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## Prospects for application of CCS in Finland

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### Abstract

In this paper, the possibilities and conditions for CCS applications in Finland are assessed. The study includes an overview of Finland's current climate and energy policy framework, mapping of large CO<sub>2</sub> emission point sources and identification of possible CO<sub>2</sub> transportation and storage alternatives. The future role of CCS in the Finnish energy system is further assessed with energy and emission scenarios created with a comprehensive model called TIMES-Nordic. There are several large CO<sub>2</sub> emission sources in Finland that could be potential candidates for CCS, including steel works, power and heat generating plants, as well as oil refineries. In 2008, the 12 largest facilities in the Finnish emission trading registry accounted for 30% of the total CO<sub>2</sub> emissions in Finland. Since the Finnish bedrock is not suitable for large-scale geological storage of CO<sub>2</sub>, captured CO<sub>2</sub> would most likely have to be transported to the North Sea or Barents Sea for long-term storage. Most of the largest CO<sub>2</sub> emitting facilities are located on the coast line of Finland, which facilitates transportation of CO<sub>2</sub> by ship. The current Finnish climate and energy policy largely focuses on increasing the share of renewable energy and nuclear power in energy conversion, which leaves less room for CCS. The preliminary results from the scenario calculations indicate that the share of CO<sub>2</sub> mitigation by CCS in Finland would be less than 10 Mt/a CO<sub>2</sub> by 2050. However, Finland has also large, stationary CO<sub>2</sub> emissions originating from biomass combustion in the pulp and paper industry. When assuming that biogenic CO<sub>2</sub> emissions would be included into the emission trading system, the CCS potential rises up to 18 Mt/a CO<sub>2</sub> by 2050.

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### 1. Introduction

Carbon capture and storage (CCS) is under extensive research and development globally. In Finland, CCS has been a part of the discussions regarding mitigation of climate change since the nineties, but has been considered expensive and not mature enough in comparison to other measures for reducing CO<sub>2</sub> emissions. The unfavourable conditions in Finland for geological storage of CO<sub>2</sub> have been another reason for the low interest towards CCS. The international recognition of the global climate change, EU's new climate and energy policy, as well as the potential

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for new technology markets has contributed to an increasing interest during the latest years. Research, development and demonstration of CCS are now carried out by several companies, research facilities and universities in Finland.

The possibilities for applying CCS in Finland are identified by a national research project called “Application of carbon capture and storage in Finland (CCS Finland)”, coordinated by VTT Technical Research Centre of Finland. The research is carried out in collaboration with the Geological Survey of Finland (GTK). The project runs from 2008 to 2010 and has a total budget of 1.4 M€. It is financed by Tekes (the Finnish Funding Agency for Technology and Innovation) and several companies, who represent CO<sub>2</sub>-intensive industry, power companies, and technology developers in Finland.

The emphasis in the project is on solutions conceivable in the Nordic geographical location and for the industry and energy infrastructure of Finland. The whole CCS chain is studied ranging from technical solutions to the possible impact of CCS on the future Finnish energy system. The outcome of the project will be a roadmap to application of CCS in Finland. The work includes energy system simulations, concept studies and modelling of capture processes, emission balances, and cost estimates for CCS. The project is mostly concerned with applications conceivable in near and mid term future. The suitability of sedimentary rock basins for storage of CO<sub>2</sub> in Finland is evaluated in the project. In this paper, the preliminary results from the project are presented.

## 2. Prerequisites for applying CCS in Finland

In this section, the prerequisites for applying CCS in Finland are reviewed. The prerequisites include the current climate and energy policy, potential for applying carbon capture in the existing energy and industry infrastructure, possibilities for transportation and storage of CO<sub>2</sub>, and a regulatory framework for applying CCS.

### 2.1. Climate and energy policy in Finland

The short term goal of the Finnish climate and energy strategy is to fulfil the binding targets set by the EU’s climate and energy package. EU’s target to reduce its greenhouse gas (GHG) emissions with 20% by 2020 from the level in 1990 [1] is divided into separate targets for the sector set by EU’s Emission Trading Scheme (ETS) and the sector outside the ETS. Targets for non-ETS sector are national and for Finland this target is a 16% reduction by 2020 in GHG emissions from the level in 2005 [2]. However, nearly all of the facilities suitable for CCS application belong to the ETS sector, which has an EU-wide target of 21% reduction by 2020 from the level in 2005. Therefore, the most important driver for utilisation of CCS in Finland is the development of the price for emission allowances in the ETS. As the ultimate target of the EU’s climate policy is to limit global warming to 2°C, EU is ready to reduce its GHG emissions by 30% in 2020 and 60-80% in 2050 from the level of 1990, if other countries contribute accordingly. This would obviously increase the pressure to reduce emissions in both sectors, which would lead to higher prices for emission allowances. In the long term, the aim is to reduce Finland’s GHG emissions by at least 80% compared to 1990 as part of an international effort [3].

The competitiveness of alternative emission reduction and energy production technologies affect the deployment of CCS. According to the RES directive [4] Finland should increase the use of renewable energy to 38% of the final energy use by 2020, which is 9.5%-points above the level in 2005. The use of renewable energy is planned to be supported in Finland by different feed-in tariffs and energy subsidy for forest fuel production [5]. In addition, taxes for fossil fuels will be raised considerably after 2010. Investment subsidies have also been discussed. In addition to this, the share of renewables in transport fuels should be 10% by 2020 [4]. In July 2010 the Parliament of Finland accepted the proposals to build two new nuclear power plants to Finland. Higher taxes for fossil fuels together with options to build two new nuclear power plants will probably reduce the interest to invest in new fossil fuel-based energy production and CCS. On the other hand, investments in biomass combustion and biofuel production may lead to potential applications for bio-CCS (biomass carbon capture and storage), but this requires modifications to the current ETS (see section 2.4).

EU has also announced a target to reduce the primary energy consumption by 20% and published an Action Plan for Energy Efficiency [6]. The target is partly contradictory with CCS, although neither EU nor Finnish regulations include any mandatory targets related to the expected energy efficiency loss due to CCS applications. Also, the future policy related to Finland’s domestic fuel, peat, is partly unclear. In the Finnish climate and energy strategy peat is mentioned as a domestic energy source, which use is considered important from a national viewpoint [7].

CCS could make peat firing possible even in the case of very challenging international climate policy. The current climate and energy strategy for Finland is focused on the short term targets and actions needed to fulfil the targets set by EU, and therefore CCS is not considered. However, both CCS and bio-CCS are recognized by the Government as possible long-term methods for assisting in turning Finland to a low-carbon nation by 2050, if the obstacles for deploying CCS are overcome [3].

## 2.2. Large CO<sub>2</sub> emission point sources

Finland's greenhouse gas emissions were about 70 Mt CO<sub>2</sub>-eq. in 2008, of which the carbon dioxide emissions accounted for 58 Mt [8]. The majority of the greenhouse gas emissions (78%) came from the energy sector, which was mostly attributed to heat and power generation. In order to assess the potential for applying CCS to existing facilities, a GIS database over the largest CO<sub>2</sub> emitting facilities in Finland was made. The database includes both biogenic and fossil or inorganic CO<sub>2</sub> emissions from facilities emitting over 0.1 Mt CO<sub>2</sub> in 2008. The database is based on emission data for year 2008 from the Finnish emission trading registry [9]. The biogenic emissions were either calculated based on annual biomass usage or gathered from environmental reports.

In 2008, the number of Finnish facilities emitting more than 100 000 t CO<sub>2</sub> was 76. In total, these facilities emitted 33.0 Mt CO<sub>2</sub> of fossil or inorganic origin, which is 56% of the total fossil CO<sub>2</sub> emissions that year (58 Mt). For comparison, these emissions amounted to 39.8 Mt CO<sub>2</sub> in 2007. The drop in emissions in 2008 was likely due to the economic recession that year. Of the fossil and inorganic CO<sub>2</sub> emissions from the 76 facilities, 56% came from power and heat production (Figure 1). Iron and steel production represented the second largest sector and oil refineries the third largest sector. The steel plant in Raahе was by far the largest single emitter, releasing 4.5 Mt CO<sub>2</sub>, followed by the oil refinery in Porvoo (Figure 2), which emitted 3.0 Mt CO<sub>2</sub> in 2008. In addition to these only four power plants had fossil or inorganic emissions exceeding 1 Mt CO<sub>2</sub> (1.0–1.4 Mt CO<sub>2</sub>) that year: the condensing coal-fired power plant at Meri-Pori (Pori) and the combined heat and power (CHP) plants of Vuosaari B (Helsinki), Naantali and Vaskiluoto 2 (Vaasa). The 12 largest facilities accounted in total for 17.4 Mt CO<sub>2</sub>, which is 30% of the total CO<sub>2</sub> emissions in Finland in 2008. These numbers indicate that emission reductions of significant proportion could possibly be achieved by applying CCS to a few of the largest CO<sub>2</sub> emitting facilities in Finland.

There is a significant amount of biogenic CO<sub>2</sub> emissions in Finland, which is mostly originating from the pulp and paper industry. When taking fossil, inorganic and biogenic CO<sub>2</sub> emissions into consideration, the pulp and paper production becomes the largest emitting sector. The ten largest pulp and paper mills accounted for >1 Mt (mostly biogenic) CO<sub>2</sub> each in 2008, with the Imatra mill being the largest at 2.8 Mt biogenic and 0.2 Mt fossil/inorganic CO<sub>2</sub>. The biogenic share in power and heat production is mostly from co-firing biomass with fossil fuels.

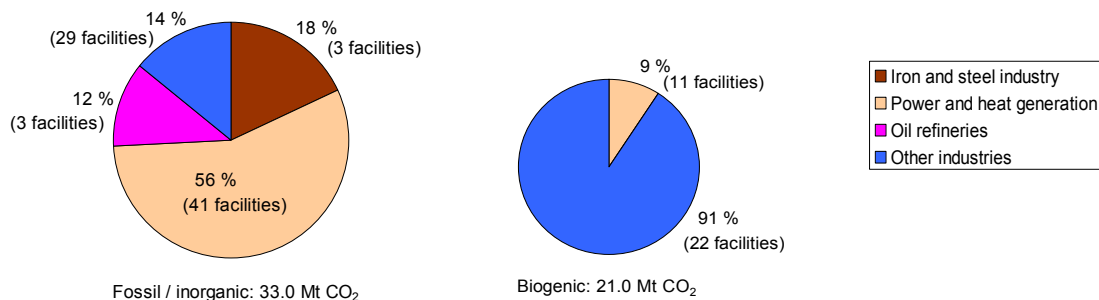


Figure 1. CO<sub>2</sub> emissions from the 76 facilities emitting >0.1 Mt CO<sub>2</sub>/a in Finland, categorized according to industrial activity (data for year 2008).

## 2.3. Possibilities for transportation and storage of CO<sub>2</sub>

A key result from the studies on the options for CO<sub>2</sub> storage is that Finnish crystalline bedrock generally does not favour large-scale CO<sub>2</sub> storage, since the free pore space in the hard granitic and gneissic rocks is minimal. Also, the prospects for storage of CO<sub>2</sub> in sedimentary rock formations of Finland and the Finnish economic zone in the Baltic

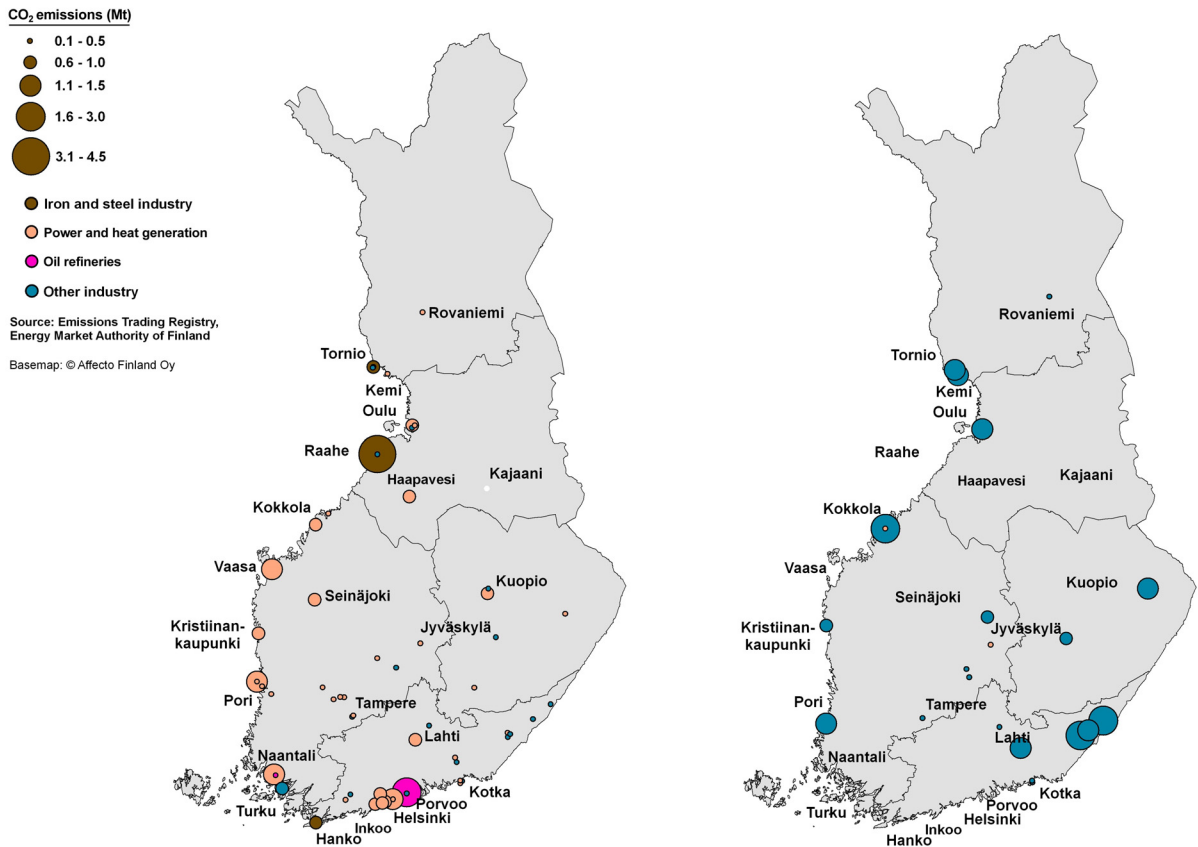


Figure 2. Maps over CO<sub>2</sub> emissions from the 76 facilities emitting >0.1 Mt CO<sub>2</sub>/a in Finland in 2008 (left: fossil and inorganic CO<sub>2</sub> emissions; right: biogenic CO<sub>2</sub> emissions). GIS map production by Matti Partanen (GTK).

Sea area are insignificant due their compactness [10]. The Finnish bedrock, which is mainly from the Precambrian age, lacks hydrocarbon reservoirs, and the occurrence of saline aquifers is unlikely [11]. However, prospects for feasible underground liquefied gas storage for CO<sub>2</sub> may occur. Therefore, possibilities for intermediate geological storage should be investigated near CO<sub>2</sub>-releasing industrial plants. Finland has large resources of magnesium silicate-containing rocks *in situ* and smaller amounts as hoisted rock and tailings. The development of mineral carbonation technologies for these resources is of some interest. Mineral carbonation could offer means for both waste rock utilisation and CO<sub>2</sub> fixation [12]. However, current technologies for that are not economically feasible.

Application of CCS in Finland would require transporting and storage of the captured CO<sub>2</sub> abroad. The most potential off-shore aquifer storage formations are situated in the North Sea and possibly also Barents Sea. The closest on-shore areas with potential aquifer formations situate in Poland and Denmark, and possibly also in Germany. Also, some theoretical aquifer potential has been reported to exist in the Baltic region [13].

Captured CO<sub>2</sub> would have to be transported to the storage sites either by ships or by pipeline. Many of the largest Finnish point sources of CO<sub>2</sub> are located along the coastline (Figure 2), which makes ship transportation an interesting option for early-stage CCS demonstration projects. However, the distances from Finnish facilities to the most likely storage sites in Denmark and the North Sea are between 1 500 and 2 500 km by ship. The overall aggregate costs of CO<sub>2</sub> transportation by ship are roughly in the range of 10 – 20 €/tCO<sub>2</sub>.

An alternative solution for a CCS infrastructure could be an on-shore north-bound pipeline stretching from the northern shore of the Gulf of Bothnia to the coast of the Barents Sea. This would reduce the transportation distance to 800 – 1 400 km. However, this is longer than existing CO<sub>2</sub> pipelines in USA, which vary between 130 and 800 km [14]. The high investment costs for the pipeline would probably be above the acceptable level for a single CCS demonstration. The costs of pipeline transportation could be significantly reduced by using a trunk line

infrastructure, where several capture plants would be connected to the same pipeline, thus sharing the investment costs.

#### 2.4. Regulatory framework

In general, Finland follows international and EU's legislation on CCS. The directive for geological storage of CO<sub>2</sub> is currently undergoing national implementation. In the ETS, Finland follows the European Commission's guidelines for monitoring and reporting of GHG emissions (MRG). In the national regulation and MRG it is clearly stated that the operator may subtract from the calculated level of emissions any CO<sub>2</sub> that is transferred out of the installation. However, the operator shall subtract only the respective fraction of mass of transferred CO<sub>2</sub> that originates from fossil fuels [15, 16]. In addition, the transferred amount of CO<sub>2</sub> needs also to be reduced from the national GHG inventory, in order to be accepted as reduction in the ETS. Production of liquid biofuels is likely to be excluded from the ETS and therefore some other incentive may be required to realize this probably economically efficient CCS application.

In the Action Plan for Energy Efficiency [6], minimum binding efficiency requirements are mentioned to be considered also for power plants if necessary. However, the actual requirements are not published. If any requirements for energy efficiency are announced, potential utilization of waste heat produced in CCS may benefit Finnish applications. In addition, removal of CO<sub>2</sub> will raise the concentration of the other components in the flue gas. Typically, emission limits are defined as concentrations in flue gases and, therefore, updates to the existing legislation may be required.

### 3. The future role of CCS in Finland

Finland's future energy system was studied with the new TIMES-Nordic model created by VTT. The TIMES-Nordic model is based on 15-region Global TIAM model [17], where all four Nordic countries (Denmark, Finland, Norway and Sweden) are added as individual regions and the rest of the Europe is divided into Western and Eastern Europe. In addition to the trade links included in the TIAM model (coal, gas, oil, electricity) the TIMES-Nordic model includes trade links for CO<sub>2</sub> transport and biofuels (liquid and solid fuels). The technology database for CCS technologies is based on results from CCS concept studies and CCS process simulations. In the scenarios, CCS was integrated to energy production and energy intensive industrial processes (pulp and paper production, oil refining, cement production). In our scenario assessments, bio-CCS is allowed in power plants, large scale combined heat and power (CHP) plants, and in pulp mills.

Figure 3 shows an example of the scenario results showing a long term potential of CCS for Finland with different CO<sub>2</sub> emission allowance prices. The allowance price increases linearly from 20 €/t CO<sub>2</sub> in 2010 to 50-90 €/t CO<sub>2</sub> in 2040. The calculations were performed both with and without bio-CCS (i.e. assuming existing ETS or extended ETS with new calculation rules for biogenic CO<sub>2</sub> emissions). The results show that if we assume that bio-CCS is included in the emissions trading system, the CCS potential rises up to 18 Mt/a CO<sub>2</sub> by 2050. Without bio-CCS the CCS potential is less than 10 Mt/a CO<sub>2</sub> by 2050.

### 4. Deployment of CCS in Finland

In Finland, the most potential facilities for CCS application are characterized by two factors: coastal location and reasonably large CO<sub>2</sub> emissions. A coastal location enables ship transportation of CO<sub>2</sub>, which is seen as the most potential means for transportation in the early phase of CCS deployment. Large facility-specific CO<sub>2</sub> emissions are needed to make the costs per capture CO<sub>2</sub> unit lower, in design, hardware and infrastructure investments. Also, large companies are considered more capable of applying CCS than small, because of the human and capital resources needed to run large projects and carbon management strategies. Large clusters of point sources might have a small benefit from synergies at least in CO<sub>2</sub> transportation and in storage arrangements.

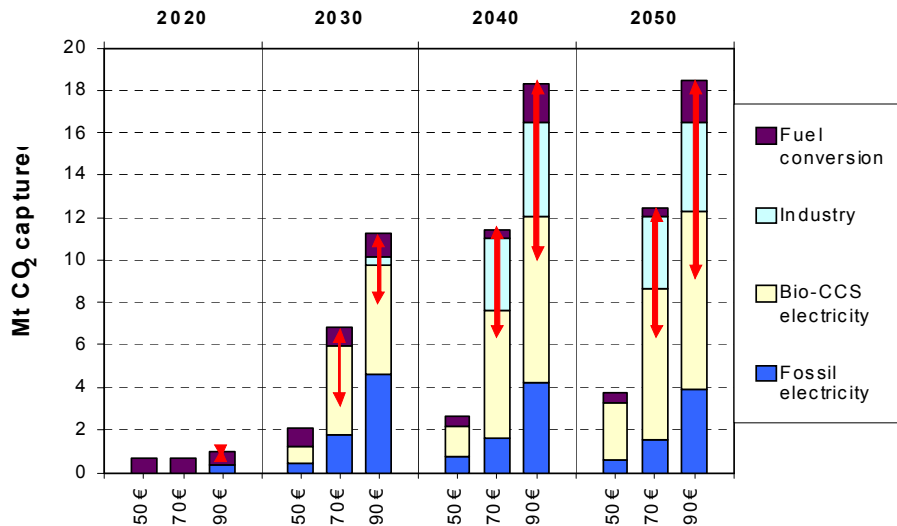


Figure 3. The impact of CO<sub>2</sub> allowance prices on the potential for CCS deployment in Finland. The allowance price is set to increase linearly from 20 €/t CO<sub>2</sub> in 2010 to 50, 70 or 90 €/t CO<sub>2</sub> in 2040. The arrows show the CCS potential decrease when excluding bio-CCS from the emission trading system in the model.

As power and heat generation in Finland is based on a wide mix of energy sources it is not as exposed to emission allowance price variations as in countries utilising mainly coal for energy production. Age and lifespan of existing facilities plays an important role in deployment of CCS in the power and heat sector, since facilities with only a few years left in operation are not potential targets, without consideration of rebuilding the plant. As only a few larger power plants are expected to be built in the near future, most potential targets for early CCS application are coal-fired power plants with several years of operation ahead and no realistic options in altering the fuel mix. Also peat fired plants may be potential candidates for CCS applications.

If a possibility for heat utilisation exists, such as in district heating systems or industrial processes, it could be an advantage for the application of CCS. A heat load enables better waste heat utilisation that leads to potential benefits in the overall efficiency compared to condensing power plants. This brings large power plants near urban areas into interest because of the proximity of a heat load. Nevertheless, only a few installations large enough on a coastal location can be pointed out.

As the largest point source of CO<sub>2</sub> in Finland is a steel mill, the iron and steel industry is seen as a potential sector for early deployment of CCS. However, iron and steelmaking processes are not the simplest processes to integrate with CCS. In the Northern part of the Gulf of Bothnia, including both Finland and Sweden, there is a cluster of steel mills and CHP plants emitting more than 10 Mt CO<sub>2</sub> per year. Collaboration within this cluster regarding CCS could be beneficial regarding technology and transportation opportunities. A few large oil refineries exist, where CO<sub>2</sub> capture processes could be more beneficial to integrate as the industry is already operating with similar processes. Cement works represent also a few large point sources of CO<sub>2</sub>, having annual emissions of about 0.5 Mt CO<sub>2</sub> and a coastal location. Nevertheless, technical options for CO<sub>2</sub> capture in cement works are limited and have not been investigated in detail. Certain gas streams in the industrial sector might also provide higher concentration of CO<sub>2</sub> than power plant flue gases, which would facilitate CO<sub>2</sub> capture. However, this potential is expected to be relatively low.

#### 4.1. Bio-CCS

There are also large CO<sub>2</sub> emissions in Finland originating from biomass combustion, both in energy production and industry. As CO<sub>2</sub> is bound to biomass in the photosynthesis, carbon capture from biomass-fired installations would lead to negative emissions on a life cycle basis, in other words removing CO<sub>2</sub> from the carbon cycle and thus

lowering the CO<sub>2</sub> content of the atmosphere. However, the current EU ETS do not recognize negative emissions from power plants, and thus no economical incentive exists for capturing CO<sub>2</sub> from biomass installations.

In general, similar technologies that are planned to be used with fossil fuels would also be applicable to bio-CCS (also referred to as BECCS). Regarding flue gas composition in energy generation applications there are no fundamental technical restrictions for applying CO<sub>2</sub> capture to biomass-fired power plants. In some processes, such as production of Fischer-Tropsch diesel or synthetic natural gas from biomass, very pure CO<sub>2</sub> streams are readily available, because the CO<sub>2</sub> needs to be removed from the process. Similar low-cost cases can be found in other biomass applications as well, for example in biogas upgrading and hydrogen production technologies. A few biomass-to-liquid (BtL) plants are currently being planned in Finland. Although pure CO<sub>2</sub> streams of a few hundred thousands of tonnes would be readily available, the mills are planned to be constructed far from the coastal line, which would increase the cost for transporting CO<sub>2</sub>.

The pulp and paper mills in Finland (and Sweden as well) emit large amounts of mainly biogenic CO<sub>2</sub>. Capturing CO<sub>2</sub> from flue gases from pulp and paper mills seems to be technically more difficult and thus more expensive than e.g. from power plants. This is mainly because of the chemicals used in the processes, which contaminate the flue gas. However, the application of CCS in the pulp and paper industry has been studied very little.

As far as biomass and biogenic emissions are concerned, for power plants the most potential and straight forward applications would be in facilities co-firing biomass with peat. Purely biomass-fired power plants are not seen as primary candidates for CCS application, since these do not currently need to reduce their CO<sub>2</sub> emissions. In addition, these installations are generally of moderate size and situated in the central of Finland. Generally fossil and inorganic CO<sub>2</sub> emissions are seen as more potential target for capture than biogenic emissions in the early stage.

## 5. Current CCS activities in Finland

There are several activities in Finland related to CCS. CCS has in recent year become more acknowledged by companies and the government as a possible measure in the future for reducing greenhouse gas emissions. Fortum and Teollisuuden Voima are planning to retrofit the Meri-Pori condensing coal-fired power plant with CCS. The target is to annually capture 1.2 Mt CO<sub>2</sub>, which is roughly 1.5% of Finland's annual CO<sub>2</sub> emissions, and transport it with tanker ships for storage in the North Sea. The objective is to make an investment decision in 2012 and thus have the system operational in Meri-Pori in 2015. The project competes for a share of the 300 million allowance rights of the European Emissions Trading Scheme set aside for subsidising installations of innovative renewable energy technology and CCS (also referred to as the NER300). Pohjolan Voima (PVO) is developing a new, large-scale (500-700 MWe) combined heat and power plant concept, which allows co-firing of several different fuels. The concept includes CCS readiness. Both Metso Power and Foster Wheeler Energy develop oxy-fuel technology. Also VTT is actively involved in CCS R&D, especially in developing oxy-fuel combustion. VTT is currently coordinating the EU FP7 project "Flexi Burn CFB", which aims to develop and demonstrate a power plant concept based on the circulating fluidized bed technology combined with CCS. Åbo Akademi, Aalto University and the Geological Survey of Finland have been involved in developing carbonation processes for minerals and industrial by-products for storage of CO<sub>2</sub>.

## 6. Conclusions

The current Finnish climate and energy policy focus on increasing the share of renewable energy and nuclear power, which leaves less room for CCS. Large distances to suitable storage formations also make CCS applications more costly in Finland. Nonetheless, there is a potential to significantly reduce CO<sub>2</sub> emissions by applying CCS to the largest CO<sub>2</sub>-emitting plants. Currently, there are plans for a CCS demonstration plant in Finland. CCS is also the only option for many industrial sectors, such as steel production, for achieving a significant reduction in CO<sub>2</sub> emissions. Bio-CCS would have a large CO<sub>2</sub> mitigating potential in Finland, but currently there are no economical incentives for promoting this.



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