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CO2 Capture and Storage: The Energy Costs

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Capturing carbon dioxide from coal (and gas) fired electricity plants. Subsequently transporting the carbon dioxide from the plant and storing it underground in (abandoned) oil/gas fields, in other geological formations or on the ocean floor. It seems like an excellent solution for continued fossil fuel use in the coming decades.

The European Union wants to have 12 large CO2 capture and storage demonstration projects in place by 2015, requiring an investment of 5 billion euro. The expectation is that this development will cause significant cost reductions, making the technology affordable by 2020. There are however two large drawbacks, it will keep costing large sums of money and the process is quite energy intensive. In this post the impact of the extra energy cost of the process on coal depletion is quantified, the economics will follow in a later article.

A short overview of carbon capture and storage

To create a nearly pure stream of carbon dioxide at the power plant for storage there are three distinct possibilities.

Post combustion, in which the mixture of CO2 and flue gases after combustion is separated by using a liquid solvent.

Pre combustion, where the fuel is processed prior to combustion resulting in a mixture of mainly CO2 and hydrogen. Both gas streams are subsequently separated, so that the hydrogen can be combusted for electricity production and the CO2 for storage.

Oxyfuel combustion, using pure oxygen instead of air when combusting resulting in flue gas that contains mainly water vapour and CO2. Both streams can easily be separated and treated further if necessary.

All three processes are already applied in several industries on smaller scales but not for storage purposes. No attempt has been made to date to capture CO2 at large power plants. The choice for the system is highly dependent on the type of power plant. For instance in a gasification coal power plant pre combustion already occurs to a large extent so this option is much cheaper for such a plant. Most coal power plants built so far do not rely on gasification. For these post combustion is the best option.

Transport can be done either by pipeline or ship towards a preferred storage site. A significant amount of depleted oil and gas fields, saline formations (porous reservoir rocks saturated with brackish water or brine) and possibly coal seams are well suited for storage. In addition, carbon dioxide injection into mature oil fields can provide enhanced oil recovery by a process called miscible gas flood.

There are approximately one hundred carbon storage demonstration projects in various scales running at the moment. Of these only three are of the scale to be somewhat representative for future large scale storage systems of a large power plant. Weyburn in Canada, an enhanced oil recovery project. There 3000 to 5000 tons of carbon dioxide have been injected since 2000 in the Weyburn oilfield on a daily basis to produce more oil. Sleipner in Norway, a saline formation 800 meters below sealevel. 3000 tons of carbon dioxide per day have been injected from the nearby Sleipner West natural gas field since 1996. The reason being strict Norwegian carbon dioxide emission taxes of 45 euros per ton of emitted CO2, making it cheaper to inject than to emit. In Salah in Algeria, were 3000 to 4000 tons of carbon dioxide have been re-injected per day the In Salah gas field since 2004. A coal power plant of 800 megawatt emits around 13700 tons of carbon per day.

The energy costs of carbon capture

Creating a nearly pure carbon dioxide stream at a power plant is unfortunately quite energy intensive. The energy costs result from several processes. Firstly the added heat needed to create temperatures of 100 to 140 degrees celsius to regenerate the solvent that captures the CO2 out of the flue gas/CO2 stream. Secondly the energy to create steam that acts as a stripping gas to remove the CO2 from the solvent. Thirdly the electricity to operate the flue gas fan and pump the CO2 to its destination were it can be compressed. Fourthly the energy costs of compression of the CO2 to make it transportable towards it's final destination were it can be stored.

Overall such processes raise the energy costs to produce the same amount of electricity in a cleaner way with 24-40% for new (supercritical) conventional coal plants using post combustion and 14% to 25% for coal based Integrated Gasification Combined Cycle (IGCC) systems using pre combustion. These systems are already initially different, conventional coal plants being more efficient then IGCC systems, which explains some of the difference.

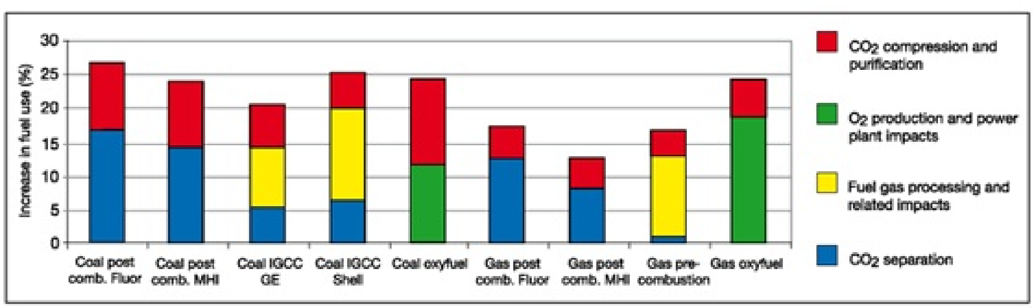

Figure 3.7 Percentage increase in fuel use per kWh of electricity due to CO_2 capture, compared to the same plant without capture (Source data: Davison, 2005; IEA GHG, 2004; IEA GHG, 2003; IEA GHG, 2000b; Dillon *et al.*, 2005).

Chart 1 - additional energy costs of carbon capture for different electricity plants, source: IPCC Special Report on Carbon Dioxide Capture and Storage.

To look at the impacts of wide scale application of CO2 capture and storage, the additional energy costs of one "carbon wedge" is taken. The carbon wedge is a concept from the University of Princeton. Telling us that if we want to stop the current growth path of CO2 emissions, we need to introduce technologies that can counter growth of annual emissions from 7 Gigatons now to 14 Gigatons by 2055. If CO2 capture and storage would count for 1 Giga ton of avoided annual emissions by 2055 or one "wedge", this technology needs to be implemented at approximately 855 coal power plants of 1000 megawatts in the coming decades.

This figure of 855 coal plants was derived by the following calculation: A 1000 megawatt coal power plant emits 5.5 Megatons of carbon dioxide per year. Converting this to carbon emissions (from CO2 to C) results in 1.37 Megatons of carbon per year. CO2 capture and storage efficiency is approximately 85%, so per power plant around 1.17 Megatons of carbon emissions per year would be reduced. Dividing 1 Gigatons of emissions by 1.17 Megatons gives 855 coal power plants.

An average 1000 megawatt coal power plant consumes 2,000,000 tons of oil equivalent fuel per year. Assuming that 25% more fuel would be needed, the additional fuel would come down to 425 million tons of fuel in oil equivalents per year to implement CO2 storage and capture at 855 coal power plants of 1000 megawatts. In 2006 coal consumption was 3090 million tons of oil equivalent per year according to the BP Statistical Review.

The effects of increased energy costs on coal depletion

If we process the 425 million tons into coal production forecasts, the effects on available energy from coal become clearer. For this I have taken the coal production scenario from the German Energy Watch Group (pdf), released a few months ago. In this scenario peak coal production is expected around 2020-2030 with at slow declining slope. When carbon dioxide capture and storage (CCS) is added the peak in energy provided shifts forward five years to 2015-2025. Furthermore the decline is much faster after the peak. The effects on more optimistic coal production scenarios would be different, because CCS would be introduced earlier before the peak that is expected later. That implies that the net energy peak would occur relatively earlier but the net energy slope after the peak will be less sharp.

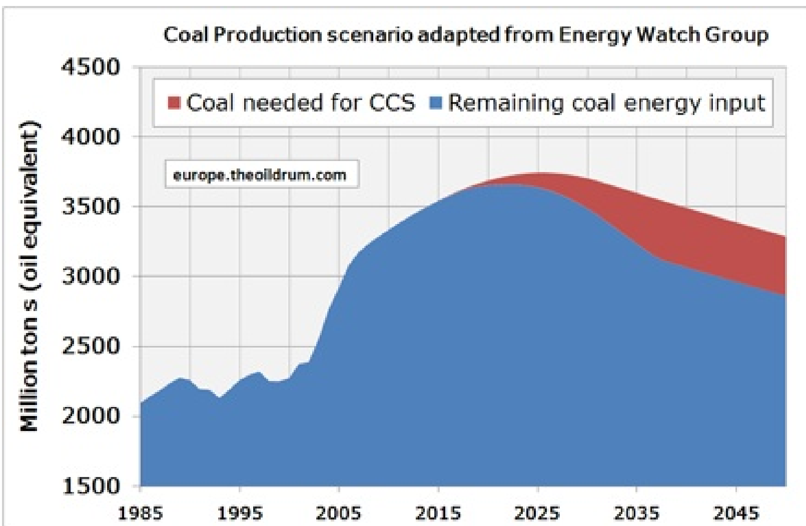

Chart 2 - Coal Production Scenario with energy input costs for Carbon Dioxide Capture and Storage (CCS). Source of Production scenario: Energy Watch Group (PDF).

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