1. Tab af EFFEKTIVITET pga. CCS 2. Merbehov pga. CCS - ENERGI 3. Merbehov pga. CCS - VAND

KILDER:

IPCC, Special Report Carbon Dioxide Capture and Storage, Summary for Policy Makers, 2005,

RECCS Plus Final Report, Wuppertal Inst., 2010
P. Viebahn et al., Comparison of Renewable Energy Technologies with Carbon Dioxide Capture and Storage (CCS)

House, Harvey, Aziz and Schrag, The energy penalty of post-combustion CO2 capture & storage and its implications for retrofitting the U.S. installed base, Jan 2009, Energy & Environmental Science, Energy Environ. Sci., 2009 DOI: 10.1039/b811608c Perspective

Last Gasp of the Coal Industry
By Gabriela von Goerne and Fredrik Lundberg.
Published in October 2008 by the Air Pollution & Climate Secretariat
www.airclim.org.

Thirsty Energy: Water and Energy in the 21st Century
World Economic Forum in partnership with Cambridge Energy Research Associates
UPDATE 2009

Water Requirements for Existing and Emerging Thermoelectric Plant Technologies
DOE/NETL-402/080108
Department of Energy, US
August 2008 (April2009 Revision)

Strategic Analysis of the Global Status of Carbon Capture and Storage
Report 2: Economic assessment of carbon capture and storage technologies.
Final Report © 2009 Global CCS Institute.

1. Tab af effektivitet

3.1.1. Efficiency loss

Energy requirements and power consumption of CO_2 capture are high, resulting in a significant decrease in overall power plant efficiencies. Compared to power plants without CCS, the efficiency of a power plant with a capture system is reduced by eight to 12 percentage points (see table[6]). The problem increases if existing power plants are retrofitted with CCS. The efficiency then drops to 21–24 per cent compared with a typical 35 per cent baseline for power plants running in many parts of the world today.[7] This efficiency penalty implies a remarkable loss of electricity production. To avoid a shortfall in electricity production it may be advantageous to construct one or more additional plants on sites when they are retrofitted with capture, in order to keep MW output the same.

Table: Loss of efficiency of power plants equipped with capture technology compared to the same plant w/o capture (table from Viebahn et al., 2006).

Type of power plant (in 2020)	Fuel	Loss in efficiency (%)
Pulverised Coal (post-combustion)	Hard coal	49 → 40
Pulverised Coal (post-combustion)	Lignite	46 → 34
Natural Gas Combined Cycle (NGCC)	Gas	60 → 51
Integrated Gasification Combined Cycle (IGCC)	Hard Coal	50 → 42
Oxy-fuel	Hard Coal	49 → 38

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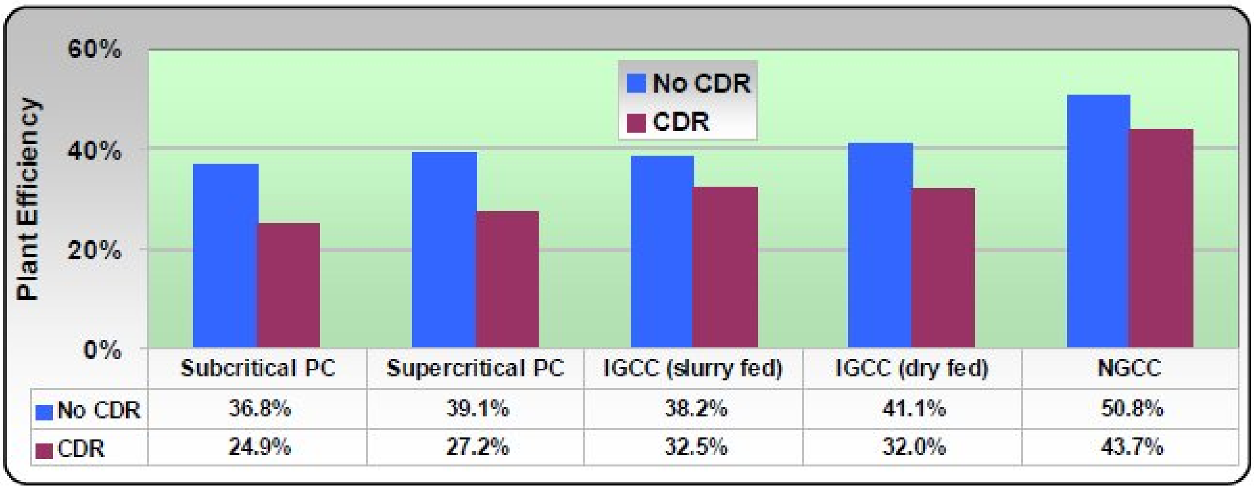

Figure 4-1. Comparison of net plant efficiencies (HHV basis) with and without CDR

[CDR = Carbon Dioxide Recovery = CO2-fangst.]

	Subcritical PC	Supercritical PC	IGCC (Slurry fed)	IGCC (dry fed)	NGCC
No CDR	36,8	39,1	38,2	41,1	50,8
CDR	24,9	27,2	32,5	32	43,7
Diff.	11,9	11,9	5,7	9,1	7,1
% *	**32%**	**30%**	**15%**	**22%**	**14%**

* NOAHs beregning

KILDE: Water Requirements for Existing and Emerging Thermoelectric Plant Technologies
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Department of Energy, US
August 2008 (April2009 Revision)

In this context, the authors introduce the term *avoidance efficiency*. The avoidance efficiency, 68 per cent in this example, implies that only 68 tonnes of CO_2 would be avoided if 100 tonnes of CO_2 were stored. They correctly point out that this should be taken into account in the calculation of CO_2 allowances.

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2. Merbehov - ENERGI

10 – 40 % (Kulkraftværker: 24 – 40 %, se fodnote)

4. *The net reduction of emissions to the atmosphere through CCS depends on the fraction of CO_2 captured, the increased CO_2 production resulting from loss in overall efficiency of power plants or industrial processes due to the additional energy required for capture, transport and storage, any leakage from transport and the fraction of CO_2 retained in storage over the long term.*

Available technology captures about 85–95% of the CO_2 processed in a capture plant. A power plant equipped with a CCS system (with access to geological or ocean storage) would need roughly 10–40%[4] more energy than a plant of equivalent output without CCS, of which most is for capture and compression. For secure storage, the net result is that a power plant with CCS could reduce CO_2 emissions to the atmosphere by approximately 80–90% compared to a plant without CCS (see Figure SPM.2). To the extent that leakage might occur from a storage reservoir, the fraction retained is defined as the fraction of the cumulative amount of injected CO_2 that is retained over a specified period of time. CCS systems with storage as mineral carbonates would need 60–

[4] The range reflects three types of power plants: for Natural Gas Combined Cycle plants, the range is 11–22%, for Pulverized Coal plants, 24–40% and for Integrated Gasification Combined Cycle plants, 14–25%.

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IPCC, Special Report Carbon Dioxide Capture and Storage, Summary for Policy Makers, 2005,

18 – 35 %

Coal mining is generally linked to drastic, extensive changes to the landscape. In most cases, the consequences of such a restructuring of the landscape are a lowering of the water table, contamination of the water by mine drainage and the creation of enormous slag heaps that have a negative impact on groundwater supply for agriculture and the surrounding ecosystems. In addition, enormous quantities of water are consumed to wash the coal and to cool coal-fired power plants. In some areas, this has led to significant water shortages in rivers and streams.

Due to the resettlement or displacement of the population, cultivable land is lost, homes and entire village communities are destroyed, resulting in social and cultural problems. Often residents are unwilling to leave voluntarily, and forced evictions occur, often with the threat or use of violence, or even, in some extreme cases, murder.

Although the latter is not the case in Germany, resettlement causes considerable problems here, too. In the region of Lusatia in Germany, more than 100 villages with a total of over 100,000 residents have been subject to (forced) eviction for coal mining (Tagesspiegel 2009). One of the last villages to fall victim to this process was Horno, a village of around 300 residents who lost their homes despite 25 years of constant fierce resistance. In western Germany, around 7,000 people were resettled for the Garzweiler II mining project. Part of the village community disappeared, and, even though a new housing estate with newly planted gardens may seem aesthetically appealing, it will not be able to replace the sense of community and wildlife habitats, which usually take centuries to create (Welt online 2004). By deploying CCS technology in the generation of power, this problem would be aggravated further, because an 18 to 35 per cent increase in coal would be required (see Section 10.3).

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LIGNITE (brunkul):
24 – 66 %

Depending on the technology, between 24 (IGCC) and 66 per cent (steam power plant) additional consumption of *primary energy* is required for the CCS-based power plants.

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18 – 32 % (kul: 21 %)

Tab. 10-1 Energy and emission-related key data of the model in 2020

	Unit	Lignite power plant mix	Hard coal power plant mix	Natural gas combined cycle power plant
A) Without CO_2 capture				
Degree of utilisation	%	47.5	49.5	60
CO_2 intensity fuel	g CO_2/MJ	112	92	56
	g CO_2/kWh	403	331	202
CO_2 intensity electricity	g CO_2/kWh_{el}	849	682	337
B) With CO_2 capture				
Degree of utilisation	%	36	41	51
Reduction	% points	11.5	8.5	9
Additional demand for primary energy	%	32	21	18
CO_2 intensity CCS electricity *before* capture	g CO_2/kWh_{el}	1,176	885	417
CO_2 capture rate	%	88	88	88
CO_2 captured	g CO_2/kWh_{el}	1,035	761	367
CO_2 intensity CCS electricity *after* capture	g CO_2/kWh_{el}	141	104	50

Source: Authors' design

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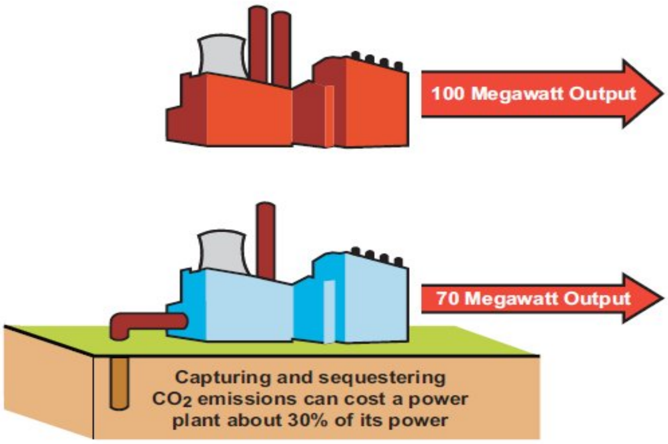
KILDE: RECCS Final Report, Wuppertal Inst., 2010

30 %

Figure 10

Efficiency Loss Due to Carbon Capture and Storage at Typical Power Plant



Source: Cambridge Energy Research Associates.
70610-5

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25 - 33 %

In general, however, it should be noted that CCS retrofits lead to an energy penalty of approximately 33 percent power. Therefore, for a unit that provides 600 megawatt-electrical (MWe) to the grid, an additional 200 MWe of generation is required with the addition of CCS equipment. In the case where the additional power is generated with a new CCS plant, based on a 25 percent energy penalty for

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KOMPRESSIONSDELEN:

6.1.3 CO_2 compression

The compression of CO_2 to the supercritical state results in a significant energy penalty of about 8 to 12 percent of the gross generation. Currently, there are programs and groups such as the Southwest

KILDE: Strategic Analysis of the Global Status of Carbon Capture and Storage
Report 2: Economic assessment of carbon capture and storage technologies.
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21 – 27 % (op til 40 %)

3.1.2. Fuel requirement

The increase in fuel required to produce a kWh of electricity depends on the type of baseline plant without capture. It is estimated at between 21 and 27 per cent but could be as much as 40 per cent.[8] The increase in fuel consumption implies an increase in coal mining activities and related environmental impacts. Although it can be assumed that security of supply will not become an issue for coal as it is for oil and gas, the increasing need for coal will nevertheless put pressure on the market, resulting in further increase in the coal price. Increasing coal use due to capturing CO_2 also implies an increase in produced CO_2 that needs to be captured, processed, compressed and stored.

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50 – 80 %

Conclusion

Achieving substantial reductions in CO_2 emissions requires either shutting down a large fraction of the current installed base of coal-fired power plants or retrofitting those plants for CCS. Previous studies have estimated that the additional fuel required (f_2) to maintain constant work output for a PC retrofit is between ~50% and 80%. An analysis of the thermodynamic limit indicates those values might be improved by harnessing more of the available waste heat and by improving the 2nd-law efficiency of temperature-swing separation systems. It appears difficult, however, to improve f_2 for post-combustion capture to below ~25% in practice. Our most likely efficiency scenario indicates that offsetting the energy penalty incurred from capturing and storing 80% of the U.S. coal fleet's CO_2 emissions will require either an additional ~390–600 million tonnes of coal, an additional ~69–92 gigawatts of CO_2-free-baseload power, or a 15%–20% reduction in overall electricity use.

KILDE: House, Harvey, Aziz and Schrag, **The energy penalty of post-combustion CO2 capture & storage and its implications for retrofitting the U.S. installed base,** Jan 2009, Energy & Environmental Science, Energy Environ. Sci., 2009 DOI: 10.1039/b811608c Perspective

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Se i øvrigt NOAHs CCS-hjemmeside:
http://ccs-info.dk/klima.html
og
http://ccs-info.dk/energypenalty.html

3. Merbehov vand

Table ES-1. Water consumption and cooling duty factors for thermoelectric power plants[i]

	Without CO_2 Capture	With CO_2 Capture	% Change With CO_2 Capture
*Water Consumption Factors (gallons per MWh net power)**			
Nuclear	720	--	
Subcritical PC	520	990	+90%
Supercritical PC	450	840	+90%
IGCC, slurry-fed	310	450	+50%
NGCC	190	340	+80%
Cooling Duty Factors (MMBtu per MWh net power)			
Subcritical PC	4.7	11	+130%
Supercritical PC	4.1	9.3	+130%
IGCC, slurry-fed	3.0	3.7	+20%
NGCC	2.0	4.2	+110%

** Based on a cooling water system utilizing wet recirculating cooling towers*

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3.1.3. Water requirement

Water supplies are already a cause of concern in many countries, including large parts of the US and China. The latest IPCC fourth assessment report has made it clear that climate change will make the situation worse. Drought affected areas will likely increase in extent. Water supplies stored in glaciers and snow cover are projected to decline, together with reducing water availability in regions supplied by melt water.[9]

Carbon capture technologies increase the water demand of coal power plants. Depending on the power plant technology used, the water consumption can increase by 10 to 20 per cent (for IGCC) and can more than double in the case of post-combustion of pulverised bituminous coal power plants, because of the large amounts of cooling water needed to run the system.[10] An associated problem at riverside power stations is that of thermal pollution. During periods of protracted heat, there can often be a choice between killing the fish by exceeding the permitted temperature or running the plant at much reduced capacity. In many locations, power demand peaks in summer as well as winter, because of air conditioning.

If a power plant cannot produce full power or is not allowed to do so when power is most needed (best price), the investment is much less attractive. If water and cooling requirements cannot be met, CCS coal power is not even an option.

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Case Study 1: Water Tradeoffs in Carbon Capture and Storage Technology

Continuing worldwide concern about climate change has brought the need for low-carbon electricity to the forefront. CCS is being promoted as a partial solution to the problem. CCS is particularly attractive in countries with large coal reserves and a heavy reliance on coal for power generation. Other countries want a stake in providing future CCS technologies. Australia, Canada, Germany, Japan, Norway, the United Kingdom and the United States have all launched programmes to promote CCS. However, there are currently no commercial-scale power plants operating with CCS, and significant technology, policy and infrastructure barriers stand in the way of large-scale CCS implementation.

Adding CCS to a power plant increases its water consumption. Two technical reasons are behind this increase. First, capturing and compressing carbon dioxide (CO_2) requires energy, reducing the efficiency of the plant and thus increasing the amount of water consumed per unit of output (see Figure 10).

Second, the technologies used to capture CO_2 consume water. CO_2 can be captured at two points in the electricity generation process, either before or after the fuel is burned.

Coal. Water use in coal mining depends on the method of mining. For example, underground coal mines use water for cooling the cutting surfaces of mining machinery and inhibiting friction-induced ignition of coal dust or gas. Surface mines often use water to suppress dust from the mining process and on roads entering the mines.[18] The majority of bituminous coal in most parts of the world is cleaned before it is burned to reduce the ash and sulphur content and increase the coal's heating value, using more water.[19]

However, water contamination, rather than use, is the primary issue in coal mining. Drainage from mines and from piles of mining waste can become acidic when sulphur-containing minerals are exposed to water and oxygen. The acidic water dissolves some metals that may be present in the rock and soil, frequently including lead, zinc, copper, arsenic and selenium. These metals are then carried with the water throughout the affected watershed and can be absorbed by plant and animal life in the food chain.[20] Water contamination is an issue in many areas where coal is mined, from the United States and Canada to China and Australia.

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Appendix

OPSUMMERING fra Wuppertal Institute:

- According to the latest industry publications and press releases, the entire CCS chain (separation, transportation and storage) is only expected to be available on a commercial scale from between 2025 and 2030.
- If CCS is only made available at a later stage, the increases in costs previously assumed for the year 2020 during the introduction of CCS would be postponed to probably 2025 or 2030. This would mean, however, that renewable energies, depending on these assumptions, would be able to produce energy more cheaply in both the low and high price scenario as early as when CCS is first introduced.

Conclusive integrative assessment of CCS for fossil fuel-fired power plants and research recommendations

- In view of the current state of technical developments, the political guidelines and the scientific studies published so far, the following six aspects must be highlighted as being essential determining factors for the introduction of CCS. Within the process, it is crucial not to look at CCS from single perspectives, but to integrate it into a holistic analysis of several options for climate protection.
  - The *technology chain* will probably not be *available on a large scale* before sometime between 2025 and 2030. Therefore the use of CCS for power plants could increasingly lose its potential role as a bridging function for renewable energies, as was originally intended.
  - The existing *potential for CCS* will be considerably restricted should there be continued significant expansion of renewables and a steady increase in combined heat and power generation in the German power supply. This effect would be accelerated by the planned lifetime extension of nuclear power plants.
  - The *relative costs of power plants with CCS and electricity generation from renewable energies* are converging: if the dynamics of the expansion of renewables in the electricity sector remain high, it is possible that individual renewable energy technologies (offshore and onshore wind power, solar thermal power plants) could compete with CCS power plants as early as in 2020.
  - The *holistic assessment of environmental impacts* shows that the CCS technology in itself is neither beneficial nor sustainable.
  - As research into the stakeholders has revealed, the *social acceptance* of CCS technology depends on, above all, the availability of *long-term stable storage sites*. An effective storage capacity of 5 billion tonnes of CO_2 can be expected to be the lower limit for Germany, as shown by a scenario analysis. As with all other estimates, however, this estimate should be treated with caution.
  - Suitable *CCS legislation* is a further essential determining factor for the introduction of CCS, as it defines the speed at which this technology can be realised.

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