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This document appeared in

Detlef Stolten, Thomas Grube (Eds.):
18th World Hydrogen Energy Conference 2010 - WHEC 2010
Parallel Sessions Book 3: Hydrogen Production Technologies - Part 2
Proceedings of the WHEC, May 16.-21. 2010, Essen
Schriften des Forschungszentrums Jülich / Energy & Environment, Vol. 78-3
Institute of Energy Research - Fuel Cells (IEF-3)
Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, 2010
ISBN: 978-3-89336-653-8

RWE’s IGCC-CCS-Project – A Way towards a Coal-based Hydrogen Technology

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1 „Where will the hydrogen in Germany come from by 2050?“

In 2009 a study [1] conducted on behalf of the German ministry of transport, building and urban affairs dealt with the question, where the hydrogen needed in Germany will be originating from within a time period until 2050. Three scenarios were investigated focusing on different assumptions concerning the development of energy use in Germany. The moderate scenario is a “business as usual” scenario assuming conservative aims to reduce greenhouse gas emissions including only small efficiency increases and only small increases in the use of renewable energies. Opposed to that, the climate scenario is characterized by stringent guidelines concerning the reduction of CO_2 emissions up to -80 % in 2050 (basis 1990). The third scenario assumes a drastic shortage of resources connected with a strong increase of prices for primary energy carriers. All investigated scenarios predict a rise in the use of hydrogen as energy carrier. For the production of hydrogen wind energy is estimated to play an important role in all time horizons. Moreover, in the long term, also coal with or without carbon capture and storage technology will be a major primary energy carrier for hydrogen synthesis with a share of about 30 – 50 % of the overall future H_2 production. To be able to cover this demand of coal for hydrogen production, it is beneficial to have a secure source of low-priced coal.

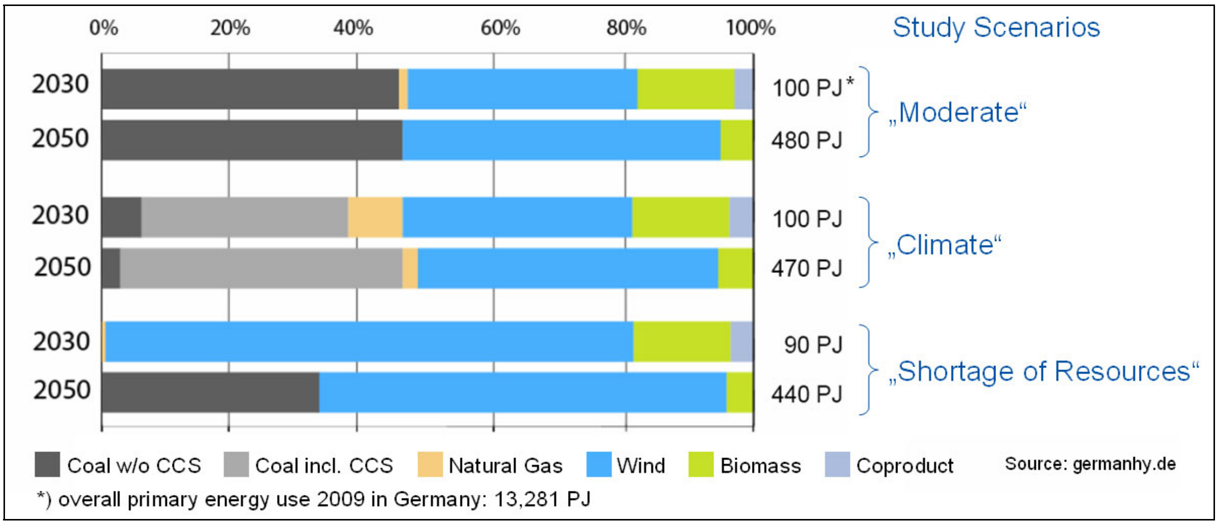

Figure 1: Shares of primary energy carriers in future H_2 production [2].

2 RWE's Rhenish Lignite Mining Area

RWE is operating three open cast lignite mines in Germany. About 3.4 bn t of approved lignite reserves are currently available in the mines Hambach, Garzweiler and Inden in North Rhine-Westphalia. The actual lignite production is about 92 Mt / a. Thereof, 9 Mt / a are processed in the refinement factories producing dry lignite in the form of coal briquettes or coal dust for industrial use and heating applications in private households. Among the approved lignite reserves, a potential of about 35 bn t of lignite have been explored. At the level of today's production rate, these reserves can contribute to secure the primary energy supply for further 350 years – a vast primary energy carrier source. RWE's lignite fired power plants are directly connected to the open cast mines via an own railway net. This way coal can be supplied independently to the power plants and factories. The overall installed capacity for power generation at 5 power plant sites is about 11 GW_{el}. The Rhenish lignite mines offer a secure national energy supply for different energy applications including potential conversion routes of lignite to chemical products or energy carriers for mobile applications.

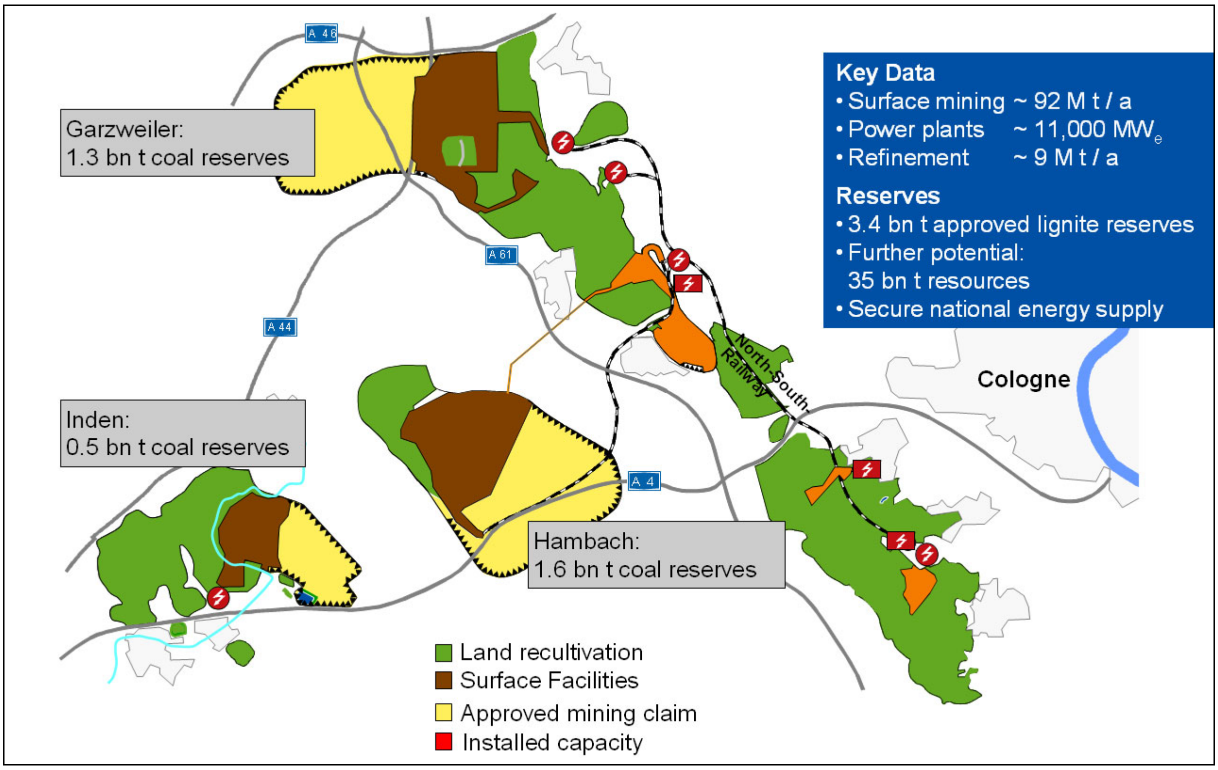

Figure 2: RWE's Rhenish lignite area is a large domestic energy reserve.

3 Gasification is Key to Multiple Products with Climate-friendly Use of Lignite

The conversion of lignite or coal in general was already realized in the 19^{th} century for lightning applications and later on also for heating and cooking in private households. In the 20^{th} century coal gasification was mainly used in crisis situations, when the supply of oil was no more ensured. Today large gasification capacities are still in operation in South Africa, where the national coal reserves are used to produce fuels. Having large coal reserves, but less oil and gas deposits China and India are developing many gasification projects to produce chemicals and different energy carriers. Gasification technology for the conversion of coal to synthesis gas ($CO + H_2$) is the door opener to a whole bunch of products needed in industrialized countries. It is an interesting opportunity for countries having large world market price independent coal deposits to reach a certain independence from foreign energy imports. Moreover, the conversion of coal to synthesis gas opens the possibility to use coal in a climate friendly way since the implementation of the CCS technology to the gasification and further conversion of synthesis gas to the desired products is easily possible.

Downstream the coal gasification the produced raw synthesis gas is conditioned further for the following process. In this step the ratio CO/H_2 is adjusted according to the requirements of the applied syntheses. CO_2 scrubbing is usually added to the process to capture CO_2 that can be stored or used in other applications afterwards. In this way one ton of lignite will yield approximately 0.86 MWh of power, 580m³ H_2, 180 m³ CH_4, 270 kg methanol or 140 l of fuels by applying an IGCC-CCS-process, a pressure shift adsorption, a methanisation, a methanol syntheses or a Fisher-Tropsch process after gas conditioning, respectively.

4 RWE's Clean Coal Power Strategy

Innovative coal technologies are as indispensable to climate protection as coal is to satisfying the world's thirst for energy. With its clean coal power strategy, RWE faces the challenge of preventing climate change and is now introducing further elements of this strategy. In this respect, carbon capture and storage (CCS) plays a key role if more substantial CO_2 reductions are to be achieved than possible by merely increasing efficiencies. If this vision is to become reality, expertise, great commitment and a high willingness to take risks are required to implement a technological quantum leap.

The development of coal-fired power plants with CCS strengthens Germany's position as a technology leader, secures export potential for manufacturers and jobs in industry. The 450 MW IGCC-CCS project is part of RWE's overall strategy aimed at developing and implementing clean coal power.

On a broad basis – in line with the energy mix in the generation portfolio – innovation lines with different horizons are being pursued both for lignite and hard coal.

RWE has launched a large-scale renewal program for coal- and natural gas-based power plants that involves using cutting-edge technology to increase efficiency for the sake of climate protection. Examples for the use of coal are the BoA 2&3 new-build projects at the Neurath power plant and the two hard coal-fired twin units at the Westfalen power plant and in Eemshaven in the Netherlands. The total new-build capacity amounts to 5,400 MW with corresponding capital costs of € 6.2 bn.

In a second horizon, RWE is developing technologies in collaboration with partners that permit efficiencies to be further increased beyond today's high level. The focus is on demonstrating the WTA (lignite pre-drying) technology, which was developed by RWE to dry moist lignite on the prototype plant at BoA 1 in Niederaussem, and on the test plant for the 700 °C technology; both lines of development will increase the efficiency of lignite fired power plants up to values of over 50 %. For these projects, RWE Power will expend approx. € 60 million.

The 450 MW IGCC-CCS project based on an integrated gasification combined cycle process is part of the third horizon, focusing on the capture and storage of the CO_2 emitted by fossil-fired power plants. In parallel, we will develop CO_2 scrubbing technologies for conventional power plants in pilot plants with the primary goal of retrofitting advanced power plants to achieve a substantial cut in carbon emissions.

The overall aim of RWE's Clean Coal Power Strategy is the continuous renewal of the power plant fleet using state-of-the-art technology that ensures both competitiveness and security of supply while protecting the climate, thus making RWE's generation business fit for the future.

5 The IGCC-CCS Project

Following the project announcement in 2006, its concept was developed and specified in all process areas and its viability verified. RWE Power – which is responsible in the Group for electricity generation in Germany – is in charge of power plant matters, while RWE Dea, which is responsible for the exploration and production of crude oil and natural gas, works on the CO_2 pipeline and storage facilities. This work goes hand in hand with our intensive efforts to establish the necessary underlying conditions, such as a regulatory framework for CCS and a communication concept for informing authorities and the public.

A combined-cycle power plant with integrated coal gasification (IGCC) was chosen as the power plant technology to be used. The use of a modern gas turbine of the F class enables the plant to achieve a gross electric capacity of approx. 450 MW. About 90 % of the CO_2 produced in the power plant will be captured, compressed, and transported via a pipeline to a storage facility. In this way 2.6 m t CO_2 per year will be stored safely over the long term.

We plan the IGCC-CCS power plant at RWE's Goldenberg power plant location in Hürth close to Cologne. The location thus resumes RWE / Rheinbraun's earlier gasification activities in connection with the development of HTW (High Temperature Winkler) gasification. It is already connected with our large lignite opencast mines via railway. For the IGCC power plant, parts of the existing infrastructure of the site can be used. Different studies have been assigned to investigate the viability of routing options for the connection of the power plant to the grid. To secure enough space for the construction of the power plant RWE has started to buy different areas adjacent to the existing RWE power plant site.

6 Process Description

Rhenish lignite from our own opencast mines serves as the fuel for the IGCC-CCS power plant. In a first process step, its moisture content is reduced from approx. 55 % to 12 % using RWE's own WTA drying technology. Subsequently, the lignite is ground by roller mills according to gasification requirements. An entrained-flow gasification with a thermal overall capacity of approx. 1,000 MW, operated at a pressure of approx. 40 bar, is employed for gasification. The hot, CO/H_2-rich raw gas is quenched to approx. 200 °C using water. The resulting high portion of steam is used in the subsequent shift stage to convert the CO into more hydrogen and CO_2.

The hydrogen-rich gas after the H_2S/CO_2 separation process is conditioned with N_2 from the air separation unit and if necessary with steam to create moderate combustion conditions and meet the legal requirements for NO_X values. The conditioned fuel gas is used to generate electricity in the combined cycle power plant (CCPP) unit. The capacity of the gas turbine (F class), which has a share of approx. 300 MW in the total electricity generation capacity of 455 MW, determines the capacity of the overall process. The „First of its kind" character of new technologies impacts the overall IGCC performance. The reliable interaction between individual process units shall be demonstrated.

7 RWE's Lignite Drying Technology

When power is generated in an integrated coal gasification combined-cycle power plant, lignite pre-drying is a matter of principle. At this point, an energetically efficient drying process can contribute to further efficiency enhancement. As an advanced method for processing and drying lignite, the WTA technology (WTA = German abbreviation for fluidized-bed drying with internal waste heat utilization) is applied to the RWE IGCC power plant. It contributes significantly to optimizing the energy efficiency and reducing emissions of the overall process. The WTA lignite drying technique has been developed by RWE. The first commercial scale drying unit is right now commissioned at RWE's Niederaussem power station. The lessons learned are identified and implemented. The continuous drying operation is safe.

The WTA technology is based on the principle of a stationary fluidized bed with low expansion operating at a slightly elevated pressure. The raw coal enters the dryer after running through a milling system reducing the grain sizes from 0 – 80 mm to 0 – 2 mm. The energy required for drying is supplied via heat exchangers that are integrated in the fluidized bed dryer and heated with steam. Drying takes place in nearly 100 % water steam atmosphere which is slightly superheated. Compared to other drying processes, lignite drying in a steam atmosphere has the advantage, among others, that the evaporated coal water can be condensed isothermally and, hence, utilized in an energy efficient way.

For the 450 MW IGCC power plant 2 drying units, having a raw lignite input of about 350 t/h and a dry lignite output of approx. 170 t/h, need to be utilized. To realize an environment-friendly use of freshwater, the condensed water from the WTA dryer will be used as quench water in the gasification process.

For the IGCC project, mechanical vapor recompression, realized as an open heat pump process, for heating the dryer is applied. The evaporated water from the coal is recompressed to about 4 bar, so that the vapor can be used to heat the heat exchangers installed inside the drier. The sensible heat of the produced vapor condensate is used for preheating the raw lignite. Part of the vapor is recirculated and employed for fluidizing the bed.

8 Coal Gasification

As gasification technology, an entrained flow gasification with subsequent water quench has been chosen for the IGCC power plant. It is envisaged to have a gasification process with an overall thermal power of approx. 1000 MW_{th}. The actual amount of CO-H_2-gas production is defined by the demand of the F-class gas turbine that is about 250,000 Nm³ / h. The use of a direct water quench system has a positive effect on the overall efficiency. The water that is needed in the following CO-shift is added directly to the raw gas stream, instead of being heated by a raw gas cooler system and afterwards being let into the gas stream. The produced raw gas ex gasifier therefore consists of about 57 vol.-% steam.

Within the gasifier, the very fine milled dry lignite from the WTA will be partly combusted in sub-stoichiometric atmosphere at a pressure of about 40 bar to a raw gas containing mainly carbon monoxide and hydrogen. The high pressure in the gasifier enables the process to have no intermediate compressor for the fuel in front of the gas turbine. Oxygen is provided by an air separation unit. Due to temperatures of about 1500 °C, within the gasifier the ash contents of the coal melt and drop from the reaction chamber through the quench zone, where it solidifies again, into a water bath at the bottom of the gasifier. The raw gas is cooled down in the quench zone to about 200 °C in a water-saturated state.

The entrained flow gasification is the worldwide most often used gasification technology. The existing large experiences in this technology are beneficial for the IGCC-CCS project. But nevertheless, the process parameters in this project ask for further technological developments regarding a scale up to the required thermal power for the fuel demand of the gas turbine and an increase in the process pressure from usually about 25 – 30 bar to 40 bar. Also the water quench technology has so far not been used with IGCC power plants.

9 Gas turbine Technology

To be able to demonstrate the IGCC-CCS technology with the highest possible efficiencies an advanced F-class gas turbine with a power output of approx. 300 MW was chosen. As one of the major components in the IGCC plant the gas turbine determines the design of the whole process significantly. With the chosen F-class technology it could be possible to realize a one train concept including the design of auxiliary components like the air separation unit, gas treatment facilities as well as CO_2 scrubbing and compression. Main process parameters influenced by the gas turbine are gasification pressure as well as fuel quantity and quality.

By separating the CO_2 from the fuel gas of the gas turbine, a gas with very high hydrogen content of about 83 vol.-% is generated. Due to the high flame velocity and reactivity of hydrogen, the fuel gas needs to be preconditioned with nitrogen and / or water to ensure a safe control of the combustion and to limit the formation of NO_X components. Compared to e.g. methane, the resulting hydrogen plus diluent fuel has a significant smaller lower heating value. Therefore, the mass flow of hydrogen-rich fuel gases will be increased by about 20 % compared to natural gas fired gas turbines and subsequently can produce up to 20 % more power if the other turbine parts, i.e. compressor and hot gas path permit this increased mass flow. The high water content in the flue gases produces a more intensive heat transfer in the turbine section, which needs to be considered in the gas turbine design. To be able to meet emission requirements, extensive tests to validate the operational range of the gas turbine combustion system need to be conducted. Furthermore it will be a major objective to raise the efficiency of the gas turbine by investigating the possibilities of low diluent combustion systems for future IGCC applications.

10 Market Potential and Profitability of Gasification Products

Not only technical challenges need to be addressed when realizing coal gasification projects. Also the market potential and market access of possible products has to be assessed. While it is relatively easy to access a wholesale market as new producer, it will be much more difficult to enter a business with small open market trade volumes. Looking at basic market characteristics of coal gasification products it is obvious, that the volume of synthetic natural gas (CH_4) and fuels for mobile applications (diesel / gasoline) in Germany is in principle large enough for a new producer to enter the market. Further more, it can be assumed that there will be a strong long term demand for these products. In contrast to this, the market volume of hydrogen is relatively small. There is a primarily industrial market where only 5 % of the produced H_2 is sold on the open market. Usually hydrogen is targeted produced where it is needed. Accessing this market will be only possible if usual market prices can be underpriced in situations where long term contracts are running out or new consumer markets are opened.

The methanol market is primarily driven by world market prices. Having a demand of about 45 m t per year worldwide, the actual production capacities are exceeding this demand. Moreover it is expected, that massive new build capacities in China and Middle East will go onstream in the next years.

A short study conducted by RWE estimated the ratios of market prices to required sales prices of gasification products. No product option reached the profitability threshold. The presented ratios for different products are only for illustrative purposes. They represent a certain market condition at a certain time for the German market. All in all it can be summarized, that oil market prices are the decisive parameter for the profitability of different products. World market independent lignite reserves usually offer earlier profitability than coal purchased abroad. Further influencing factors that can vary significantly by time are regional product market, CO_2 allowances and equipment prices.

11 Conclusions

For the expected hydrogen demand in the following 40 years, coal will be, next to different other sources like wind energy, an important energy source especially in the long term. Gasification technology can contribute to an effective production of hydrogen from coal that can also be realized in a climate friendly way if carbon capture and storage techniques are applied to the processes. The lignite reserves in Germany present an important option for an emerging hydrogen economy that is independent of world market prices and can offer security of supply. The profitability of hydrogen and other coal derived products depends highly on oil and gas prices as well as on the local market situation. Overall, coal gasification technologies and domestic coal reserves offer the opportunity to support an emerging hydrogen economy significantly.

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