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

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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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**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.

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**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.

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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 Report 2007-6 (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.

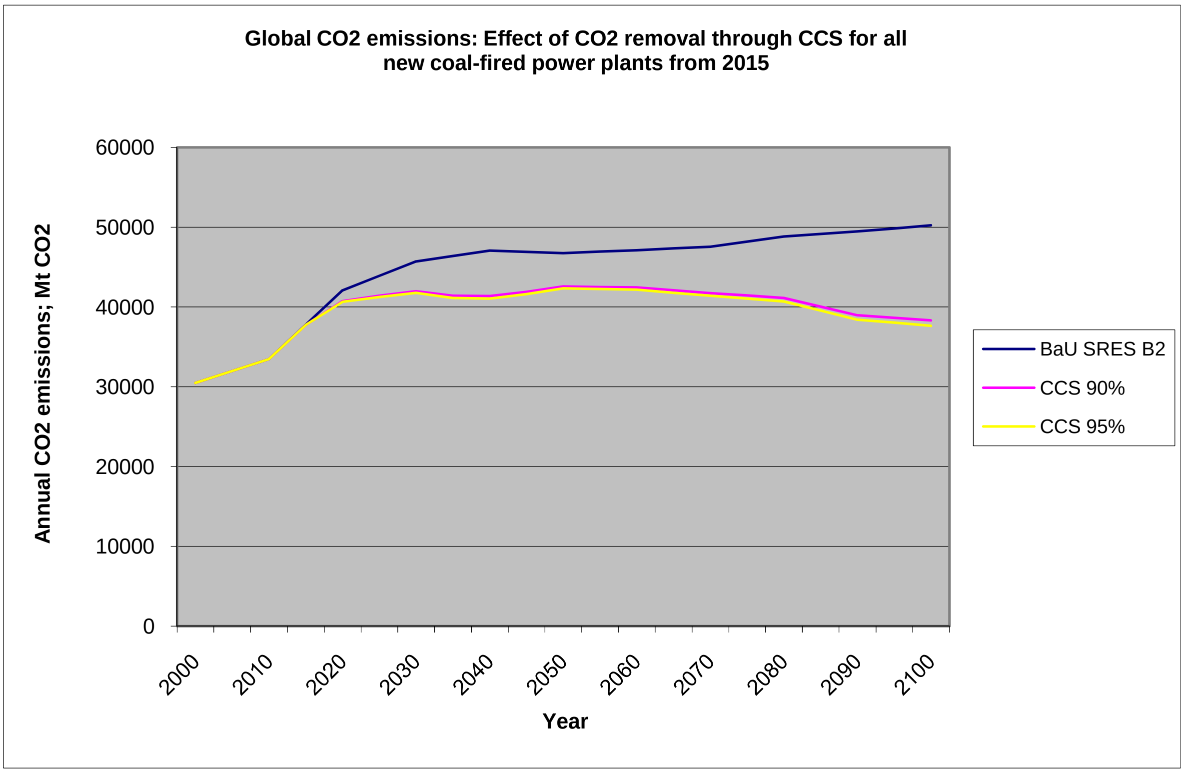


**Figure 1. Comparison of global $CO_2$ emission for the B2 BaU scenario and the CCS scenarios.**

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.

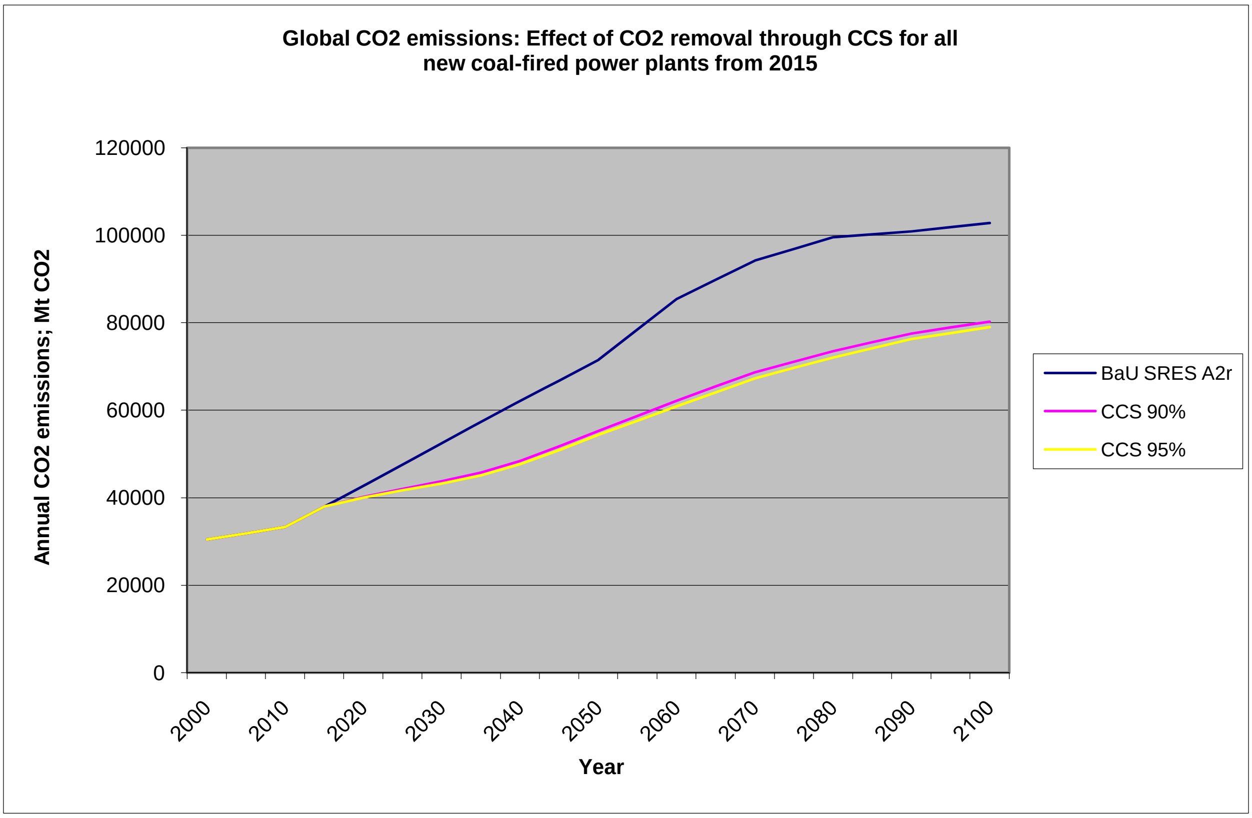


**Figure 2. Comparison of global $CO_2$ emission for the A2r BaU scenario and the CCS scenarios.**

# 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.

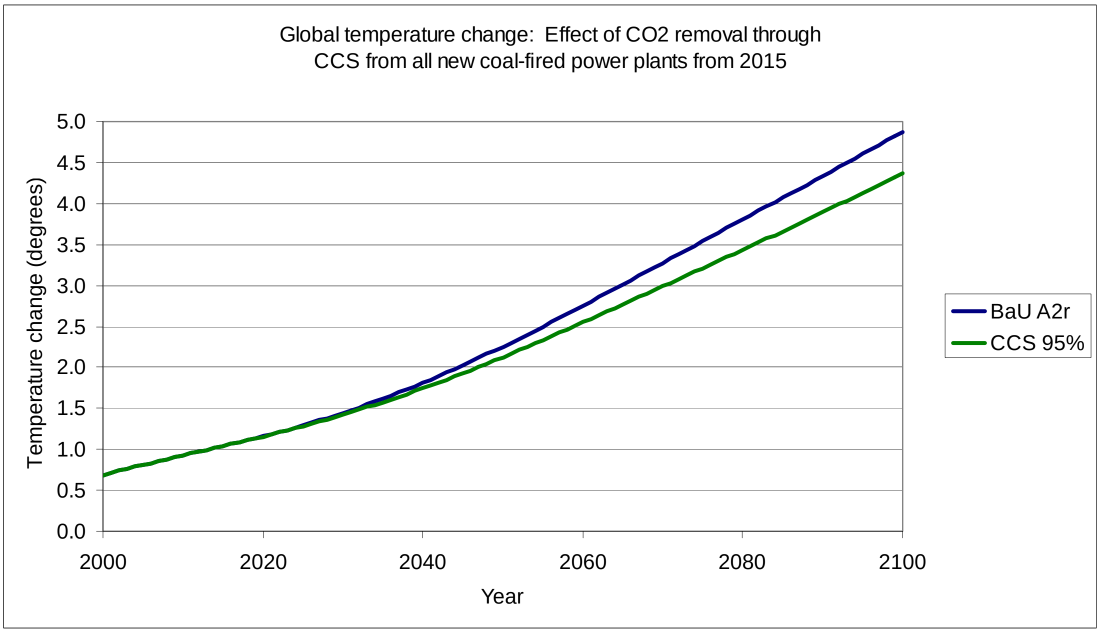


**Figure 3. Temperature effect of 95% $CO_2$ capture rate for all new coal-power from 2015 compared to the A2r reference scenario.**

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

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