Sund Energy for
Nordic Innovation Centre (NICe) and Top-level Research Initiative

CCS in the Nordic countries
in a renewable/climate neutral future (2050)

Overview of possible future developments and advice for funding

September 2010

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I. Executive summary

The Nordic Innovation Centre (NIC) is supporting the Top-level Research Initiative in getting an overview of the carbon capture and storage (CCS) technology and potential in the Nordic countries which will serve as basis for funding future CCS projects.

There are two studies in parallel:
– The main study on the overall technology and potential in a reference scenario (completed by VTT and partners)
– This smaller study on the role of CCS in a future with more renewable energy (completed by Sund Energy and partners)

The scope of this study has been refined in dialogue with the steering group and NICe, to **evaluate the energy picture over time with more renewable energy in the Nordic region and the role of CCS in becoming climate neutral by 2050.** The focus is therefore less on the technology and more on the overall energy picture, realism of cutting different emission sources and possible contributions of CCS in the different Nordic countries given that the countries are using much more renewable energy.

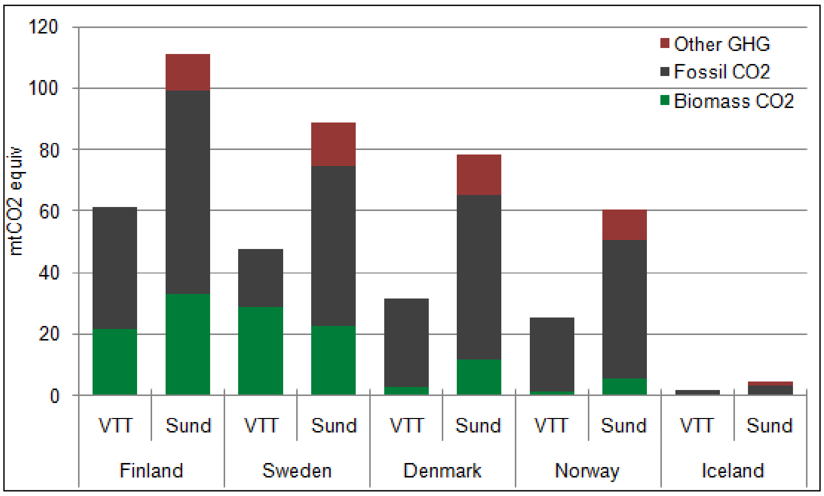
Team

The study is lead by Sund Energy with support from the Bellona foundation and TNS Gallup (societal). There have been several meetings with Nordic Innovation and the steering committee, including a workshop in Copenhagen with the full steering committee, stakeholders and VTT with partners, for interim discussions.

Scope and approach

This study looks at the role and possible contribution of CCS in a 2050 renewable/ CO_2 neutral Nordic region, with the total energy perspective in mind. So, a top-down complementary view to the bottom-up picture painted by looking at all large sources and what could be captured. The first difference is in which emissions to study. The main study by VTT looks at stationary sources larger than 0.1 $mtCO_2$, see Figure 1 for a comparison of historic emissions used in the studies.

Figure 1 – Emissions included in Sund Energy and VTT studies (data for 2007)



Source: VTT and Sund Energy interim report June 2010

This study has looked at the full energy picture and how all emissions need to be considered, both large stationary that could have CCS and all other emissions. As a basis for the 2050 picture we consider both historic emissions and 2020 plans. Further, we have added a view on realism in meeting targets in the various areas of energy use, as we have observed that private choices in households are not guaranteed to be climate neutral quickly. From a decision-making perspective it may be quicker and safer to install CCS at a large source rather than waiting for many individuals to change their car and heating system. To test the realism in this, we have talked to stakeholders in each country.

Our approach has been stepwise in developing scenarios:

1) Map current energy use and emissions in each country
2) Map political targets and plans in each country for 2020 and comment on realism (including on role of CCS)
3) Develop scenario for climate neutral 2050: total energy picture, emissions, and CCS

We have also looked at synergies between the countries, such as advantages of planning for the region rather than for each country. Finally, in our advice on areas to support with research funding, we have considered CCS in a global perspective and suggested areas where the Nordic countries may have a distinct advantage or special situation that will not be covered better in other regions. One such area is capturing CO_2 from industrial use of biogenic energy sources, allowing for negative contributions to the overall emissions, making it easier to reach "neutral" faster.

It is important to see the full picture of energy and emissions. For today, an overview of all emissions (also biogenic) provides a wider scope for sustainable solutions. For the future, a wider range of operational aspects can be considered for more realistic and sustainable total picture with "right" amount of CCS. It would also be easier to analyse impacts of changes to assumptions, such as changes in energy efficiency, relative attractiveness of abatement solutions and/or energy mix with changes to price, costs, and value of abatement/cuts in emissions.

Figure 2 – Nordic emissions

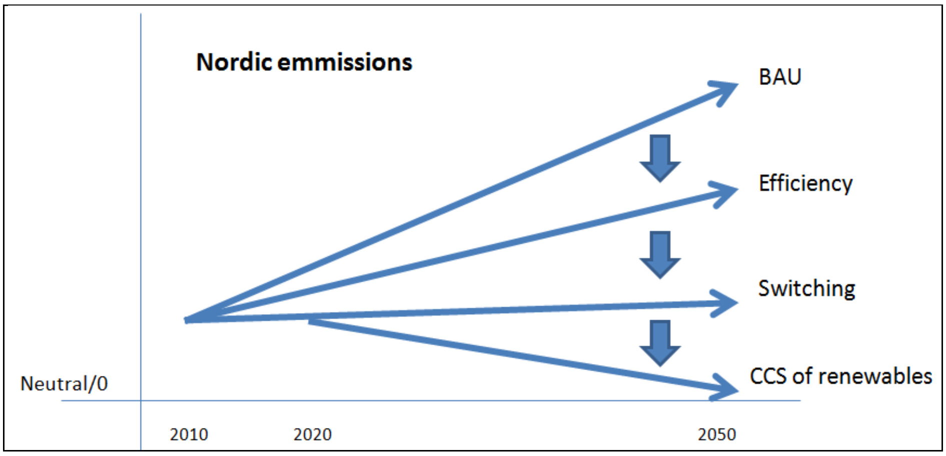
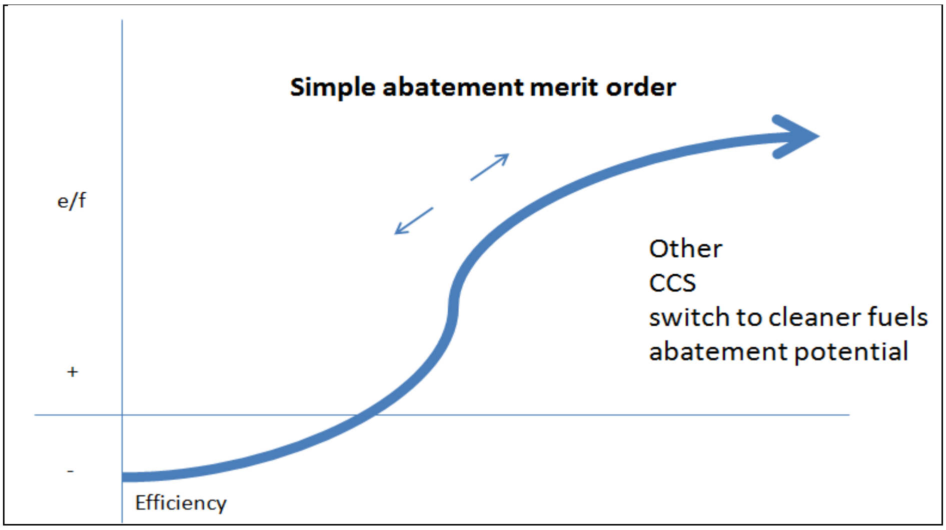


Figure 3 – Simple abatement merit order



As the schematics in figure 3 shows, there is a merit order of abatement where efficiency is lowest but not guaranteed: if this is followed, the business-as-usual scenario with continued growth could be in steps.

After analysing the full energy and emissions picture today, reviewing current plans and evaluating good overall solutions to reach a climate neutral position by 2050, we see CCS playing a role, especially on mitigating emissions from biogenic sources in the Nordic countries. The figure below illustrates how this may play out in each of the Nordic countries.

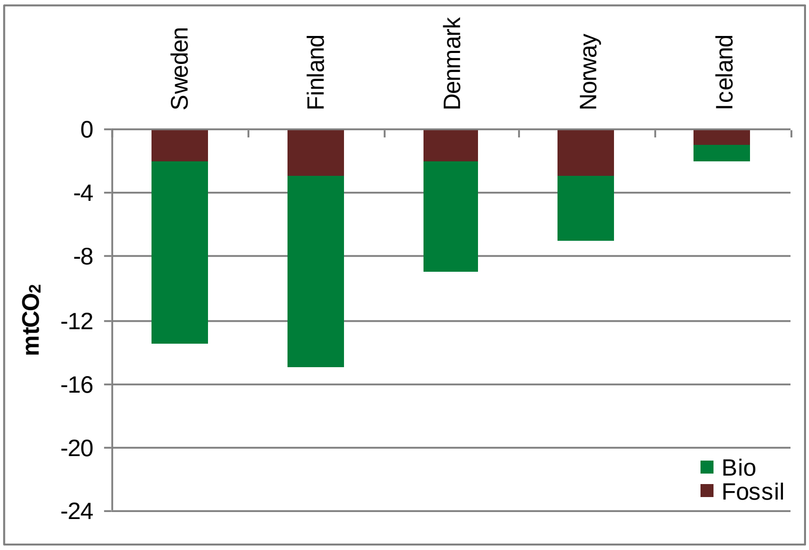
Conclusions and recommendations

CCS can play an important role in making the Nordic countries as a whole CO_2 neutral. First, CCS can reduce emissions from both large heavy industry and fossil fuelled power stations by 90 per cent or more. Even with a large potential for more renewable energy supply, the possibility of using fossil fuels with only minimal emissions may be enough to trigger large investments in CCS. Since some greenhouse gas emissions are very difficult and/or expensive to avoid (such as methane emissions from livestock and heavy transport emissions), CCS could add additional (and perhaps larger) value by enabling facilities combusting or processing large amounts of biomass (on its own or in combination with fossil fuels) to have net negative greenhouse gas emissions. Negative emissions could offset more expensive and impractical emissions in other sectors. This would reduce overall cost of achieving a given emission reduction target (ie carbon neutrality), and therefore the political viability of setting such targets and the accompanying policy measures (assuming that costs would remain a major driver in public policy). Our findings are that it is indeed possible for the Nordic region as a whole to go carbon neutral by leveraging carbon negative CCS in combination with fuel switching to more renewable energy sources.

World-leading expertise in the fields of bioenergy (SE, FI), large scale thermal power generation (DK, FI), process industry (SE, NO) and CCS (NO, DK) makes the Nordic region exceptionally well positioned to take a lead in the development of carbon negative value chains. To do so, several steps could be taken. Initially, there should be some consideration of how to treat biogenic emissions, and how to incentivise capture of these as well as fossil fuels from large stationary sources. Moreover, it is important to take an integrated and innovative approach, and search for solutions across technological, cultural and national boundaries. Further, if new plant (using fossil or biogenic) plan for capture from early stages, integrated solutions may well be more economic, and innovation here could well reduce costs more than further R&D in each part of the plant and capture facilities. This will be easier with less “silo thinking” and a more joint approach to challenges and values. A Nordic approach may be beneficiary in working across disciplines and professions to achieve synergies and learning. The Nordic region already displays a diverse and low carbon energy supply portfolio. Integrating CCS could contribute further, and add to the security of energy supply and for developing renewable energy sources. Multiple benefits could arise from this:

- Reduced global cost of achieving a carbon neutral system by optimizing bioenergy and fossil energy
- Strengthen the Nordic pulp and paper industry for world class performance, as well as adding to the viability of other industry in the region
- Allow emissions where and when competitive (such as allowing some fossil fuels for transport)

Figure 4 CCS in Nordic countries 2050 in a renewable/climate neutral scenario



Source: Sund Energy analysis 2010

By taking the lead for energy source integration, the Nordic region could not only succeed in its environmental ambitions but also build a platform for global technology export. A globally leading competence cluster for CCS on biomass could well be within reach. For this, it may be useful to consider new aspects of CCS:

- Incentives framework for negative emissions
  - Long term policy development: How will accounting and emission quotas for biogenic emissions develop?
  - Technology incentives for large energy and industry facilities combusting and/or processing biomass/biofuels – what is best?
- Plant integration
  - Heat and energy integration and other aspects – how could they reduce both investment and operating costs?
- Commercial framework for steady energy supply
- Optimization on <u>both</u> cost and emissions
- CCS technologies for fluctuating power generation
  - E.g. when wind and hydro power is base load
  - CCS in (large) CHP plants – a Nordic niche?
- Capture technologies for integrated plants
  - Fuel mixing (bio + fossil) impacts capture technologies
  - For manufacturing industry and power generation alike
  - Capture technologies for pulp & paper plants
- Ship transport of CO_2
  - Considering Nordic geography and shipping competence, develop this niche
  - Energy efficient liquefaction
  - Ship-to-injection interface
- Possible value from the CCS chain
  - Making investments and operations attractive to investors
- Public acceptance for CCS

We recommend seeing CCS increasingly as an integrated part of the full energy and emissions picture, and that the perspective of the investors as well as consumers is kept in mind when designing terms and conditions for power and industry to use the technology. R&D should therefore in addition to the current focus on improving the technology (which happens globally also), consider models for reducing risk, improving attractiveness for the investors, operators and society in general.

II. CCS: What it is and how it can contribute?

CCS - Carbon Capture and Storage combines technologies for capturing carbon dioxide from point sources with methods for transporting the gas to suitable permanent geological storage locations where it is injected into sedimentary layers deep below the ground surface or under the seabed.

Carbon capture technologies

Three basic technologies have been widely discussed when it comes to CO_2 capture from stationary sources. All three technologies have their advantages and disadvantages. Selection of technology is affected by the maturity of the technology, grass root or retrofit CO_2 capture plant and the specific application of the technology. These basic technologies are:

Pre-combustion

The technology will require the generation of hydrogen by the reforming process, where gas is converted to hydrogen and CO_2. Hydrogen is then used to fuel the power plant. The advantage of the technology is that the lower CO_2 capture cost due to its high concentration. The disadvantages are: (1) added cost of the reforming process, (2) lower overall efficiency due to the energy required for the reforming process, (3) prototype turbine is used for the hydrogen fuel thus the higher efficiency turbines cannot be used during the immediate future. (4) More CO_2 is produced due to the lower efficiency. The technology can only apply to new build facility and most likely on a R&D type of development. This technology was thoroughly investigated by Hydro in the 1990's but was abandoned due to its high cost. BP's Miller field project was also based on this technology and was also cancelled due to its high cost.

Post-combustion

This technology is developed by several companies based on the conventional amine absorption process. Most of the processes and their integration are similar. The differentiators are efficiency of the solvent and energy required for regeneration of solvent. Disadvantages of the technology are:

- Low flue gas pressure and low CO_2 concentration in the flue gas lead to very large equipment and high cost.
- The conventional amine solvents, which capture CO_2 by chemical reaction, require high energy to release the captured CO_2 from the solvent and could increase the total cost of capture by 50% or more depending on the cost of energy.

The advantages are:

- Most well developed and can be employed today.
- Can retrofit into the existing power plants.

There are many technologies in the market at the different stages of maturity. The most well-known technologies are those offered by Mitsubishi Heavy Industries (MHI), Fluor and Cansolv. Newer developers are Aker Clean Carbon and Alstom, which are based on chilled ammonia technology. Many projects were initiated based on the absorption technology but no commercial plant is yet to be built due to its high cost.

Oxy-fuel combustion

Nearly pure oxygen is used for combustion that would result in a flue gas composed of mainly CO_2 and H_2O and a small amount of inert gas and oxygen. However, if fuel burned in pure oxygen, the resulting flame temperature would be excessively high and could exceed limitations in metallurgy. Large quantities of flue gas are therefore recycled to control the combustion temperature. The advantage of the technology is that flue gas will mainly consist of CO_2 and water, thus CO_2 capture becomes relatively easy. The disadvantages are: (1) production of pure oxygen will be costly and require substantial amounts of energy, (2) depending on the quantity of the inert in the flue gas additional processing will be required. For example, if CO_2 is used for enhanced oil recovery, the excessive oxygen must be removed to a very low level with a catalytic oxidation process. A pilot project was commissioned by Total in south France. However, the Lacq project focused on the feasibility of storing CO_2 in a depleted reservoir rather than the oxy-fuel technology.

Of the three technologies, both pre-combustion and oxy-fuel combustion are still in the R&D phase. Although future CO_2 capture may be based on these developments, for the immediate application, post-combustion is most applicable and will be further discussed in the following sections.

Background and history of CCS

Gas treating technologies have been around for over 80 years. Companies like UOP, BASF, Fluor, Technip, Shell etc. have been active in this area for many years. Most of the effort has been concentrated in the syngas and natural gas treating industries, which normally deal with high CO_2 partial pressure stream with or without sulphur components in the feed gas. For example, UOP's hot potassium carbonate, BASF's activated MDEA, Shell's Sulfinaol and Fluor's DGA processes are commonly used for many applications.

For the CCS application, most of the above technologies cannot be applied efficiently because the CO_2 source is normally at atmospheric pressure and with a low CO_2 concentration. One of the first companies to offer technology for the recovery of CO_2 from a low pressure CO_2 source is Fluor of the United States. The company used the conventional amine solvent (MEA) for this application. The first commercial plant was built in Bellingham (Massachusetts, USA) to recover CO_2 from gas turbine flue gas for the beverage industries –beer and coca cola. The plant was shut down many years ago because the power plant was not operating due to high fuel gas cost. The process required large investment and high energy consumption; however, the high cost of CO_2 product can be justified by the high value of the end products.

During the last couple of decades, new technologies have surfaced. Among them are MHI's CDR process (Kansai-Mitsubishi proprietary Carbon Dioxide Recovery), Cansolv's DC-103A solvent and some newer developments such as Alstom's chilled ammonia process, Siemens' amino acid technology and Aker Clean Carbon's new amine solvent. Due to the low CO_2 partial pressure, these technologies require large equipment and high amine circulation rate making both investment and energy consumption very high to justify the commercial CCS projects. Many pilot plants have been built and operated, but essentially no commercial CCS plant has been built. MHI has built several large scale CO_2 capture plants based on their technology in Japan, Malaysia and India. These plants are mainly for making urea; therefore the high CO_2 capture cost can be justified by the added value of urea over ammonia.

The CO_2 capture cost based on the existing technologies is roughly around \$70 to \$100 per ton of CO_2 captured depending on the source of CO_2 and location of the plant. The cost is too high to justify CCS purely based on environmental concern. A few projects were initiated based on enhanced oil recovery (EOR), for example at Halten in Norway and in Dubai in the Middle East. However, the cost of capture is still too high and platform modification is also too expensive to justify the EOR projects.

Transport

With few exceptions, CO_2 sources will be at a distance from suitable storage locations, hence the requirement to arrange safe and cost effective transport. Considering the volumes involved and the long time perspectives onshore and offshore highpressure pipelines will make up the backbone of any transport network. Complementarily, ship tanker transport will be especially attractive during the ramp-up period and for singular point sources at near-sea locations. The challenge of large scale CO_2 transport is rather economical than technological, since both pipeline and ship transport display long and successful track records with near-zero incidents or leakages.

Storage

A critical factor for the general acceptance of CCS as an effective climate mitigation tool will be the verification of safe storage locations, preferably remote from populated areas. The long term containment of the gas must be secured and mechanisms for proper monitoring of potential leaks and the gas disbursement in the reservoirs must be in place. Much scientific focus has been and is still directed at capture technologies but increased attention is now given to the characterization of potential geological storages and to the long term consequences of permanent underground CO_2 storage.

CCS as a solution

Equipment for CO_2 captured is large and investment is high. It is not practical to install capture facilities of non-stationary sources such as auto mobiles, airplanes or ships. CCS is only feasible for stationary source of CO_2 emissions. The stationary sources of CO_2 in the Nordic countries are mainly from power plants and industries.

The bulk of CO_2 emissions come from the coal fired power plants and from industrial emissions in Demark, Sweden and Finland. Although much discussed in Norway, CCS from gas fired power plants is still in the development phase and its installation is uncertain due to the high cost. There is a drive in Denmark toward wind power, which is expected to reduce CO_2 emission in the country. Much progress has been made in Sweden and Finland on use of wood chip for power generation. However, capture from renewable power plant, which could provide opportunity for negative carbon emission, is not yet investigated.

In the future, CO_2 emissions are expected to decrease due to continuous efficiency improvement in power plants, capture and storage of CO_2 from the power plant flue gas and wind power application. However, to achieve CO_2 neutral in 2050, much progress will be needed in both technology and government policies. National and regional development of infrastructure for rapid deployment of both transport and storage will be critical for capture plant investments.

Costs

To analyse the role of CCS in a more climate-focused future than the reference case of the VTT study, we have started from a global and overall energy perspective. Technology is developed globally, and with the assumption that the world wants to be climate neutral, technology costs of being able to do this will fall. That means CCS unit costs will fall, making it more economic than today to capture CO_2 from other sources than the already planned coal (and gas) fired power plant, such as smaller units and other fuels. We have not in this report covered exact capture cost reductions and their speed, but assume that it will be more economical and in smaller scale than today.

Regional differences will also be present in the availability of suitable geological storage, where the North Sea seems to offer great opportunities and where both Finland and Sweden seem to be at a disadvantage due to its granite-based geology. Therefore, this is an area most suited for regional cooperation.

Traditional CCS

Capturing CO_2 from power plant flue gas is inherently expensive, due to low CO_2 concentration and pressure, which require large equipment to process the flue gas. Many technologies have been developed, which are mainly based on new solvents. However solvent development alone may not be able to lower the cost of capture to a reasonable level to justify the commercial installation. A typical breakdown of the capture plant cost is as follows:

Absorber	44%
Regeneration	24%
Quench Cooler	19%
Flue gas Blower	5%
CO_2 compression	10%

From the above list it could be concluded that the absorber design and construction must be optimized to lower the capital cost of the plant. Many innovative designs have been proposed, for example MHI’s steel plate construction and Cansolv’s concrete tower. Both options could substantially lower the cost of the absorber in transportation and construction comparing with the conventional absorber tower. With experience it is expected that the cost can be further reduced.

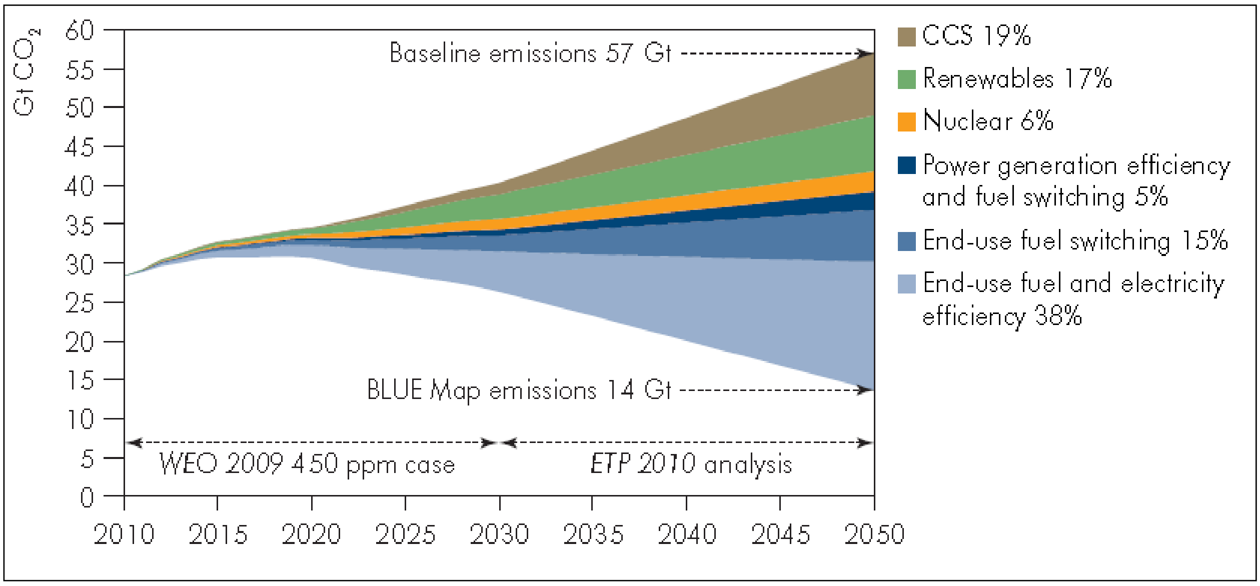
One other area of attention is the energy required to regenerate the solvent. For a combined cycle power plant approximately 15% of energy is lost to regenerate the rich solvent, if the bulk of the CO_2 in the flue gas is to be captured. The cost of energy could add up to 30 to 50% of capital cost depending on the cost of the fuel. Innovation is needed to explore the possibility of utilize the low grade heat from the power plant.

Use of CCS to capture biogenic emissions from power and industry
Much progress has been made in Sweden and Finland on use of wood chip for power generation, Because of low energy content in the biomass, transportation could be costly for industries without their own energy source (like pulp and paper). Proposals have been made to produce bio-diesel or biogas to ease the transportation. However, conversion costs and the loss of efficiency could make these proposals prohibitively costly.

Global perspective

Global developments in technology/cost, payability for climate and actual emission reductions will all impact what is realistic, economic and “best” solutions for the Nordic countries. For assumptions on future global developments, we have looked at work by the International Energy Agency (IEA). They assume that CCS is a vital addition in CO_2 abatement technology, with an expected share of 19% of all reductions or 8 gigatons on a global basis. However, it seems to be seen as having a role as “last resort”, after efficiency improvement, fuel switching, nuclear and renewables are maximised. So if these other methods are less successful, the need for CCS may be greater to meet the same targets. On the other hand, when CCS becomes a clearer alternative, there may be more innovation in other solutions. This adds uncertainty (and costs) to developing CCS. Further, there are societal risks related to large-scale CCS. We cover these, as well as possible business opportunities, and suggest further studies in making CCS an attractive solution for both investors and voters. Other technologies may develop and in addition, other values of carbon (and methane) could impact the order of preference in abatement choices. For this study, we have assumed a growing interest in abatement, lower costs of CCS with higher use globally.

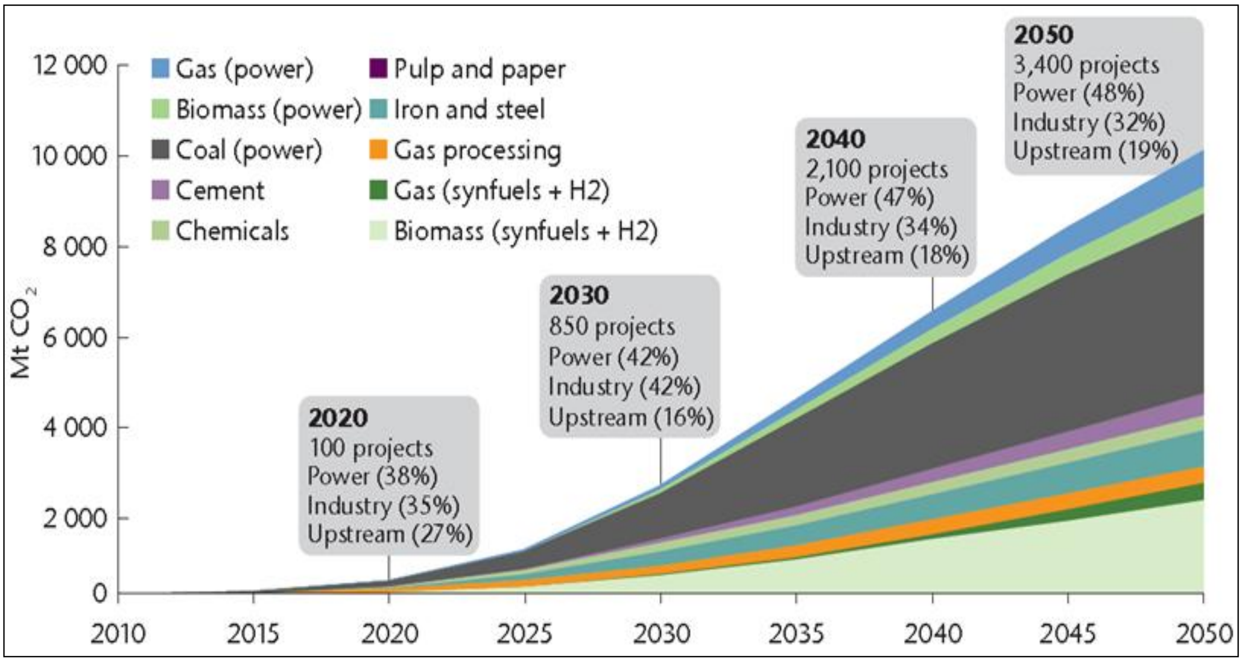
Figure 5 Key technologies for reducing global greenhouse gases by 2050



Source: IEA, Energy Technology Perspectives, 2010

The IEA has also (in 2009) looked at where CCS will be used in the future and how many projects could be expected globally. As the overview below shows, capturing CO_2 from coal in the power sector is expected to be the largest use of CCS. As in Norway, there are also expectations for gas fired power plant to have CCS. In addition, biomass and industrial emissions are expected to grow significantly.

Figure 6 CCS for many types of emissions by 2050



Source: IEA, CCS Technology Roadmap to 2050, 2009

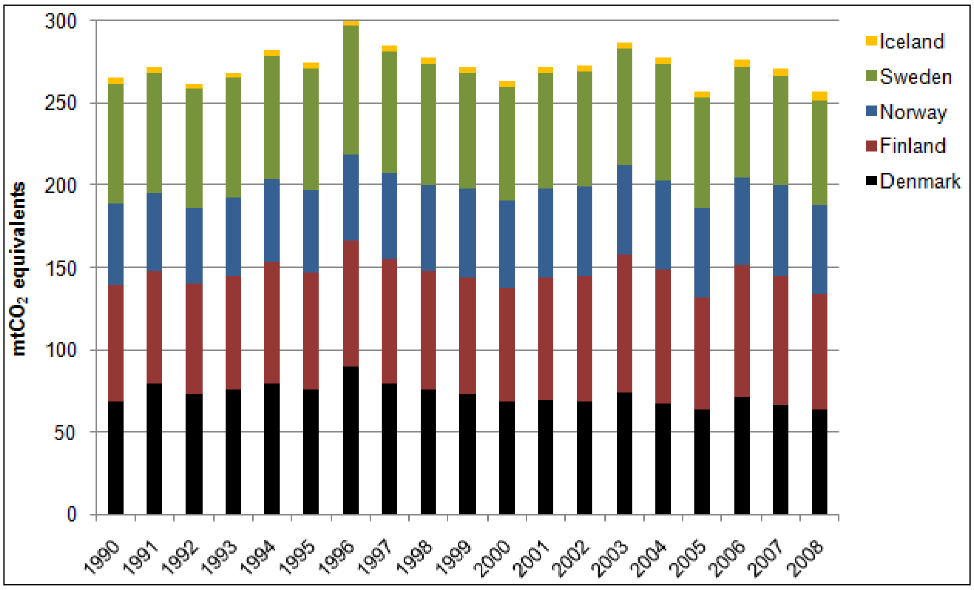
The EU 20-20-20 policy aims to reduce emissions by curbing consumption and increasing the share of renewables. The success in this will impact the need for CCS. Comparing to the EU average, the Nordic countries have a lower share of emissions from power and heat, partly due to the large share of hydro and nuclear. They have a higher share from transport, partly for the same reason, and partly due to distances and a high share of cars in the population. Finally, there is a higher share from oil and gas than in the EU, mainly because there is a larger share of this industry in Norway and Denmark.

III. Energy, emissions and plans in the Nordic countries today

This section gives an overview of emissions and current plans/outlook to 2020. This is to give a starting point for the 2050 scenario in section V.

Although the Nordic countries have much renewable energy, mainly hydro, wind and bio fuels, the per capita emissions are well above world average. This is the case in most developed countries, and has to do with transportation and industry. In Denmark and Finland, there are also significant emissions from power generation with fossil fuels. Iceland has very low emissions, both due to a large share of geothermal energy and a small population (with less total capacity for transport emissions, for example). Below is an overview of the Nordic emissions and their development since 1990, the base year for the Kyoto protocol.

Figure 7 Nordic countries' reported greenhouse gas emissions since 1990

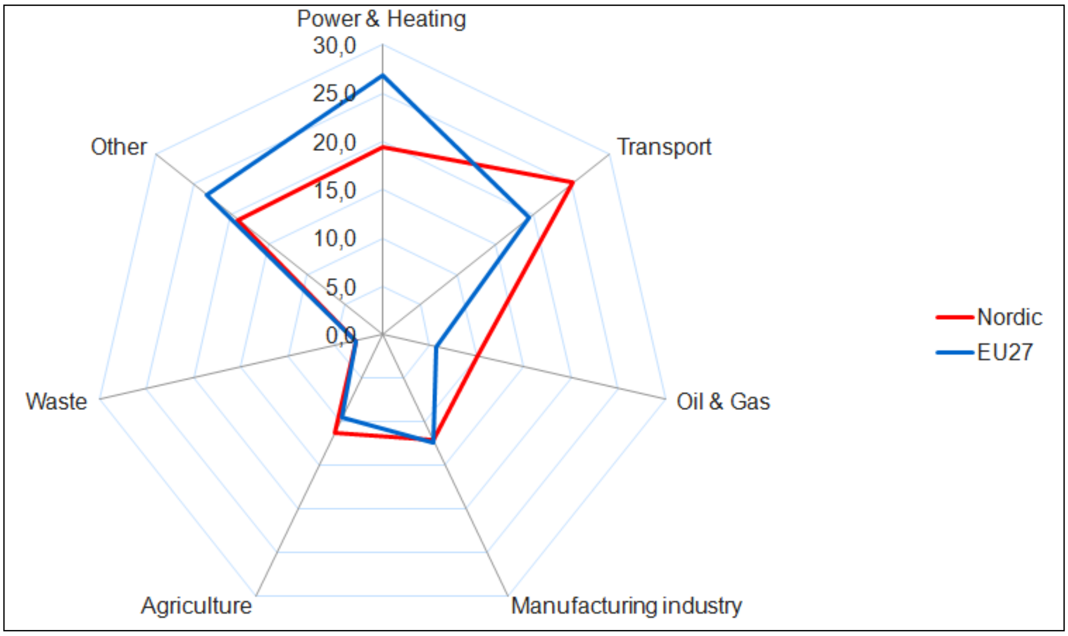


Source: European Environment Agency, EU GHG Data Viewer, 2010

There are some significant national differences that should be mentioned:

- Hydro power in Norway and geothermal energy in Iceland have provided not only low/ no emission from power generation but also cheap energy. This has given high energy intensity, mainly in industry (aluminium smelters and other metals) but also as household consumption patterns are coloured by low cost, domestic energy
- Denmark has had domestic natural gas, which has been used for heating and cooking, lessening dependency on electricity. Electricity is largely produced from coal-fired power plants. There has been an aversion to use expensive electricity (compared to gas) and to get too dependent on imports of oil and coal. This has resulted in a well developed infrastructure for both gas and district heating, which will be easier to convert to biogenic fuels than for example the Norwegian infrastructure
- Sweden, on the other hand, has developed both nuclear (with a parenthesis of a moratorium that was not entirely effectuated) and renewable energy in the form of imported waste for heat and bio fuels for heat and industrial use. Compared to the other countries, Sweden has focused more on reducing emissions from transport, and has converted more of its transportation sector to gas (natural gas and biogas)
- Finland already uses a large share of renewable fuels for energy production, both power and heat. Finland imports its natural gas only from Russia. A second source has not been available also because of that the market potential turning to other fuels and a choice was made to develop nuclear for additional power demand. At the same time a huge support package for renewable energy production was approved.

Figure 8 Comparing GHG emissions - percentage share per sector 2008



Source: European Environment Agency, EU GHG Data Viewer, 2010

Fossil sources

The largest emissions of climate gases in the Nordic countries are from fossil sources. Of these, transport (the largest emitting sector) is responsible for a quarter of all reported emissions in the region. Power generation accounts for 19% while industrial energy for 12% of total emissions.

Biogenic sources

Nordic emissions of greenhouse gases in 2008 were 348 million tonnes. Of this, 92 mtCO_2 were from biogenic sources. Biogenic emissions, which arise from the combustion or processing of biomass, are not counted under the Kyoto protocol or the EU emission scheme. That means they are considered "climate neutral". Therefore, these policy structures provide no incentive to reduce biogenic emissions, even if these emissions are also adding to the atmospheric concentration of greenhouse gases; the climate simply does not know the difference. Reducing biogenic CO_2 emissions is therefore equally good for the climate as reducing fossil CO_2 emissions. Opportunities to reduce biogenic emissions should therefore be welcomed and incentivised. (The European Commission is currently working on adapting policy structures for this purpose).

More than 80% of the Nordic biogenic emissions were in Sweden and Finland, mainly in the pulp and paper industry. 30-40% of the greenhouse gas emissions from these two countries are from biogenic sources. This reflects a combination of demand and availability of resources in these countries. It has also resulted in valuable skills in improving technology and economics for this energy type. These skills may well be built on to further reduce the emissions in the country by capturing the CO_2 and being able to count this capture as "CO_2-negative". See also case study on Finnish pulp and paper industry and potential for CO_2 capture, below.

An important option for reducing emissions in existing power plants and heavy industry factories being implemented in the Nordic countries is to replace all or some of the fossil fuel or feed stock with biomass sources. For example, Vattenfall has undertaken to replace up to 30% of the coal used in their power plants in Denmark with biomass, and the Norwegian ferro-silicon industry is determined to replace the coke currently being used as reducing agent with bio-coal. While this means that the amount of fossil CO_2 emitted will decrease, the amount of biogenic CO_2 emitted will increase correspondingly. This offers increased scope for negative emissions.

Table 1 –Fossil and biogenic climate gas emissions in the Nordic countries in 2008

		DENMARK	FINLAND	ICELAND	NORWAY	SWEDEN	TOTAL
	Total emissions including biomass, excluding LULUCF	76	103	5	59	106	348
REPORTED	**CO_2 from fossil and other greenhouse gas emissions**	64	70	5	54	64	257
	Energy Industries, of which:	24	24	0	17	11	77
	Power and Heat	21	21	0	1	7	50
	Oil and Gas	3	3	0	16	3	26
	Manufacturing Industries, of which:	8	18	2	13	18	58
	Energy for manufacturing industries and construction	5	11	0	4	11	31
	Industrial Processes	2	7	2	9	7	27
	Solvent and other product use	0	0	0	0	0	1
	Transport	14	14	1	15	21	65
	Commercial/Institutional	1	1	0	1	1	3
	Residential	4	2	0	1	2	8
	Agriculture	12	8	1	6	10	37
	Waste	1	2	0	1	2	7
BIO	**CO_2 from biomass, of which:**	12	33	0	5	42	92
	Power and Heat	6	7	0	1	11	25
	Manufacturing and Construction, of which:	1	19	0	2	25	48
	Pulp and Paper	0	19	0	2	23	44
	Transport	0	0	0	0	1	1
	Residential and Commercial	4	5	0	2	4	16
	Net fossil emissions of greenhouse gases in 2008	**64**	**70**	**5**	**54**	**64**	**257**

Source: European Environment Agency, EU GHG Data Viewer, 2010

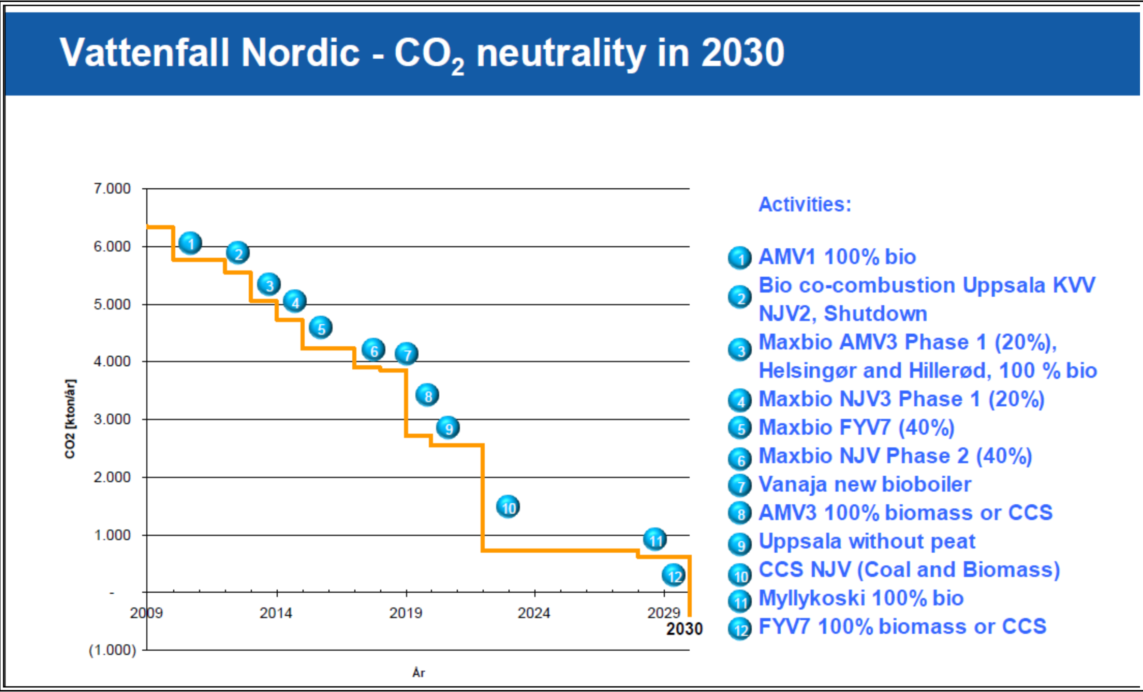
Vattenfall aims to be CO_2 neutral by 2030

Vattenfall Nordic has announced the target that its power generation should be CO_2 neutral by year 2030. In essence this rests on three strategic pillars:

- Fuel switch from coal to biomass
- Expand wind power generation
- Mature and deploy CCS technology

As can be seen in illustration xxx, Denmark is the one Nordic country where Vattenfall is planning the most active program. In all capital spending around 10 bDKK should yield 4 mtpa CO_2 emission reductions or 78% of the total. These numbers include carbon dioxide removed also from combustion of biomass. (These projections were made in February 2009, before the announced delay of the CCS project at Nordjyllandverket.)

Figure 9: Vattenfall Nordic targets



Source: Vattenfall 2010

Plans for 2020

This section covers current plans, for energy and climate emissions in the Nordic Countries in 2020. Not because there will be a large share of CCS, but because it seems to be as far as governments and other stakeholders are able to be relatively concrete about measures. Therefore it is an indication, among others, on developments to 2050. Having said that, it is clear that even 2020 targets are relatively uncomfortable to commit to for many stakeholders, especially compared to the situation 10-20 years ago when number seemed to appear with more clarity in energy scenarios. As many of the countries (as well as the EU itself) see large uncertainties, we have added some stakeholder views and own commentary on the realism of the current plans as well.

All the Nordic countries are planning to use more renewable energy in the future. The preferred types and areas of use vary significantly between the countries and so does the overall ambition level. Hydro power is a very large part of the renewable energy picture today, but has some limits to further growth. Wind has large potential and there is also high growth in other renewable energy forms.

All the Nordic countries have plans to reduce the use of fossil fuels, improve efficiency and have a larger share of renewable energy in their primary energy mix. Drivers are diverse and vary in time:

- There is always an element of cost, and extreme oil prices have lead to strong focus on the strain on the economies of being dependent on expensive oil, especially in the recent years of recession.
- Security of supply (reduced exposure to foreign supplies of energy) is a driver with varying strength, but is publicly stressed for oil in Denmark and for import of electricity and natural gas in Finland. Perceived vulnerability will reduce the share of these energy forms in the preferred final mix.
- Climate and other environmental aspects are active parts of energy policies, and especially Sweden has been very clear on becoming climate neutral by drastically reducing its use of fossil fuels.

The EU has its own strategy. The three EU member countries in the Nordics also need to take the 20-20-20 in 2020 policy into account, where 20% of total final energy consumption should come from renewable energy sources, on top of measures (such as some CCS) to reduce climate gas emissions by 20% compared to 1990 levels. This cut in emissions is split between sectors covered by the EU ETS, which are to reduce emissions with 21% compared to 2005 levels, and non-EU ETS sectors where each country has negotiated its own target. For Denmark, Finland and Sweden, we have thus also referred to their national action plans submitted at the end of June 2010 to the European Commission, where they reported how they intend to achieve their targets.

The EU overall strategy is made operational in directives on efficiency, use of renewables and in particular bio fuels (also in transportation), etc. These directives are meant as guidance for each country’s policy and domestic measures. The EU has standardised the formulas for calculating emissions as well as the reporting format, making the countries’ reporting consistent and comparable. However, Norway and Iceland do not report on this and Norway also disagrees with the calculation formula for renewables. We have therefore chosen to look at the reporting to the UN, as this is most comparable for all Nordic countries, both for historical and estimated 2020. Each country’s policies are outlined below, based on their Fifth National Communication reports to the United Nation’s Framework Convention on Climate Change (UNFCCC) in late 2009 and early 2010. Then we comment based on EU expectations and own views on realism. For 2050 we have developed a scenario for the Nordic countries to be climate neutral, given today’s calculation methodology.

Denmark

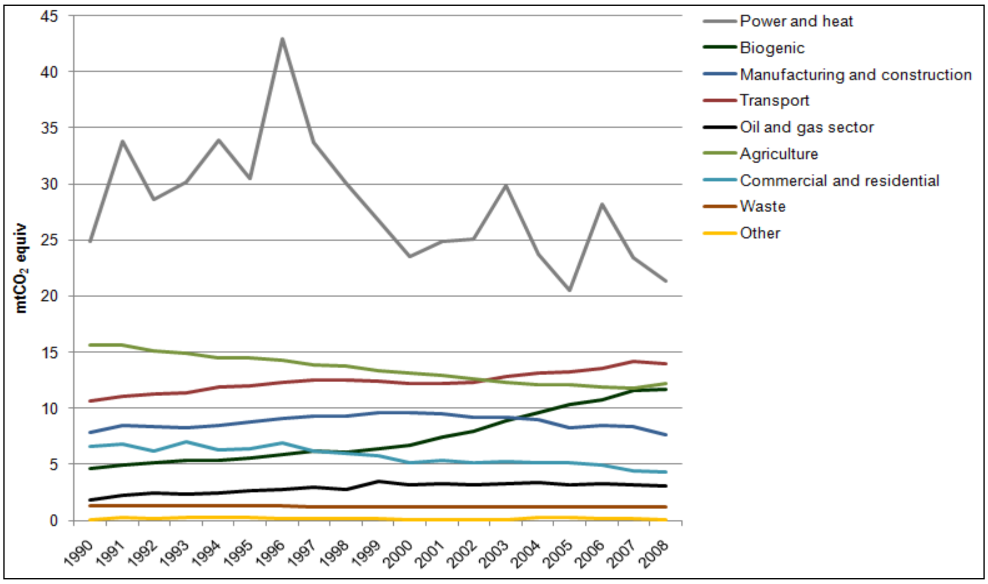
Denmark has a strong programme on increasing the share of renewable energy, especially wind but also biomass. This will, in addition to reducing emissions (already 10% down from 1990 in 2010) also contribute to security of supply and reduced dependence on imports of energy, such as oil, gas, coal and electricity.

Current situation

As can be seen from the figure below, the largest emissions are by far from power and heat. This sector also has the largest variation, as both demand and generation varies with temperature, wind, needs for import (as well as exports). There were large electricity imports in 1990 and 2005, and exports in 1991, 1996, 2003, 2006. Still, the general trend of these emissions is down.

The second largest emitting sector is transportation, and these have increased by 33% since 1990. The largest increase in emissions – more than double since 1990 – is from biogenic sources. NO_x emissions are cut by 32% and methane by 4% since 1990.

Figure 10 Biogenic and fossil emissions in Denmark since 1990



Source: European Environment Agency, EU GHG Data Viewer, 2010

Denmark – plans to 2020

Within the framework of EU binding targets, renewable energy should account for 30% of final Danish energy use in 2020, up 13 p.p. from 2005. Denmark is also committed to a 20% reduction in non-ETS emissions from 2005 to 2020 and is negotiating its burden sharing on ETS emissions for the period following 2012 with the European Commission. Assuming an overall 20% reduction on 1990 levels equal to the EU average, Denmark would still need to reduce its emissions by 8 $mtCO_2$ equiv compared to 2008 by 2020.

During 2008-2012, nearly half of Denmark's emissions are covered by the EU ETS, so the scheme is an important cost-effective tool integrated in the national climate strategy. Energy and CO_2 taxes also drive investments towards low emission solutions and they are to be increased since 2008 by 1.8% p.a. up to 2015. Other measures include a switch from coal and natural gas to biomass for electricity generation, further investments in cogeneration and renewables (wind and biogas), as well as business and government energy efficiency programs. CCS is not discussed, as Denmark currently plans to become independent of fossil fuels. In this respect, the 'Climate Commission' is expected to publish a plan in September 2010. Among sectors not covered by EU ETS, addressed by the Government's 2010 climate policy brief to the Parliament, CCS was not mentioned as it is considered irrelevant in these fields. So far, efforts to reduce emissions from transport have failed, despite promotion of lower emission fuels (such as biomass) and differentiating vehicle registration taxes based on emission standards. Danish authorities are stepping up efforts to promote greener transport alternatives, seemingly mainly by promoting electric vehicles powered by wind energy. Overall, the role of electricity as an energy carrier is expected to increase in the medium and long term.

In its 2010 national communication to the UNFCCC, Denmark presented a projection of emissions dated February 2009, including policy measures in place or expected to be implemented. Under a range of macroeconomic assumptions built on data available before the economic downturn and including high oil prices, the exercise estimated an over delivery of the target by 1 $mtCO_2$ equiv. The main reductions would be achieved in energy, with the switch from coal and gas to biomass and biogas in cogeneration seen as delivering high emission reduction.

DONG Energy – stakeholder interview

Use of bio energy in the future

DONG Energy is Denmark's largest power generator (50% of power and 40% of district heating). Today 87 % originates from fossil fuels power plants and the remaining is wind and hydro.
DONG will increase its use of biomass by 5 by 2020 (2 mill t). In order to achieve this goal DONG will have to import biomass from Europe and elsewhere. DONG expects CO2 emissions to be reduced with 50% by 2020.

Energy mix in 2050

By 2040 DONGs power production will be based on 15% thermal and 85% renewable energy. Wind will play a major part in the renewable picture, but biomass will also be important.

Realism behind abatement of CO2 from renewable

For Europe to achieve its goals CCS has to be applied in large scale.
However, DONG has no concrete plans for CCS. They have no new coal power plants under development and they are following the CCS development with great interest.

Energy efficiency

DONG sees only very small potential for energy efficiency in their power plants as most of them are relatively new.

Energistyrelsen – stakeholder interview

Use of bio energy in the future

In Denmark biogas is presently used in heat&power plants and not in the transport sector.
It is more cost efficient to substitute natural gas with biogas as input to heat&power plants than as input to the transport sector.
In Denmark relatively small heat&power plants fired with natural gas have been built throughout the country. The natural gas saved by substitution can later be used in the transport sector.
Per today biogas has substituted natural gas with ca. 4 petajoule (ca. 0,5 % of Denmark's gross energy consumption).
The objective for 2020: 10-20 petajoule. In order to achieve this goal cost optimization is required. (1 – 2,5%)
Today a mixture of organic industry waste and livestock manure is the input to the biogas production in Denmark. More or less all available organic industry waste is presently used. For the future one will have to utilize more livestock manure + other components. The production process is the barrier. It will not be advisable to accelerate the upgrading process, but to use the next 3-5 years for further optimization of process.

Energy mix in 2050

There is a political vision and probably also in the future a political objective to achieve a fossil free Denmark by 2050. Bioenergy will then be an important contributor.

Realism behind abatement of CO2 from renewable

Energistyrelsen is clearly more skeptical to CCS than previously. Not reject totally.

Energy efficiency

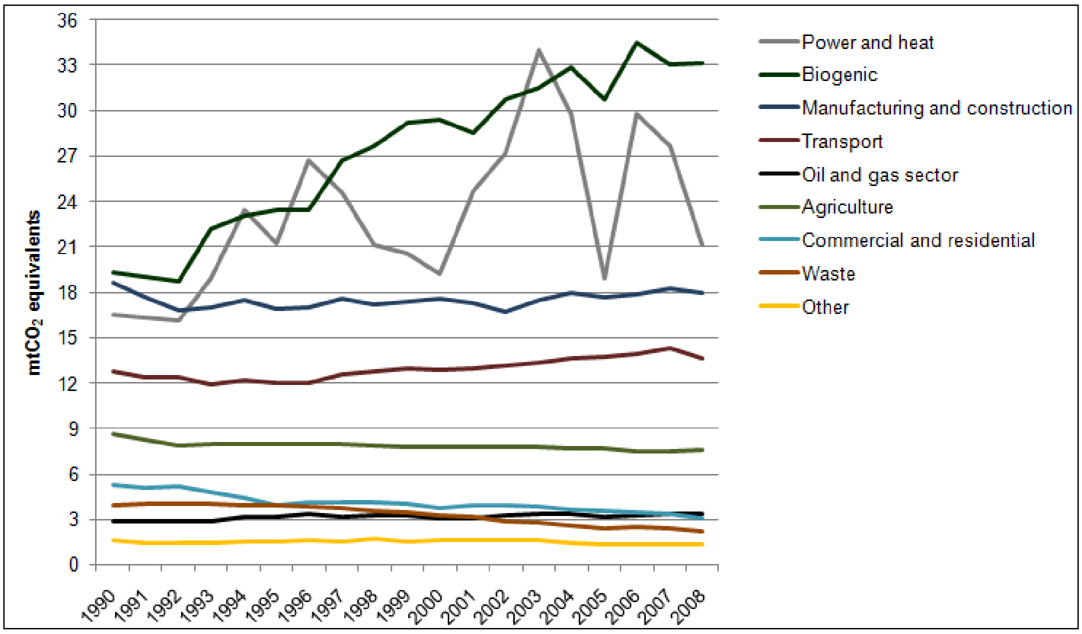
In 2008 an agreement was made that the gross energy consumption should be reduced with 4% from 2008 level in 2020.

Finland

Current situation

Greenhouse gas emissions in Finland were 70 mtCO_2 equiv in 2008, at the same level as in 1990 and in line with commitments under the Kyoto protocol. On average, a Finnish person emits more than 13 tCO_2 equiv each year, higher than the average for European countries.

Figure 11 Biogenic and fossil emissions in Finland since 1990



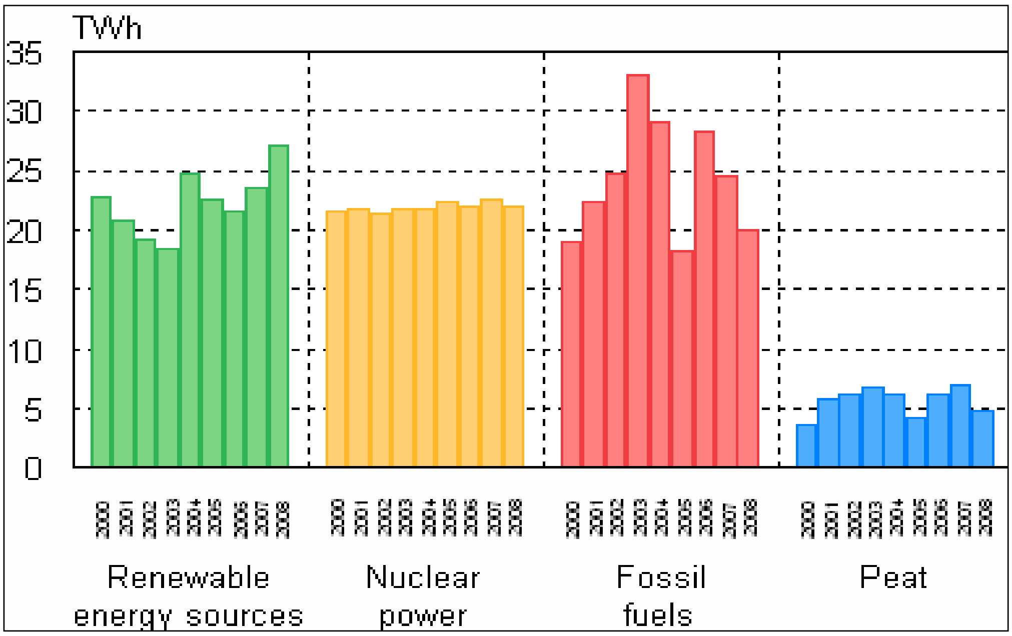
Source: European Environment Agency, EU GHG Data Viewer, 2010

The largest and most variable source of emissions in Finland is the power and heat generation sector, which uses a changing mix of fossil fuels. For electricity generation, base load is covered by nuclear, black liquor from the pulp and paper industry and other biomass. Gas and coal are used for electricity and heat production in CHP plants, balancing with hydropower according to need and availability. Total emissions from power and heat were 21 mtCO_2 equiv in 2008 (30% of total), but could vary from 16 mt to 34 mt, from year to year.

Similar to Sweden, energy and transportation are large emissions sources in Finland. Energy industries' share has varied from 28% to 44% in total because of weather, energy supply structure (Nordpool, Russia, Estonia) and economic trends. There is also a strong correlation with use of fossil fuels and peat.
Manufacturing and construction is down 20% to 11mtCO_2 equiv, and transportation has a 6% increase to 13.5 mtCO_2 equiv. There has been a halving of CH_4 that has been compensated by increase in CO_2. A decrease in rail and aviation has been compensated by road traffic – both freight and passengers.

There have been different developments in smaller sectors. In the industrial and chemical processes we have seen an increase from 5 to 7 mtCO_2 equiv, significantly SF_6.
Residential and commercial has seen a cut of 30% to 6 mtCO_2 equiv.
Finland has seen a remarkable improvement in waste management and agriculture has had a reduction of 12% to 1992 levels then remaining stable.

Figure 12 power and heat generation by source in Finland



Source: Statistics Finland, 2009

Finland – plans to 2020

Finland has pledged to increase the share of renewables in final energy use to 38% by 2020. This is less than Sweden, but almost twice the average share for the EU as a whole. Finland is also bound by the EU to reduce its greenhouse gas emissions by 2020 with a probable 21% in sectors covered and a negotiated 16% in sectors not covered by the EU ETS, compared to 2005. This is equivalent to a 20% overall reduction from the base year 1990 and implies reductions of 14 mtCO_2 equiv from 2008 levels (average annual reductions of 2.6%).

In light of these commitments, Finland has in 2009 adopted a national strategy, outlining several measures that need to be taken to curb emissions. For example, energy efficiency agreements in all sectors of the economy have either been adopted or are in negotiation, aiming to reduce energy demand from baseline projections by 36 TWh within 2020. This entails more cogeneration for the residential and industry sectors, subsidised energy audits, and a slowdown in the annual increase in electricity demand from 2.6% (1997-2006) to 1.2% (2007-2020). To meet the renewables target, special focus will be given to biomass, with wood-based energy to account for 55% of renewable energy use in 2020 –through, for instance, doubling energy from wood chips. Moreover, a feed-in tariff will be approved for wind and biogas already this autumn (2010) which means 850 -950 new wind mill units. Financing the energy/ climate projects consists of investment subsidies worth EUR 550m annually since 2009. Since Finland relies on imports for 70% of its energy needs (Fifth National Communication to UNFCCC), it is not surprising that the parliament has recently granted permits for new nuclear reactors to two non-profit consortia.

The Fifth National Communication to the UNFCCC has forecasted emissions to 2020 based on the additional measures needed and envisaged for meeting the EU targets. This scenario considers a tripling of wood chips production to 12 million m^3, increased deployment of wind, as well as use of crop biomass and waste-to-energy solutions. Thanks to higher prices for emission allowances and therefore energy prices, the use of transport fuels, other fossil fuels and peat would decrease more than the assumed improvements in energy efficiency. This scenario estimated 68.5 mtCO_2 equiv for 2020 and it was based on assumptions made before the economic downturn.

Finland – stakeholder interviews

Ministry of Employment and Economy (TEM)
CCS for renewables might happen for large units in pulp and paper/ forest industry and rest products. No domestic storage available, so ship transport planned from west coast. Lack of storage and long distances a problem for transport and viability for CCS. Envisage first units running in 2015-2020 and some experience earliest by 2025.

Pohjolan Voima (PVO) and Finnish Energy Industries
PVO recently received permit to build nuclear plant (through subsidiary TVO). 4 pulp and 2 paper plants capture and direct CO_2 to precipitated calcium carbonate (PCC) plants. PCC used since 1993 as filling and coating material in paper and paper board. 3 bio-diesel plants under planning –different teams of one forest industry player in cooperation with other energy actors . Planned to use wood as fuel and CCS later on (each represent a reduction of 1Mt/a). Peat benefits of feed-in tariff, despite not being acknowledge by EU as renewable fuel.

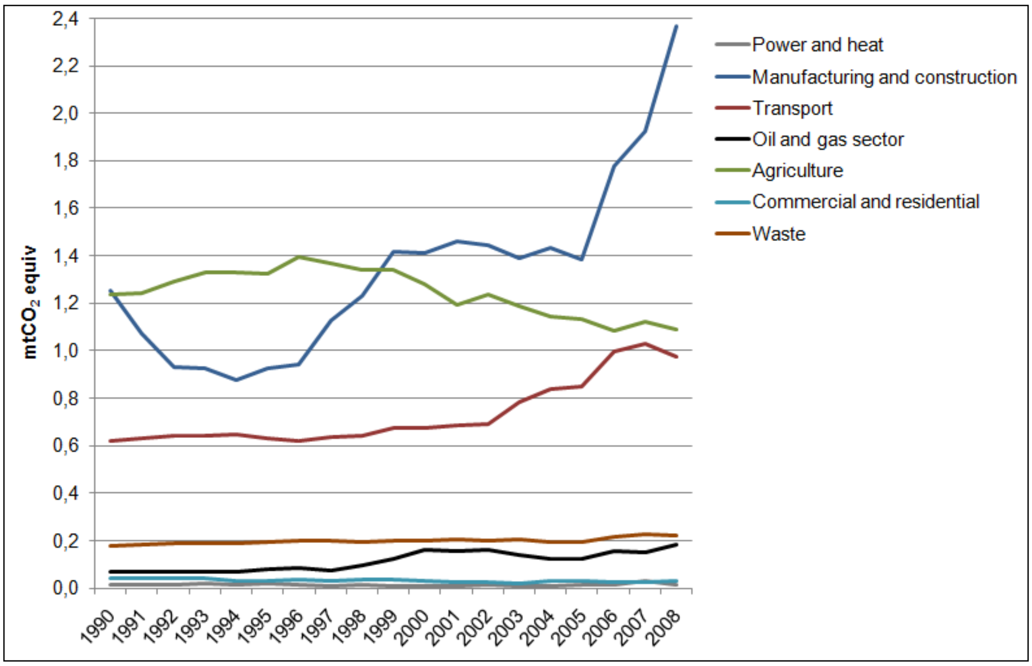
Natural gas industry – GASUM
Biogas development and use of LNG in small ferries and ships
Starting project with CLEEN together with Fortum (STEM and SGI from Sweden involved here) and on zero-carbon energy production, including CCS

Fortum
Fortum in partnership with Siemens and Mærsk are in one of the fossil CCS demonstration plants expected to be co-financed by the EU. Financial support is also needed from the state. Siemens is to provide the technology, while Mærsk would handle transport and storage of CO_2. (Danish North Sea). The reduction of CO_2 from this plant, located at Meri Pori, is 50% and would result in about 1.2 mtCO_2 being captured. In the long run, Fortum sees large scale carbon, free CHP production, also including CCS, and possibly also CCS from renewables. Again, the location is thought to be on the Finnish West Coast. Large scale carbon free CHP could see CCS in the long-run on Finnish West coast, also from renewable. Alternatives to transportation would be use of CO_2 in growing algae (for fuel) or mineralization (PCC).

Iceland

The climate gas emissions are very low in Iceland. There has been an increase in manufacturing and construction, partly due to industries locating to the country and benefiting from the cheaper land and cleaner electricity. With geothermal energy, the emissions from power and heat are negligible.

Figure 13 biogenic and fossil emissions in Iceland since 1990



Source: European Environment Agency, EU GHG Data Viewer, 2010

- Biogenic (non-fossil) is reported as 0 and thus not shown
- Iceland's GHG emissions in 2007 were about 4.5 mtCO2-eq
- Transportation, other fuel combustion (mainly fisheries) and industrial processes most important sources
- Emission growth mostly due to increased transport work and heavy industry production
- Heavy industry emissions have nearly doubled since 1990
- Production of aluminium, ferrous alloys and other energy intense industrial goods is growing due to the availability of low-cost and reliable electricity supply
- Strong, consistent growth in transport emissions
- Land-use change emissions down 20% since 1990
- Main measures: Forestation
- 80% of total energy supply is renewable
- Iceland has the highest per capita energy production (and use) in the world

Iceland – plans to 2020

Iceland is not part of the EU and is largely exempted from participation in the EU ETS (at least until 2013), so there are no binding targets for renewable penetration or emission cuts to 2020. Energy use is based almost entirely on renewable sources, and net energy-related CO_2 emissions from geothermal are considerably lower than fossil alternatives. Moreover, Iceland is seeking to store the CO_2 already separated from geothermal steam into basaltic rock, potentially providing an effective global alternative for storage of CO_2 that would be captured as a part of CCS projects throughout the world after 2020.

Since stationary combustion has low emissions, policy efforts are focused on mobile sources (road traffic, fishing fleet) and on keeping industrial process emissions as low as possible –by eliminating

PFCs from aluminium production, for example. Diesel fuels are taxed less than oil, hydrogen and electric cars are exempted from excise taxes, while public transport is cheaper since vehicle tax by weight was replaced by a fee based on covered distance for heavy trucks. New and refurbished fishing vessels are being phased in, as they have better emission standards than old ones. Authorities also see a large potential in sequestering carbon through forestation.

In its recent submission to the UNFCCC, Iceland presents two scenarios up to 2050, where the level of aluminium and ferrosilicon production –a large source of process emissions– represents a main assumption. Basically, if a lot of industry is set up by 2015 emissions would increase to 6 $mtCO_2$ equiv with little change in any but industrial processes, otherwise emissions remaining at their post recession level to 2020–below the 4.88 $mtCO_2$ equiv recorded in 2008.

Green Building Council – stakeholder interview

Iceland green building council is recently set up to promote green buildings.
Improved energy efficiency is not a high priority as Iceland has a surplus of sustainable, renewable energy supply.
Focus on urban planning to reduce the need for transportation.
Sustainable and non-toxic materials.
On climate change measures and policy.

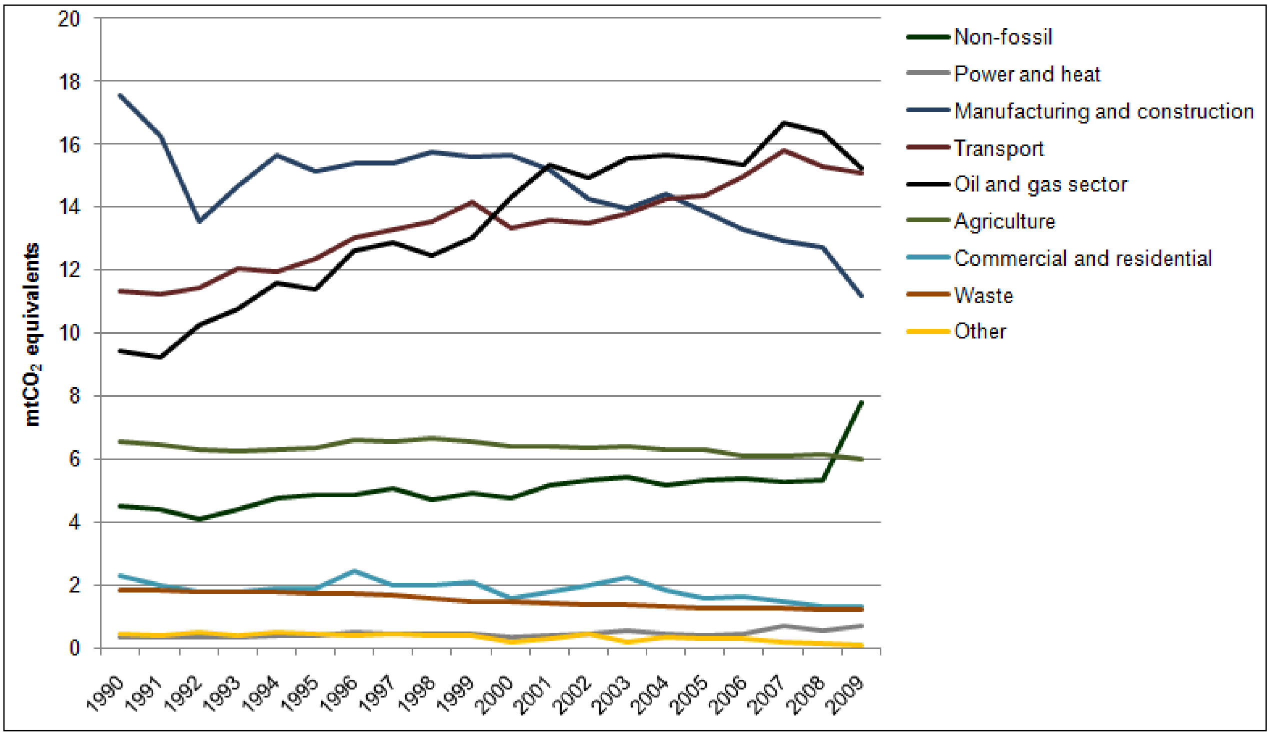
Large potential for improved energy efficiency in shipping and fishing fleet – companies offering energy management services (Marorka).

Road transport:
Close to a very big shift, many are shifting to bio-methane (CH4) produced in landfill gas recovery and biogas plants by retrofitting petrol cars. Seen as a step before getting to electric drives – hybrid drives would render the two strategies compatible.
One company is developing systems to produce biofuels (DME – dimethyl ether, a diesel-like liquid fuel) from CO_2 from geothermal plants (Carbon Recycling)
The financial crisis (including a currency crisis) gives a strong drive to substitute some import of oil with locally produced fuels (methane, electricity, hydrogen)
CCS – large uncertainty concerning the viability of basaltic CO_2 sequestration/mineralization.

Norway

In Norway, greenhouse gas emissions in 2009 were slightly above 50 $mtCO_2$ equiv, roughly the same amount as in 1990 and in line with the Kyoto target for 2012. This gives an average of 10.5 tCO_2 equiv per capita per year. However, this level hides a considerable recession made reduction over the last years and, as seen in the nineties, this is not sustainable as the economy recovers. In addition, not counted biogenic emissions of CO_2 are today at 5.3 $mtCO_2$ equiv, an increase from the 4.5 $mtCO_2$ equiv registered in 1990. Over the past two decades, greenhouse gas emissions have increased slightly, albeit with varying evolutions across the emitting sectors.

Figure 14 biogenic and fossil climate gas emissions since 1990



Source: European Environment Agency, EU GHG Data Viewer, 2010
Statistics Norway, 2010 and estimations by Sund Energy

The main point source emitter today is the oil and gas sector with 14 $mtCO_2$ equiv (28% of the total), nearly 75% more than in 1990. Gas powered generation on the Norwegian continental shelf contributes considerably to this, but fugitive emissions are still important and erratic numbers in time confirm how difficult these are to handle. Refineries and the emissions from coal in Svalbard are included as well, but these have not increased much since 1990.

The construction and manufacturing industry is also an important source of emissions, contributing 12.5 $mtCO_2$ equiv (25% of the total). Thanks to improvements in energy efficiency and some fuel switching, energy related emissions have stayed constant at 3.5 $mtCO_2$ equiv despite growth in output. Moreover, industry players have embarked on a sustained gradual reduction of emissions from industrial processes, by as much as 35%. In the chemical industry –which halved its process emissions– the largest cuts came from nitric acid production, while within metal production a high impact came from the phase-out of SF_6 in aluminium and magnesium foundries (2 $mtCO_2$ equiv) and of PCFs in aluminium production (2.5 $mtCO_2$ equiv).

Due mainly to a surge in road traffic for passengers and freight, transportation has become the main source of greenhouse gas emissions in Norway, with more than 15 $mtCO_2$ equiv. Road traffic accounted for 2/3 of this, while domestic sea and air transport –which both registered increases as well since 1990– accounted for 16% and 7% respectively. Emissions from international air and sea transport are currently not included in international commitments, but it is worth mentioning that with today's accounting Norway's emissions from international sea transport would almost double total emissions from transport.

A particularity for Norway is the nearly carbon neutral supply of power and heat. In the residential and commercial sectors, emissions have decreased by 55% and 16% respectively, to 0.7 $mtCO_2$ equiv each, mainly as a result of switching heating systems from fuel oil/ gasoil to electricity, heat pumps and biomass. Emissions from heat and power generation have increased from 1990 as some gas fired generation has been built on the west coast, but are still as low as 0.5 $mtCO_2$ equiv. Despite a near doubling in the amount of waste per capita, emissions from landfills are down 33% to 0.8 $mtCO_2$ equiv as more waste is recycled or incinerated for energy.

With 6 $mtCO_2$ equiv, agriculture is the last important source of emissions in Norway. CO_2 from fuel and other energy needs accounts for 30% of these, while the rest is a mix of methane and nitrous gas. There is a slight downward trend in emissions from agriculture since 1990 is mostly due to the increased concentration of land ownership and associated energy efficiency, while other emissions have been constant over the period.

Norway – plans to 2020

Norway has pledged to exceed its commitment under the Kyoto protocol by 10 p.p. and reduce its annual greenhouse gas emissions by 30% of the 1990 level by 2020. This corresponds to 12-14 $mtCO_2$ equiv plus an additional 3 $mtCO_2$ equiv uptake in forest sinks. Two thirds of the reduction would be achieved nationally and the rest through acquisition of quotas from international markets. Over 70% of domestic emissions are either covered by the EU ETS or/and subject to a CO_2 tax.

In its most recent National Communication to UNFCCC, Norway has projected emissions to 2020 according to policy measures in place in autumn 2008 and a range of macroeconomic assumptions not fully covering the impact of the economic downturn. The exercise estimated total emissions of 56.5 $mtCO_2$ equiv, suggesting also that increased oil prices could reduce this by 1.3 $mtCO_2$ equiv.

In February 2010, an inter-ministerial task force lead by the Climate and Pollution Agency released a study which builds on measures already in place and suggests pathways to achieve the 2020 goal. The baseline scenario of 'Climate Cure 2020' estimates a further increase in emissions, up to 59 $mtCO_2$ equiv by 2020, despite improvements in energy efficiency of 1% p.a. in transportation, the oil sector and industry. Actually, the baseline scenario sees emissions from industry stable until 2030, with emissions from the petroleum sector continuing to mount to 2020 and slowly decreasing thereafter due to lower production. Emissions from transportation are expected to increase at least until 2030 with current policy measures in place. The baseline included the coming on stream of the Mongstad CCS plant in 2014, which was recently put on ice by the Government. 'Climate Cure 2020' concluded that all solutions with a cost below NOK 1100 per tCO_2 must be implemented to achieve the targeted cuts, estimating an annual cost of NOK 5 billion in order to achieve the 30% desired reduction. In 2009, the general tax level on CO_2 was on average NOK 214 per tonne.

Meanwhile, the economic downturn has already brought emissions in 2009 to their 1990 levels and as the recovery proceeds, with a strong focus on climate, the authors believe they will not get back to pre-recession levels. In fact, greenhouse gas emissions in Norway could decrease to 40 $mtCO_2$ equiv by 2020, 20% below 1990 levels. There is scope for lowering emissions from all sectors in Norway.

By 2020, the oil and gas sector can see a 25% decline in emissions to 12 $mtCO_2$ equiv, partly due to decreasing levels of activity as oil production from the NCS has already started to decline and is being replaced by gas production. Reductions will be achieved by preventing methane leakage and diminishing flaring, as well as from the gas powered generation on the NCS. In power and heat, we expect the Mongstad centre to be fully operational by 2020, emitting and capturing nearly all of the 1 $mtCO_2$ per year. We expect this to be the only unit retrofitted with CCS within this time frame.

In manufacturing and construction, we see a continued trend of lowering emissions from industrial processes, achieving reductions of nearly 2 $mtCO_2$ equiv by 2020. Energy related emissions will be reduced thanks in part to better energy efficiency, but also by replacing fossil fuel combustion with biomass. We consider that carbon neutral emissions from pellets in manufacturing could increase by 1.5 $mtCO_2$, replacing a similar amount of fossil emissions. These will not be captured in 2020, but there is potential for this in the long run.

In transportation, road traffic accounts for the largest share of emissions and will continue to do so in the foreseeable future. Better fuel efficiency for fossil driven vehicles, as well as improved public transport in urban areas will contribute to most of the 20% reduction to 12 $mtCO_2$ equiv. Achieving the 10% target for renewable fuels in transportation by 2020 will require, apart from the gradual introduction of electric vehicles, a considerable deployment of bio fuels –biodiesel, bio ethanol, biogas–. Neutral biogenic emissions from these could account for 0.5 $mtCO_2$ equiv in 2020.

With better land and livestock management, emissions from agriculture will also be reduced, for example as methane from manure is turned into biogas. Using this to power and heat the farms is able to reduce both fugitive emissions and those from energy use. Based on the current potential and starting level for biogas in Norway, we expect emissions from agriculture to be reduced by less than 20% by 2020, down to 5 $mtCO_2$ equiv.

NVE (Norges vassdrags- og energidirektorat) –stakeholder interview

Use of biogenergy in the future

No prognosis

NVE is estimating a certain increase in use of bio energy in Norway in the future, but not a dramatic increase.

Energy mix 2050

No sign of large scale increase in use of bio energy in Norway up to 2050.

CCS on renewable

“This is a technological question”.

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Heidelberg (Norcem) –stakeholder interview

Use of bio energy in the future

Norcem has two cement plants in Norway: Brevik and Kjøpsvik

Today Norcem uses waist based fuel with 70-90%. Bio energy content (2009: 85000 ton).

The cement plant at Brevik has surplus of CO2 quotas.

The share of bio energy in their total energy consumption is increasing to 50% of total energy consumption at Brevik and to 30% at Kjøpsvik (for example animal flour: Brevik 10000t and Kjøpsvik 5000t).

Energy mix in 2050

Norcem will also in the long perspective have a substantial consumption of fossil fuels. Their upper limit on use of biomass will be approx. 70% in Brevik and 50% at Kjøpsvik.

Realism behind abatement of CO2 from renewable

By 2020 Norcem plans for a full scale CCS plant at Brevik.

Norcem will start up a test project on CCS at Brevik on behalf of European cement industry. Applied for support from Gassnova.

Energy efficiency

Here are still large potential. The most effective projects have already been taken. Norcem has generally speaking many technical solutions based on low power prices. Therefore compared to other cement plants, Norcem has a high power consumption. Norcem will switch to more energy efficient technologies when the present technologies become obsolete.

Yara International –stakeholder interview

Use of bio energy in the future

In the fertilizer industry production of ammonia is the most energy consuming process. From ammonia nitric acid is generated, which is one of the main components in fertilizer production. All ammonia production in Norway takes place at Porsgrunn.

Ammonia can in principle be made from all kind of carbons. However, it is very unlikely that Yara in the foreseeable future will use other sources than hydrocarbons for their ammonia production. It is more likely that Yara will cease their ammonia production at Porsgrunn than building a new plant for gasification of biomass. The only feasible use of renewable energy by Yara could be use of biomass in production of steam in their external boilers. However, as of today this has not been considered.

Energy mix in 2050

Ammonia production at Porsgrunn in 2050 looks for the time being not very likely with no pipeline for supply of natural gas to the area in the foreseeable future.

Realism behind abatement of CO2 from renewable

”Remove first where it is cheapest.”

Energy efficiency

The energy cost is 70-80% of the total cost of producing nitrogen. Yara has continuously projects for energy efficiency (some with Enova support).To 2020 a maximum increase in energy efficiency of 5% might be possible. Yara is also engaged in projects for correct fertilization (nitrogen efficiency).There are substantial environmental gains here.

Norsk Industri - stakeholder interview

Use of bio energy in the future

Norsk Industri has made a report on renewable energy. The report identifies four main focus areas where of bio energy is one.

The Government wants to double use of bio energy in 2020 from 2008 (+14 TWh). However, this does not seem realistic at the moment. The actual increase in use of bio energy has been 0,7 TWh annually which is too low in order to meet this goal.

”Use of bio energy in 2020 is dependent on the Government’s willingness”

Energy mix in 2050

Presently 65% of the energy consumption of the Norwegian industry is renewable. Natural gas, fuel oil, coal and coke comprises the other 35%. Over time, gas and fuel oil will be totally phased out. (Example Borregaard converts now from fuel oil to bio energy)

By 2050 80% of the energy consumption of the Norwegian industry will be renewable (20% coal and coke). Bio energy will be 15% vs. 3-4% today (pulp and paper industry).

Realism behind abatement of CO2 from renewable

All CO2 from use of fossil fuels by Norwegian industry will gradually be captured. By 2020 all new process plants will have CO2 capture. Norway is in the lead in research on carbon capture from industry.

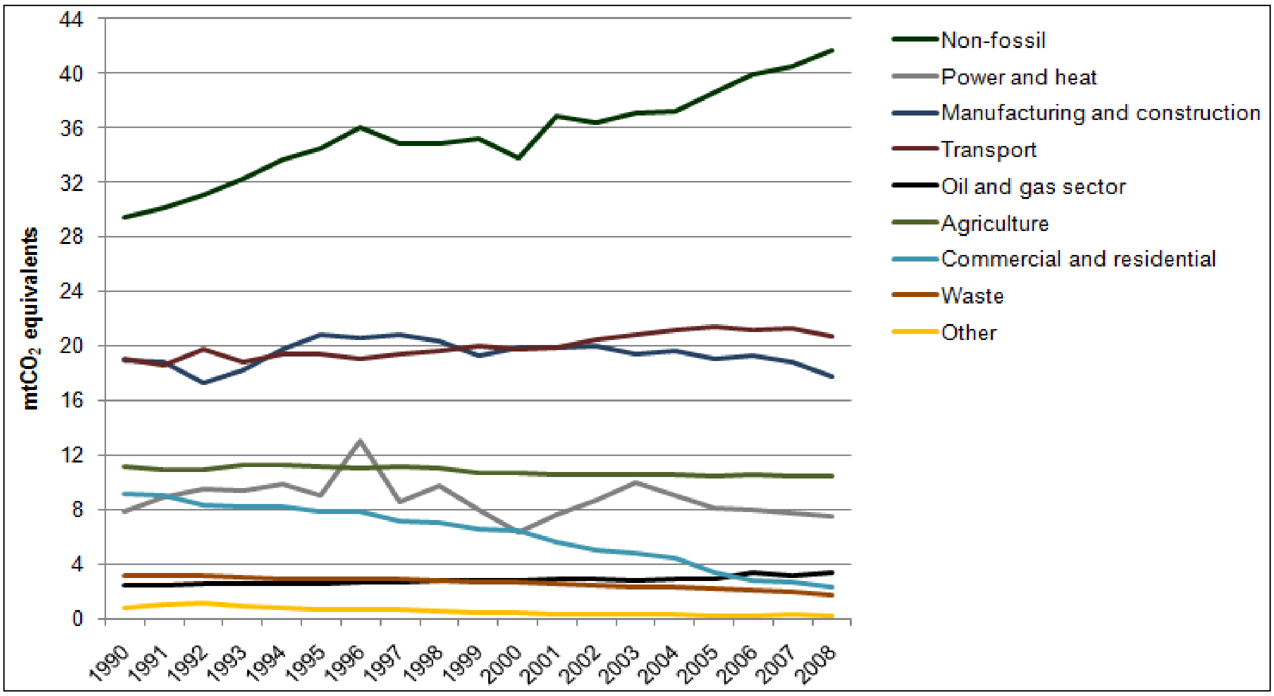
Energy efficiency

McKinsey has made a study for Norsk Industri that concludes that the energy consumption of the industry will be reduced by 30% (27 TWh) by 2020 compared to 2007.This is a theoretical potential. Hereof a reduction of ca 12 TWh is profitable, but in order to get a full reduction, economic incentives must be introduced.

Sweden

In 2008, greenhouse gas emissions in Sweden were 64 $mtCO_2$ equiv, down 12% from 1990 levels. Unlike in Norway, the performance is not mainly due to recession, as emissions peaked in 1996 at 78 $mtCO_2$ equiv and have been decreasing ever since. In per capita terms, Sweden emits annually 6.8 tCO_2 equiv, which is considerably lower than the average of its Nordic neighbours and all other developed countries. Not counted biogenic emissions of CO_2 add considerably to this picture, with as much as 23.5 $mtCO_2$ equiv, especially in the pulp and paper industry. The main categories of emitters have registered varying evolutions.

Figure 15 Greenhouse gas emissions in Sweden since 1990



Source: European Environment Agency, EU GHG Data Viewer, 2010

The largest source of emissions in Sweden is transportation, which started out at 19 $mtCO_2$ equiv in 1990, grew to 21.5 $mtCO_2$ equiv in 2005 and has been since slowly decreasing to around 20.5 $mtCO_2$ equiv. Road traffic has been increasing steadily and accounted for all but 1.5 $mtCO_2$ equiv of all these emissions throughout the period. The recent reduction in emissions comes only thanks to a strong commitment for alternative fuels, such as gas and bio fuels, as Sweden has the least fuel efficient car park in the EU (Swedish Environmental Protection Agency, 2009).

Manufacturing and construction accounted in 2008 for some 18 $mtCO_2$ equiv and a growing share (from 26 to 28% of total) of Swedish emissions since 1990. Emissions from fuel combustion in this sector have also been fluctuating considerably, especially in the pulp and paper sector, but overall they went down 12% to 10.5 $mtCO_2$ equiv. On the contrary, emissions from industrial processes have been on a slow upward trend towards 7 $mtCO_2$ equiv, driven by an almost 50% rise in output. Increasing emissions have been registered in cement and lime production (by 25% to 2 $mtCO_2$ equiv), and from the consumption of halocarbons and SF6 for refrigeration and air conditioning equipment (from none to 0.8 $mtCO_2$ equiv), while emissions of N_2O from nitric acid production decreased by 66% to 0.25 $mtCO_2$ equiv. All other emissions from industry processes have been relatively stable since 1990 on the background of increased efficiency and larger output.

Power and heat production has been a volatile source of emissions since 1990, registering more than 13 $mtCO_2$ equiv in 1996 and a minimum of 7.5 $mtCO_2$ equiv (12% of total) in 2008, with higher levels in some years due to limited availability of hydropower and increased use of coal and fuel oil. Smoothing out volatility, emissions from power and heat generation have on average been on a continuous downward trend. Thanks to a swift switch from individual heating with fuel oil to district heating, heat pumps and biomass, the residential and service sectors achieved a remarkable 74% reduction of emissions over the period, from over 9 mtCO_2 equiv in 1990 to below 2.5 mtCO_2 equiv in 2008. Emissions from waste were also reduced significantly, by 45% down to 1.7 mtCO_2 equiv, thanks to the levying of a landfill tax and the use of waste in district heating. Waste became thus a source of significant "negative emissions" in Sweden, replacing fossil fuels in heating instead of releasing methane in the atmosphere in landfills.

Agriculture is also a large source of emissions in Sweden, with slightly more than 10 mtCO_2 equiv in 2008 and an overall reduction of 0.8 mtCO_2 equiv since 1990. Unlike in Norway, energy related emissions in this sector increased by 15% to nearly 2 mtCO_2 equiv, whereas methane and N_2O emissions decreased by 1 mtCO_2 equiv. Half of this reduction comes as a result of lower livestock numbers, while the other half is the outcome of better land and manure management. Increasing production of biogas from agricultural waste arises thus as a sensible means to reduce emissions from agriculture, and current programs to use of bio methane to fuel tractors can turn it into a "carbon negative" source of energy.

Sweden – plans to 2020

Under the burden sharing agreement set up by the EU as part of 20-20-20 targets, Sweden would in 2020 meet half of its final energy use from renewable sources, the highest share among all EU countries. It also pledged to reduce greenhouse gas emissions with 40% from 1990 to 2020 in sectors not yet regulated by the EU ETS such as transport, housing, waste, agriculture, forestry, aquaculture and some industry. This is more than double the 17% required by the EU and means reductions in emissions of 20 mtCO_2 equiv, two thirds in Sweden and the remaining third through the Clean Development Mechanism (CDM) and Joint Implementation (JI) investments.

Three action plans for 2020 prepare the transition towards a low-carbon society in Sweden. First, Sweden will increase renewables penetration to 48-52% by 2020, from 44% at present. This would be achieved by phasing out fossil fuels for heating and expanding cogeneration/ district heating, by improving and expanding the renewable electricity certificate system, by creating capacity to feed-in renewables in the electricity network and increasing wind power generation to 30 TWh (of which 10 TWh offshore).Parliament has also recently voted to allow the replacement of old nuclear units with several new reactors. Secondly, there are plans to improve energy efficiency by 20% compared to 2008 in terms of energy use per unit of GDP. Policies in this area envisage energy efficiency funds of SEK 300m per year for 5 years, the design of energy specifications for technology procurement, the elaboration of 'smart metering' requirements and the carrying out of energy audits for all large energy consumers before 2014. Thirdly, Sweden acts to gradually break the fossil fuel dependency in transportation, through a more differentiated CO_2 tax for vehicles and tightening of emission standards, as well as by increasing the diesel tax. The uptake of bio fuels is also part of Swedish policy, aiming a blend of 10% ethanol in petrol and 7% biodiesel by 2020 (from selected sources), with legal requirement for filling stations to offer at least one renewable transport fuel.

In the latest National Communication to the UNFCCC, Sweden has presented an estimation of its emissions in 2020 based on European and national policy instruments in place in June 2009. This exercise delivered a 16% reduction in emissions compared to 1990, corresponding to an estimate of 60.4 mtCO_2 equiv. Sweden expects to deliver further domestic reductions of 2.5 mtCO_2 equiv through European and national measures yet to be decided upon, as well as 6.7 mtCO_2 equiv of reductions internationally.

Sweden – Stakeholders

Stora Enso AB –stakeholder interview

JH, as part of his overall scope, is responsible for all environmental reporting in the Group. This is handled in Sustainability Data Management (SDM) and linked to the financial Hyperion reporting. They comply with the principles of the Greenhouse Gas Protocol by the WBCSD.

Reporting of CO2-eqv emissions is split according to the protocol by
- Scope 1, direct emissions, from fossil fuel combustion,
- Scope 2, indirect emissions from purchased electricity (grid factors)
- Scope 3, other emissions from procured services and impact, including transport

CO2 emissions from biomass fuels is reported separately.

In 2009 levels CO_2 emissions, mtpa split on the three scopes from point sources (()=fossil):

Scope		Finland	Sweden
1		1,7	0,2
2		0,3	0,06
3	global 3,7 mtpa		
Biomass fuels		6,6	4,0

Scope 1, the bulk of emissions is from the use of fossil fuels. For the pulp, paper and board production In Sweden, Stora Enso have seven large point sources.
Internally generated biomass fuels such as black liquor, waste water treatment sludge, bark, wood waste and biomass based waste is used for energy production.
Scope 2, energy procured from Vattenfall and Fortum, mostly hydro and nuclear (naturally); Germany NG and China coal-based.
Scope 3, largest share is transport

Emissions have been steadily reduced over the last years. Forecast is continued reductions through energy efficiency measures and investment projects in multi fuel boilers. Stora Enso has as a target to reduce the CO2 emission by 20% by the end of 2020. The target is normalised to production.

Scenario 2050: We discussed Stora Enso's plans going forward and the basic approach is that bio-based combustion is carbon-neutral with responsibly handled re-forestation as is the case in the Nordic countries. Furthermore, reducing the fossil dependency by gradual transfer to biomass is a cornerstone in the energy sourcing strategy. "CCS is alien" to their activities today but could be considered given the right incentives over time. There is no view on compensating for the Scope 1 emissions by applying CCS to biomass within forrseeable future.

JH expressed the view that the above discussions most likely represent also very much of the general positions of the forest, pulp and paper industries.

Excerpts from the Royal Swedish Academy of Engineering Sciences, "Vägval Energi", January 2009

"The Royal Swedish Academy of Engineering Sciences, using the IPCC's conclusions as a starting point, has produced a report entitled **"A Swedish Zero Vision for Greenhouse Gas Emissions"** to explore how they can reduce emissions of greenhouse gases right now and bring them down to zero within a period of thirty-five years. In the report they state that existing technology can have a major impact but they also highlight areas where more development is needed.

It is their opinion that it is possible to achieve zero emissions, i.e. a balance between emissions and storage, but a specific and targeted action plan is needed. Three areas are of strategic importance to move them away from fossil energy and eliminate emissions of greenhouse gases: developing "the electric society," utilising forests and agriculture, and carbon capture and storage.

• In order to develop "**the electric society**" they need an affordable supply of electricity without greenhouse gas emissions. By making their electricity consumption more efficient and adding electricity generated by wind, solar and water, they could, for example, convert their entire fleet of private cars into electric vehicles. The power grid and tariffs need to be developed so that the local electricity supply can also come, for example, from individual wind power stations through so-called smart grids.
In the longer term the transmission capacity needs to be expanded so that electricity from sources such as large solar panel parks in Southern Europe can supplement Swedish water power.

• **Agriculture and forestry** are of great significance for the climate, both in terms of emissions and in absorbing greenhouse gases. If Swedish forests and farmland are cared for correctly, growth and thus also the carbon sink could be increased, and emissions of carbon dioxide and methane from natural processes in the ground could be reduced. Also, the residual products and bi-products from the forest and forest industry could be put to better use if they are not only used in district heating and for power production. By developing new technology they could also be used as raw material for a second generation of biofuel.

V. Scenarios for future energy and emissions

After looking at the current situation and goals for energy and environment in the Nordic countries, we have put together the countries' expected consumption and emissions. This is a total energy picture, so it includes all emissions, stationary as well as mobile. We are only looking at a goal of becoming CO_2 neutral using renewable energy more than today, not other scenarios, as this is meant as a complement to the main study by VTT, where the use of CCS in existing and future stationary sources is the main focus. An early conclusion is that the success in reducing emissions from transportation (and other consumption reduction) will impact the overall need for and value of CCS. Of the CCS uses, we have looked more at how industry using bio fuels could use CCS to become "carbon negative" by capturing gas otherwise omitted, as bio fuels are seen as neutral today. We will here cover each sector, its consumption, main use of fuel, share of renewables and role of CCS.

However, important cuts can be achieved from both stationary and mobile sources by replacing fossil fuels with biomass in manufacturing-, and transportation, as well as for residential and commercial heating. As the CO_2 from burning biomass in large units can be captured and stored, negative net emissions can be achieved to offset some of the fossil emissions which cannot be removed.

Assumptions and clarifications

A renewable/ CO_2 neutral future – what does it mean?

Energy is renewable when it is not a finite energy form, such as oil, gas and coal. Traditionally, this has meant wood, straw and other bio fuels. Developing countries still have a large share of their energy from this being used in households, but are now trying to electrify households. In the Nordic countries, we have been lucky and have a large potential for renewable energy for electricity, both hydro power (Norway has almost all electricity from hydro), geothermal (almost all electricity and heat in Iceland), wind (very large share of power generation in Denmark) and biogenic fuels (both biomass and biogas, for example). In addition to a large potential for more wind generation, both offshore and onshore, there are other future potential generation technologies that could be relevant by 2050, such as wave, fresh water – sea water osmosis, and more. However, many of these energy forms have a limit to how large a share they can have of the total energy picture, partly due to cost, and partly due to space, running patterns and other constraints. Solar energy is not considered a large potential in this region, but with better technology and lower costs, it should perhaps not be excluded in the long run.

Some are calling nuclear energy "renewable", as this is a term increasingly used for CO_2-free energy, but we have not selected that interpretation, as uranium is finite. However, large use of nuclear power in Finland and Sweden is expected to continue and naturally contribute to the climate neutral future in the Nordic countries.

Typically, some industry has own waste products that are biogenic and can be used for own energy. This is already done in large scale in pulp and paper industries in Sweden and Finland. There is also a growing use of waste for heat plant in Denmark, Sweden and Finland.

There are clear plans to increase the use of renewable energy in transportation. This could either mean using bio fuels directly in the car, or using electricity from renewable sources. We have found this transformation slower than many had expected previously, and see that CCS could well be easier and faster than changing the transportation mode of several countries, especially in the most sparsely populated areas.

Counting emissions

Climate reporting is still a relatively new activity and there are several inconsistencies in reporting of data. The Kyoto Protocol is managed by the UN, and countries report status as well as forecasts to track progress on their commitments. There are several types of greenhouse gases (carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, etc.) normally converted to the warming potential of carbon dioxide i.e. CO_2-equivalents. The focus is on fossil fuel emissions, but all countries report also emissions from biogenic energy sources. Standards for emission reporting from energy use of biomass are fairly good, but there are higher inconsistencies in the category LULUCF, which includes deforestation and emissions from cropland. Biomass emissions are not seen as important, as they are counted as neutral in energy use, while commitments under the Kyoto Protocol and to the European Commission are usually based on emissions excluding LULUCF. Countries also have slightly different practices in how they report future emissions. Some base this on extrapolations of past developments (even if it results in an increase), while others envisage measures to reduce emissions and report expectations below the targets they have committed to.

The emissions are counted in the emitting country, so electricity generated in Denmark and used in Norway, for example, impacts the Danish emissions. Further, there is a development in the life cycle of some fuels, such as hydrogen, that are showing higher overall emissions than anticipated earlier. Thereby, some of the “emission free” energy sources are now being regarded differently.

In light of this, the accounting system for emissions may well change between now and 2050 (and even 2020). However, the current policies and definitions of a “climate neutral” future are all based on this accounting, so we will also use this in demonstrating how the Nordic region could reach climate neutrality, as defined today.

An important implication of this is that it is possible to be “CO_2-negative”. One example of this is making biogas from manure that otherwise would emit methane (more climate potent than CO_2[1]) and using this biogas to replace fossil fuels in transportation and power/ heat generation. Another is capturing and storing emissions from biogenic sources. Including some “negative emittions” in the accounting will make it more realistic to reach neutrality earlier.

Sustainability
Normally when this word is used these days, it is to indicate that a sustainable solution is kind on the environment. However, there is another interpretation also: Sustainable solutions are able to be economic. Many new energy solutions are being subsidized to get quicker into the energy systems, but subsidies of large parts of the economy are not sustainable, as we are seeing in Europe today. So, by 2050 we assume that most of the energy needs to be economically sustainable as well – bringing a further challenge to making a realistic total energy scenario.

Payability and the place of CCS in the merit order of abatement

As the people of the world are more concerned about climate change, the ability and willingness (priority) to pay to reduce the man-made impact on it can increase. Conversely, if the concern falls (some indication this year), there may be less payability for cutting emissions. In this report we have assumed growing climate concern, and a global goal of long term climate neutrality. That means that all countries will make an effort, so we do not have a hypothetical situation of only the Nordic countries changing their energy systems. The payability could well take the shape of a global cost/ tax for CO_2, or just caps by country making energy with emissions more expensive. If a single global cost in a liquid market is expected, there will be a merit order of abatement expressed in cost per ton ($/t). As there are many types of abatement, ranging from efficiency to new renewable energy, it can be difficult to estimate today where CCS will be in this merit order.

[1] About 24 times in a 100 year perspective, more than 80 in a 20 year perspective.

Figure 16 – Nordic emissions

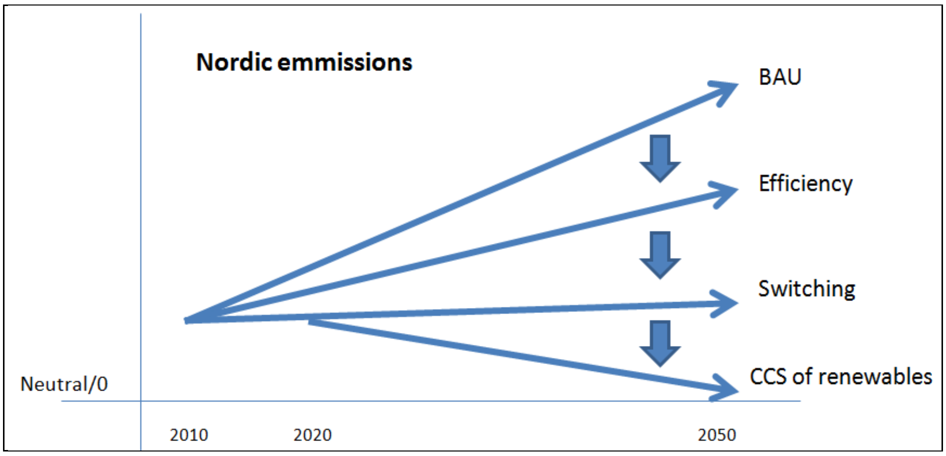
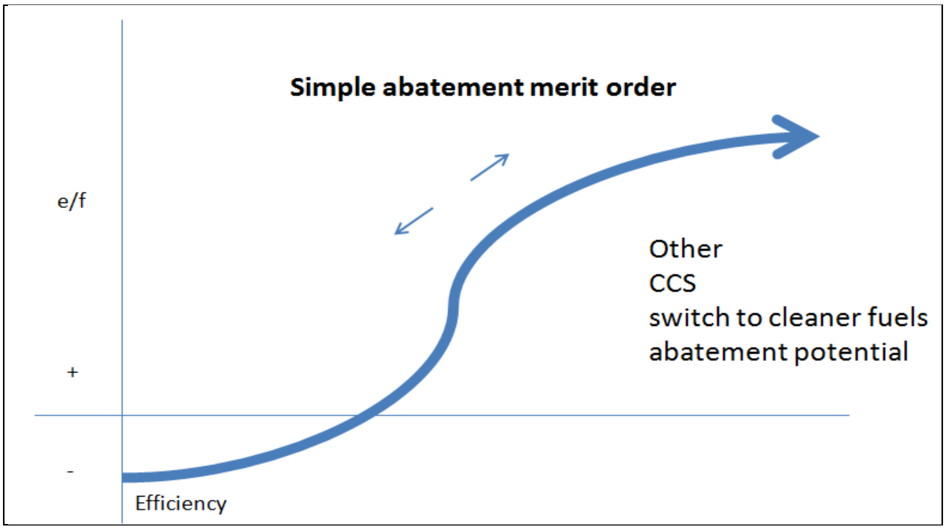


Figure 17 – Simple abatement merit order



However, we have seen that some of the "already economic" measures, such as energy efficiency, are not being effectuated. That means that planners cannot assume that all measures will be taken in a clean order and that some more expensive measures may well be taken before all the cheaper measures globally have been exhausted. This is how the logic is for CCS in the Nordic countries (mainly Norway) today – it should be done and further developed in the countries that can afford it. If the future has a global price and merit, it may be cheaper to do much abatement in some of the countries that have high emissions per capita, due to inefficiency. As energy prices rise (and especially as subsidies are lifted) this is happening already to some degree, but not as fast as some had hoped. Even in the Nordic countries, the role of taxes, tax rebates and subsidies are impacting energy preferences and levels of efficiency, albeit in different ways:

1) In Denmark, subsidies related to burning bio fuels for power generation have increased the generating capacity able to do this – normally coal generators – and these fuels are used to maximise subsidies (with the option to burn coal for the rest of the time).
2) In Norway, tax rebates on heavy fuel oil for heating in some industry could well keep oil burning as preferred fuel longer than otherwise and delay conversion to bio fuels
3) In Norway, the introduction of CO_2 tax offshore has improved energy efficiency and triggered storage of separated CO_2 at Sleipner.
4) In the future, technology may make valuable products from CO_2, and this would bring Carbon capture in a different light. See separate discussion in the following chapter.

Future developments will depend on several factors, including cost of energy and cost/taxes on emissions. All of which is unclear, and new possible solutions are launched constantly. One example is the recent suggestion from the Norwegian Prime Minister leading the group responsible for financing climate measures in developing countries (as promised in COP15). He needs an annual sum of $100bn and has, partly in light of the recession in the developed countries, suggested high CO_2 taxes on international air and ship transport emissions. This could again impact mode of transportation, overall emissions (and need for the traditional sources to cut to meet targets), location of industry, and more.

Transportation

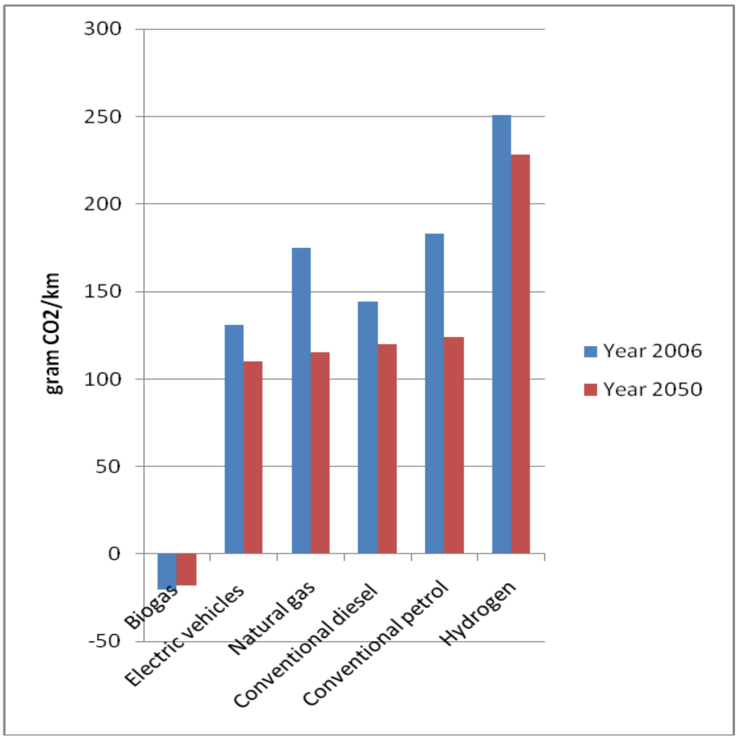
Whether transportation continues as today, largely with oil products, makes a dramatic shift to electricity or converts to bio fuels will greatly impact emissions as well as demand for each of the energy forms used. As in the other sectors, the main assumption will be that the world wishes to emit less CO_2, so better technology for fuel efficient and emission free transportation will develop. Already many new vehicles can take advantage of cleaner fuels, so probably only a small share of 'classic' cars would still use petrol or diesel in 2050.

Electric vehicles exist today and are expected to grow in use. This will, in itself, increase the demand for electricity. Further, the life cycle emissions are currently quite high, compared to current and most future fuels. Equally, hydrogen has a high life cycle emission of CO_2, as it is frequently produced from hydrocarbons (oil and gas, for example). If this is made from geothermal energy, then emissions are naturally lower, but that brings issues of location and transport to the markets. Biogas is currently the only CO_2 negative transportation fuel. Although there needs to be built much more capacity, in the longer term this should be possible. Meanwhile, there are natural gas and other bio fuel solutions that could be a better bridge to this future than for example electricity.

Importantly, one does not exclude another, and there will probably be a diversity of transportation technologies in the future. In addition, it is assumed that there will be better public transportation, both more tempting to more people and more emission efficient than today, as local fleets are easier to convert to renewable when refuelling infrastructure is developed. New plane fleets would be considerably more energy efficient and new technology would allow a large share of bio in the fuel mix for planes, significantly lowering emissions. Sea transport could grow to 2050, but we also expect a shift away from oil, especially as international shipping emissions will have been long counted and large global players will have sought the deployment of new fuels. Gas and bio fuels would be commonly used for ferries, while personal boats could be propelled by electricity.

Capturing CO_2 from automobiles is difficult. To reduce emissions in this area, the vehicle mix must be changed. Use of hydrogen cars will be a challenge for the Nordic countries because of the large territory and small population, making economical hydrogen distribution very difficult. With CCS on the production of hydrogen, the CO2/km would fall dramatically (from the highest today of all technologies considered – see table below).). However, although electricity supplies are more readily available a life-cycle analysis for electricity points out the need for cleen generation, possibly including CCS.
In recent work, we have observed different logics between Nordic countries, especially when it comes to renewable energy and transportation. In Sweden, there is a large use of biogas, which is rapidly reducing emissions from transportation. In Denmark, on the other hand, biogas is used for CHP (near the production) and not considered for transportation. At the current outlook, Denmark does not seem to meet its 20-20-20 requirements of renewable energy in transportation, even if adding biogas to the transporation fuels would count as CO negative, as the following figure illustrates.

Figure 18 Comparison of emissions by transportation technologies 2006 and 2050



Source: Energistyrelsen, based on COWI update 2010

Industry

One of the biggest questions for the energy situation in the Nordic countries is what the future of heavy industry will be in the region. There are several options, and trend is emerging: Although the plants were built here throughout the last century in the promise of cheap energy (and labour), the markets and new plants to feed these are often far from Northern Europe, such as China or Qatar. When there is enough capacity in other countries, there may be less need for the heavy industry in this region. This will take a large part of the power demand out, which again will impact the power system with regard to balancing as well as need for new generation.
Much of the newer plants would have lower emissions, due to higher efficiency with better technology and more focus on energy costs.

Demand could decrease also in the pulp and paper industry, also since the information society in 2050 would use less paper than today.

Fuel use

Industry needs energy that can cover their needs securely and affordably, and they will continue to display stronger preference for fuels which have these qualities. Constraints on emissions are likely to play an important role in the relative affordability of fuels, but it is impossible to tell at this point what the role of oil price would be in this in 2020, even less so in 2050. However, in a world of high carbon prices and increasingly scarce and expensive oil, traditionally one would say energy has to come from either coal with CCS or natural gas –with or without CCS. That might well be the case for part of the industry, but one current trend already in less heavy industry is the use of bio fuels –such as black liquor in pulp and paper, especially in Finland and Sweden. This is today counted as emission free, although it has both CO_2 and particles. Capture of such emissions would, with the current accounting system, provide negative emissions and less local pollution. Typically, CO_2 from industry is cheaper to capture comparing to flue gas from power plants.

Ultra Low CO_2 Steelmaking (ULCOS)

Would steel making still be a viable business in 2050 for the Nordic countries or EU? ULCOS, an EU program, was launched by 48 partners and is currently in progress. In the interim report several energy sources were investigated including gas, coal, hydrogen, biomass and electricity. Phase 1 of the study has been completed and the report issued. Phase 2 will investigate some of these options in further detail. It is expected that the study holds promises for reducing CO_2 emissions and for economic viability in a post-Kyoto, carbon constrained world. CCS for steel making is a necessity and biomass is a clever option to keep open.
The Nordic countries should wait for conclusions of this study before launching their own program.

Offshore oil production
Only Denmark and Norway have oil production today, and in both countries production is falling. This will result in an overall reduction in emissions from the sector, however with continuous maturity of the fields; energy consumption per barrel of oil produced will increase, as water content in the reservoir fluid increases. It is expected that offshore power generation will remain the main source of energy to compress the gas from oil production, stabilize the reservoir fluid for transportation to market and to provide energy for pumping and living quarters on the platforms. This can be produced at the field (normally gas turbine) or with electricity from shore (current preference in Norway).

Electrification by installing subsea cables and transformers may not be the right solution. Reasons are:

- Cost of electrification will be very high. It may not be the best way to allocate the financial resources
- Most of the offshore oil production is stabilized on the platform to meet market and tanker specifications by heating up the reservoir fluids. The heating requirement is normally provided by waste heat from the power generation turbines. Using electricity delivered from shore for heating will not be economical
- There is a shortage of energy at times in Norway, as little generation is built and often (other?) measures may be easier.

It may be better to encourage the operators to use energy efficiently by providing economic driving forces such as the CO_2 tax imposed in the Norwegian sector. Furthermore, oil production from the Nordic offshore is expected to fall significantly, thus CO_2 emission from offshore may not be a large issue in the 2050 time frame.

Refineries
The demand for the high octane gasoline and ultra-low sulphur specification of the diesel fuel has increased the demand of hydrogen. Since hydrogen is produced from the reforming process, i.e. breaking up hydrocarbon to produce hydrogen and CO_2, production of CO_2 from refineries has increased. However, CO_2 capture from the refining process is cheaper than capturing the gas from the power plant, because gas from the reforming process has a higher CO_2 concentration and pressure. Capture with the conventional amine process is more efficient and less costly than the specially-developed amine processes for capturing CO_2 from the power plant flue gas. This could be seen as a low hanging fruit for CCS.

Gas processing
Onshore gas plants will require electricity to drive the compressors and steam for the fractionation trains. New gas plants normally designed to purchase electricity the grid only generate enough steam for the fractionation trains. For the older plants, however, steam boilers are installed for both power generation and steam production. Some of these boilers are open cycle and relatively small, thus having low efficiency and also making CCS capture costly.

For the onshore gas and oil processing plants, CHP will offer an interesting alternative to increase energy efficiency. CCS for the low hanging fruit such as reformer off gas should be collected first.

Residential and commercial
With more appliances and better economic conditions in all the Nordic countries, the energy demand is still growing, well above previous expectations. The Nordic countries have a large share of electricity, even for heating, in their energy mix. In some cases, this is replacing central heating with fuel oil, which is an improvement, but in other cases, it prevents central heating systems that could have used district heating or bio fuels directly.

CCS of bio

Capture emissions from biogenic sources

CCS on Renewable

- CCS in renewable power plants is not yet being considered
- Power plant efficiency could be increased with CHP
- Adding CCS to a renewables combustion plant could provide opportunity for negative carbon emission
- Technology to integrate renewable power plant and CCS yet to be investigated
- Cost is likely to be high due to low energy intensity of the bio-fuel and inherent high cost of the capture plant
- Should keep the simplest form of biomass, because transportation (as opposed to China) may not be an issue, i.e. both algae production and power plants are located near shoreline.
- Concept study is required to define R&D needs.

Scenario of emissions for the Nordics in 2050

Based on the above analysis of current situation, plans, and expected realistic developments, a future picture of energy and emissions has been developed. It takes in all the assumptions and conditions described above and in addition a full energy view to ensure realism from a cost, income as well as operational and regulatory perspective. The table below summarises this, while the following sections describe each country in more detail.

Table 2 – Greenhouse gas emissions in the Nordic countries in 2050, metric tons

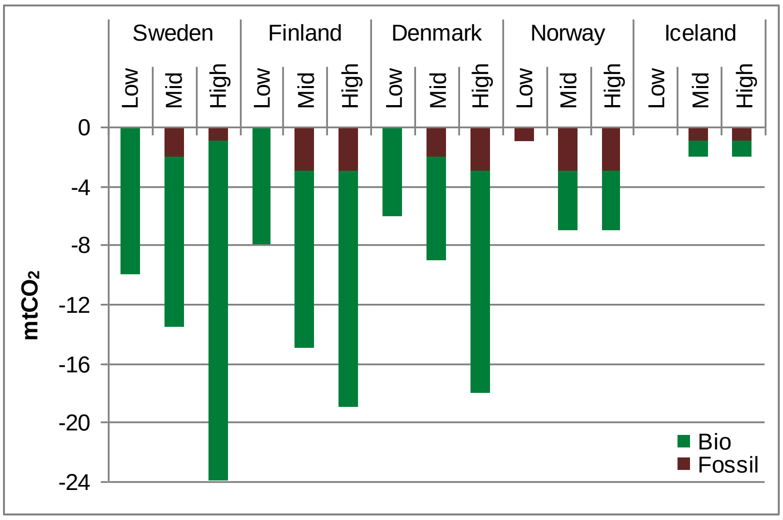
		DENMARK	FINLAND	ICELAND	NORWAY	SWEDEN	TOTAL
	Total emissions including biomass, excluding LULUCF	24	44	2	17	43	130
REPORTED	**CO_2 from fossil and other greenhouse gas emissions**	9	13	2	11	12	47
	Fossil CCS	-2	-3	-1	-3	-2	-11
	Energy Industries, of which:	1	2	0	2	2	7
	Power and Heat	1	2	0	0	2	5
	Oil and Gas	0	0	0	2	0	2
	Manufacturing Industries, of which:	3	3	0	3	3	11
	Energy for manufacturing industries and construction	2	1	0	1	1	5
	Industrial Processes	1	2	0	2	2	6
	Solvent and other product use	0	0	0	0	0	0
	Transport	1	2	1	2	1	6
	Commercial/Institutional	0	0	0	0	0	0
	Residential	0	0	0	0	0	0
	Agriculture	2	3	1	2	4	12
	Waste	0	0	0	0	0	0
BIO	**CO_2 from biomass, of which:**	24	46	2	13	45	130
	Bio CCS	-7	-12	-1	-4	-12	-36
	Power and Heat	6	15	0	2	13	36
	Manufacturing and Construction, of which:	3	9	0	3	10	25
	Pulp and Paper	0	14	17	2	0	33
	Transport	5	5	1	3	8	22
	Residential and Commercial	3	4	0	2	3	11
	Net fossil emissions of greenhouse gases in 2050	0	-2	0	4	-2	**0**

Source: Sund Energy analysis 2010

The table shows gross emissions first, and then reported emissions. Of the total reported CO_2 of 47 MT, 11 will be captured giving a net of 36 MT. A large part of energy has been switched to bio, which is not “counted”. Capturing 36 MT of biogenic sources, will give a “credit” of 36, against the net reported emissions of 36 MT, making the Nordic region CO_2 neutral.

From the table, it can be seen that the countries are not all climate neutral. Norway is expected to be climate positive, Sweden and Finland climate negative and Denmark and Iceland neutral. Together this makes the region neutral and may well be more economic than striving for neutrality in each country. ***Synergies and relative strengths have been considered, both for the region as a whole and for each country, to combine in a more optimal way to become climate neutral with renewables and CCS.***

Figure 19 Outcome of 2050 climate neutral scenario - role of CCS

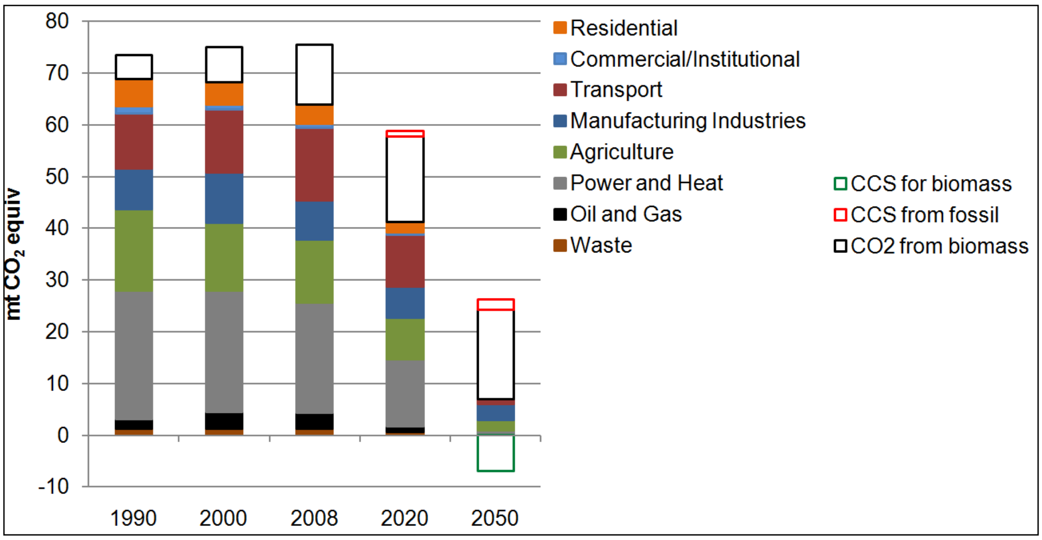


Source: Sund Energy analysis 2010

Denmark in 2050

If Denmark manages to redesign its electricity and transportation sectors so as to minimise carbon footprint, it will stand a good chance for becoming carbon neutral in 2050. CCS would have to play a major role in this though, capturing and neutralising 2 $mtCO_2$ from fossil sources and as much as 7 $mtCO_2$ from biogenic sources that can be counted as negative.

Figure 20 – Historic and scenario greenhouse gas emissions for Denmark in 2020 and 2050



Source: Sund Energy based on **European Environment Agency, EU GHG Data Viewer, 2010**

We assume Dong Energy would have achieved its turnaround to 85% renewables in the energy mix on time in 2040 and that wind power would be a significant important contributor to Denmark's electricity mix. Fossil emissions from power and heat would have thus decreased to just 3 $mtCO_2$, of which 2 $mtCO_2$ fitted with carbon capture technology. As turning biomass into coal is now being perfected, the remainder of emissions, as high as 24 $mtCO_2$ could be biogenic. CCS technology may not be seen as needed or attractive by the Danes in 2010, but by 2050 as much as 7 $mtCO_2$ of their biogenic emissions could be captured, giving large negative emissions.

Emissions from industry in 2050 would mostly come from energy use in the processing sector, but thanks to a switch to biomass for electricity and heat we suppose only 3 $mtCO_2$ would still be fossil, another 4 $mtCO_2$ being biogenic emissions of which 1 $mtCO_2$ could be captured. This amount of negative emissions should be enough to offset those from processes in the cement sector, leaving manufacturing and construction with net fossil emissions of 2 $mtCO_2$.

Assuming Denmark will have large amounts of electricity from wind, a smart electricity grid and an effective battery fast charge infrastructure, probably about half of its transportation could be fuelled by renewable power. Bio fuels could cover demand from the remaining fleet, emitting 5 $mtCO_2$ that are considered carbon neutral, with net 1 $mtCO_2$ from natural gas mixed with bio methane. In the residential and commercial sectors, a switch to renewable fuels –especially biomass- could replace fossil emissions with biogenic ones, while energy efficiency, better insulation and a warmer climate could take even biogenic emissions down to 3 $mtCO_2$ equiv.

In agriculture, about half of greenhouse gas emissions would probably keep coming from fertilizers and land management, with the remainder would be accounted for mostly by livestock. With better manure management and increased use of crop waste, biomass and biogas could be available to fuel part of the transport sector –including agricultural equipment. In this situation, we suggest for Denmark net emissions of 2 $mtCO_2$ equiv from agriculture in 2050.

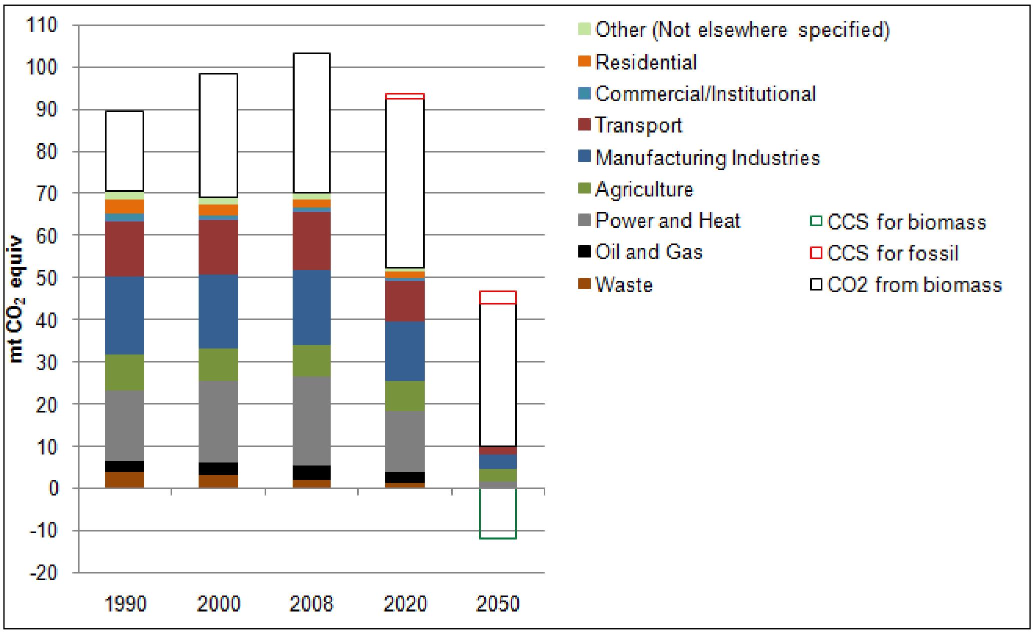
Denmark could become climate neutral by 2050, without counting efforts to include international offsets.

Finland in 2050

Outlining options for cutting emissions by at least 80% to 2050, the Finnish Government sees the need for a 4.5% annual reduction in greenhouse gas emissions beyond 2020, provided the interim goal of 20% is met. In a carbon neutral scenario, even larger emission reductions are needed in all emitting sectors, and especially in power and heat generation, manufacturing and transport.

Fully decarbonised heat and power is difficult, but we assume that by scaling up nuclear Finland would phase out all oil and coal without CCS from the generation mix by 2050. We also suggest that 2 $mtCO_2$ could be captured from coal plants, while peat (counted as fossil) would stay in use. Natural gas would supplement bio methane in cogeneration plants. Overall, we suggest emissions from fossil sources in the power and heat sector of 2 $mtCO_2$. The gradual switch to biomass would add 10 $mtCO_2$ of biogenic emissions compared to 2008. If only 2 $mtCO_2$ from biogenic sources are captured (CCS in thermal plants is difficult), the power and heat sector would be decarbonised. Biogenic CCS counted as negative is the only difference leading us to a lower emission scenario than the Government's vision of emissions in 2050.

Figure 21 – Finland: Emissions in Nordic neutral scenario



Source: Sund Energy based on **European Environment Agency, EU GHG Data Viewer, 2010**

In manufacturing, most fossil emissions come from pulp and paper. The industry could play a key role in lowering the Finnish footprint domestically. With increased efficiency and slightly decreasing activity, energy could come exclusively from biomass, phasing out by 2050 emissions from fossil fuels. We assume the sector will only emit 14 $mtCO_2$ of biogenic emissions, of which 7 $mtCO_2$ in the larger units would be captured. This makes pulp and paper carbon negative. We also assume that emissions of CO_2 from the cement, iron and chemical industries would decrease, with the remainder partly switched from fossil to biogenic by 2050. CCS would be possible for steelworks and cement. We suggest 4 $mtCO_2$ could be counted as fossil (of which 1 $mtCO_2$ captured from processes in cement production), while 5 $mtCO_2$ would be biogenic (and 3 $mtCO_2$ of this, partly in the steel industry, could be captured). These assumptions imply net neutrality in emissions from these industries. Overall, industry would give 7 $mtCO_2$ of negative emissions.
With improved efficiency, Finnish scenarios assume 30% cuts in emissions from transport, while 10% savings could come from rationalization of logistics. We thus assume fossil fuel combustion would only emit 2 $mtCO_2$ equiv. According a forecast by the Finnish Energy Industries up to 50% of vehicles could change to electricity until 2050 when 40% would choose chargeable hybrid and only 10% then would remain on petrol or diesel as fuel. Agriculture would probably still account for 3 $mtCO_2$ equiv in 2050, mostly as methane from livestock and direct soil emissions. Finland could

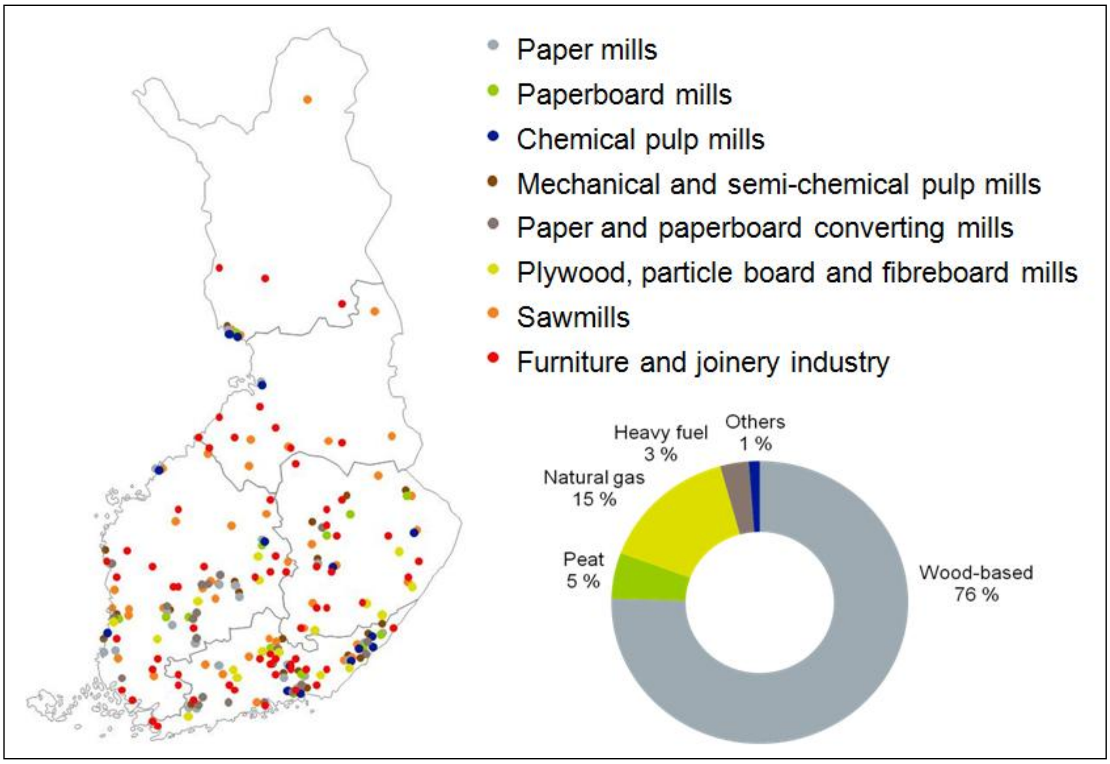
reduce fossil emissions to 10 $mtCO_2$ in 2050. In this scenario, the 12 $mtCO_2$ of CCS for biomass assumed in power and industry would lead to 2 $mtCO_2$ negative net fossil emissions.

CASE STUDY: CCS for biogenic emissions in the pulp and paper sector in Finland

According to the latest Technology Roadmap for CCS from the International Energy Agency, 1% of CCS projects in 2050 could be in pulp and paper, capturing and storing 40-50 $mtCO_2$ p.a. The forest industry provides 70% of Finland's renewable energy and accounts for one third of electricity use in Finland. In 2008, the pulp and paper industry emitted 22.6 $mtCO_2$ (22% of total fossil and biogenic emissions excluding LULUCF), of which biogenic emissions accounted for 18.7 $mtCO_2$ (57% of total biogenic emissions).

The government wants to triple the production of wood chips by 2020 and support development of second generation bio refineries. Three bio-diesel plants are in planning, each developed by a team consisting of one forest industry player and some other energy actor. They would use wood as fuel and it may be an option to capture CO_2 later.

Figure 22 – Location of forest industry in Finland and energy use by fuel type (2008: 67.7 TWh)



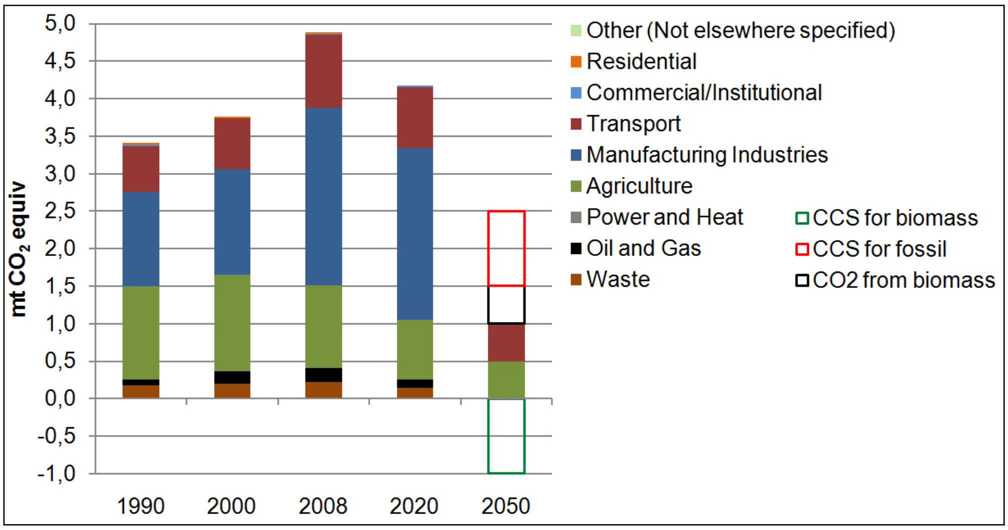
Source: Finnish Forest Industries, 2010

According to the Ministry of Employment and Economy, CCS in the pulp and paper industry could be viable for larger units. The problems they see are the long distances for transport and the lack of storage possibilities in the country and so far also in the Baltic Sea Region. The first units could be operational in 2020 and some experience could be gained. Geographically, the units might be located on the west coast, allowing for ship transport. There is also an ongoing research project (Carbonates in Energy Technology; 2008-2011) which is looking at storage or use of captured CO_2 as carbonated minerals in Finland, instead of finding storage sites in Norway or Russia.

Iceland in 2050

With an abundance of cheap and clean energy from geothermal, Iceland could become carbon neutral by 2050. However, it is likely that Iceland will continue to host several energy intensive industries. Government scenarios expect metal production to continue to be an important source of process emissions, so a long-term target could be to fit CCS and capture the corresponding fossil emissions. We assume that efforts at increasing the natural carbon sinks would allow a switch to biomass for part of the energy intensive industry. In this case, 1 mtCO_2 would be biogenic and 1 mtCO_2 would still be from fossil sources and would be captured. Supposing then that the biogenic emissions are also captured, manufacturing would have 1 mtCO_2 negative net emissions.

Figure 23 – Iceland: Emissions in Nordic neutral scenario



Source: Sund Energy based on **European Environment Agency, EU GHG Data Viewer, 2010**

Due to very low population density, large distances between localities, harsh climate and lack of transport alternatives, the use of large vehicles is common in Iceland. While we expect some bio fuels to be produced locally as forestation proceeds or imported and then blended in the fuel mix, as well as electric cars to be used in Reykjavik and some hydrogen cars for heavy traffic, some fossil fuels would probably still be used in transportation (especially for the fishing fleet), emitting 0.5 mtCO_2 equiv in 2050.

Agriculture would also see a reduction in emissions from better livestock and land management, similar to the other Nordic countries, but at least 0.5 mtCO_2 equiv would still be emitted in 2050. All in all, Iceland could become climate neutral on its own.

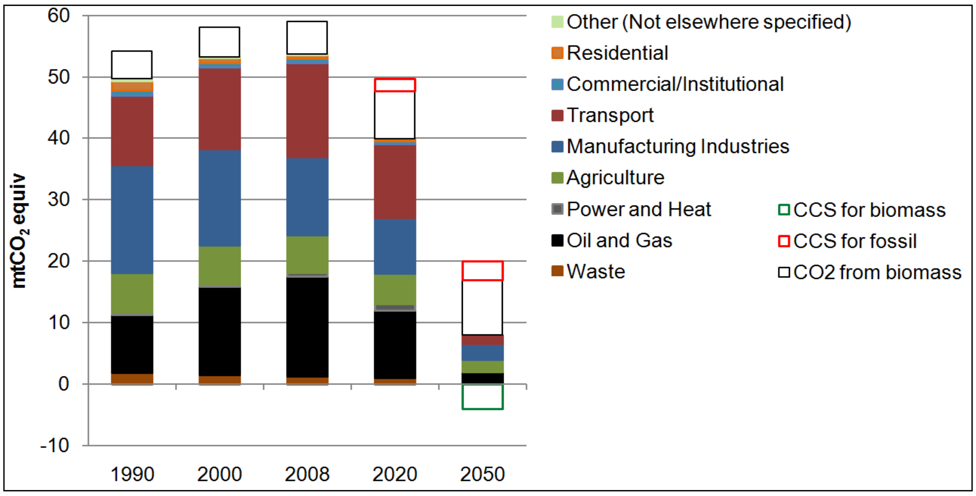
Norway in 2050

Due to large distances, low population density –though increasing slightly, especially in the south–, continued activities on the NCS, as well as a high relative cost of cutting emissions domestically, we do not believe that Norway can become carbon neutral in 2050 on its own and by means of only domestic emissions reductions.

The oil and gas sector will most likely still see some activity in 2050, although at significantly lower levels than today and with better technology. Offshore wind might replace natural gas in powering operations on the functional platforms, but 3 $mtCO_2$ equiv would probably still be emitted in the oil sector, partly from unavoidable leakage of methane. In power generation, higher population and rebound effects, together with the electrification of transport, will lead to at least 10% increase in demand compared to 2008, despite efficiency improvements. We expect Mongstad to remain the only gas fired plant and refinery with CCS technology in Norway, additional supply coming from offshore wind, biomass -including algae- and new small hydropower.

Assuming industry does not shut down in Norway, manufacturing and construction would also see a fall in emissions, as well as a switch to biomass for energy. In our scenario building exercise, we see potential for two new CCS units in the sector – the cement plant at Brevik capturing fossil CO_2, as well as one unit capturing CO_2 from biomass, which would be accounted as negative.

Figure 24 – Norway: Emissions in Nordic climate neutral scenario



Source: Sund Energy based on **European Environment Agency, EU GHG Data Viewer, 2010**

In transport, the deployment of bio fuel and electric cars could probably replace most fossil fuels by 2050. We suppose electrical power could propel more than half of the car fleet, while most of the rest would be hybrids, including biogas and second generation bio fuels. We also suppose air transport to increase to 2035, followed by a reduction as high-speed rail connections are opened on routes like Oslo–Stavanger, Oslo–Bergen and Oslo–Trondheim. In this context, we see fossil fuel emissions down from 12 to 1.5 $mtCO_2$ equiv, with biogenic emissions up six-fold to 3 $mtCO_2$ equiv.

As the climate gets warmer, agriculture could expand and become more productive. With higher population in the south, demand for meat and dairy products could increase slightly despite lower use per capita. Productivity should grow, so Norway could have less livestock in 2050. We assume manure would be captured and used as biogas, while improved land management would remove associated emissions as crop waste would be turned into biogas. Biomass and biogas could power and heat the farms, as well as fuel the tractors, so agriculture emissions could be 2 $mtCO_2$ equiv.

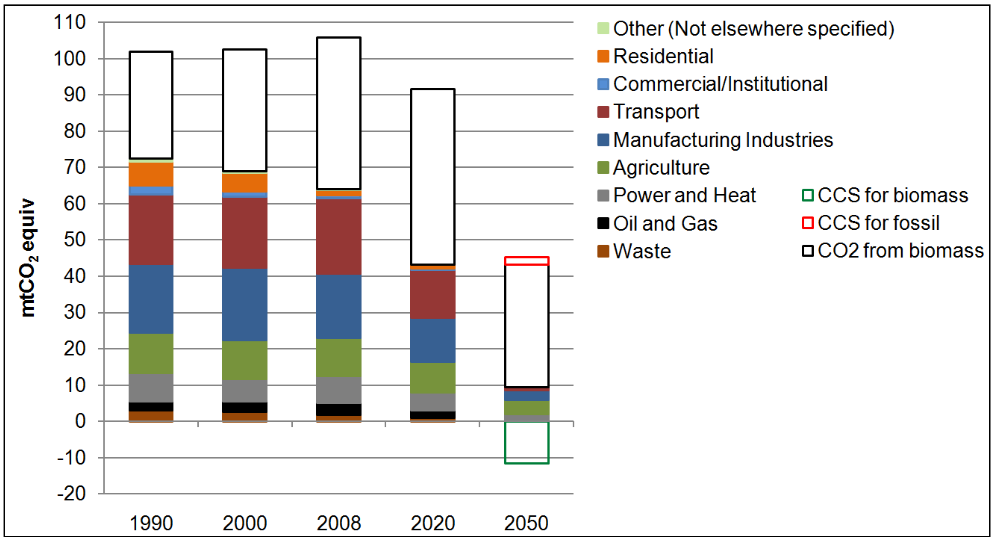
Considering all these, Norway would still have 4 $mtCO_2$ equiv of fossil emissions in 2050, to be offset by overall negative emissions in the other Nordic countries.

Sweden in 2050

Sweden has the lowest per capita emissions in the Nordic region, being well positioned to become carbon neutral domestically by 2050. In order to achieve this, emissions from the four main sources –power and heat, transport, manufacturing, agriculture– would have to be removed almost entirely, and we believe this is feasible provided strong political commitment, including for CCS.

Under the burden sharing agreement of the European Union, Sweden would see by 2050 a large increase in energy efficiency, so we suppose overall electricity demand could decrease by 10% compared to 2008, despite the large uptake in transportation. In this context, one can imagine most demand for electricity covered by nuclear, hydropower and wind. Biomass would go to decarbonise mobile emission sources, but some would also fuel CHP units to provide carbon-free electricity and heating for the commercial and residential sectors. We suggest capturing 2 $mtCO_2$ equiv emitted by large bio-CHP plants, giving negative emissions.

Figure 25 – Sweden: Emissions in a climate neutral scenario 2050



Source: Sund Energy based on **European Environment Agency, EU GHG Data Viewer, 2010**

We assume emissions related to manufacturing and construction would decrease considerably by 2050. Pulp and paper companies have an important role in this, using biomass for energy needed in the production process, releasing biogenic emissions –they give most of Sweden's CO_2 biomass emissions. As the sector shrinks slightly, switching entirely to biomass could lead to 14 $mtCO_2$ from biogenic sources in 2050. If we suppose capture of 10 $mtCO_2$ of the biogenic emissions in the large units, pulp and paper could offset fossil emissions in both manufacturing and other sectors.

With plans for fossil-free transportation by 2030, Sweden could be importing biomass for bio fuels in 2050, in addition to using most of its domestic potential. We assume one third of the car fleet, especially buses and heavy duty trucks, would be powered by biomass, with biogas contributing to half of this. Natural gas would be a backup fuel to bio methane in case of shortage. While road traffic could become fully decarbonised, sea and air transport would still see some fossil fuel use. We estimate transport to account for 1 $mtCO_2$ equiv in fossil and 8 $mtCO_2$ equiv in biogenic emissions in 2050.

A warmer climate will benefit agriculture in Sweden. Similar to Norway, we assume more people would demand slightly more meat and dairy products, but productivity will also grow, so livestock in Sweden could have decreased considerably by 2050. This might even make it difficult for farmers to produce enough biogas, from less manure and only slightly more crop waste. Emissions from agriculture could be reduced by 2050 to some 4 $mtCO_2$ equiv. Overall, Sweden could have negative emissions of 2 $mtCO_2$ equiv in 2050.

VI. Some observations and key issues to focus on in a renewable future

Balancing energy, especially power, to meet demand with fluctuations in supply

With much renewable sources and nuclear, the power generation sector will have a challenge balancing its generation to match demand. Typically, nuclear plant run base load (flat). Wind mills will naturally depend on the wind, which is at times unpredictable and at times lacking in cold spells. Therefore, there is a need for balancing power capacity. This is today covered to a large degree by gas plant, and some coal plant in Europe. Hydro power can also be used more variable than other capacity. Further, the large share of heavy industry in the region has been a source of flexibility, as they may at times turn off at peak periods, freeing capacity to other areas of demand.

This aspect of the power market needs to be considered when building new capacity and changing not only the fuels but the technology of power generation in the Nordic countries, especially if it is expected less heavy industry and much new capacity requires base load to be economic.

It has so far been assumed by planners of CCS that they will run base load and mainly on coal plant (lowest cost per abated ton CO2). One gas plant planned for intermittent supplies has had CCS considered for it (Kårstø in Norway), but this has since been cancelled. Two developments can be seen for the future generation mix.

- The market will be more vulnerable and more difficult to balance with less flexible and less predictable generation capacity
- There will be a greater need for balancing power, as demand continues to be peaky and there is less base load industry to turn down

A renewable generation mix would require expansion of the grid, both within countries and between countries. This is already under way. In addition, managing demand down and making it more flexible will be cost efficient solutions that many grid operators are considering in meeting their future balancing challenges.

It is expected that more generation can also be in large industrial and municipal CHP, and partly by biogenic sources. Further, it is expected that other countries will face the same challenges and that technology will develop to improve the agility of CCS to meet a higher need for variable generation patterns. Several studies have been made of this in Great Britain, where a strong move to lower CO2 emissions have resulted in strong emphasis on nuclear, wind and CCS, realising that gas plant for peaking may be difficult to get economic. ***This question is complex and could well be worth studying further. One way to improve both the economics and agility of plant could be to integrate power generation with CCS, rather than viewing CCS as a simple add-on to an existing plant.***

Actual CCS projects – case study from Norway

Of the Nordic countries, it is Norway that has been leading the planning of and spending on CCS projects for the last 6 years or so. Many projects have been studied by several parties, but two projects have had the largest attention: Mongstad and Kårstø. Both are gas fired generation, and both are now postponed significantly. This short review is intended to draw learning from the processes, so that this may be avoided in the other countries and in the future even in Norway.

Why CCS?

Norway has a very high dependency on hydro power, making the country vulnerable to dryer years, and has already had a few critical situations with extreme electricity prices. The transmission system operator (TSO) is concerned about security of supply and is investing in mobile reserve generators to avoid rationing. These would be placed at critical points short of energy, typically along the west coast of Norway, and would run on natural gas. Norway is a large producer of natural gas, but hardly uses any of it at home. There has been a difficult political situation around using natural gas, partly as it is bound to increase CO_2 emissions compared to hydro power. On the other hand, electricity demand is increasing and there are limits to how much more hydro capacity it is possible to build (largely for environmental reasons). Gas power plants have been suggested for many years along the coast (typically where the gas is brought to shore), causing strong political tension (including the resignation of a prime minister). Much research was put into how to make "gas power generation CO_2-free", with large funds made available to projects through Gassnova (and Climit). The current coalition government agreed on a compromise during its "kick-off" at Soria Moria (also the name of its founding policy): Build gas power generation with CCS from the start ("from day one"). This allowed for planning of both Kårstø (now running) and Mongstad. In addition to being a political tool to allow for new power generation, CCS was to show the world how to reduce emissions (ethical argument based on Norway's oil riches) and perhaps become a new area of income for Norway.

How CCS?

Kårstø was the first plant where CCS was going to be implemented. The owner of the plant, Naturkraft (originally Statoil, Hydro and Statkraft, now only Statkraft and Statoil) were ready to build after years of planning and negotiations. The CCS process was therefore getting urgent to have something at start-up. Bidders were reluctant to work on this project before they were paid for their efforts. Government agencies were given tasks to look at different part of the chain: sources, technology and possible EOR. Later it was concluded that the power plant was not running base load and would result in very high unit cost of captured CO_2. First delay was to 2009, now there is a plan to integrate the power plant with the gas processing plant (one of the largest sources of CO_2 in Norway). This will give base load running of the power plant and also reduce some of the emissions from the processing plant – making the capture project more tempting. An integration study was commissioned, however, the study concluded that the unit cost of CO_2 capture is cost prohibitive.

The next plant was CHP at Mongstad, in conjunction with the Statoil refinery. This was to be a full scale plant able to test capture technology on several types of emissions (gas fired generation as well as emissions from the refinery) and would start with a small scale test facility before going full scale. Partners included Statoil, Shell and Dong Energy in addition to the government. This was called Norway's "moonlanding" by the ex-prime minister. Much time and money has been invested, and the test plant is now being developed. However, due to the delay of the test facilities, the full scale plant will proceed without waiting for the conclusion of the pilot facilities. The full scale plant has, after much discussion and increasing budgets, been delayed (decision will not come during this government period, i.e. to 2014).

Other projects have been studied at Tjeldbergodden (with EOR), in Grenland and at Ormen Lange, and both rejected, because the Government will not make additional commitments after the costly commitment made to Kårstø and Mongstad. The political statement of no gas fired power generation without CCS is one of several reasons no other gas power plants have been decided in the last 5 years, making the power situation more critical and resulting in more imported electricity from coal and nuclear fired generation from other countries.

Now what?

As other countries are progressing with their CCS plant, Norway may want to rethink its strategy and main drivers for CCS: It will not be leading the world to new technology, there are several competitors to Norway's technology (Aker Clean Carbon is getting more practice in the UK than at home) and it will not be a significant measure in abating Norwegian emissions. The famous Sleipner project of separating some CO_2 out of the natural gas (to meet quality requirements in the markets) and injecting it in the geological formation below the field is continuing, and is similar to projects in other countries, such as Algeria. There is much interest in this activity, and this could be an area of business at some point. Meanwhile, other countries, such as Denmark and Qatar, are finding value in using CO_2 for EOR, which may be a competitor to such business.

Research is continuing, as Toppforskningsinitiativet is an example of, and especially technology is being favored in these projects. Other countries are also looking at possible value that could make the solutions more (economically) sustainable long term and in addition how society could accept this as a solution, both from money and safety perspectives.

What can we learn?
All change and policy is easier when the purpose and drivers are clear and motivating. The Norwegian government wanted to please its voters by showing action – less action could have the effect that the voters judge CO_2 as less of a problem and will not reduce their own emissions (larger). Also, the large investments needed will necessarily be compared to other use of those funds, both domestically and abroad. As can be seen from the opinion poll among Norwegians (societal aspects), there is less understanding for CCS as a good climate measure, compared to others (such as more wind and hydro power). This could be explained with unclear goals, high costs or lack of understanding, all of which should be learning points for other countries trying to introduce CCS. The UK government(s) have been clearer: The need to reduce CO_2 significantly, want to give a boost to CCS (with condition of knowledge sharing, like the other EU countries funding this) and hoping for lower unit costs by capturing coal generation and comparing with measures like offshore wind. They too are offering business opportunities to participants, based on many studies showing the CCS will (have to) be large globally to meet climate targets.

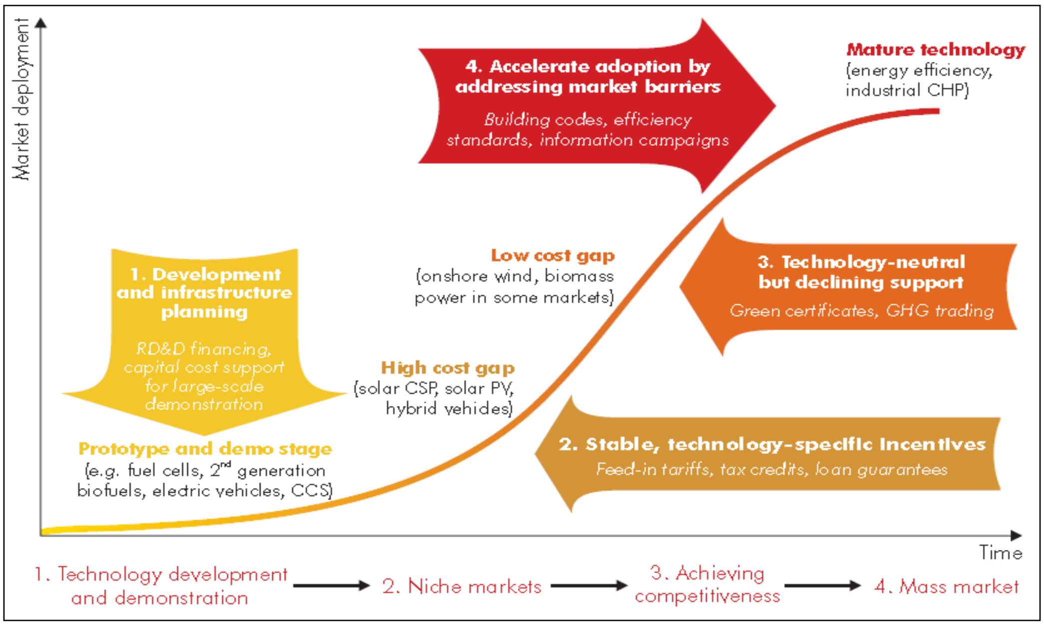
Advice
We will recommend countries considering CCS as a key measure for own abatement to compare with other measures. This needs to have a focus on economics at several levels (investor, emitter, country) and in addition realism related to decisions. It may be easier to make one decision for a large volume than assume that thousands of consumers change their ways (as we have discussed under societal aspects), but even these decisions can take years and are not guaranteed, as we have seen in Norway. Therefore, we would recommend that some research is directed towards these areas. In addition, ways of finding value in carbon should be considered. There are several initiatives for this today in many areas, from EOR to specific products. As this is a global opportunity and challenge it must be assumed that many players will be innovative here, so as a minimum, a scenario should be considered where capture of CO_2 is made for money, something that will change the way we think about abatement in general and also CCS. Within the period of 2050, this should not be excluded, making it important that CO_2 solutions and infrastructure for them are robust to possible changes in the future, from technology and also from business models.

Policy and how to make it happen

Changing consumption patterns, especially those related to economic growth, are difficult for most governments. Many paths have been tried already in the climate challenge:

- Reasoning and appealing to lower consumption. Cheap but less effective than desired
- Economic incentives for renewables, efficiency, etc. Temporarily only – longer term solutions should be economically sustainable
- Support to R&D – including cleaner technology. Easier, but also no guarantees of impact
- Higher prices to force efficiency: Effective but could be seen as political suicide

Figure 26 – Policies for supporting low carbon technologies



Source: IEA, Energy Technology Perspectives, 2010

The EU is currently implementing its 20-20-20 policy, and also in the process of reviewing its realism. It is clear that funding technology alone does not guarantee deployment. Also, favourable terms must be evaluated on their relative merits in the full energy and environment picture. That means that other, competing, initiatives could make investors perceive risks and be less in favour of the investments or operations the countries wish to have implemented.

We recommend seeing CCS increasingly as an integrated part of the full energy and emissions picture, and that the perspective of the investors as well as consumers is kept in mind when designing terms and conditions for power and industry to use the technology. ***R&D should therefore in addition to the current focus on improving technology (which happens globally also), consider models for reducing risk, improving attractiveness for the investors, operators and society in general.***

Innovative business models – value of CO_2 can be positive

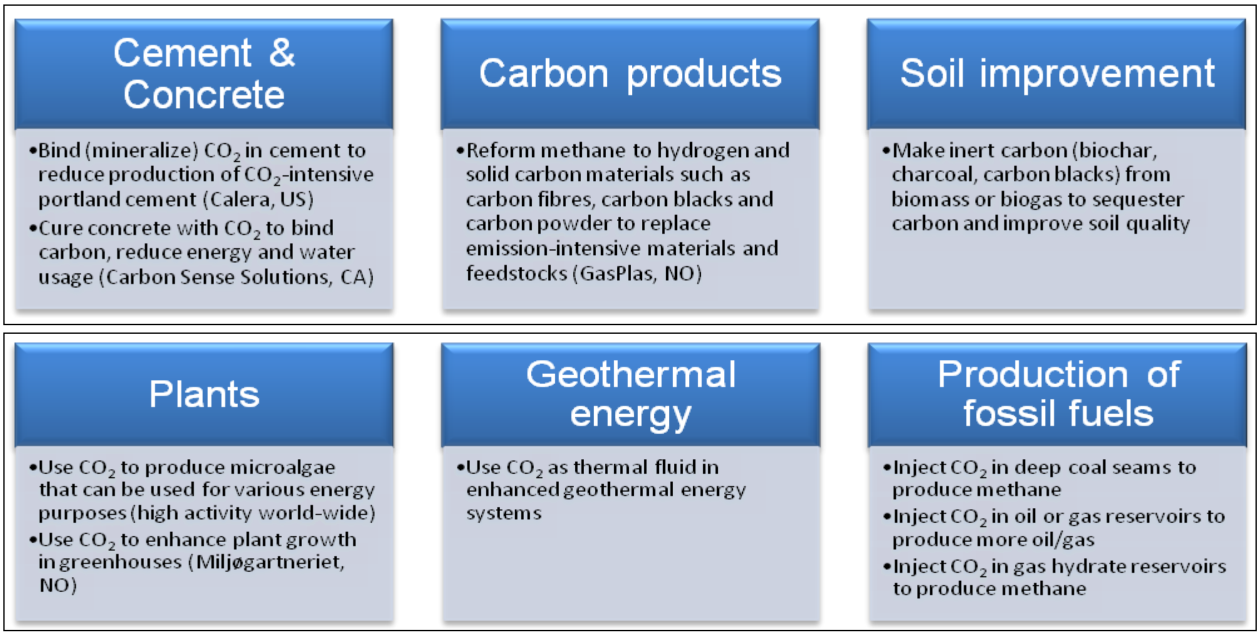
EOR and other use of CO_2
Finding value for large amounts of CO_2 is difficult, but may not be impossible in 2050. Enhanced oil recovery (EOR) is seen as a possibility. For Norwegian deep water, the cost of platform modification is too high to justify EOR projects (e.g. the Halten project; similar conclusion for UK's Miller project). Denmark is more attractive because of the platform design philosophy (low cost installation). There are a number of major challenges for EOR:

After initial years of CO_2 injection into the reservoir, CO_2 will be produced together with oil. The concentration of CO_2 in the associate gas will increase. A CO_2 capture plant would be required to remove CO_2 from the associated gas and recycle into reservoir. During the construction period, oil production must be halted. Loss of revenue and cost of offshore installation makes EOR projects difficult to justify. Perhaps EOR would have a better chance onshore and in the shallow water regions such as Middle East, where the water depth is in the order of 15 meter as opposed to 150 plus meters in the North Sea.

For the EOR project, fresh CO_2 is only needed for the initial years (5 to 10 years), while life of the CO_2 capture plant could last 30 years. High investment and low utilization of the CO_2 capture plant further erode the economics of most of the EOR projects. One possible way to alleviate this is to identify multiple EOR projects at nearby fields or provide other transport means such as CO_2 ships.

With a positive value of carbon, or at least other, lower cost solutions for deployment, the merit order of its abatement would change. Again, today's CCS could be moved up the merit curve, while the capture separation element, of CCS may well be more attractive. Below is a short overview of possible areas that could develop into sustainable business before 2050:

Figure 27 – Possible future business values from carbon

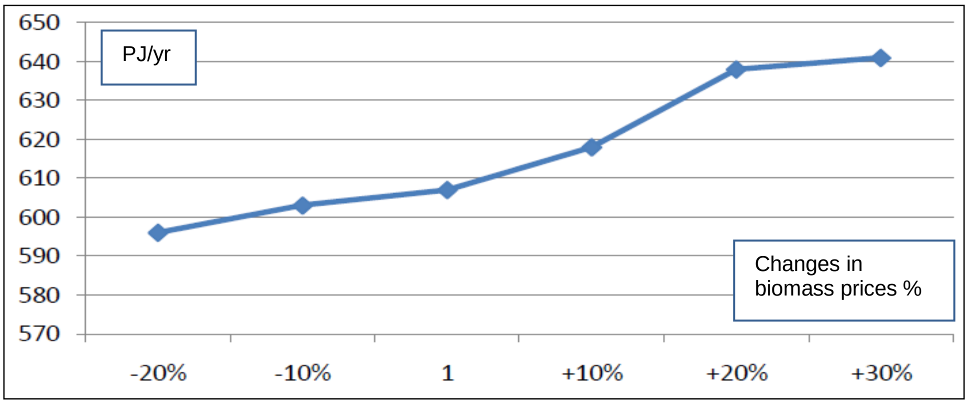


Technology and relative attractiveness

As there is more R&D in many energy forms, their relative merits change, both in terms of cost and emissions. In addition to improving current generation technologies, solar is developing and recent studies show that the new solar technologies are becoming cheaper than nuclear. This will, as an example, impact both the need for further measures (such as CCS) and their relative position in the abatement merit order.

Figure 20 illustrates changes in fossil fuel demand (PJ/yr) from changes to biomass prices. In Denmark a 20% increase is biomass price is expected to increase the use of fossil fuels by about 30 PJ/yr.

Figure 28 – Expected consumption of coal, oil, and natural gas (PJ/yr) at different changes to prices of biomass (lower biomass price gives lower fossil fuel consumption, higher biomass price gives higher fossil fuel consumption)



Change in biomass price
Source: Denmark's Energy Forecast

Replace coal with bio-coal: RWE of Germany

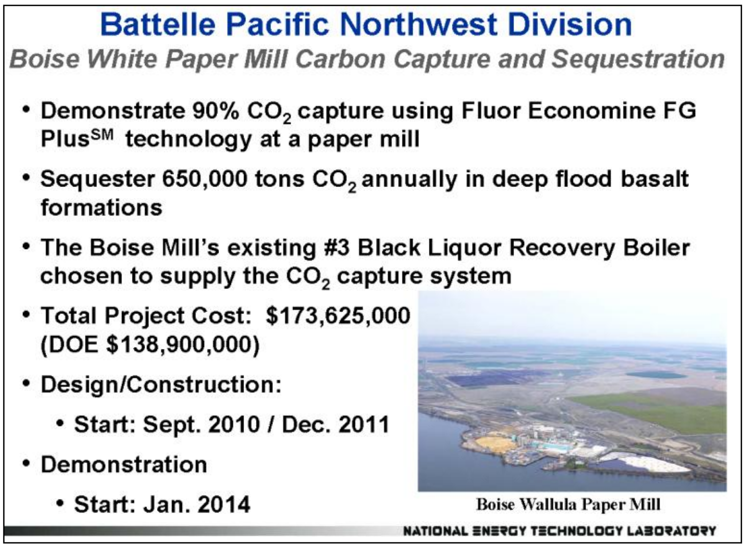
In their search for ways to reduce CO_2 emissions, energy producers are increasingly becoming enthusiastic about the possibilities offered by "bio-coal". According to Leonhard Birnbaum, Board Member of German utility RWE, bio-coal 'has the potential to decarbonise our existing coal-power infrastructure'. Birnbaum was present last Monday in the town of Duiven in the Netherlands at the ground-breaking ceremony of one of the first commercial-scale plants for the production of bio-coal pellets. This plant, built by a joint-venture of Dutch technology company Topell Energy and RWE Innogy, will use the new process of "torrefaction" to turn wood residues into a type of bio-coal that can be used as a perfect substitute for coal in power plants. With the new product, RWE subsidiary Essent, the largest Dutch utility, hopes to be able to replace no less than half of the coal it uses in some of its coal-fired power plants. A reason for Ewout Maaskant, CEO of Topell, to proclaim that torrefaction represents 'a breakthrough for second-generation bio fuels!' Topell will be building at least four more torrefaction plants in various parts of the world in the coming years.

CO_2 capture from the renewable power plant, which could provide opportunity for negative carbon emissions, is not yet investigated. Cost of the capture plant is likely to be high due to low energy intensity of the bio fuel and the inherent high cost of the capture plant. Since we are not aware of any study made to capture CO_2 from biogenic power plant, the cost figure cannot be quantified. We therefore recommend initiating a concept study so that cost can be quantified and areas of research and development can be identified.

Pulp and Paper also relevant in the US

One project for CCS in the pulp and paper sector received $500,000 in funding in October 2009 from DoE in the United States under the Recovery Act. “Battelle Memorial Institute worked with Boise White Paper LLC and Fluor Corporation to demonstrate geologic CO_2 storage in deep flood basalt formations in the State of Washington. Fluor Corporation will design a customized version of its Econamine Plus™ carbon capture technology for operation with the specialized chemical composition of exhaust gases produced from combustion of black liquor fuels.” The project was competing with 11 other for a second phase of funding, but did not qualify among the top three.

Figure 29 – CCS for pulp and paper in the US



Source: National Energy Technology Laboratory, June 2010

Societal aspects

There are several societal aspects to consider when it comes to CCS. We will cover two here, largely as an illustration:

1. What do the voters want? How should the government ensure that the "right" amount of climate gas emissions into the atmosphere are reduced, and what is the best way to do it? What should each country do, what is the role of trading or morale in this, and so on.
2. If CCS is chosen, how can it be accepted by the population? Which fears are important to understand and how can risks be reduced? What are the alternatives and attitudes to these?

Both Iceland and Norway have recently seen challenges in how a country can look at a long term best solution for society in a situation where each member of the society may not want to deal with the challenge personally and may not see the long term implications of doing so. Iceland's politicians need to deal with a banking crisis that could have serious long term implications for the country if not dealt with. This has been a test of democracy at voter level. Norway's politicians are trying to gauge the people's interest in solving climate challenges and fulfilling the political "moon landing" of CCS. This has been a test in democracy at parliament level.

The Nordic countries have a high degree of democracy and individualism. The politicians will try to understand the voters' wishes for the country and preferences on how to get there. In the case of climate, this is complicated in all countries. There may be a consensus in the country that climate issues need to be faced and emissions cut globally (especially China, it seems from papers). However, when it comes to individuals making changes to their life, there is almost an opposite message, as emissions from private consumption often rise (except in recession or at extremely high prices). This makes politicians (and some NGOs) reluctant to make people change. An easier, albeit more expensive, measure may then be CCS.

Most people in Europe are not familiar with CCS, and what it means of benefits or risks to society. With a limited knowledge, some fear leakage from geological storage while others dismiss CCS as a solution "as it only takes 90% of the emissions" without understanding that 95% recovery can be achieved without penalty in unit capture cost (waiting for the perfect 100% solution). Finally, in the implementation phase, there are concerns about impact on the immediate area around storage – reduced property values-risk of "houses falling into the ground" – hence the expression NUMBY (not under my back yard).
So, community acceptance would require a better understanding of both risks and benefits, both in the immediate area and globally, both in the short and (very) long term.

Human factor – community buy-in – how to make it happen?
One way to ensure higher public acceptance for example in CCS projects may be to include societal aspects in the planning process of national as well as Nordic solutions for CCS. Often, the technical developers focus on the technical aspect first, then market, pricing, and finally, after much time and investment in the developing of the project, they might find out that the public, including voters, local inhabitants, environmental groups etc, are against it, even if it is the "best" solution.. This might cause much negative attention towards the project and the companies behind it, and it might delay the project or stop it completely.

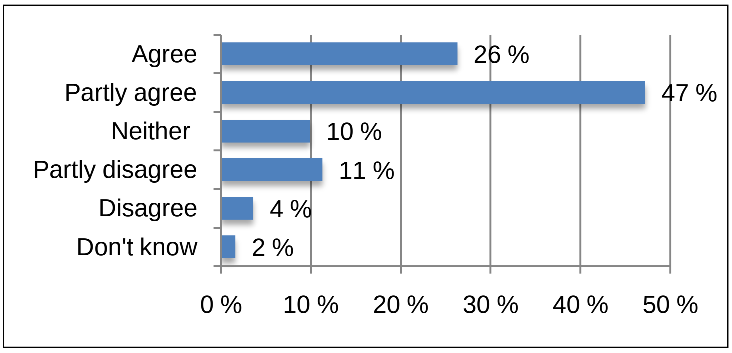
If societal aspects are considered early in the process, the solutions might get more realistic. If the local population, voters, environmental groups etc are on board from the start you don't risk this causing project failure.
When you include societal aspects you might look at:

- Survey public opinion on perceptions, preferences, fears, etc
- The societal costs of the project
- Options – is this the best option for the region, or is something else better when you look at the bigger picture?
- Effect on surroundings (own and others) – environment, climate, people, work etc
- Worries concerning security, property value – NUMBY (not under my back yard) etc

Case study: Popular opinion towards CCS and renewables in Norway 2009-2010

Familiarity with CCS is very low in Norway, despite being frequently discussed in the media. However, higher familiarity leads to a far more positive view of CCS. Simpler language and display of domestic applications of the technology are important ways to build public support. The Nordics is arguably the most climate-conscious region in Europe. According to Eurobarometer from November 2009[1], it ranked as the most important among a range of global issues in both Sweden and Denmark, while coming out as the second most important in Finland. In TNS Gallup Climate Barometer 2/2009, conducted in Norway at approximately the same time (October 2009), climate change ranked fifth among a somewhat longer list of political challenges to Norway. However, among leftist and centrist voters, climate change came out as the most important issue. The Norwegian study also found strong belief in anthropogenic climate change (74 % agreed), including a majority across all political affiliations.

Figure 30 – Opinion of Norwegian public to statement 'Climate change is man-made'

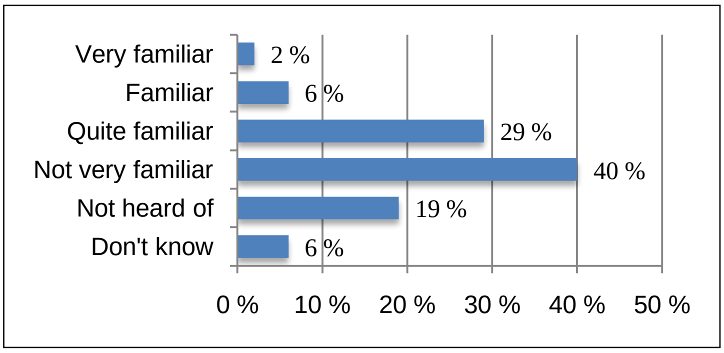


Source: TNS Gallup, Climate Barometer, October 2009.

Familiarity with CCS in Norway
Norway is a special country when it comes to CCS due to several large-scale projects under implementation. It is frequently discussed in the media, and this is confirmed by survey results from February 2009, where 62 % of Norwegians reported that they had read about CCS during the last month (TNS Gallup Climate Barometer 1/2009).

However, despite being a hot topic in Norwegian climate politics, only 8 % of the population say they are familiar or very familiar with CCS as a way of reducing climate emissions. 19 % have never heard about CCS, while 40 % have heard only a little. This suggests that communication on CCS is not very consistent and easy to understand for the public.
The term CCS – carbon capture and storage – is in itself complicated and very technical, and needs to be better explained to the public if familiarity is to increase. Discussions in the media often end up with references of millions of tons of $CO2$ to be captured, like Prime Minister Jens Stoltenberg when defending the Mongstad delays on NRK Dagsrevyen (May 5, 2010). Lack of completed projects to show off, including the numerous delays with both the Kårstø and Mongstad projects, also makes it difficult for the public to assess whether or not the technology is successful.

Figure 31 – Norwegian public familiarity with CCS as a way of reducing climate emissions

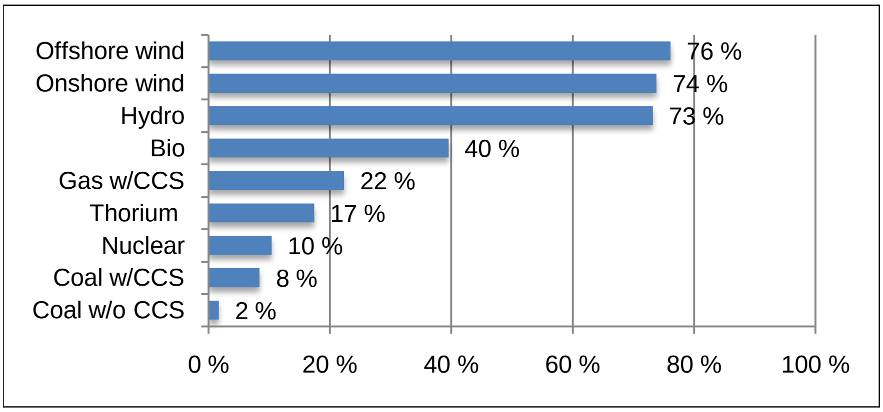


Source: TNS Gallup, Climate Barometer, March 2010.

CCS compared to renewable energy

In 2009, TNS Gallup surveyed Norwegian attitudes towards different energy sources, including gas and coal power with and without CCS, nuclear power, and a range of renewable energy sources. The survey also analysed what people associate with the different energy sources, for instance which sources they see as contributing to reduce climate emissions (TNS Gallup Climate Barometer 1/2009[1]). These results prompted the Minister of Oil and Energy to admit that “some of us have a considerable job to do” in strengthening public acceptance and approval for the technology[1].

Figure 32 – Share of Norwegian public agreeing that the following energy sources contribute to reducing climate emissions



Source: TNS Gallup, Climate Barometer, 1/2009.

An important reason for this is of course that almost all Norwegian electricity comes from hydro power. Gas power has been a hot topic through many years in Norway, clearly influencing the view of gas power, even with CCS. With hydro power being the alternative, gas power even with CCS is perceived as a less climate friendly way of generating electricity. This could be different in other countries.

National vs. global focus

In a global context, however, Norwegians have a more positive impression. 64 % agree that development of technology for CCS is “important” in order to cut global carbon emissions. Norwegians apparently see the need for CCS on a global scale, but they do not consider the technology as important to cut climate emissions in Norway, at least not when compared to renewable energy sources.

Implications for policy-makers and research

Public acceptance is important if CCS is to occupy a central part of climate policy over the long term, given the large public investments needed. At present, familiarity is very low even in Norway, one of the countries where CCS has been highest on the agenda. The good news is that higher familiarity leads to far more positive impressions. Those who agree that gas power with CCS “contributes to reduce climate emissions”, have a far more positive view of gas power with CCS in general. Building familiarity matters.

Therefore, in order to build public support, more efforts are needed in communicating to people what CCS is about, and why it is being developed. In this process developing a simpler and less technical language is crucial, and a step all stakeholders, government, industrial and research, should support.

However, despite low familiarity with the technology, 64 % of Norwegians nonetheless agree that CCS is “important” in order to cut global carbon emissions. This suggests that in addition to low familiarity, another key challenge to policy-makers is to explain the need for CCS also their own country. This could be addressed by pointing to large domestic emissions sources where CCS could be installed, including future applications of CCS to bio power stations.

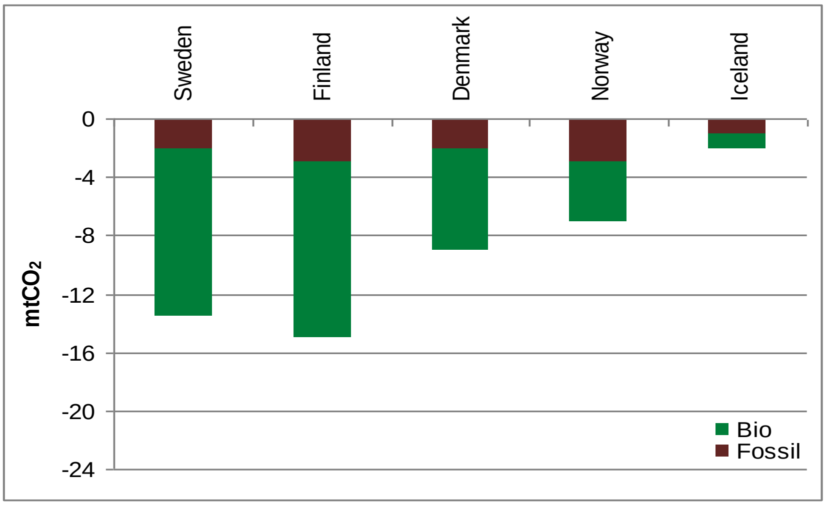
VII. Conclusion: Role of CCS in making the Nordic countries CO_2 neutral

Our scenario for 2050 shows one picture (of many) of possible emission reductions for the region to become climate neutral, assuming more renewables in electricity generation (wind and bio mainly) and increased use of bio fuels in industry, transport and residential. The role of CCS will be to reduce emissions further than what efficiency and fuel switching can achieve, so we envisage CCS applied at some fossil energy sources, but more at biogenic sources. An underlying assumption here is that globally, technology will be available to capture and store CO_2 at lower cost than today. Further it is assumed that there could well be competitive advantages for the Nordic countries in the use of biogenic fuels in industry, where emissions are possible to capture. This way it will be possible to counter remaining carbon emissions in transportation and industry. We are also not excluding possible added values in the carbon chain in the future.

CCS can play an important part in even making the Nordic countries CO_2 neutral. It can contribute to negative emissions, which could be a great advantage as countries realise that every incremental ton of reduced emissions may get more expensive. Some of the key areas to achieve this would be to capture CO_2 from biogenic sources, both in power and industry.

There is some synergy in treating the region as one CO_2-neutral area, as there is larger potential for CO_2 negative contributions through bio-CCS in Finland and Sweden than in Norway, Denmark or Iceland.

Figure 33 – Nordic countries 2050 – renewables/climate neutral scenario: CCS



Source: Sund Energy analysis 2010

Carbon Capture and Storage (CCS) could play a vital role in reducing CO_2 emissions in the Nordic countries. However, the main application may not be in the power sectors. Capture cost from some of the other stationary sources, such as refineries, petrochemical plants, cement plants and steel plants, could be cheaper than that of the power plants. Perhaps one should identify the low hanging fruit and start CCS from these lower cost options. However, CO_2 emissions from these areas only contribute to less than a quarter of the total. Eventually CCS from power plants will be required to achieve CO_2 neutral in 2050.

Capital cost of a capture plant today a large part of capture costs of CO_2 (\$60-80/t). In addition, heat will be required to regenerate the rich solvent, capture cost. The overall cost would be in the neighbourhood of \$100 per ton, too costly for a commercial project.

With the current softening of the construction industry and clever design and construction method, there is potential for a substantial reduction in the capital cost of the capture plant. The overall efficiency of a CCGT power plant with CO_2 capture is at best around 50%, leaving plenty of room for improvements. Many countries are working on this now, outside of the Nordic region.

Although population growth in the Nordic countries is expected to be low, energy consumption will continue to grow. Unless there is a large scale application of renewable energy such as wind, hydro and biomass, emissions will continue to increase over the years. To become greenhouse gas neutral in 2050, much work from the government and the private sectors will be required.

As energy prices harmonise and cost of labour remains high in the region, it is expected that some energy intensive industry will relocate to other parts of the world. This could lead to reduced, global emissions as new plants should be expected to be less emission intensive. In addition, these new locations may be closer to energy sources and/or product markets, resulting in somewhat less transport emissions. For the Nordic region this will clearly become a political issue, balancing economical development and employment with climate gas policies.

Nordic synergies and how to find value in cooperation

Reach targets through cooperation

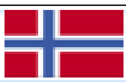
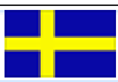
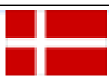
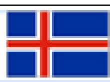
Characterizing the Nordic countries is the overall public acceptance of the global warming as a result of anthropogenic emissions of greenhouse gases. Therefore we already have a history of implementing green policies, albeit different in the five countries. Public perception is also in favour of even tougher climate measures at least relative to the situation in the US, China and possibly also to an EU average.

The Nordic countries are each relatively small economies but all have comparatively advanced climate policies in place. Climate mitigation measures and technologies imply huge commitments in research and implementation of new or modified energy systems. Seeking to optimize future efforts the Nordic region should work for acceptance of an overall carbon neutrality rather than national. This would open new perspectives and could prove more economically sustainable than sub-optimized, national solutions. Simply put, climate targets are easier to reach through close, regional cooperation.

Build on the relative strengths

The following illustration indicates (subjectively, but still) the countries' relative strengths in some of the most crucial areas for emission reductions. The region should aquire for instance generic carbon capture technologies from regions where capture at large scale will play an important role but be sure to apply skills in areas where there are competitive advantages. By recognizing and combining each country's advantages development synergies will be found.

Table 3 – Relative strengths of the Nordic countries

					
CCS	✔		✔	✔	
EOR	✔			✔	
Wind	✔	✔	✔	✔	✔
Geothermal					✔
Pulp & Paper		✔	✔		
Algae	✔				
Mineralization			✔		✔
Bio-energy		✔	✔	✔	
CO_2 shipping	✔			✔	
Hydropower	✔	✔	✔		
EV	✔	✔	✔		

Building regional collaboration always means compromising and “giving up” national interests. The Nordic region is probably in a unique situation and could succeed thanks to long standing political cooperation in the Nordic Council and to very close cultural, ethnical and geographic links. Finding agreement on climate mitigation measures and synergetic cooperation between five sovereign states is probably no easier in any other region of the world.

Synergy and Integration
The Nordic countries have a unique opportunity to develop the biomass industry by integrating the strengths of individual countries. These strengths could be summarized as follows:

- Norway: Algae production from fishery and CCS technology
- Denmark: Wind power and EOR
- Iceland: Geothermal and hydrogen powered vehicles
- Finland and Sweden: Forest industry and biogenic power generation

Forest industry and biogenic power generation
To achieve CO_2 neutral in 2050, much effort is required. Potential synergy of the Nordic countries should be fully integrated to achieve the maximum result for the region. Renewable energy in the region perhaps can be developed by utilizing the strength of each country.

- Maximize wind power production by following the example of Denmark. Both onshore and offshore wind power should be investigated in Norway, Sweden and Finland.
- Utilize natural resources in Iceland (geothermal) to produce power and hydrogen. Learn from Iceland on hydrogen production and hydrogen powered vehicles.
- Develop the biogenic power generation based on experiences gained in Sweden and Finland. Install CCS for the biogenic power flue gas to achieve negative CO_2 emission.
- Switch over to algae as the third generation biogenic fuel for power plants. Integrate the knowledge from the Norwegian fish industry for large scale algae production.
- Utilize the waste heat and CO_2 in the flue gas to promote algae production.

Even with the best of effort, it is unlikely CO_2 capture costs can be reduced to economically feasible levels for its installation. A dramatic change in approach is required. Perhaps the best alternative is NOT TO BUILD IT. We can explain by building a scenario.

- Mass produce algae as third generation bio fuel for power plants. Locate the power plant near the shore to avoid long distance transportation of algae. To promote algae production, both CO_2 and heat will be required. These can be provided by flue gas from the biogenic power plant. Typically, the flue gas from the power plant will be around 100°C, perhaps sufficient to provide heat for algae production due to high volume. CO_2 concentrations will be in the range of 3 to 9% depending on the power plant design. Note that in the fish farm industry, pure CO_2 is diluted with air before injecting into the algae production tank.
- Maximize power plant efficiency via CHP and use the remaining low grade heat in the flue gas to heat the seawater pond for algae production. CO_2 in the flue gas is absorbed in seawater and feeds algae growth. Note that seawater will absorb the CO_2 given sufficient resident time.

Key recommendations for further research and studies

Break down the silos!
Much effort is invested in climate mitigation policies in each Nordic country and naturally enough, based on the prevailing, local conditions. The flip side of the table 3 matrix is that research and development in the five countries is not enough coordinated and not oriented towards regional synergies. As on many other issues, progress and challenges are often not communicated across borders, probably leading to sub-optimal use of valuable and scarce resources. Technologies are today developed in "silos" with little cross discipline collaboration. Nordic Innovation Centre could be an extraordinary effective vehicle for coordinating Nordic climate research.

These are some opportunities for integration not yet studied, such as:

- Between power plant and CO_2 capture process
- Between bio power generation and CCS
- Between algae production and bio power generation
- Between pulp & paper production and carbon capture
- Integration of renewable energy sources in power grids
- Regional CCS in transport and storage (Baltic and North Sea, respectively)

Conclusively, a fast track to synergies: Remove country silos → Joint Nordic research!

Fit CCS into a carbon neutral energy supply
The Nordic region already displays a diverse and low carbon energy supply portfolio. Integrating CCS is a key success factor – for security of energy supply, for developing renewable energy sources and for achieving "negative emissions" to compensate for remaining fossil emissions.

- Commercial framework for steady energy supply
  - Optimization on <u>both</u> cost and emissions
- CCS technologies for fluctuating power generation
  - e g when wind and hydro power is base load
- Capture technologies for integrated plants
  - Fuel mixing (bio + fossil) impacts capture technologies
  - For manufacturing industry and power generation alike

By taking the (technology) lead for energy source integration the Nordic region would not only succeed in its environment ambitions but also build a platform for global technology export!

Competence cluster for CCS on biomass
Carbon neutral is not the same as "Fossil free"; With CCS for negative emissions, the economically most sensible solutions could be deployed where fossil fuels are still cost competitive (long haul road transport) emissions are offset against "negatives".

- Incentives framework for negative emissions;
- Accounting mechanisms for "negative CO_2"
- Long term policy development
- Capture technologies for pulp & paper plants
- Plant integration
- Recycling

For the Nordic region there could be multiple benefits in taking the policy and technology lead in CCS on biomass:

- Reduce overall carbon neutral system cost by optimizing bio and fossil
- Strengthen Nordic Pulp & Paper industry for world class performance
- Allow fossil fuels for transport where and when cost competitive

Regional CCS infrastructure
Just as capture costs seem prohibitive to many CCS projects, finding optimal transport and storage solutions can be crucial for the economical viability. The Nordic region is essentially divided in two geographical spheres, the North Sea and the Baltic Sea, respectively. Regional synergies would be tangible in the development of cost efficient solutions for both transport and storage in these two areas. For the public acceptance, probably the safe storage offshore would be the most

attractive why such development should take on a transparent approach. These are some topics suitable for further research within the Nordic Innovation Centre framework:

- Geological storage in the Baltic Sea region
- Transport infrastructure in the Baltic Sea region
- Ship transport of CO_2
- Public acceptance for CCS, societal aspects – how to include in national planning for realism?

Full picture view

It is important to see the full picture of energy and emissions.

Today:

- Overview of all emissions (also biogenic) provides wider scope for sustainable solutions

Future:

- Operational aspects can be considered for more realistic and sustainable total picture with "right" amount of CCS
- Possible to sensitivities /what-if analyses, such as
  - More/less efficiency
  - More/less attractive solutions for abatement and/or energy mix with changes to price, costs, value of abatement/cuts in emissions

  Build a Nordic model for energy and emissions to optimize not only by country but by region, with sensitivity analysis of varying assumptions

Other Possible Study Topics

- Develop bio-fuel renewable power plant utilizing CO_2 in the hot flue gas to produce algae. Identify the research needs by doing a concept study. Explore synergies among the Nordic countries
- Develop concept to integrate power generation and CCS plant in order to stabilize power supply
- Study potential for heat integration between power plant (coal or gas fired) with the CO_2 capture plant. Find a way to utilize the low grade heat discharged to atmosphere
- Provide economic driving force for onshore and offshore industries to maximize energy efficiency and minimize GHG emission

Appendixes

Appendix 1 – Historic and foresighted emissions in Denmark to 2020 and 2050

	DENMARK	1990	2000	2007	2008	2020	CCS 2020	Net 2020	2050	CCS 2050	Net 2050
	Total emissions including biomass, excluding LULUCF	**73,52**	**75,01**	**78,39**	**75,55**	**58,80**	**-1,00**	**57,80**	**33,20**	**-9,00**	**24,20**
REPORTED	**CO_2 from fossil and other greenhouse gas emissions**	**68,92**	**68,29**	**66,85**	**63,85**	**42,20**	**-1,00**	**41,20**	**9,00**	**-2,00**	**7,00**
	Counting CCS for fossil for graph	**0,00**	**0,00**	**0,00**	**0,00**		**1,00**			**2,00**	
	Energy Industries, of which:	**26,70**	**26,79**	**26,59**	**24,38**	**15,00**	**-1,00**	**14,00**	**3,00**	**-2,00**	**1,00**
	Power and Heat	24,90	23,57	23,42	21,32	14,00	-1,00	**13,00**	3,00	-2,00	**1,00**
	Oil and Gas	1,80	3,21	3,17	3,06	1,00	0,00	**1,00**	0,00	0,00	**0,00**
	Manufacturing Industries	**7,87**	**9,59**	**8,41**	**7,63**	**6,00**	**0,00**	**6,00**	**3,00**	**0,00**	**3,00**
	Energy for manufacturing industries and construction	5,49	6,10	5,77	5,28	4,15	0,00	**4,15**	2,00	0,00	**2,00**
	Industrial Processes	2,24	3,39	2,54	2,26	1,80	0,00	**1,80**	1,00	0,00	**1,00**
	Solvent and other product use	0,14	0,10	0,10	0,09	0,05	0,00	**0,05**	0,00	0,00	**0,00**
	Transport	**10,70**	**12,25**	**14,20**	**13,96**	**10,00**	**0,00**	**10,00**	**1,00**	**0,00**	**1,00**
	Commercial/Institutional	**1,42**	**0,92**	**0,81**	**0,84**	**0,50**	**0,00**	**0,50**	**0,00**	**0,00**	**0,00**
	Residential	**5,18**	**4,28**	**3,62**	**3,50**	**2,00**	**0,00**	**2,00**	**0,00**	**0,00**	**0,00**
	Agriculture	**15,66**	**13,12**	**11,82**	**12,19**	8,00	**0,00**	**8,00**	2,00	0,00	**2,00**
	Waste	**1,27**	**1,23**	**1,22**	**1,24**	0,70	**0,00**	**0,70**	**0,00**	**0,00**	**0,00**
	Other (Not elsewhere specified)	0,12	0,11	0,18	0,11	0,00	0,00	**0,00**	0,00	0,00	**0,00**
BIO	**CO_2 from biomass**	**4,60**	**6,72**	**11,54**	**11,70**	**16,60**	**0,00**	**16,60**	**24,20**	**-7,00**	**17,20**
	Counting CCS for biomass for graph	**0,00**	**0,00**	**0,00**	**0,00**		**0,00**			**-7,00**	
	Power and Heat	2,08	3,96	6,37	6,45	9,45	0,00	**9,45**	12,00	-6,00	**6,00**
	Manufacturing and Construction	0,59	0,55	0,70	0,84	1,84	0,00	**1,84**	4,00	-1,00	**3,00**
	Transport	0,00	0,00	0,02	0,02	1,02	0,00	**1,02**	5,00	0,00	**5,00**
	Residential and Commercial	1,57	1,97	4,29	4,14	4,00	0,00	**4,00**	3,00	0,00	**3,00**
	Other	0,36	0,24	0,16	0,26	0,30	0,00	**0,30**	0,20	0,00	**0,20**
		68,92	**68,29**	**66,85**	**63,85**			**41,20**			**0,00**

* Only additional emissions on top of those already recorded in 2008 are shown

Appendix 2 – Historic and foresighted emissions in Finland to 2020 and 2050

	FINLAND	1990	2000	2007	2008	2020	CCS 2020	2020	2050	CCS 2050	2050
	Total emissions including biomass, excluding LULUCF	**89,64**	**98,49**	**111,14**	**103,22**	**93,38**	**-1,00**	**92,38**	**58,69**	**-15,00**	**43,69**
REPORTED	**CO_2 from fossil and other greenhouse gas emissions**	**70,35**	**69,11**	**78,07**	**70,13**	**53,45**	**-1,00**	**52,45**	**13,00**	**-3,00**	**10,00**
	Counting CCS from fossil for graph	**0,00**	**0,00**	**0,00**	**0,00**		**1,00**			**3,00**	
	Energy Industries, of which:	**19,42**	**22,31**	**31,01**	**24,47**	**18,00**	**-1,00**	**17,00**	**4,00**	**-2,00**	**2,00**
	Power and Heat	16,56	19,20	27,69	21,15	15,50	-1,00	**14,50**	4,00	-2,00	**2,00**
	Oil and Gas	2,86	3,11	3,32	3,32	2,50	0,00	**2,50**	0,00	0,00	**0,00**
	Manufacturing Industries	**18,61**	**17,57**	**18,24**	**17,91**	14,05	**0,00**	**14,05**	**4,00**	**-1,00**	**3,00**
	Energy for manufacturing industries and construction	13,36	11,94	11,45	10,80	8,00	0,00	**8,00**	1,00	0,00	**1,00**
	Industrial Processes	5,07	5,50	6,69	7,03	6,00	0,00	**6,00**	3,00	-1,00	**2,00**
	Solvent and other product use	0,18	0,12	0,10	0,09	0,05	0,00	**0,05**	0,00	0,00	**0,00**
	Transport	**12,79**	**12,84**	**14,26**	**13,63**	**10,00**	**0,00**	**10,00**	**2,00**	**0,00**	**2,00**
	Commercial/Institutional	**1,98**	**1,18**	**1,08**	**0,90**	**0,50**	**0,00**	**0,50**	**0,00**	**0,00**	**0,00**
	Residential	**3,28**	**2,56**	**2,28**	**2,13**	**1,50**	**0,00**	**1,50**	**0,00**	**0,00**	**0,00**
	Agriculture	**8,67**	**7,79**	**7,50**	**7,57**	7,00	**0,00**	**7,00**	3,00	0,00	**3,00**
	Waste	**3,97**	**3,27**	**2,38**	**2,20**	**1,50**	**0,00**	**1,50**	**0,00**	**0,00**	**0,00**
	Other (Not elsewhere specified)	1,64	1,60	1,33	1,33	0,90	0,00	**0,90**	0,00	0,00	**0,00**
BIO	**CO_2 from biomass**	**19,29**	**29,38**	**33,07**	**33,09**	**39,93**	**0,00**	**39,93**	**45,69**	**-12,00**	**33,69**
	Counting CCS from biomass for graph	**0,00**	**0,00**	**0,00**	**0,00**		**0,00**			**-12,00**	
	Power and Heat	0,34	3,75	6,12	7,21	10,21	0,00	**10,21**	17,21	-2,00	**15,21**
	Manufacturing and Construction, of which:	14,05	20,70	20,86	19,49	21,49	0,00	**21,49**	19,00	-10,00	**9,00**
	Pulp and Paper	13,03	19,56	20,01	18,76	17,00	0,00	**17,00**	14,00	-7,00	**7,00**
	Transport	0,00	0,00	0,01	0,23	2,23	0,00	**2,23**	5,23	0,00	**5,23**
	Residential and Commercial	4,15	4,49	5,53	5,42	5,00	0,00	**5,00**	3,50	0,00	**3,50**
	Other	0,75	0,44	0,56	0,74	1,00	0,00	**1,00**	0,75	0,00	**0,75**
		70,35	**69,11**	**78,07**	**70,13**			**52,45**			**-2,00**

* Only additional emissions on top of those already recorded in 2008 are shown

Appendix 3 – Historic and foresighted emissions in Iceland to 2020 and 2050

	ICELAND	1990	2000	2007	2008	2020	CCS 2020	Net 2020	2050	CCS 2050	Net 2050
	Total emissions including biomass, excluding LULUCF	**3,41**	**3,76**	**4,51**	**4,88**	**4,17**	**0,00**	**4,17**	**3,50**	**-2,00**	**1,50**
REPORTED	**CO_2 from fossil and other greenhouse gas emissions**	**3,41**	**3,76**	**4,51**	**4,88**	**4,17**	**0,00**	**4,17**	**2,00**	**-1,00**	**1,00**
	Counting CCS from fossil for graph	**0,00**	**0,00**	**0,00**	**0,00**		**0,00**			**1,00**	
	Energy Industries, of which:	**0,08**	**0,17**	**0,18**	**0,20**	**0,10**	**0,00**	**0,10**	**0,00**	**0,00**	**0,00**
	Power and Heat	0,01	0,01	0,03	0,01	0,00	0,00	**0,00**	0,00	0,00	**0,00**
	Oil and Gas	0,07	0,16	0,15	0,19	0,10	0,00	**0,10**	0,00	0,00	**0,00**
	Manufacturing Industries	**1,25**	**1,41**	**1,92**	**2,37**	2,30	**0,00**	**2,30**	**1,00**	**-1,00**	**0,00**
	Energy for manufacturing industries and construction	0,38	0,45	0,43	0,37	0,30	0,00	**0,30**	0,00	0,00	**0,00**
	Industrial Processes	0,86	0,95	1,48	1,99	2,00	0,00	**2,00**	1,00	-1,00	**0,00**
	Solvent and other product use	0,01	0,01	0,01	0,01	0,00	0,00	**0,00**	0,00	0,00	**0,00**
	Transport	**0,62**	**0,67**	**1,03**	**0,97**	0,80	**0,00**	**0,80**	0,50	0,00	**0,50**
	Commercial/Institutional	**0,01**	**0,01**	**0,02**	**0,02**	0,02	**0,00**	**0,02**	0,00	0,00	**0,00**
	Residential	**0,03**	**0,02**	**0,01**	**0,01**	0,00	**0,00**	**0,00**	0,00	0,00	**0,00**
	Agriculture	**1,24**	**1,28**	**1,12**	**1,09**	0,80	**0,00**	**0,80**	0,50	0,00	**0,50**
	Waste	**0,18**	**0,20**	**0,23**	**0,22**	**0,15**	**0,00**	**0,15**	**0,00**	**0,00**	**0,00**
	Other (Not elsewhere specified)	0,00	0,00	0,00	0,00	0,00	0,00	**0,00**	0,00	0,00	**0,00**
BIO	**CO_2 from biomass**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**1,50**	**-1,00**	**0,50**
	Counting CCS from biomass for graph	**0,00**	**0,00**	**0,00**	**0,00**		**0,00**			**-1,00**	
	Power and Heat	0,00	0,00	0,00	0,00	0,00	0,00	**0,00**	0,00	0,00	**0,00**
	Manufacturing and Construction	0,00	0,00	0,00	0,00	0,00	0,00	**0,00**	1,00	-1,00	**0,00**
	Transport	0,00	0,00	0,00	0,00	0,00	0,00	**0,00**	0,50	0,00	**0,50**
	Residential and Commercial	0,00	0,00	0,00	0,00	0,00	0,00	**0,00**	0,00	0,00	**0,00**
	Other	0,00	0,00	0,00	0,00	0,00	0,00	**0,00**	0,00	0,00	**0,00**
		3,41	**3,76**	**4,51**	**4,88**			**4,17**			**0,00**

* Only additional emissions on top of those already recorded in 2008 are shown

Appendix 4 – Historic and foresighted emissions in Norway to 2020 and 2050

	NORWAY	1990	2000	2007	2008	2020	CCS 2020	2020	2050	CCS 2050	2050
	Total emissions including biomass, excluding LULUCF	**54,23**	**58,03**	**60,44**	**59,01**	**49,61**	**-2,00**	**47,61**	**23,96**	**-7,00**	**16,96**
REPORTED	**CO_2 from fossil and other greenhouse gas emissions**	**49,75**	**53,29**	**55,15**	**53,71**	**41,90**	**-2,00**	**39,90**	**11,00**	**-3,00**	**8,00**
	Counting CCS from fossil for graph	**0,00**	**0,00**	**0,00**	**0,00**		**2,00**			**3,00**	
	Energy Industries	**9,78**	**14,67**	**17,38**	**16,88**	**14,00**	**-2,00**	**12,00**	**4,00**	**-2,00**	**2,00**
	Power and Heat	0,33	0,36	0,71	0,53	2,00	-1,00	**1,00**	1,00	-1,00	**0,00**
	Oil and Gas	9,45	14,31	16,67	16,35	12,00	-1,00	**11,00**	3,00	-1,00	**2,00**
	Manufacturing Industries	**17,55**	**15,66**	**12,92**	**12,71**	**9,10**	**0,00**	**9,10**	**3,50**	**-1,00**	**2,50**
	Energy for manufacturing industries and construction	3,67	3,93	3,58	3,61	2,00	0,00	**2,00**	1,00	0,00	**1,00**
	Industrial Processes	13,68	11,55	9,16	8,92	7,00	0,00	**7,00**	2,50	-1,00	**1,50**
	Solvent and other product use	0,19	0,18	0,19	0,19	0,10	0,00	**0,10**	0,00	0,00	**0,00**
	Transport	**11,31**	**13,34**	**15,78**	**15,30**	**12,00**	**0,00**	**12,00**	**1,50**	**0,00**	**1,50**
	Commercial/Institutional	**0,81**	**0,67**	**0,71**	**0,68**	**0,40**	**0,00**	**0,40**	**0,00**	**0,00**	**0,00**
	Residential	**1,48**	**0,90**	**0,76**	**0,66**	**0,40**	**0,00**	**0,40**	**0,00**	**0,00**	**0,00**
	Agriculture	**6,54**	**6,39**	**6,11**	**6,14**	5,00	0,00	**5,00**	2,00	0,00	**2,00**
	Waste	**1,82**	**1,49**	**1,26**	**1,22**	**1,00**	**0,00**	**1,00**	**0,00**	**0,00**	**0,00**
	Other (Not elsewhere specified)	0,46	0,18	0,21	0,13	0,00	0,00	**0,00**	0,00	0,00	**0,00**
BIO	**CO_2 from biomass**	**4,48**	**4,74**	**5,29**	**5,30**	**7,71**	**0,00**	**7,71**	**12,96**	**-4,00**	**8,96**
	Counting CCS from biomass for graph	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**			**-4,00**	
	Power and Heat	0,16	0,24	0,55	0,60	1,00	0,00	**1,00**	2,00	0,00	**2,00**
	Manufacturing and Construction, of which:	2,52	2,36	2,53	2,44	3,94	0,00	**3,94**	6,44	-3,00	**3,44**
	Pulp and Paper	1,99	1,94	2,01	2,03	2,00	0,00	**2,00**	2,00	-1,00	**1,00**
	Transport	0,00	0,00	0,00	0,00	0,50	0,00	**0,50**	3,00	0,00	**3,00**
	Residential and Commercial	1,80	2,14	2,21	2,25	2,25	0,00	**2,25**	1,50	0,00	**1,50**
	Other	0,00	0,00	0,00	0,00	0,02	0,00	**0,02**	0,02	0,00	**0,02**
		49,75	**53,29**	**55,15**	**53,71**			**39,90**			**4,00**

* Only additional emissions on top of those already recorded in 2008 are shown

Appendix 5 – Historic and foresighted emissions in Sweden to 2020 and 2050

	SWEDEN	1990	2000	2007	2008	2020	CCS 2020	2020	2050	CCS 2050	2050
	Total emissions including biomass, excluding LULUCF	**101,87**	**102,58**	**106,64**	**105,80**	**91,56**	**0,00**	**91,56**	**56,76**	**-13,50**	**43,26**
REPORTED	**CO_2 from fossil and other greenhouse gas emissions**	**72,43**	**68,85**	**66,17**	**63,96**	**43,15**	**0,00**	**43,15**	**11,50**	**-2,00**	**9,50**
	Counting CCS from fossil for graph	**0,00**	**0,00**	**0,00**	**0,00**		**0,00**			**2,00**	
	Energy Industries, of which:	**10,25**	**9,15**	**10,89**	**10,83**	**7,00**	**0,00**	**7,00**	**2,00**	**0,00**	**2,00**
	Power and Heat	7,82	6,33	7,75	7,47	5,00	0,00	**5,00**	2,00	0,00	**2,00**
	Oil and Gas	2,43	2,82	3,14	3,36	2,00	0,00	**2,00**	0,00	0,00	**0,00**
	Manufacturing Industries	**18,89**	**19,89**	**18,80**	**17,77**	**12,15**	**0,00**	**12,15**	4,50	**-2,00**	**2,50**
	Energy for manufacturing industries and construction	12,29	12,88	11,63	10,69	7,00	0,00	**7,00**	2,00	-1,00	**1,00**
	Industrial Processes	6,26	6,73	6,88	6,79	5,00	0,00	**5,00**	2,50	-1,00	**1,50**
	Solvent and other product use	0,33	0,28	0,28	0,28	0,15	0,00	**0,15**	0,00	0,00	**0,00**
	Transport	**19,03**	**19,70**	**21,23**	**20,69**	**13,00**	**0,00**	**13,00**	**1,00**	**0,00**	**1,00**
	Commercial/Institutional	**2,57**	**1,45**	**0,98**	**0,85**	**0,50**	**0,00**	**0,50**	**0,00**	**0,00**	**0,00**
	Residential	**6,58**	**5,00**	**1,66**	**1,52**	**1,00**	**0,00**	**1,00**	**0,00**	**0,00**	**0,00**
	Agriculture	**11,18**	**10,63**	**10,42**	**10,39**	8,50	**0,00**	**8,50**	**4,00**	**0,00**	**4,00**
	Waste	**3,12**	**2,61**	**1,93**	**1,74**	**1,00**	**0,00**	**1,00**	**0,00**	**0,00**	**0,00**
	Other (Not elsewhere specified)	0,83	0,41	0,26	0,16	0,00	0,00	**0,00**	0,00	0,00	**0,00**
BIO	**CO_2 from biomass**	**29,44**	**33,73**	**40,47**	**41,85**	**48,41**	**0,00**	**48,41**	**45,26**	**-11,50**	**33,76**
	Counting CCS from biomass for graph	**0,00**	**0,00**	**0,00**	**0,00**		**0,00**			**-11,50**	
	Power and Heat	1,31	6,14	9,83	11,01	13,01	0,00	**13,01**	13,01	0,00	**13,01**
	Manufacturing and Construction, of which:	24,29	23,78	24,60	25,00	27,00	0,00	**27,00**	21,00	-11,50	**9,50**
	Pulp and paper	21,91	21,89	22,50	23,05	22,00	0,00	**22,00**	17,00	-10,00	**7,00**
	Transport	0,00	0,06	0,93	1,10	4,00	0,00	**4,00**	8,00	0,00	**8,00**
	Residential and Commercial	3,81	3,72	4,77	4,43	4,00	0,00	**4,00**	3,00	0,00	**3,00**
	Other	0,02	0,02	0,34	0,30	0,40	0,00	**0,40**	0,25	0,00	**0,25**
		72,43	68,85	66,17	63,96			43,15			-2,00

* Only additional biomass emissions on top of those already recorded in 2008 are shown

Symbols and abbreviations

p.a. – per annum
p.p. – percentage points
GHG- Green House Gasses
UNFCCC – United Nations Convention on Climate Change
LULUCF – Land Use, Land Use Change and Forestry
CDM – Clean Development Mechanism
JI – Joint Implementation
CCS – Carbon Capture and Storage
EOR – Enhanced Oil Recovery
NCS – Norwegian Continental Shelf
CHP – Combined Heat and Power
PFC – Perfluorocarbons
SF_6 – Sulphur hexafluoride
CO_2 – Carbon dioxide
CH_4 – Methane
N_2O – Nitrous oxide

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