Development of Carbon Capture and Storage technology.

A real full-size Pilot Plant and complete engineering of a 250 Mwe commercial plant.

Seminar at IVA
Tuesday January 29th, 2019

Lars Strömberg
Lippendorf CHP
1800 MWe, 42% efficiency, in operation 2001
“The CO$_2$ free power plant”

- When Vattenfall acquired the German large coal plants, an ambitious program to develop CCS was initiated.
- Work started in 1997 and continued until 2012. About 2.5 billion SEK were spent, plus a considerable amount of EU research money.
- We joined STATOIL in their CCS project at Utsira in the Seipner field to learn about carbon storage and later also transport.
- It was early identified, that the dominant cost item was the capture part, while storage and transport constitutes only about 10 - 20 % if the storage is available, not too far away. (500 km).
- This is the case in all our neighboring countries, as Denmark, Germany and Norway, but not in Sweden.
- Studies regarding a suitable capture technology were initiated. From 2002 we focused on oxyfuel technology, since this had the lowest cost and could become a real zero emission technology.
Oxyfuel, the preferred option

At present the most competitive and preferred technology for coal.
Why Oxy-fuel technology?

- Oxyfuel technology was the technology giving lowest costs
- It is suitable for coal and have relatively little development work left
- We can build on our good experience with present PF technology
- "Zero emission" possible
Oxyfuel - ”Zero Emission” ????

- It is possible to process the CO\textsubscript{2} after the boiler to reach
  - > 98 % capture rate (100 % technically possible)
  - > 99.9 % purity (Food grade or technical grade - a choice)
- The gases contained in the off gas is beside CO\textsubscript{2} mainly
  - Argon
  - Nitrogen
  - Water vapour
- No sulphur oxides will be emitted to air
- No nitrogen oxides will be emitted to air
- All particulates will be removed, including all solid metals and submicron PM
- Mercury and other liquid/gaseous metals captured
The cost to avoid CO2 emissions
Levelized Cost of Electricity LCOE for Integrated CCS projects (coal and gas)

Figure 1: The Levelised Cost of Electricity (LCOE) of integrated CCS projects (blue bars) compared to the reference plants without CCS (green bars).
CO₂ Avoidance Costs – Price of EUAs to Justify Building CCS Projects vs. Plant w/o CCS

Figure 13: CO₂ avoidance costs for possible plants commissioned in the mid 2020s – the price of EUAs required to justify building CCS projects vs. a plant without CCS from a purely economic point of view (calculated on the same basis as Figure 12)
Emission Rights cost/price on Nasdaq Commodities

Källa: Nasdaq Commodities, Energiföretagen

Lars Strömberg

Oktober 2018
The oxyfuel pilot plant
Chalmers Oxyfuel test rig
View of the Schwarze Pumpe Pilot Plant  June 2008
View of the Oxyfuel Pilot Plant
Burning coal in the oxyfuel pilot plant
Some of the oxyfuel burners
Results from 2009 until May 2012

Operating hours 17 000
Captured amount of CO2 15 500 t
CO₂ - removal rate > 93 %
CO₂ - purity > 99.7 %

- Stable oxyfuel operation
- All emission and safety values contained
- Interaction between all plant components and subsystems validated
- Over 50 tests with Boiler, ASU, CO2 plant and all other components
- Plant availability very high
- Integration of a "cold DeNOx"

4 different burners tested

New tail end concepts commissioned with good results
The 250 MW demonstration plant
CCS Demonstration Plant
Jänschwalde Unit G
Demonstration Plant Jänschwalde – Technical data

- New-build single block at existing power plant site
- Capacity 250 MWe
- Efficiency (net) 38 %
- Separated CO$_2$: 1,34 Mio.t/a
- Specific CO$_2$-emissions reduced from about 1000 g/kWh to 36 g/kWh
- In principle no sulfur, no nitrogen oxides, no metals or particulates emitted to air.
Water-steam cycle CCS unit G
Oxyfuel unit G – technical data

Forced-circulation once through tower boiler

State of the art steam parameters
- steam temp. 600/610/610 °C
- steam pressure 286 bar
- steam massflow 178 kg/s

Specifications:
- fired with dry lignite (dryer included)
- flue gas recirculation to 27% oxygen
- gas pre-heater
- DeNOx in 2nd draught (optional)
- CO₂ sealing gas system
- CO₂, O₂ alarm devices
- Co-firing of residual gases from PFBD
Storage
CO2 Injection Ketzin
Storage of CO$_2$ in a Saline Aquifer in the sea bed since 1996

The Sleipner field. Oil and gas production facilities. (Source: STATOIL)

CO$_2$-injection into the saline aquifer Utsira. (Source: STATOIL)
The CO₂ capture and storage principle

The CO₂ can be captured from the flue gases from the fuel before the combustion process.

The CO₂ is cleaned and compressed to a liquid state.

The CO₂ is pumped as a liquid down into a porous rock formation for permanent storage.

- The rock has 5 – 20 % porosity.
- It is the same type of formation as where oil and gas is found.
- It remains liquid due to its own hydrostatic pressure.
- There is no pressure difference between the liquid CO₂ and the surrounding (there are no walls).
There exists more storage capacity within Europe (and in the world) than the remaining fossil fuels.

Source: Franz May, Peter Gerling, Paul Krull
Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover
Demonstration Plant Jänschwalde – Potential storage sites

**I. Brandenburg**
Storage in deep saline aquifers (pipeline 50/140 km)

**II. Altmark**
EGR pilot project in cooperation with Gaz de France (pipeline 300 km)
Conclusions

• If we were allowed, we can build a CCS coal plant with a net efficiency of 38% (LHV) already today and (almost) zero emissions.
• The plant would be profitable at a CO$_2$ price of about 40 €/ton CO$_2$
• Since we were hindered by political reasons, anyone is welcome to share the experience we have gained with the six large supercritical lignite units and from the CCS pilot and demo plant FEED study.
• All knowledge is directly transferrable to biomass combustion. The CO$_2$ avoidance cost would be higher (about 55 €/ton CO$_2$)
• Storage is impossible at a reasonable cost in Sweden, but not in Denmark or Germany, and in the Norwegian North Sea.
The Oxyfuel Technology progressed nicely under full sail
But the European CCS programme ran on ground....
CO₂ release from combustion of different fuels

![Bar chart showing CO₂ release from different fuels]

- Coal: 340 kg/MWh th
- Lignite: 350 kg/MWh th
- Heavy fuel oil: 250 kg/MWh th
- Gas: 150 kg/MWh th
- Peat: 400 kg/MWh th
- Biofuel (wood): 200 kg/MWh th
- Lignite briquettes: 300 kg/MWh th
- Petrol: 250 kg/MWh th

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January 2019