Hellfritsch, S.; Gampe, U.: Modern Coal-fired Oxyfuel Power Plants with CO2 Capture - Energetic and Economic Evaluation. In: ENERDAY Workshop on Energy Economics and Technology. Dresden, 2007

MODERN COAL-FIRED OXYFUEL POWER PLANTS WITH CO_2 CAPTURE – ENERGETIC AND ECONOMIC EVALUATION

Dipl.-Ing. Stefan Hellfritsch *
Prof. Dr.-Ing. Uwe Gampe
Chair of Power Plant Technology, Dresden University of Technology, Germany
* Corresponding author: stefan.hellfritsch@tu-dresden.de phone +49 351 463 33096 fax +49 351 463 37753

Abstract

This article presents first results from the techno-economic evaluation of a 1000 MW_{el} oxyfuel lignite-fired power plant with advanced supercritial steam parameters and CO_2 capture. The process is based on a reference design that was developed using the same boundary conditions and near-future conventional power plant equipment which reflects the next generation of lignite-fired power plants with efficiencies close to 50 %.

The results show, as expected, that there is a considerable decrease in electric power plant efficiency due to the sequestration of the produced CO_2. However, preliminary estimations for the investment costs of the main components and operational costs reveal benefits for a scenario in which emitted CO_2 has a certain price, according to the certificate system for the EU started in 2005.

Based on these data an assesment scheme is presented that allows for evaluation of the process both from an energetic and an economic point of view. The evaluation is based on only a limited number of parameters as input and makes a clear difference between captured CO_2 and avoided CO_2 emissions.

Keywords: CO_2, capture, oxyfuel, avoidance, costs

Introduction

CO_2 sequestration from large point sources like coal-fired power plants is more and more attracting the attention of policymakers, power utilities and manufacturers. One option is to adopt oxyfuel technology, that means burning the coal with pure oxygen instead of air, followed by subsequent cleaning and conditioning of the CO_2-rich flue gas stream. This process is rather efficient as compared to other options for CO_2 capture, and finally most parts of it are based on the process layout of conventional coal-fired power plants where there exists great experience in engineering and operation.

One of the first steps towards industrial application is the erection of a 30 MW_{th} pilot plant in Schwarze Pumpe which will be put into operation by 2008. In parallel to that, basic research on oxyfuel combustion, CO_2 conditioning and overall system design is still going on.

One of the key aspects in this is to show the technical and economic feasibility of the process, both recognising the cost increase for power generation as well as the remarkable amount of CO_2 that can be sequestered.

Reference power plant without CO_2 capture

In order to evaluate power generation from fossil fuels with CO_2 capture, a reference case is needed. At first instance this will be current technology, e.g. a lignite-fired power plant with a net efficiency of about 43% and supercritical steam parameters of 580 / 600 °C (live steam and reheater steam, respectively). However, accounting for the fact that CO_2 sequestration technologies are not yet on the market, another reference should be taken which reflects the state-of-the-art of conventional power generation in future. For a timescale of 2010-2020, lignite-fired power plants are expected to feature fuel pre-drying units and advanced supercritical steam parameters of 600 and 620 °C.

This type of plant was chosen as reference for the assessment of an lignite-fired oxyfuel power plant with CO_2 capture. Both plants share the key parameters affecting the efficiency of a coal-fired power plant, i.e. steam parameters, condenser pressure as wells as internal heat and pressure losses. The power cycles have been modelled using the *Ebsilon* simulation environment. Table 1 provides an overview to the reference power plant with its main data.

Table 1: Parameters of the lignite-fired reference power plant (technology in 2015)

Raw lignite LHV 9010 kJ/kg moisture 54.5% **Pre-dried lignite** LHV 19700 kJ/kg moisture 12.0% **Desulphurisation unit** SO_2 removal 99.0 %	**Gross power output**	1000 MW_{el}
	Net power output	940.3 MW_{el}
	Fuel mass flow (raw lignite)	752.8 t/h
	Live steam	2559 t/h 600 °C / 275 bar
	Reheater steam	620 °C / 60 bar
	Condenser pressure	40 mbar
	gross efficiency	53.1 %
	net efficiency	49.9 %
	specific CO_2 emissions	807 kg/MWh

The lignite-fired oxyfuel power plant with CO_2 capture

Oxyfuel technology with CO_2 capture represents one of the most promising options for CO_2 sequestration from fossil fuel power generation. As a derivative of the reference power plant described above, a model was developed for an oxyfuel power cycle with CO_2 capture (figure 1).

The power plant concept features a cryogenic air separation unit for oxygen production which requires compressed air at the inlet. In addition to conventional flue gas cleaning equipment, there is also a flue gas condenser, a desiccant dryer for full water removal and an inerts removal unit for the extraction of excess oxygen, nitrogen and argon. The conditioned CO_2 is compressed to 100 bar and supplied for transport with a purity of 96 %. Table 2 indicates the flue gas composition at different process positions. The oxyfuel process requires recirculation of large amounts of flue gas back into the boiler, which is to moderate the combustion temperature by replacing the missing air nitrogen. A rather efficient recycle method is to transfer the heat from hot flue gases exiting the boiler to the colder recycle stream and to the oxygen required (see figure 1). Thus, the electrostatic precipitator and the recycle fan can operate at lower temperatures and have a lower power consumption, while the thermodynamic efficiciency is also improved due to the hotter gases entering the combustion. The key data of the optimised oxyfuel concept are also summarised in figure 1.

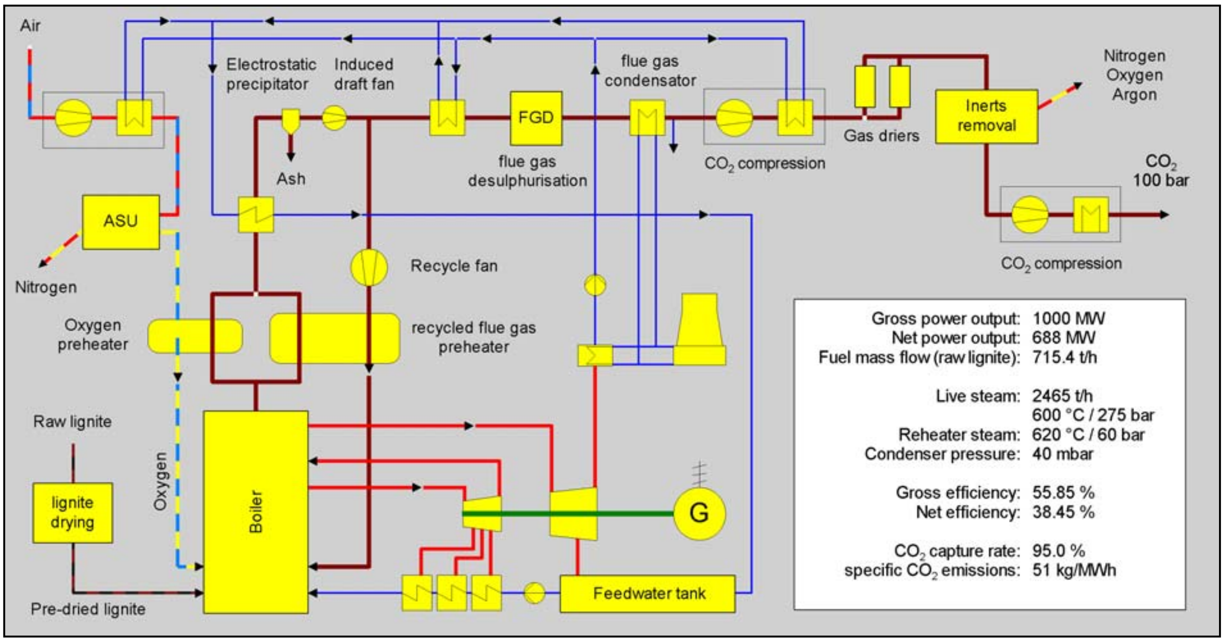

Figure 1: Process layout and main data for a lignite-fired oxyfuel power plant with CO_2 capture

The process scheme in figure 1 is optimised for efficiency. For instance, all the condensate preheaters which are normally heated by extraction steam from the low-pressure turbine are replaced. Instead, low-temperature heat is recovered from various components in the power plant, such as the compressors of the air separation unit and the CO_2 compressors.

Table 2: Flue gas compositions at different positions in the oxyfuel process

% vol.	at boiler exit	before compression	product gas
CO_2	56,3 %	82,2 %	96,0 %
N_2	6,4 %	9,2 %	2,3 %
O_2	3,0 %	4,4 %	1,4 %
Ar	0,4 %	0,6 %	0,2 %
H_2O	33,5 %	3,7 %	20 ppm
SO_2	0,44 %	0,03 %	0,04 %

Methodology for the assessment of power plants with CO_2 capture

CO_2 sequestration power plants should not alone be evaluated by means of their lower efficiency or, on the other hand, by the amount of CO_2 captured. Rather it has to be calculated how much CO_2 emission could be avoided and what is the cost per ton of avoided CO_2. So it becomes clear that the definition of a reference scenario (without CO_2 capture) is fundamental to such an assessment. Figure 2 compares the CO_2 balances and net power out of three types of power plants.

The upper case in figure 2 is a CO_2 capture plant (CAP) that only emits a fraction (1-c) of its produced CO_2 to the atmosphere. For the same net power output, a conventional power plant (REF) would produce and emit less CO_2. The CO_2 avoidance factor v of CAP compared to REF for a given net power output can be expressed as:

$$v = 1 - \frac{\eta_{ref}}{\eta_{cap}}(1-c)$$

where η_{ref} and η_{cap} are the net efficiencies of the refence power plant and the CO_2 capture plant, respectively, while c is the CO_2 capture rate of CAP.

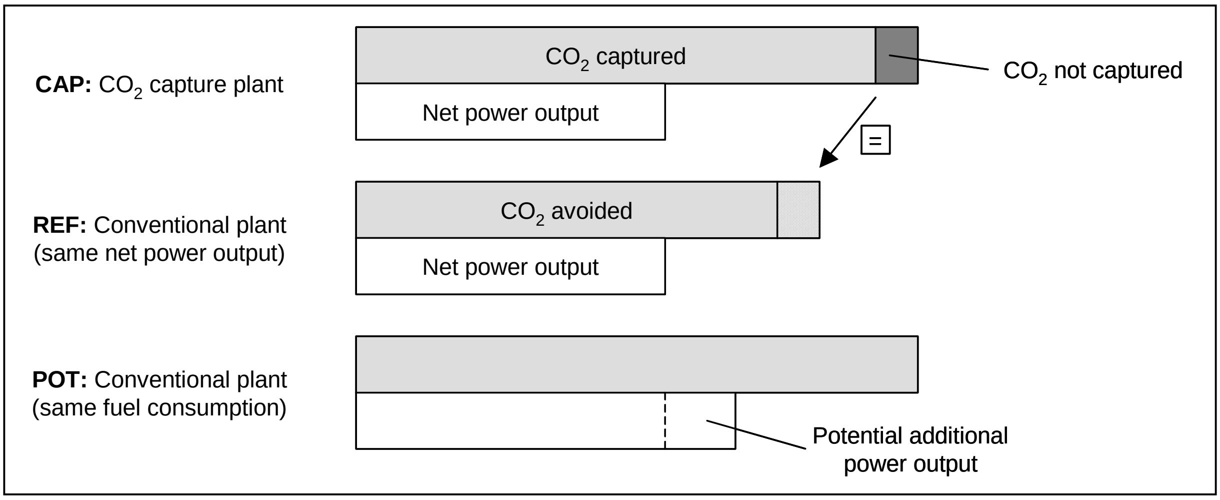

Figure 2: Example scenarios to derive the energetic cost of CO_2 avoidance by sequestration

The flow rate V of CO_2 avoided in tons per hour becomes:

$$\dot{V}_{CO2} = \frac{P_{net}}{\eta_{ref}} k_{CO2}\, v \quad = P_{net}\; k_{CO2}\left(\frac{1}{\eta_{ref}} - \frac{1}{\eta_{cap}}(1-c)\right)$$

P_{net} is the net power output of the reference plant, while k_{CO2} describes the specific CO_2 production rate of the fuel in tons per kWh_{th}.

Energetic expense of CO_2 emission avoidance

In order to assign an energetic value to the amount of CO_2 avoided, the potential additional power output ΔP_{pot} of a reference plant should be used (POT in figure 2) which has the same fuel consumption as the capture plant. This accounts for the fact that the capture plant makes stronger use of fuel ressources which eventually could have been converted into electric power in conventional power plants.

$$\Delta P_{pot} = \frac{P_{net}}{\eta_{cap}}\left(\eta_{ref} - \eta_{cap}\right)$$

Finally, the energetic expense in kWh_{el} for avoiding one ton of CO_2 emission can be expressed as:

$$\frac{\Delta P_{pot}}{\dot{V}_{CO2}} = \frac{\eta_{ref}\left(\eta_{ref} - \eta_{cap}\right)}{k_{CO2}\left(\eta_{cap} - \eta_{ref}(1-c)\right)}$$

Figure 3 shows the energetic costs for CO_2 avoidance in relation to the capture system efficiency and the conventional power plant efficiency which is used for reference.

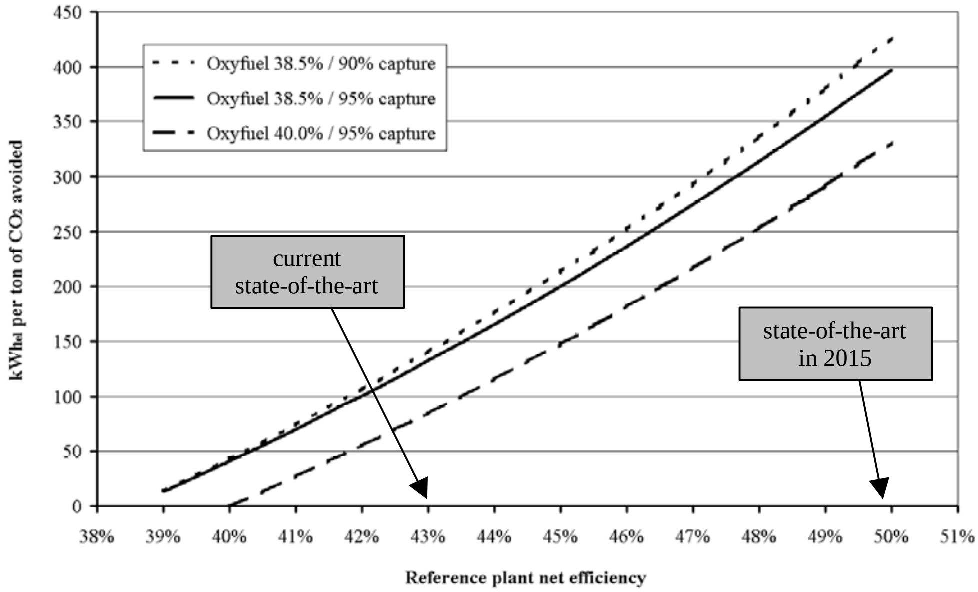

Figure 3: Energetic cost of CO_2 avoidance for different capture plant performance parameters

Cost of electricity

The cost of electricity production is always higher when applying carbon dioxide capture and sequestration (CCS) technologies. Preliminary estimations show that the specific investment costs for the lignite-fired oxyfuel concept described above will be 20-50% higher than for the reference plant. However, CO_2 certificate prices are expected to increase over the next decades, so CO_2 avoidance will become more favorable. Compared to today's level, the costs of electricy could be 20-150% higher due to the costs for emission allowances.

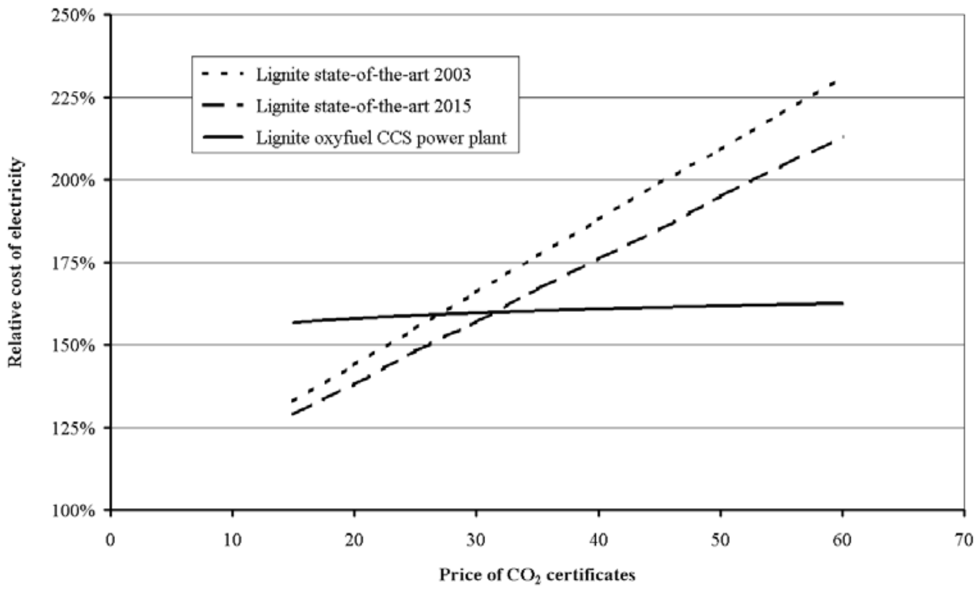

Figure 4: Prospective costs of electricity generation from lignite

From figure 4 can be seen that there is a breakeven between conventional power generation systems and CCS technologies depending on the type of capture system and the reference chosen. The results presented are based on economic data of existing lignite-fired power plants, assuming 25% higher investment costs for the oxyfuel plant than for the reference plant with the same technology. Note that transport and storage costs for the compressed CO_2 are not yet included. According to [2] these will be in the range of 2-4 EUR per ton of CO_2 for first deployment projects.

Conclusion

This article presented the current state of our work in the field of oxyfuel technology evaluation for lignite-fired power plants. An optimised capture plant concept was introduced together with a virtual reference concept (without CO_2 capture) that is based on the same advanced steam power plant technology. It was shown that the energetic cost of avoided CO_2 can be calculated from only a few key parameters of the capture plant. Finally, an outlook was given to the prospected economic performance of oxyfuel power plants with CO_2 capture.

Literature

[1] Gampe, U.; Hellfritsch, S.; Gonschorek, S.: Oxyfuel Technology for Fossil Fuel-fired Power Plants with Carbon Sequestration - Technical and Economic Feasibility.
ENERDAY Workshop on Energy Economics and Technology, 21 April 2006, Dresden

[2] Wildenborg et.al.: Building the cost curves for CO_2 storage – European sector.
IEA Greenhouse Gas R&D Programme report no. 2005/2, February 2005

[3] Gonschorek, S.; Klemm, M.; Löser, J.: Oxyfuel Technology – an option for the reduction of CO_2 emissions from coal-fired power plants in Germany.
Greenhouse 2005 International Conference, 13-17 November 2005, Melbourne (AU)

[4] Hellfritsch, S.; Gilli, P.G.; Jentsch, N.: Concept for a Lignite-fired Power Plant Based on the Optimized Oxyfuel Process with CO_2 Recovery.
VGB PowerTech, Vol. 84, 8/2004, VGB PowerTech e.V., Essen