case 6 at less than10 € per tonne.

Another significant benefit is that removing up to 2.5% $CO_2$ from natural gas will result in a 2.5% increase in the sales volume of the gas based on heating value and will therefore be more valuable per tonne. Gas exports to Europe in 2012 were worth 242 billion NOK (€30 billion), which translates into an additional ~1.7 billion NOK (€210 million) per year if the $CO_2$ is removed and replaced with pure methane.

As natural gas sweetening projects will capture potentially larger volumes of $CO_2$ – storing up to 3 Mt/year may be feasible – they could even kick-start an EOR project. They will also provide a continuous source of $CO_2$ which is necessary to start an EOR project. This will create a market for $CO_2$ in the Nordic region that the land-based industry can sell to thereby reducing their costs for CCS.

It will be difficult to modify the existing infrastructure of pipelines to accommodate CCS due to the high cost of construction in explosive areas and the safety of supply. This case was therefore calculated based upon a yet to be determined source of $CO_2$ from any new oil and gas field – either at Utsira, or at the new frontiers in Northern Norway and the Arctic. Natural gas sweetening is a particularly interesting option in areas where the $CO_2$ concentration of the natural gas is high. Finally, an interesting aspect is that $CO_2$-EOR can be a reason to open up gas fields that were previously considered uneconomical due to the high $CO_2$ content.

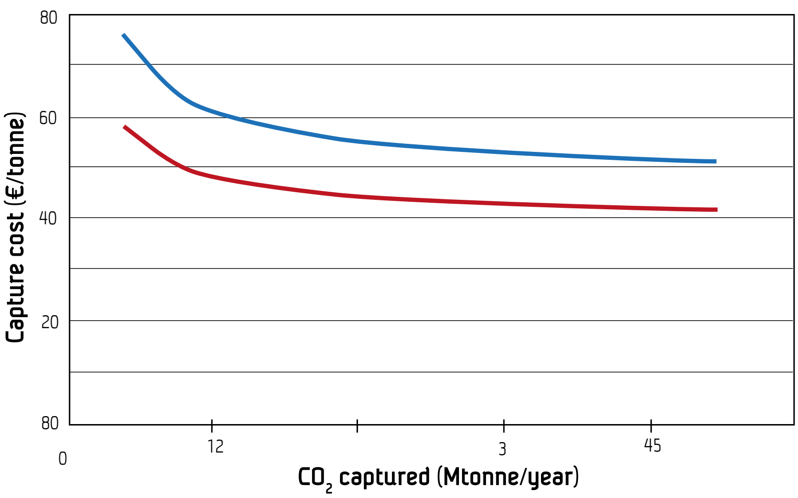
### Case 7: Sweetening the deal

Challenge: CCS expensive, EOR possible solution
- Prior EOR projects failed due to lack of steady supply of $CO_2$

Opportunity: remove and store more of $CO_2$ present in Norway's natural gas currently exported to Europe

Location: close to source & sink
- Onshore, close to the source
- New oil and gas fields at Utsira
- Arctic or Northern Norway with high $CO_2$

Steady $CO_2$ supply:
- Currently export 100 billion $Sm^3$/annually at 2.5%
- Economies of scale significant for volumes of $CO_2$ captured of up to 2-3 M tonnes/year



**Economies of scale for natural gas sweetening capture costs**

## Industrial CCS: $CO_2$ clusters and joint storage sites will reduce costs

The Skagerak industry cluster is a collection of large industrial sources of $CO_2$ (see map for the various industries included). These sources are not only located in close proximity, but within a short distance of a potentially joint storage site in the Gassum formation on the Danish continental shelf, or via easy ship transportation to the well-characterized Utsira formation off the Norwegian coast. The potentially large scale of this $CO_2$ cluster could also make it a candidate for $CO_2$-EOR projects in nearby oil fields, thus reducing costs even further.

The proposed hub is at Hirtshals in Denmark, or alternatively Kårstø in Norway. The final location will probably be chosen based on its proximity to the first capture site, with transport by ship to either Gassum or Utsira.

The Portland cement plant in Ålborg, Denmark and the Norcem cement plant in Brevik, Norway are among the lower-cost projects. The Norwegian Government (via Gassnova) has already awarded Norcem a project for a CCS test facility at their Brevik plant (see picture) where four capture technologies are currently being evaluated for use in cement plants.

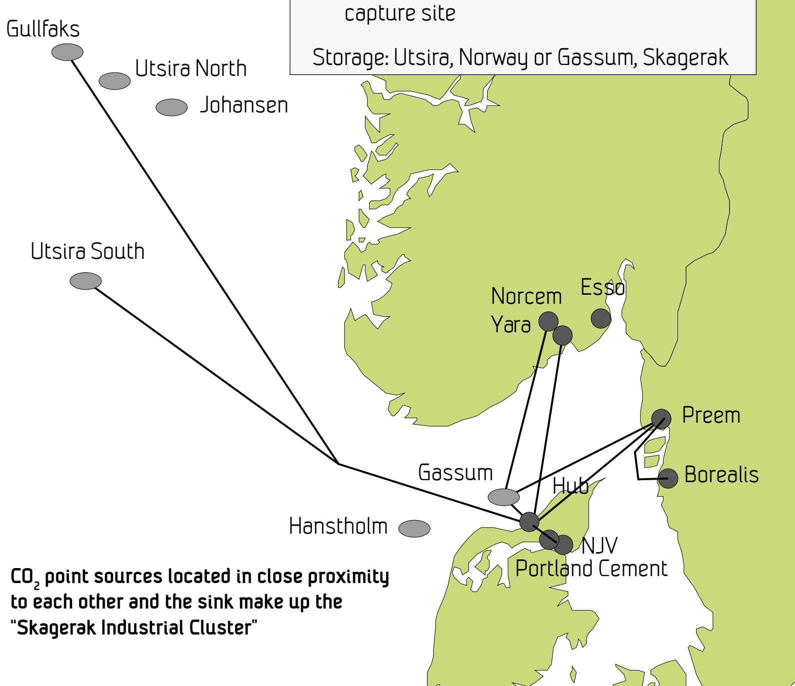
**Case 3: Skagerak industry cluster**

Capture sites:
- Esso refinery, Norway
- Norcem cement plant, Norway
- Preemraff refinery, Sweden
- Borealis chemical plant, Sweden
- Portland cement, Denmark
- Nordjyllands verket, Denmark

Transport: via ship

Hub:
- Kårstø, Norway
- Hirtshals, Denmark
- Location chosen closest to first capture site

Storage: Utsira, Norway or Gassum, Skagerak




**$CO_2$ point sources located in close proximity to each other and the sink make up the "Skagerak Industrial Cluster"**

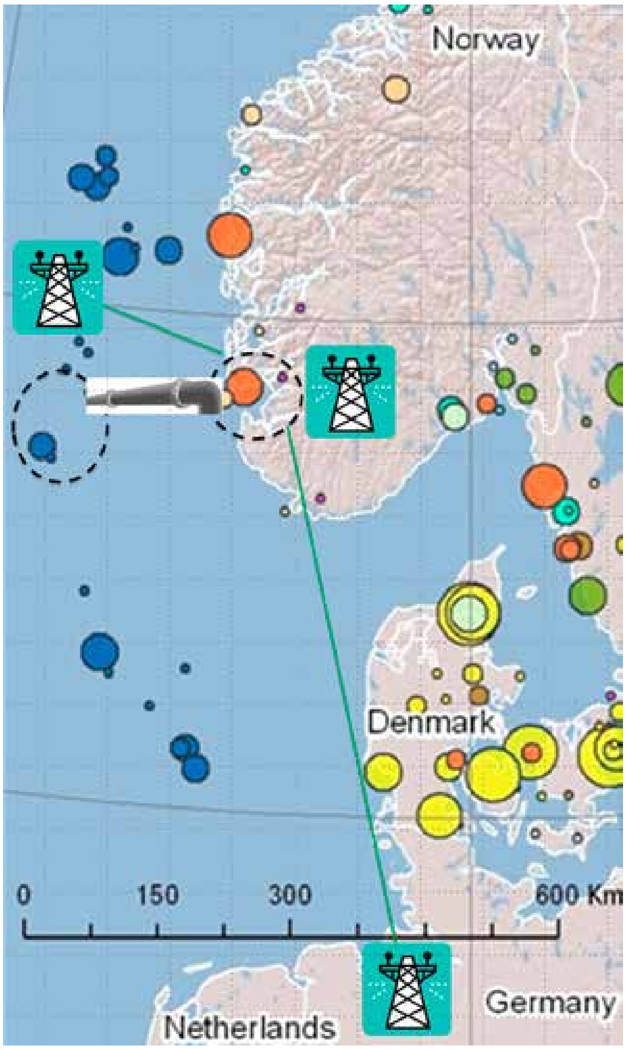
**World's first $CO_2$ capture test facility in cement industry Norcem Brevik - Norway**

## New large natural gas plants with CCS: exporting low-carbon electricity to Europe

**Case 6: Zero emission power production**

**Scope: Large-scale power plant using Combined Cycle Gas Turbines with CCS**

- Economies of scale: 2000 MW plant
- Five Combined Cycle Gas Turbines
- $CO_2$ emissions: 5 Mt/year for possible use in EOR
- Capture: MEA post-combustion 5 $MtCO_2$/y, 5.6 $MtCO_2$/y, 3.9/7.8 %$CO_2$
- Location: Stavanger
- Transport and storage: Utsira via pipeline
- Power end use:
  - Electrification
  - Export to Europe
  - Metals industry, e.g. aluminium
- $CO_2$ end use: EOR




The roadmap analysis shows that a large-scale (2,000 MW) onshore power plant built for supplying offshore oil fields, or Norwegian 'green' production of aluminium, is also highly economical. The size of the power plant is scaleable, but could consist of five combined cycle gas turbines with $CO_2$ emissions totalling 5 Mt/year. This will also allow the use of the $CO_2$ for an EOR project in a nearby oil field, reducing costs even further, while the platform itself is electrified with zero $CO_2$ emissions. The low estimated costs of this CCS project are due to the economies of scale.

Such a project will help advance CCS technology for gas-fired power plants, facilitating the Nordic industry in its bid to become a leading provider of this critical low-carbon technology.

# Transporting $CO_2$ across the Nordic region

## The importance of ship transport for the Nordic countries

A unique aspect of Nordic CCS is the focus on clusters of $CO_2$ point sources. This is due to the region's relatively small point sources of $CO_2$ and the need to ship it across national borders in order to utilize joint storage sites. In 2010, there were 284 sources emitting >100 Kt of $CO_2$ in the Nordic countries, with numerous potential combinations of clusters evolving over time. The $CO_2$ will be transported via ship or pipeline.

An important part of the ongoing work in the NORDICCS project is the comparison of the costs of ship and pipeline transport for different applications. Costs are calculated as a function of volume and distance.

Although transport of $CO_2$ by ship or pipeline is usually calculated on a case-by-case basis, the results showed that the distance required to make ship transport more cost-efficient than corresponding pipeline transport increases with increasing volume. More generally, it can be stated that ship transport is most cost-efficient for relatively small volumes of $CO_2$ over longer distances and is therefore often the optimal solution during the build-up of a cluster.

Indeed, it is often difficult to know in advance the sizing of a pipeline that may potentially connect to multiple sources over time – and costs rise quickly for under-utilized pipelines. The results showed that for 45 of the 55 largest sources located along the coast in the Nordic region, ship transport will be the most cost-efficient individual mode of transport.

For example, the results in the figure on page 13 show that for the 10 most economical cases calculated in our cost analysis, ship transport was the most favorable in 8 of the cases, with pipeline most favorable in the remaining two cases.

# The NORDICCS CCS roadmap

Our analysis of potential CCS projects in the Nordic region suggests that by starting 8 new projects by 2050, at an estimated cost of € 3.8 billion according to our calculations a total of 20 Mt of $CO_2$/year can be stored by 2050. Indeed, the Nordic countries would be well on the road to carbon neutrality if this route was followed. The scenarios that would need to be implemented by 2050 are shown in the figure:

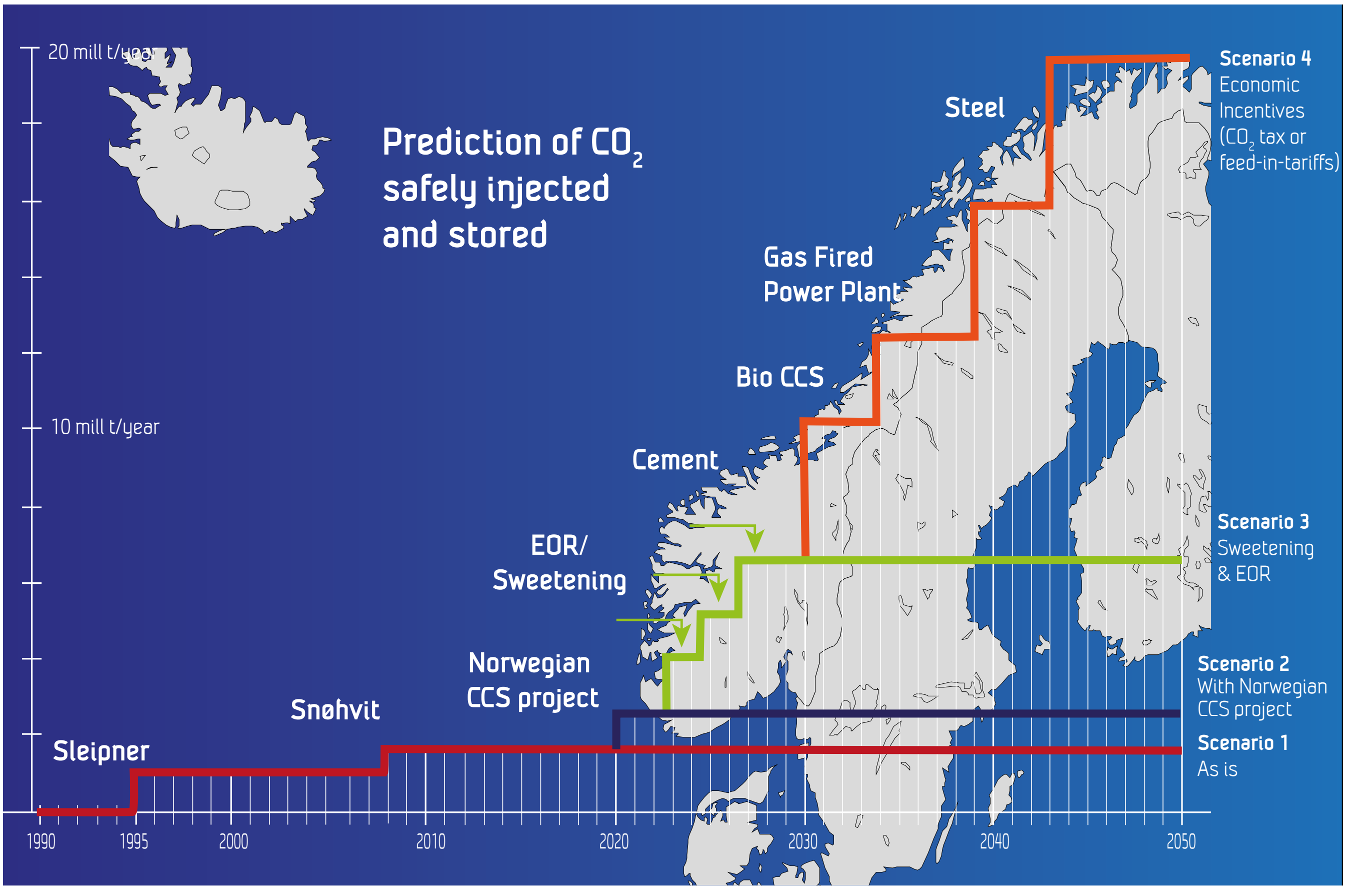
**Scenario 1** illustrates where we stand today, with Statoil currently capturing and storing 1.7 Mt of $CO_2$/year at the Sleipner and Snøhvit oil and gas fields in the North Sea and Barents Sea, respectively. The Sleipner field will come to the end of its life towards 2030. However, other nearby fields are coming online and $CO_2$ will be available from the Gudrun field as early as 2017.

**Scenario 2** illustrates the Norwegian Government's commitment to implement a CCS project by 2020, abating ~1 Mt of $CO_2$/year. Our economic analysis of the project suggests that natural gas sweetening should come online next, as it has the potential to be relatively low cost and therefore have a lower threshold of implementation than industrial or power CCS projects (as illustrated in Scenario 3).

**Scenario 3** indicates that the next, natural step is to implement new gas sweetening projects that could reasonably come online towards 2020. A very conservative estimate of two to three projects are assumed by 2050, capturing a total of ~4 Mt of $CO_2$/year. Their potential to provide a steady long-term supply of large volumes of $CO_2$ makes them good candidates for $CO_2$-EOR, helping to reduce costs even further. EOR projects therefore create a market for $CO_2$ where it can be delivered to an offshore storage site from land-based industry – lowering the threshold for starting industrial CCS projects in the Nordic region.

**Scenario 4** shows the most economical industrial CCS projects, with two cement cases emitting 2.7 Mt $CO_2$/year and 0.9 Mt $CO_2$/year ranking second and sixth, respectively; and one steel plant emitting 4 Mt $CO_2$/year ranking fifth. New Nordic CCS projects should therefore focus on these industries as they have no other means of abating $CO_2$. A pulp and paper plant emitting ~2 Mt $CO_2$/year is also among the 10 most economical cases. Combining a pulp or paper plant in Sweden or Finland, or a bioenergy project with CCS is a viable part of the Nordic solution to meet climate goals and can even deliver carbon negative solutions.

CCS combined with a gas- or coal-fired power plant is also potentially viable. Indeed, an exciting opportunity exists in Norway to create a project that can use Norwegian natural gas to fuel a large-scale power plant with CCS, where sufficient $CO_2$ is captured to start an EOR project. The power from the plant can then be supplied to nearby oil fields, or for 'green' aluminium production, or exported to Europe if a market exists. However, in order to implement Scenario 4, changes are urgently needed to the framework conditions for CCS.




NORDICCS CCS Roadmap for the implementation of CCS towards 2050

# Framework conditions needed for Nordic CCS

## Additional policy measures are essential to drive CCS demonstration and deployment

### The EU ETS

The current European carbon market is not proving effective: the cost of carbon emission allowances is too low to incentivize CCS. However, it should be maintained as a long-term mechanism for driving CCS and options to improve the system considered. A restructuring is needed to elevate the ETS price to a level which will incentivise environmental friendly investments like CCS. One potential solution is to place a $CO_2$ tax on products imported from countries outside the EU ETS. This would turn the ETS into a global system, making it possible for European industry to compete, while providing environmentally friendly products. However, this could have unwanted side effects in the global competitive market and disturb normal market mechanisms.

Biogenic $CO_2$ emissions are also currently not included under the ETS, which means that there is no incentive to capture and store it via CCS (Bio-CCS). The ETS should therefore be revised to include biogenic sources of $CO_2$ so that, for example, pulp production can be a target for CCS applications in Finland.

Finally, it is essential that additional policy instruments are implemented in order to drive CCS demonstration and deployment.

### Government support

As with any large complex project, CCS incurs significant financial risk due to requirements for new infrastructure, e.g. pipelines, export terminals for $CO_2$, new storage sites etc. As a transitional measure – it will be a need for governments to co-invest in establishing the first CCS plants through capital grants. However, the risk involves not only CAPEX (i.e. the cost of establishing the project), but also the additional operational costs over the lifetime of the project (40+ years). The issue of long-term financial reliability must therefore be addressed as a matter of urgency in order to enable CCS deployment. Government funding for CAPEX has been key to the implementation of large-scale CCS projects in US and Canada, which is reasonable since a 'first-of-a-kind' unit will always be more expensive than an 'nth-of-a-kind' unit. However, for CCS to succeed, there must be a clear long-term business case.

In the Nordic region, it may be important for governments to help fund the development of the first large-scale storage sites in the North Sea at a location such as Utsira in Norway, or the Gassum formation in Skagerak. This could take the form of a central storage site where all the Nordic countries could have rights to store $CO_2$ and all the Nordic governments could share in developing associated storage and transport hubs.

### CCS Certificates for fossil fuel suppliers

Another potential policy change is a shift from 'emitter pays' to 'supplier pays. A portfolio standard could be set up that demands that fossil fuel suppliers have a minimum share of low-carbon energy in their energy supply or produce certificates equivalent to this. For example, in order to sell one tonne of natural gas, a supplier would need to buy CCS Certificates (CCSCs) offsetting the emissions caused which would be on the order of 2.3 tonnes of $CO_2$. In other words, the supplier of the fuel takes responsibility for disposing the $CO_2$ after use.

Suppliers of fossil fuels are therefore obliged to include CCS as a share of their production. This can be achieved by trading CCSCs from other projects, or performing CCS themselves. Industry/power production with CCS receives a certificate per "clean" unit produced. The main advantage is that a specific binding target would be set for CCS deployment by policymakers, while the market sets the price for the certificates to fulfil the volume. A certificate scheme would ensure cost sharing, distributing the extra cost of CCS to all fossil value chains, not only specific emitters. It therefore has a potentially minimal impact on carbon leakage issues. It is also more likely to be politically accepted since the certificate obligation is with the supplier who will therefore include the carbon abatement cost in the product price for fossil fuels. And CCSCs can work together with the ETS system.

### EOR in oil and gas production

In order to establish a market for $CO_2$, one option for the Nordic region may be to ensure future oil and gas projects are set up to include $CO_2$-EOR as part of their production facilities on- and offshore..

#### $CO_2$ tax

There is some support for a $CO_2$ tax from industry stakeholders. However, the cost of emissions will have to be high before CCS is deployed and it may be difficult to gain political acceptance. However, a low tax may help to meet operational costs if additional CAPEX support is also available. A more positive approach may be a reward system for CCS operators in the form of reduced taxes, or to make a larger share of the taxes connected to emissions. This could incentivise the development of projects, thus reducing the tax burden and providing a better solution for the climate – also known as 'green taxes'.

#### Feed-in tariffs

Feed-in tariffs (FiT) are long-term contracts based on the cost of generation for a particular technology. They often involve a tariff decrease where it ramps down over time in order to stimulate innovation and technology improvements. Some of the risks involved with FiT are over or under compensation, which is more difficult for CCS than for renewables as there will be fewer and larger projects and the implementation of capture technologies will depend on the right price level for the tariff. A similar incentive, 'Contracts for Difference' is currently before Parliament in the UK. This provides incentives for investments in low-carbon electricity projects, and will likely become law in 2013. In 2013, the UK government also established a carbon price floor in order to secure a minimum price for emissions for companies included in the ETS.

FiT already exist for renewables in Finland – it is not unreasonable to establish a similar mechanism for CCS.

#### Emission performance standard

An emission performance standard (EPS) will only be effective as a long-term mechanism once the carbon price has risen sufficiently to support CCS and the technology is mature. However, it is a powerful tool if the level is correctly designed. This has led to introduction of CCS in Canada.

#### Legislation

Environmental legislation can be a highly effective tool in promoting environmental change. For example, two very successful environmental laws have been implemented in Norway:

1. In 1971 and further strengthened in 1985,the petroleum law has strictly regulated flaring in oil and gas production
2. In 1991, a $CO_2$ tax was introduced (currently 410 NOK/tonne of $CO_2$)

Together, these laws resulted in the Norwegian oil industry becoming the most energy efficient in the world by 2006, measured in $CO_2$ released per barrel of oil produced. Two commercial CCS projects also became economical due to the tax, both involving natural gas sweetening, i.e. removing $CO_2$ from the natural gas for storage at Sleipner in 1996 and the Snøhvit LNG plant in 2008.

This is an example of how laws can be used if the market does not make CCS happen. On the other hand, it is difficult to make CCS mandatory at this stage as the technology is not yet fully mature and demonstration projects are still needed to scale up the technology and reduce costs.

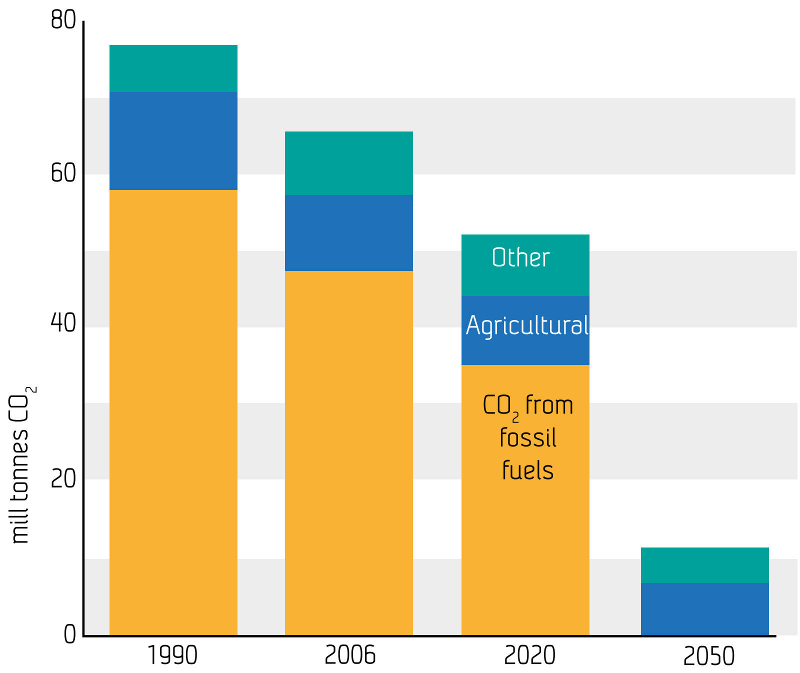
#### MRG for shipping of $CO_2$ – a necessity for Nordic CCS to happen

One issue that must be resolved in order for CCS to happen in the Nordic region is that the transport of $CO_2$ by ship is currently not allowed under the ETS – only by pipeline. This is a problem for instance in the Skagerrak area because Nordic CCS applications may require $CO_2$ to be shipped from sources in Sweden and Finland across national borders for offshore storage in Denmark and Norway. In order for shipping to be allowed under the ETS Directive, a Monitoring and Reporting Guideline (MRG) must therefore be established and the NORDICCS project has created a working group to start work on a MRG for shipping of $CO_2$.

In conclusion, the most effective tools for driving CCS demonstration and deployment in the Nordic countries are:

- Initial government support for building som pioneer plants- preferably in a competitive bid process
- Provide a mechanism for supporting operation of these plants (OPEX) making a safe environment for investments to happen
- CCS Certificates for fossil fuel suppliers, or 'green' offshore tax incentives could be such a mechanism
- The inclusion of biogenic $CO_2$ sources under the ETS
- Support measures to restructure the ETS system to get a robust floor price for emission quotas.
- A MRG to allow shipping of $CO_2$ under the ETS

# Appendix 1 - Status of CCS in the Nordic countries




## Denmark

Denmark is progressive in its plans to reduce $CO_2$ emissions: 80% of its energy currently comes from fossil fuels and it aims to achieve 100% renewable energy by 2050 (see figure).

In April 2009, the Danish Parliament's Energy Policy Committee published a report stating that the Government will strive to introduce $CO_2$ injection and storage in North Sea oil fields with a view to enhancing oil production, provided this can be done in a safe and environmentally sound manner.

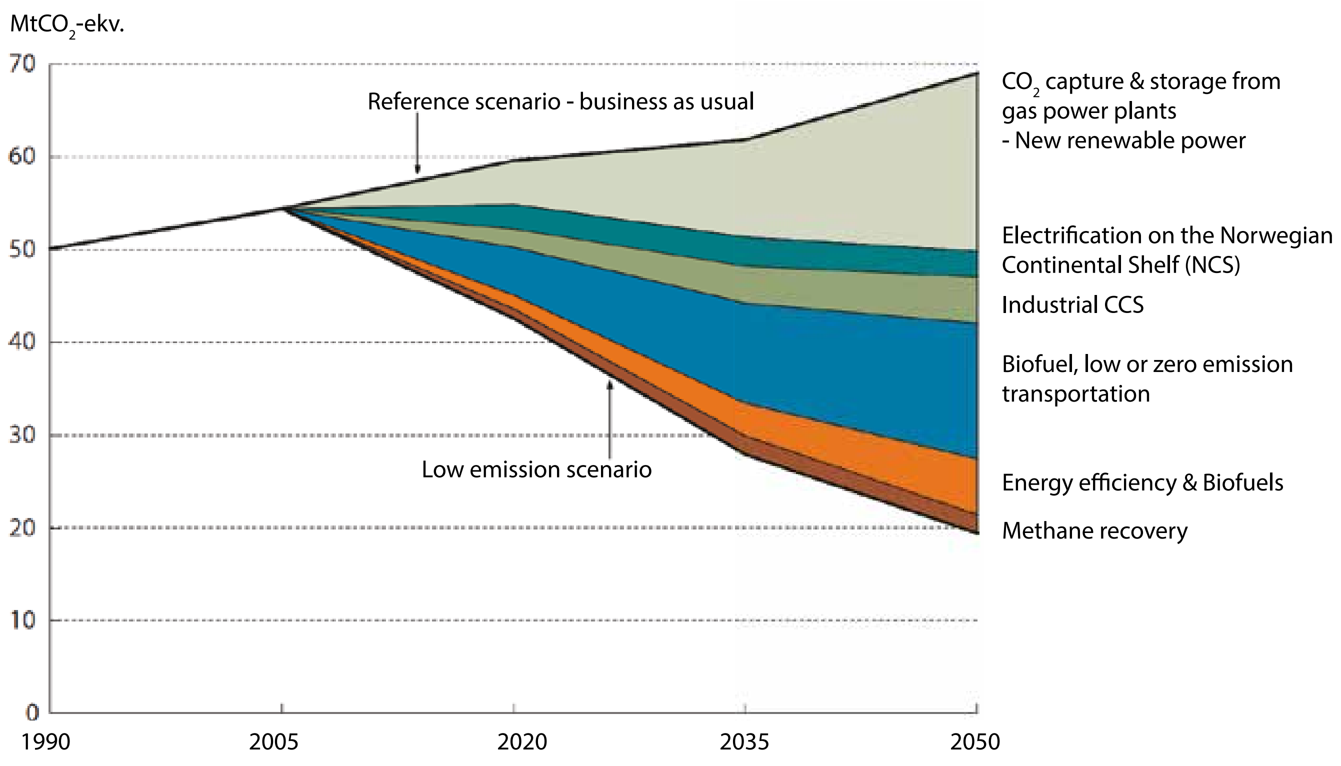
## Norway

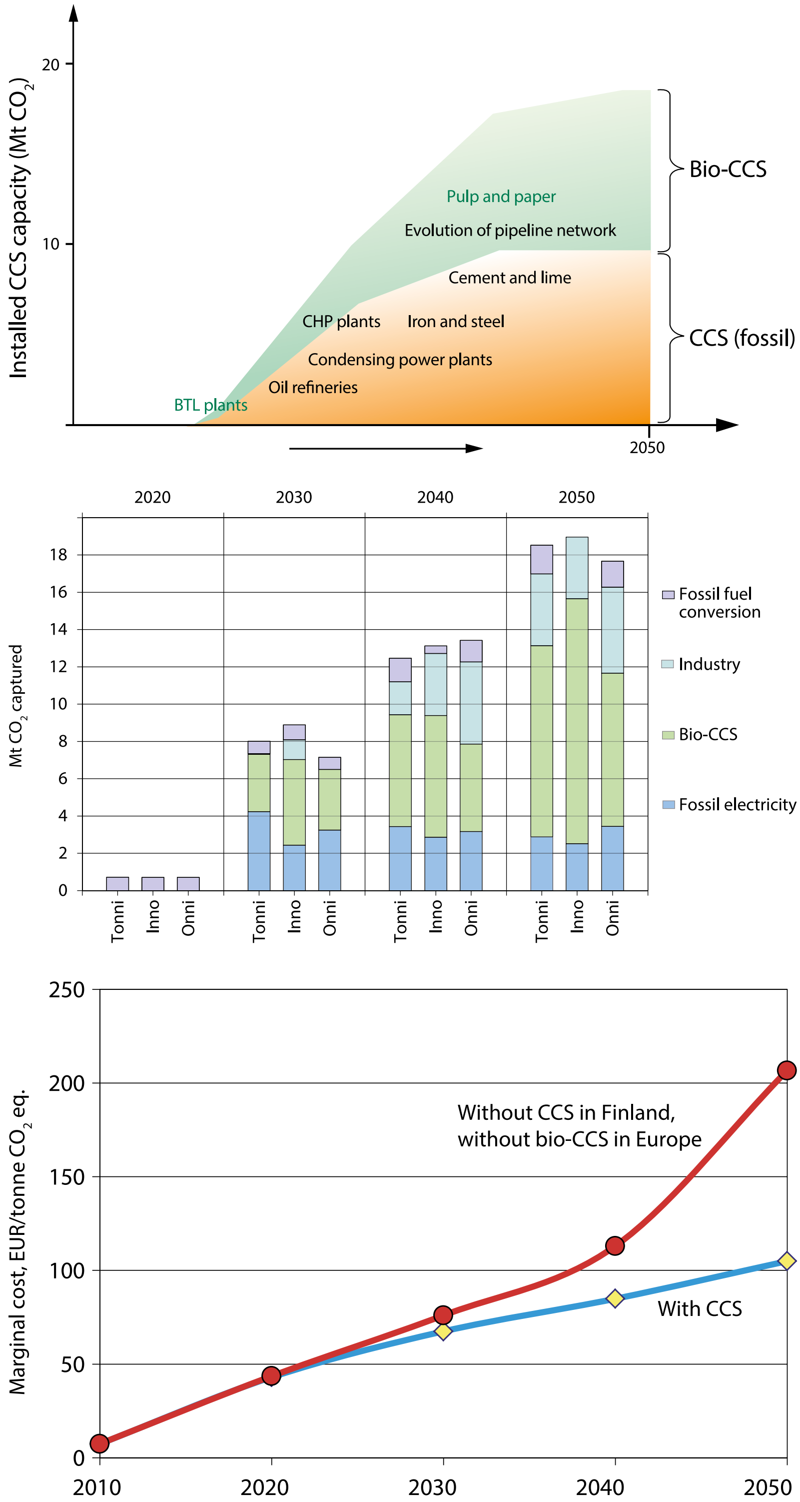
A unique characteristic of Norway is that its power supply comes almost totally from hydropower (97%). Its $CO_2$ emissions originate from oil and gas production (29%), industry (25%) and transportation (30%).

Norway has set a goal to become carbon neutral by 2050, as stated in the 2011-2012 Bill 21 issued by the Norwegian Department of the Environment. This means $CO_2$ emissions must be reduced by 12-14 Mt by 2020 relative to the reference base (business-as-usual).

The Norwegian government has shown strong support for CCS by funding significant R&D activities. Statoil has also implemented two of the world's first industrial-scale $CO_2$ storage projects, Sleipner and Snøhvit, capturing and storing ~1.7 Mt of $CO_2$ every year. They are an excellent example of how safe $CO_2$ storage is: at Sleipner, for example, the $CO_2$ is contained under an 800 m thick layer of gas-tight cap rock and cannot seep into the atmosphere – it will probably remain stored in the geological layer for thousands of years.

The extra costs associated with the compression and injection of $CO_2$ at Sleipner amounted to ~US$100 million due to the high costs of implementing technologies offshore. However, the incentives for $CO_2$ storage were clear: the natural gas not only contains 8% $CO_2$ which has to be cleaned, but Norway introduced a $CO_2$ tax in 1991 which further incentivized offshore storage.






**Potential for application of CCS in Finland**

## Finland

Most of Finland's power production comes from fossil, bio and nuclear, with extensive industrial-scale use of biomass.

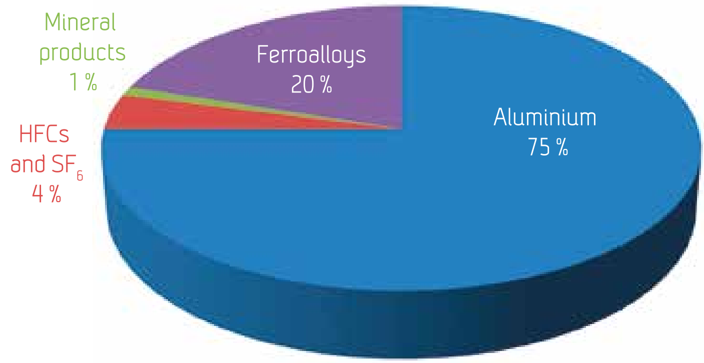
The Finnish government adopted its foresight report on long-term climate and energy policy in 2009, with a target to reduce GHG emissions by at least 80% by 2050 (over 1990 levels). VTT has also undertaken a strategic project, "Low Carbon Finland 2050" to assess the role of new technologies in moving Finland to a new low-carbon economy. The analysis defines two low-carbon storylines, "Tonni" and "Inno", which differ in the levels of radical technological breakthroughs and degree of urbanization etc. by 2050. In both scenarios, CCS contributes significantly to $CO_2$ reductions (~15%).

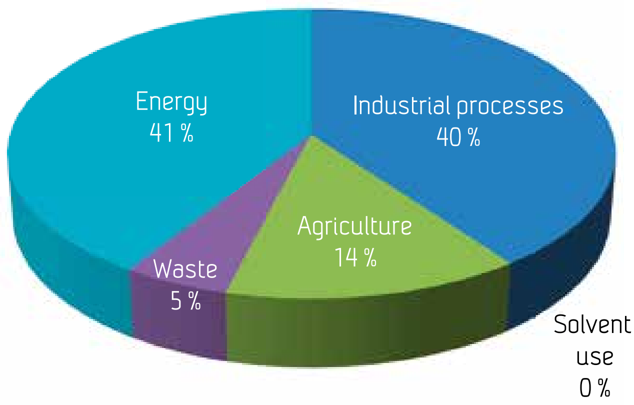
The main challenge for Finland is that no large-scale storage sites are in close proximity. Bio-CCS is a highly promising option due to its significant pulp and paper industry, and biomass-based power generation. However, a prerequisite is that negative emissions via the capture and storage of biogenic $CO_2$ are rewarded under the EU Emissions Trading Scheme (ETS), which is currently not the case.

The current Finnish Law on capture and storage of $CO_2$ (29.6.2012/416) says that $CO_2$ can only be transported to another EU Member State for geological storage. However, Norway is now part of the EU-ETS, and has implemented the CCS Directive. The Finnish CCS law would not conform to the EU's CCS Directive if it would forbid $CO_2$ transportation to Norway for purposes of geological storage.

## Iceland

Iceland's primary energy supply is 85% renewable energy from hydro and geothermal sources. Hot water and heat is mainly from geothermal heating with an extensive district heating system. Close to 100 % of its electricity is generated from renewables, 75% of which is hydropower the rest geothermal. In 2010 the total annual $CO_2$ emission was 4.5 Mt, 41% originating mainly from fossil sources for transportation and fisheries, and 40% from industrial processes. The metal industry, aluminium and ferroalloys, were the source of 85% of the emission from industrial processes in the year 2010. Iceland´s goal is a 50-70% reduction in GHG by 2050 compared to 1990.



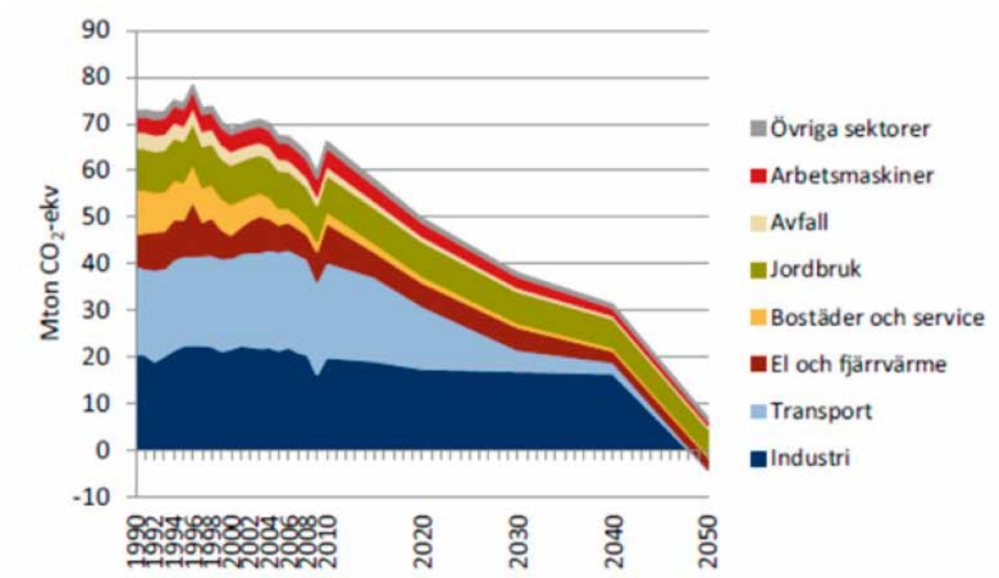

**Key objectives**

- Carbon tax on fossil fuels
- Use of small rather than large cars in the public sector
- Higher taxes on large cars than small cars
- Increased investment in public transportation and bike trails
- Increased production and use of bio-fuel
- All fishmeal factories switch to renewable energy
- Carbon storage by afforestation and re-vegetation of wasteland
- Restoration of wetlands
- Research and innovation (mineral storage of carbon, geothermal energy development etc.).

## Sweden

Sweden's power supply comes mainly from hydropower (53%) and nuclear power (40%), resulting in low $CO_2$ emissions. There is also widespread use of combined heat and power plants – predominantly using biofuels – where the heat from the power plant is captured for district heating. Sweden is therefore on a trajectory to meet its short-term climate goals.

$CO_2$ emissions originate mainly from industries such as pulp and paper, cement, steel, refining, as well as transport. There is a focus on reducing fossil fuels in transport and increasing wind power, in parallel with an overall focus on energy efficiency. In its official roadmap, "Färdplan 2050", Sweden proposes to reduce $CO_2$ emissions by ~85% by 2050. In one of the two scenarios in the report, CCS is assumed to account for a major share of $CO_2$ reductions in the industrial sector, but is not applied until ~2040.



# Appendix 2: The role of CCS in reducing Nordic $CO_2$ emissions

Viewed as one region, the Nordic countries have aligned their ambitions with the Carbon-Neutral Scenario (CNS) shown in the recent IEA report, “Nordic Energy Technology Perspectives (NETP)” in which GHG emissions must be reduced by 85% by 2050 (compared to 1990 levels), with carbon credits used to offset the remaining 15%.

Because of the unique reliance on renewables in the power sector (see Table 1), Nordic electricity generation is characterized by relatively low $CO_2$ emissions of ~100 g $CO_2$ per kWh –considerably lower than the global average of ~550 g/kWh and the EU average of 430 g/kWh.

In the NETP 4 degree scenario, emissions from electricity generation decrease significantly to 10% by 2050 (over 2010 levels) due to an increased share of renewables in the energy mix from 60% in 2010 to ~80% in 2050. The IEA’s 2°C Scenario (2 DS) goes even further, achieving almost carbon negative due to a switch to wind power, biomass, nuclear fossil-fuel switching and CCS. In the 2DS and CNS, 20-30% of the reduction in industrial $CO_2$ is achieved by using CCS in the iron and steel, pulp and paper, chemicals and cement sectors by 2050: in the 2DS, 7 Mt of $CO_2$/year is captured by Nordic industry by 2050; in the CNS, 6 Mt of $CO_2$/year (Table 2). In both scenarios, CCS becomes the most important technology after 2030 for reducing $CO_2$ emissions from industry.

The VTT scenarios, Tonni and Inno, applied to the Nordic energy mix represent a more optimistic view of CCS compared to the NETP scenarios, largely due to bio-energy with CCS (Bio-CCS ), which is mainly applied to biodiesel plants. CCS is integrated into steel plants and other fossil based industrial emission is in line with the NETP scenarios. (Targets for $CO_2$ abatement by CCS for the different scenarios are summarized in Table 2). In the NETP CNS, ~8 Mt $CO_2$ are captured annually in the power sector from biomass-fired power plants in Finland and Sweden via CCS. Taking into account CCS in fuel transformation and industry, a total of ~20 Mt of $CO_2$ are captured annually in the Nordic region by 2050 (Table 2), of which 12 Mt come from industry and transportation (Table 1). The report suggests that for the CNS, CCS must account for more than 25% of emissions reductions from industry.

| | GHG Emissions Targets (% reduction in $CO_2$ equivalents) Reference 1990 | Renewable target (%) | CCS Target Removal (M tonnes CO2 Eq.) | | Carbon Taxes/laws |
|---|---|---|---|---|---|
| | **2050** | **2020** | **2050 Industry** | **2050 Power** | |
| **Denmark** | 100% renevable energy | 30 | - | - | 100% renewable energy by 2050 50% of el. wind power by 2020<br>Phase out coal power plants by 2030[10] |
| **Finland** | - 80% | 38% | 13 M tonnes | 3M tonnes | Regulations on the use of hydro power<br>Decisions on licenses for new nuclear plants |
| **Iceland** | - 50 -70% | 64% | | | |
| **Norway** | -100% | 67.5 | 3M Tonnes | 19 M Tonnes | 2/3 of emission reductions in 2030 will be domestic, rest through flexible mechanisms |
| **Sweden** | -100% | 49% | | | law to protect some rivers from hydro power<br>limitation on new nuclear |
| **EU Roadmap** | -80% | | | | |
| **Nordic Goals from IEA Nordic Energy TechnologyPerspectives** | -100 | | 12 M Tonnes | 8 M Tonnes | |

**Table 1: GHG emission targets and CCS removal targets for the Nordic countries**

| Country | CCS Target (Mt) | | | Source |
|---|---|---|---|---|
| | Industry | Power | Total | |
| Nordic ETP | 12 | 8 | 20 | International Energy Agency (2013), Nordic Energy Technology Perspectives, OECD/IEA |
| Nordic ETP 2 DS | 7 | 8 | 15 | International Energy Agency (2013), Nordic Energy Technology Perspectives, OECD/IEA |
| Nordic EPT CNS | 6 | 8 | 14 | International Energy Agency (2013), Nordic Energy Technology Perspectives, OECD/IEA |
| Toni | 9 | 25 | 34 | VTT Green Energy, 2013; BECCS in pulp &paper |
| Inno | 10 | 21 | 31 | VTT Green Energy, 2013; BECCS in pulp & paper |
| Norway | 3 | 19 | 22 | Lavutslippsutvalget, 2006 |
| Finland | 14 | 4 | 18 | VTT Green Energy, 2013; Includes BECCS in pulp and paper ind. |

**Table 2: Targets for the application of CCS to meet 2050 climate goals for the Nordic countries**

# Appendix 3: Methodology for CCS case studies

The overall basis for the calculations is a cost level set at 2012 in euros; escalation is CPI in Eurostat; rate of return is 8%; and lifetime of the project is 25 years.

Capture plant: in the calculation of capital expenditure (CAPEX), it is assumed that the plant is nth-of-a-kind (the first plants will be more expensive). A generic cost level is assumed, i.e. Rotterdam. The cost estimation also assumes a brownfield site, i.e. an existing industrial area and an extension of the existing plant, using existing office and welfare buildings with no additional operating organization. Existing infrastructure, power, steam, cooling water, process water, demineralised water etc. is used, with no purchase cost for land, no piling and no additional costs for offices, canteens and other secondary buildings.

There is no additional pre-treatment of the flue gas. $CO_2$ is delivered at 70 bar, 20°C, with capture technology based on Tel-Tek's amine-based process (see Table 1 for parameters). Flue gases and all utilities are brought to the capture plant. Owner's costs are not included. Detailed factor estimates are as per the $CO_2$ Capture Project (CCP1-2006 & CCP2-2009) and include first fill of chemicals. Cooling water temperature is 8°C + 15°C. The capture plant is at the peak value of $CO_2$/hour (not average). All operational costs (OPEX) are presented as 8,760 hours operating time per year (Table 2). Cost estimates are based on flow diagrams and equipment list. The equipment list includes information on typical size, pressure, temperature and materials. Equipment costs (including costly equipment such as compressors, air separation units and power turbines) are based on either budget quotations, or estimated with a common database (Aspen in plant cost estimator).

Natural gas sweetening: although a high pressure MEA process is assumed, a MDEA process is most likely to be applied. Costs for gas sweetening will therefore be re-assessed over the coming year – as MEA requires less steam (and therefore energy) it has the potential to reduce costs even further. N.B. Utilizing the $CO_2$ for EOR, as well as the increased heating value of the natural gas due a reduction in the amount of $CO_2$, will also reduce costs significantly. Location factors: these are divided into additional costs (CAPEX), reduced efficiency (CAPEX) and special conditions (OPEX) – see Table 3.

Transport and storage: the condition of the $CO_2$ when passing the "borders" has a pressure of 70 bar and temperature of 0° to 30°C at sea level. The cost estimation must be done with the same tool (simple) in order to compare the results. The method should be verified with a more sophisticated system.

Sensitivities: the estimates are analyzed in order to ascertain the main cost drivers: energy cost, investment cost, rate of return, operating hours/year and chemicals.

**Table 1: Variable cost factors capture plant**

| Variable cost | Unit | Unit cost (€) |
|---|---|---|
| Electric power | kWh | 0,1 |
| Steam (low pressure) | Tonne | 15 |
| Natural gas | $Sm^3$ | 0,3 |
| Town water | $m^3$ | 0,015 |
| Cooling water | $m^3$ | 0,0015 |
| MEA (85%) | kg | 1,8 |
| NA2CO3 | kg | 0,6 |
| Active coal | kg | 5,5 |
| Corrosion inhibitor | kg | 1,9 |
| Destruction of used MEA | kg | 0,25 |

**Table 2: Generic price list for common utilities:**

| Fixed cost | Unit | Unit cost (€) |
|---|---|---|
| Operator | hour | 50 |
| Administrator | hour | 60 |
| Maintenace | of CAPEX/an | 4 % |

**Table 3: Location factors**

| Extra cost (CAPEX) | Reduced efficiency (CAPEX) |
|---|---|
| Travel and living cost of "imported" constructors | Ex-situation under construction (work permit) |
| Extra transportation cost | Waiting time |
| Extra for ex-proof installations | Rain/snow |
| Long-time renting of special equipment (cranes) | Cold weather |
| Special systems for type of industry | |

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**The NORDICCS CCS Center**
The Nordic CCS Competence Centre (NORDICCS) is a virtual Centre involving major CCS stakeholders from academia, R&D institutes, and industry in the five Nordic countries.

NORDICCS promotes realization of CCS in industry and society as a whole. This is accomplished by pooling knowledge, exploiting RD&D results, utilizing industry experience, and sharing information between stakeholders.

NORDICCS is at the same time a platform for staging discussions and developing strategies on challenges, opportunities, and reduction of barriers to CCS implementation. In this way, industry-driven innovation is stimulated, synergies are created, utilization of resources is optimized, and stakeholders are strengthened.

NORDICCS serves the needs of decision makers, industrial companies, and the general public to obtain access to updated information and knowledge about CCS as a climate change strategy.

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