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CO_2 capture, storage and reuse potential in Finland

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Abstract

Economical feasibility and potential of CO_2 capture, storage and reuse in Finland was evaluated under the National Programme on Technology and Climate Change (Climtech). In Finland, no suitable geologic formations exist to sequester CO_2. The nearest potential CO_2 sequestration sites are offshore oil and gas fields in the North Sea and Barents Sea, which would mean a transport of 500–1000 km for captured CO_2. With current knowledge, capturing CO_2 near the storage sites and investing to new cross-border electricity transmission capacity seems the most feasible option for Finland. Storing CO_2 as solid mineral carbonate could be an option in the future, since large resources of suitable silicates exist in Finland as natural minerals and as wastes of mining industry. The reuse potential of captured CO_2 is less than 0.5% of the annual CO_2 emissions.

1. Introduction

The application of CO_2 capture, storage and utilization technologies from Finland's perspective was studied in the National Programme on Technology and Climate Change (Climtech) [1]. The objective of the programme was to support mitigation of climate change and attainment of the national climate change mitigation objectives, by contributing to technological choices, research, development, commercialization and implementation. The time scale for the technologies studied extends to about 2030.

Most of the greenhouse gas (GHG) emissions in Finland are due to fossil fuels combustion. The annual GHG emissions, for example, depend on hydropower production in the Nordic countries, demand of heating energy and the degree of economic growth. On average, in the

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1990s, the total GHG emissions have grown slightly, but the annual variation has been quite large due to variation in hydropower production and imported electricity. In 1999, CO_2 emissions from fossil fuel combustion were 56.8 million tonnes of CO_2-eq., which is about 3 million tonnes more than in 1990. The total GHG emission of all Kyoto gases were roughly about the same level as in 1990 because of decreases of emissions in other sectors like waste management and agriculture. The net growth of the forest biomass caused a biological sequestration impact varying annually between 10 and 35 million tonnes in the 1990s [2]. Only a small fraction of this biological net sink can be accounted in the fulfillment of the Kyoto Protocol commitments according to the agreements made in the Bonn and Marrakech negotiations between the parties to the Climate Convention.

In Finland, no suitable geologic formations exist to sequester CO_2. Also, oceans nearby Finland are not deep enough for considering CO_2 storage in oceans. The nearest potential CO_2 sequestration sites are offshore oil and gas fields and saline aquifers in the North Sea and Barents Sea. This would mean a 500–1000 km CO_2 transport depending on the location of the CO_2 capture plant.

The objective of the paper is to consider the feasibility of CO_2 capture, reuse and storage in Finland in the control of Finnish national GHG emissions. Due to long transport distances, a part of the research was focused on the application of technologies in Finland and part of the work was concerned with application of CO_2 capture and storage technologies near the storage sites and importing the energy in the form of electricity or hydrogen to Finland. The CO_2 reuse potential in industry was also assessed in the study. Further, possibilities to sequester CO_2 in solid silicate rocks were considered.

2. Industrial CO_2 capture and utilization in Finland

Currently, industrial needs for CO_2 are mostly covered by captured CO_2 in Finland. Three CO_2 capture plants exist in connection with hydrogen, alcohol and calcium chloride production. The total capacity of these capture plants is about 70 000 tonnes of CO_2 per year. Finland's beverage industry also has additional CO_2 capture plants, which reduces the amount of purchased CO_2 for beverage production. CO_2 is also produced for greenhouses by burning fossil fuels.

In Finland, the greatest CO_2 consuming industries are pulp and paper, beverage, food processing and metal industries. Recently, especially in the Finnish pulp and paper industries, innovative CO_2 gas applications has been developed and they are presently in use at a number of large mills. The CO_2 applications have been introduced especially for recycled paper. In food processing industries, CO_2 usage has also grown to increase food safety. In the 1990s, Finland's beverage sales increased from 230 million to 360 million liters. It is assumed that beverage production in Finland may still increase by some degree, but not in the same extent as in the 1990s. The potential to reuse captured CO_2 in industry is less than 0.5% of Finland's anthropogenic emissions. On the other hand, various industrial processes like pulp and paper manufacturing processes, could offer niches, wherein CO_2 capture process could become economical. The possible growing industrial need of CO_2 in Finland may not be covered by existing CO_2 production plants, which motivates to look for new processes to capture and produce CO_2.

3. Large scale sequestration of CO_2 in Finland

3.1. Storing CO_2 as mineral carbonate

Although no geologic formations exist to sequester CO_2, storing CO_2 as mineral carbonate could be an option, since large resources of suitable silicates exist in Finland as natural minerals and as wastes of mining industry. However, mineral carbonation may be very energy consuming and thus in a recent study [3] reaction pathways with minimum energy input were addressed. The reaction kinetics of mineral carbonation with and without catalytically active contaminants were studied. The effects of gas composition and pressure were analysed for Finnish $Mg_3Si_2O_9H_4$ (serpentine) and $Mg(OH)_2$ (brusite) samples. It was concluded that the mineral carbonation process has to involve the release or activation of the mineral's MgO content before the reaction with CO_2 to $MgCO_3$, which could imply a two-stage process. Water catalyzes the carbonation reaction somewhat, which makes the use of serpentine (its 10–14 wt% crystal water is released) more attractive than other MgO-containing minerals (olivine, forsterite). CO_2 will have to be transported to a suitable mineral deposit since transporting minerals to/from CO_2 emission sources will present unacceptable costs. Fortunately, process integration with mining activities may be very advantageous from cost and energy consumption points of view, possibly allowing for, e.g. higher valuable metal extraction rates as well. Most of the mineral deposits are found in Central and Northern Finland. Further research will concentrate on reaction kinetics and large-scale integrated processing based on direct, dry carbonation of MgO-containing mineral with pressurized CO_2 from a separate capture process.

3.2. Feasibility of CO_2 capture and storage from Finland's perspective

As CO_2 capturing would be more economical on a large scale, the largest CO_2 emitting point sources were evaluated. The largest CO_2 emitting plants in Finland are oil refineries, coal-fired power plants and steel works. From five to ten plants, there is more than 1 million tonnes of CO_2 production annually. In the pulp and paper industry, increased amounts of biofuel used in energy production has reduced fossil CO_2 emissions considerably. In principle, it would be possible to capture CO_2 from gas streams of forest industry and hence reach even a negative emission level. However, presently there are no such emission accounting rules, which would make this economically feasible. The CO_2 emissions of coal-fired condensing power plants vary a lot from year to year. If the annual amount of rainfall is high in the Nordic countries, hydropower production is high and more electricity is imported to Finland. During dry seasons Finland exports electricity, which is mainly produced by condensing coal-fired power plants (see Fig. 1). To meet the GHG emission reduction targets in the long term, the CO_2 sequestration might be one option among many emission reduction alternatives.

The economic feasibility of CO_2 capture by conventional chemical absorption was evaluated for 660–790 MW_e conventional natural gas fired combined cycle (NGCC) and for 360–500 MW_e pulverized coal once through boiler (PF). The CO_2 capture process was integrated with a green field power plant. The estimated costs of 1000 km pipeline transmission to a storage site and offshore storage of CO_2 were included in the evaluation. The data were collected from literature for power plant concepts and for CO_2 capture process. For transmission and storage

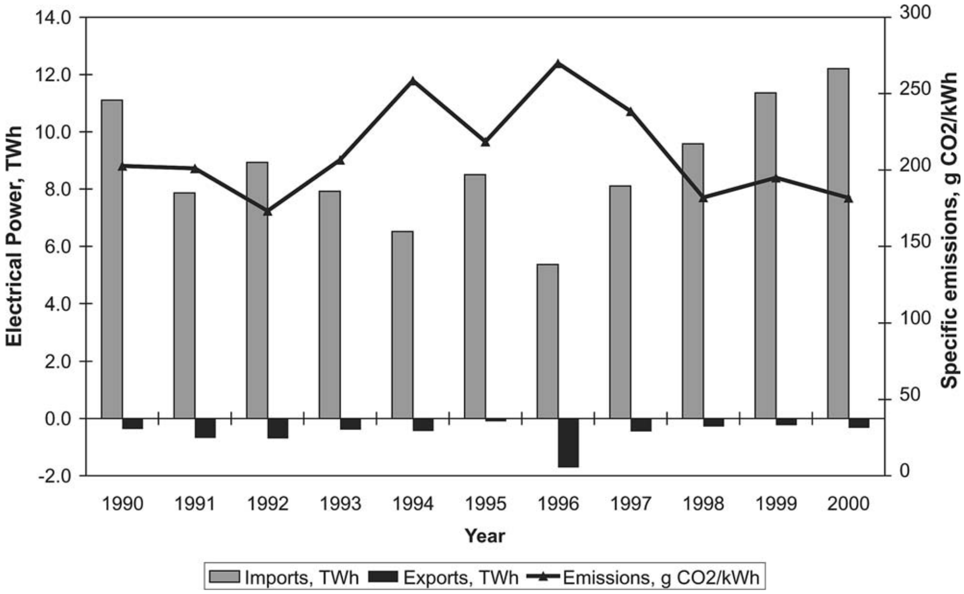

Fig. 1. Finland's imports and exports of electricity as well as specific CO_2 emissions in electricity production, g CO_2/(kW h).

of CO_2 and energy, a spreadsheet-based model recently published by IEA Greenhouse Gas R&D Programme [4] was used as well. The results of the evaluations are presented in Figs. 2 and 3. The electricity market price is the average electricity price in the Nordic Power Exchange, which is the world's first international commodity exchange for electrical power.

As shown in Figs. 2 and 3, the production cost of electricity would be about two times higher than the average electricity market price in Finland if the investment and operating costs of CO_2 capture, transport and storage were included. For coal power plant, the corresponding electricity production cost would be about three times higher than the current market price of electricity.

Different options for CO_2 management were also evaluated. These included:

1. Natural gas is imported by existing pipeline and electricity is produced by NGCC in Finland. The captured CO_2 is transported by a 1000 km onshore pipeline and sequestered offshore.
2. Carbon-free fuel, i.e. hydrogen, is imported into Finland by a 1000 km onshore pipeline. In this scenario, fuel is decarbonized near the storage site and CO_2 is sequestered.
3. Electricity is produced near the sequestration place and imported into Finland. Cross-border DC electricity transmission capacity is increased by a given amount.

In Fig. 4, investment costs for the above scenarios are shown. In the calculations, fuel power has been increased to cover the losses of electricity transmission, initial gas compression and/or gas transport. Preliminary results indicated that CO_2 transport or electricity transmission would be the most economically feasible options with such long transport distances. Considering

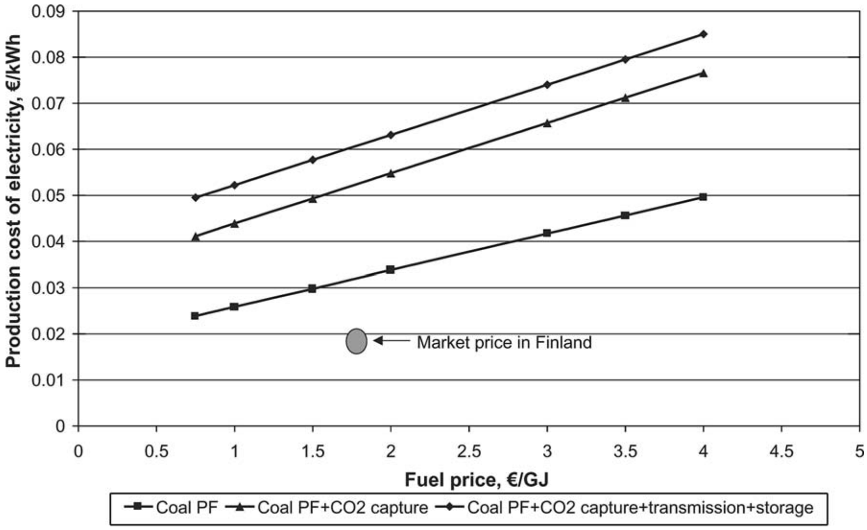

Fig. 2. Power production costs for a condensing coal-fired power plant with CO_2 capture (includes gas compression), 1000 km onshore pipeline transmission of CO_2 and offshore CO_2 geological storage (discount rate 5%, plant life 25 years, operating time annually 8000 h).

environmental and safety issues as well, electricity transmission would become the most feasible option. However, it should be noted, that the investment costs of hydrogen alternative have remarkable uncertainty, and more detailed analysis should be performed before final conclusions can be drawn.

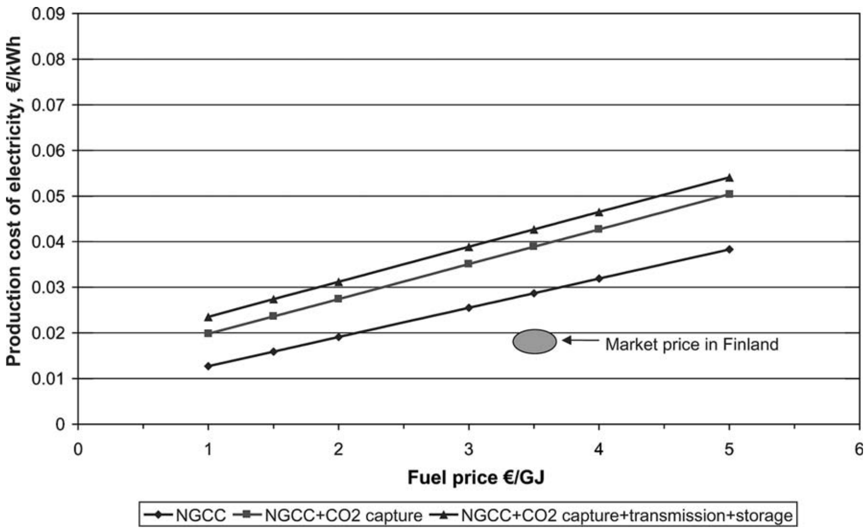

Fig. 3. Power production costs for a condensing natural gas fired power plant with CO_2 capture (includes gas compression), 1000 km onshore pipeline transmission of CO_2 and offshore CO_2 geological storage (discount rate 5%, plant life 25 years, operating time annually 8000 h).

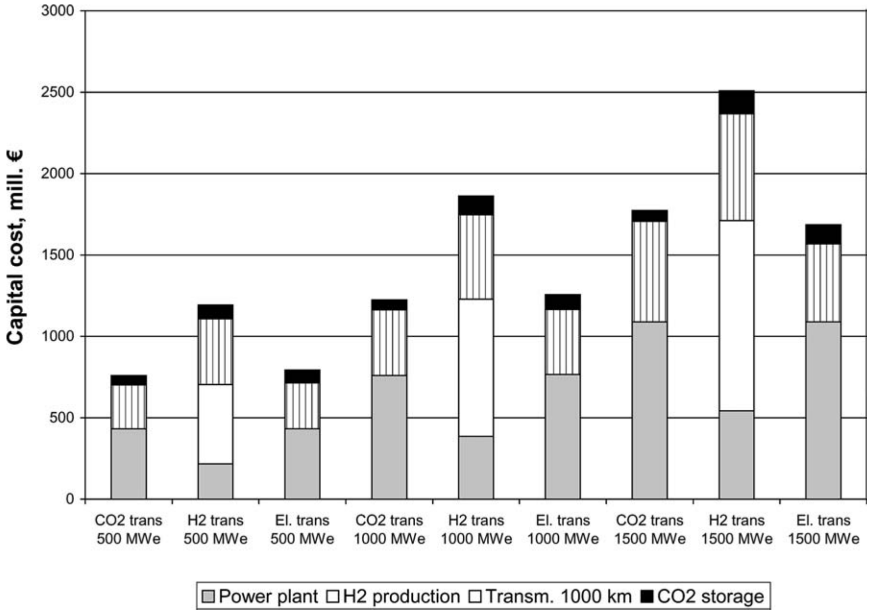

Fig. 4. Comparison of investment costs of three CO_2 management scenarios for Finland.

4. Discussion and conclusions

The lack of long-term CO_2 storage sites in Finland and long transmission distances to the closest storage sites abroad would be the greatest barriers to overcome before the implementation of the CO_2 capture and long-term storage technologies in emission management. The production cost of electricity would be approximately doubled for NGCC with CO_2 capture, onshore transmission and offshore storage. For coal, the electricity production cost would be even higher despite the assumed high annual operating time (8000 h/a). Presently, the operating times for condensing coal-fired plants are much lower (2000–4000 h/a).

Mineral carbonation could be an option for Finland to store CO_2. However, the reaction kinetics of carbonation process have to be further investigated before any final conclusions can be made.

The potential to reuse captured CO_2 in industry is less than 0.5% of Finland's anthropogenic emissions. On the other hand, various industrial processes like pulp and paper manufacturing processes, could offer niches, wherein CO_2 capture process could become economical. However, few CO_2 reuse options in Finland offer long-term carbon sinks.

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