CICERO Report 2008:03

Large-scale carbon capture and storage for coal-fired power: Effect on carbon dioxide emissions and global warming

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April 2008

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Tittel: Large-scale carbon capture and storage for coal-fired power: Effect on global carbon dioxide emission

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CICERO Report 2008:03

Oppdatering av CICERO Report 2007:06

6 sider

Finansieringskilde: Sargas AS

Prosjekt: Globale CO_2 utslepp – effekt av karbonhandtering i kolfyrte kraftverk

Prosjektleder: Asbjørn Torvanger

Kvalitetsansvarlig: Asbjørn Aaheim

Nøkkelord: Karbonhandtering, globale CO_2-utslepp, global oppvarming, kolfyrte kraftverk

Sammendrag: Scenaria i denne rapporten viser at storskala innføring av karbonhandtering i nye kolfyrte kraftverk frå 2015 kan redusere globale CO_2-utslepp med 8-18% i 2030 og 22-25% i 2100. Den globale oppvarminga per 2100 blir redusert frå 4,9 til 4,4 °C. Desse estimata er sensitive med omsyn på valet av business-as-usual scenario, både når det gjeld totale CO_2-utslepp og når det gjeld kraftproduksjon basert på kol, og dei avheng også av andre føresetnader, slik som klimasystemet sin sensitivitet med omsyn på CO_2-konsentrasjonen i atmosfæren.

Språk: Engelsk

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CICERO Report 2008:03

Update of CICERO Report 2007:06

6 pages

Financed by: Sargas AS

Project: Global CO_2 emission – effect of CCS in coal-based power production

Project manager: Asbjørn Torvanger

Quality manager: Asbjørn Aaheim

Keywords: Carbon capture and storage, global CO_2 emissions, global warming, coal-fired power plants

Abstract: The scenarios in this report show that large-scale deployment of carbon capture and storage technologies for new coal-fired power plants from year 2015 may reduce global CO_2 emissions by 8-18% by 2030 and 22-25% by 2100. By 2100 global warming is reduced from 4.9 to 4.4 °C. These estimates are sensitive to the Business-as-Usual scenarios chosen, both for total CO_2 emissions and for power production based on coal, and to other assumptions, such as the climate sensitivity.

Language of report: English

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Preface

This report is financed by Sargas AS. It has been prepared in the period March-April 2008. It is an extended version of CICERO Report 2007:06 (Torvanger, 2007), where the effect on global warming has been included. The background is the CO_2 capture technology developed by Sargas AS and the pilot facility for CO_2 capture at the Värtan coal-fired power station in Stockholm operated by Fortum Värme and Sargas AS that started its operation in November.

1 Introduction

Carbon dioxide capture and storage (CCS) is the process of collecting CO_2 emissions from power plants or large industry sources, transporting the captured gas to a suitable location, and injecting it underground in deep geological formations. This technology is being promoted by both scientists and policy-makers as one of the most promising alternatives for large-scale reductions of greenhouse gases to fight global warming.

Because major emitters, including China, India, and the United States, all have significant coal reserves, coal is likely to play a major role as an energy source for many decades to come – even with aggressive policies in place to address climate change. As a result, CCS is anticipated to be an important part of any portfolio of alternatives for near-term, substantial reductions in global carbon dioxide emissions. However, despite growing interest in CCS technology, there are still several major barriers to creating and maintaining large-scale, widespread CO_2 storage sites. Among these barriers are high and uncertain costs, inadequate regulatory systems, and limited public awareness.

In this report we examine the potential of large-scale CCS in the coal-fired power sector to reduce global CO_2 emissions, and to reduce global warming. The calculations are based on a CCS scenario where, from 2015, all new coal-fired power facilities on a global scale install technology to capture CO_2. One can discuss the likelihood of all coal-fired power production being CCS-based from 2015 at the global level. Therefore this scenario should rather be interpreted as showing the maximum potential of reduced CO_2 emissions at global level if there are no obstacles to the introduction of CCS in coal-based power production from 2015 onwards. On the other hand, there is also a sizeable CCS potential for retrofitting old power plants with post-combustion capture facilities, a substantial CCS potential for industrial processes, gas-fired power plants, and for gas and oil if and when a centralized hydrogen-based fuel system for vehicles is developed.

All CO_2 is assumed to be safely stored in geological formations. The reduction in CO_2 emissions is compared to total global CO_2 emissions, thus including emissions from energy use and from changes in land use and forestry. The time horizon is up to the end of this century.

2 Method, scenarios and data

Two Business-as-Usual (BaU) scenarios from IIASA are employed.[1] These scenarios are part of a larger family of emission scenarios from the SRES (Special Report on Emission Scenarios) work by IPCC, and which have been used as a basis for projections of climate change contained in the IPCC reports. These scenarios include separate scenarios for coal use by power producers.

The first scenario is B2, which is a medium to low emission scenario, where population growth and income growth are moderate, and where fossil based energy technology development, and non-fossil based energy technologies show moderate progress. In this scenario the average annual growth rate of global CO_2 emissions in the period 2000-2100 is 0.5%, whereas the growth rate of coal-based power production is 0.9%.

[1] Confer: http://www.iiasa.ac.at/web-apps/ggi/GgiDb/dsd?Action=htmlpage&page=series

In comparison, the second scenario, A2r, has relatively high population growth, low income growth, and low technology development for non-fossil energy technologies. The present trend in global emissions is much closer to this scenario than the B2 scenario. In this scenario the average annual growth rate of global CO_2 emissions in the period 2000-2100 is 1.2%, whereas the growth rate of coal-based power production is 1.6%.

Two CCS scenarios are developed. In both scenarios CCS is introduced for all new coal-fired power plants from 2015 onwards. A CO_2 capture facility is likely capable of capturing 95% of emissions, but in practice this rate can be reduced by some percentage points if there are disturbances while in operation. To check the sensitivity of global emission reduction from a slightly reduced capture rate we include a 90% capture scenario.

Based on these scenarios, the following steps are undertaken to calculate the effect of the CCS scenario on global CO_2 emissions and global temperature until 2100:

1. Convert annual coal-based power production from EJ to Mt of CO_2, based on a conversion factor from EJ to TWh, and from TWh to Mt CO_2 based on the energy efficiency from coal use in electricity production (using data from IEA and the average efficiency from year 2000).[2]

2. Assume that global coal-based power production remains the same in the CCS scenarios as in the BaU scenarios.

3. Insert linear phase-out of non-CCS coal power starting in 2015 and ending up with zero emissions from such plants by 2050.

4. Fill the gap between coal-based power production in the BaU scenarios and residual non-CCS coal-based power capacity by new CCS-based power plants that are able to capture 90% or 95% of CO_2 emissions. This means that from 2050 onwards, 90% or 95% of all coal-based power related emissions are captured.

5. Calculate reduced annual CO_2 emission form coal-based power and subtract this from global BaU emissions.

6. Draw global CO_2 emission curves for each of the BaU scenarios and for the CCS scenarios in the period 2000–2100.

7. Calculate the temperature response of reduced CO_2 emissions with the help of CICERO's Simple Climate Model (SCM).

3 Effect on global CO_2 emissions

The resulting CO_2 emission curves are shown in figures 1 and 2, and the reduction in absolute figures and percentages compared to BaU for 2030 and 2100 are shown in Table 1.

[2] The conversion factor from EJ coal-based electricity production to Mt CO_2 is 243.

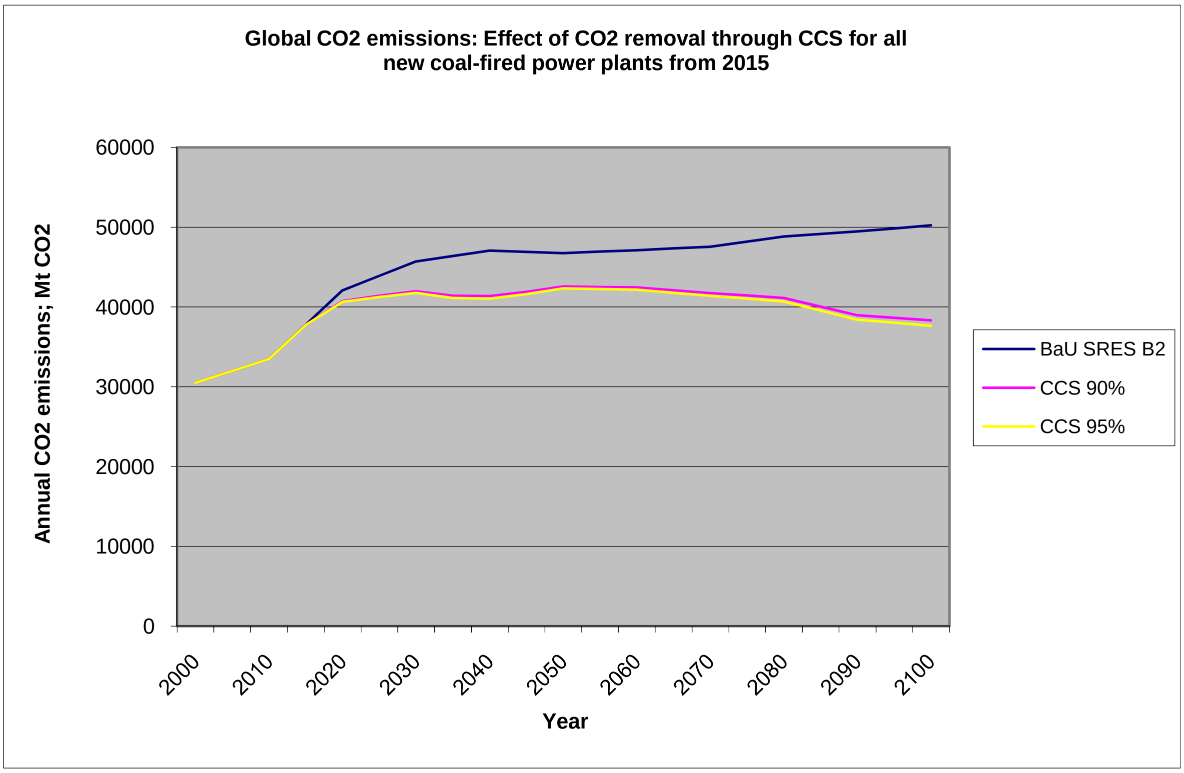

Figure 1. Comparison of global CO_2 emission for the B2 BaU scenario and the CCS scenarios.

The figures show that global CO_2 emissions are gradually reduced from 2015 due to CCS, ending up at 22-25% reduction by 2100. Since the A2r scenario involves about a doubling of coal-based power production compared to B2, the volume of CO_2 emissions reduction is also doubled in this scenario compared B2. The reduction is at 23-24 Gt CO_2 for A2r and 12-13 Gt CO_2 for B2, highest for the 95% CCS capture scenario. Overall we note that there are only minor differences on global emission reduction from a capture rate of 95% or 90%.

BaU scenario	Year	2030		2100	
	CCS scenario capture rate; %	Reduction in emissions; Gt CO_2	%	Reduction in emissions; Gt CO_2	%
B2	90	3.7	8.2	11.9	23.8
	95	3.9	8.6	12.6	25.1
A2r	90	8.7	16.6	22.5	21.9
	95	9.2	17.5	23.8	23.2

Table 1. Emission reductions in CCS scenarios compared to BaU scenarios in 2030 and 2100.

By 2030 the global emissions reduction in the CCS scenarios compared to the A2r scenario is around 17-18% compared to 8-9% for the B2 scenario. In absolute numbers the reduction is 4 Gt CO_2 for B2 and 9 Gt CO_2 for A2r.

Figure 1 shows that global CO_2 emissions by 2100 in the CCS scenarios are down to the 2015 level in the B2 scenario.

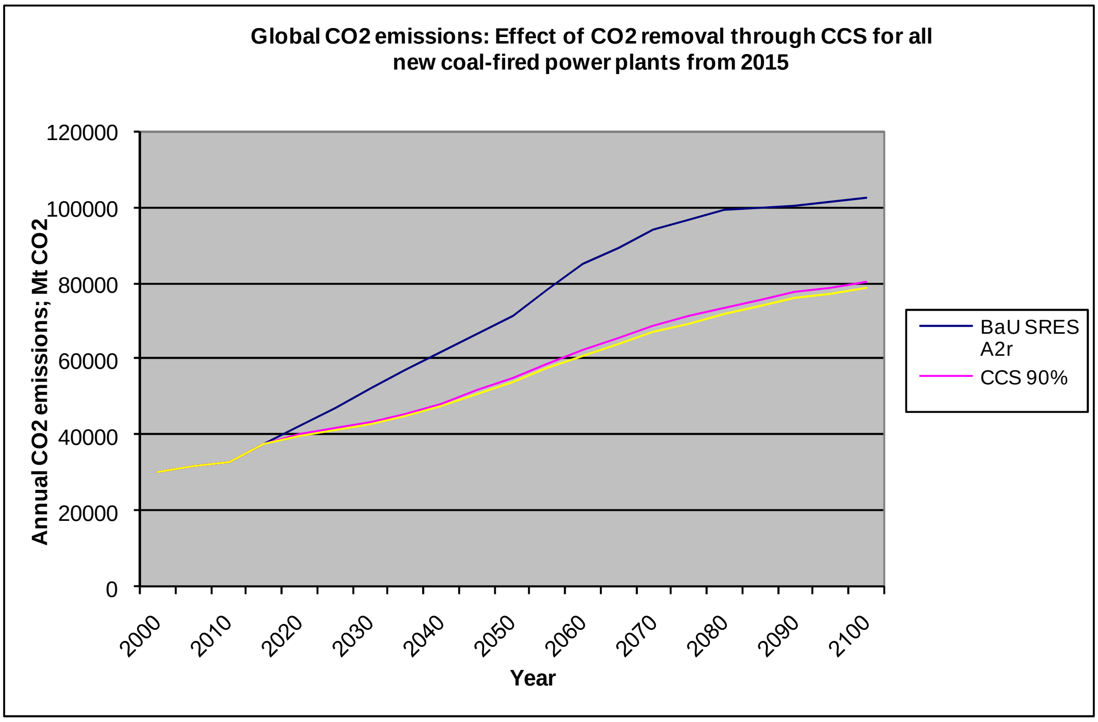

Figure 2. Comparison of global CO_2 emission for the A2r BaU scenario and the CCS scenarios.

4 Effect on global warming

To calculate the global temperature change from reduced global CO_2 emissions the CICERO Simple Climate Model (SCM) is used (Fuglestvedt and Berntsen, 1999; Fuglestvedt et al., 2000). The SCM calculates global mean concentrations from emissions of 24 gases and radiative forcing for 30 components (including stratospheric and tropospheric O_3, direct and indirect effects of aerosols). The global mean temperature change is calculated by an energy-balance climate/up-welling diffusion ocean model developed by Schlesinger et al. (1992), which has a prescribed climate sensitivity. The climate sensitivity is set to the best guess value 0.8 $^{\circ}C/Wm^{-2}$ in our study.

In the SCM the historical development in global concentration of CO_2 is calculated using a scheme based on (Joos et al., 1996). The CO_2 module uses an ocean mixed-layer pulse response function that characterizes the surface to deep ocean mixing in combination with a separate equation describing the air-sea exchange (Siegenthaler and Joos, 1992). It also includes changes in CO_2 uptake by terrestrial vegetation due to CO_2 fertilization. For the other gases standard values for lifetime/adjustment time are used. Indirect effects of CH_4 on tropospheric O_3 and stratospheric H_2O as well as effects on its own adjustment time, are taken into account. Parameterizations of tropospheric O_3 and OH as function of NO_x, CO, VOC and CH_4 are taken from IPCC-TAR (Ramaswamy et al., 2001) as well as concentration-forcing relations.

We limit the analysis to the highest emission growth reference scenario, that is A2r, and the CCS scenario where 95% of CO_2 in the exhaust from new power stations is captured. The resulting temperature response of this CCS scenario is shown in Figure 3.

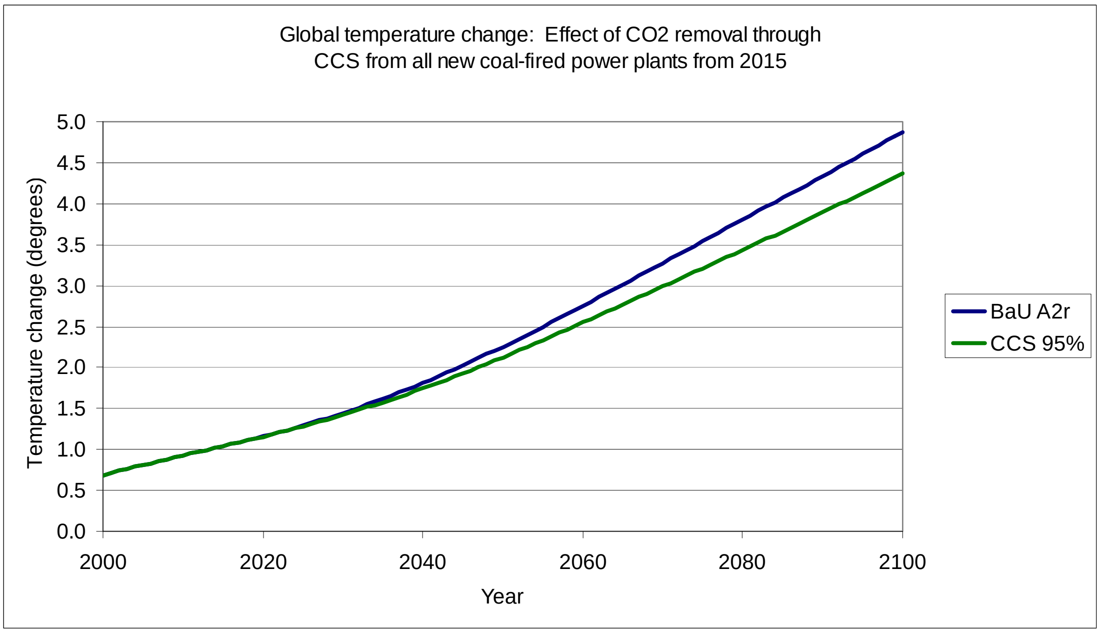

Figure 3. Temperature effect of 95% CO_2 capture rate for all new coal-power from 2015 compared to the A2r reference scenario.

In the reference scenario A2r the global warming commitment due to human-related release of greenhouse gases is 4.9 °C above pre-industrial global mean temperature by year 2100. Due to reduced global CO_2 emissions in the CCS scenario the temperature increase is reduced by about 0.5 °C, that is to 4.4 °C, equivalent to a reduction of about 10% in global warming from pre-industrial level till the end of this century.

5 Summary

The scenarios analyzed in this report show that large-scale deployment of carbon capture and storage technologies for all new coal-fired power plants from year 2015 onwards can reduce global CO_2 emissions by 8-18% by 2030 and 22-25% by 2100 compared to the reference scenario. The global reference emission scenarios include both energy-related CO_2 emissions and emissions due to land-use change and forestry. Compared to the reference scenario global warming by end of this century is reduced by 0.5°C, which is about 10% less warming from pre-industrial level. These CCS scenarios are illustrations only, and are sensitive to the climate sensitivity and the business-as-usual scenarios chosen, both for total CO_2 emissions and for power production based on coal. Since no cost calculations are inluded in the analysis the realism of the CCS scenarios chosen as part of a wider climate strategy has not been assessed.

Acknowledgements

We thank Jan S. Fuglestvedt for valuable comments while preparing this report.

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