Zero Emission Fossil Fuel Power Plants
ZEP European Technology Platform,
Perspective of an Energy Supply Company

Heinz Bergmann
RWE Power, Germany

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Table of Contents

• Challenge of climate change
• Future role of fossil fuels
• Current efforts to increase power plant efficiency
• Cost comparison of main CCS-technologies
• Pilot and demo projects of German utilities
• CO2 storage potential in Germany
• Expected support of EC/politics
• Summary
The composition of the atmosphere has changed more significantly in the past century than in the previous two thousand years.

Anthropogenic changes in the composition of the atmosphere modify the equilibrium of a complex system.

Considered on a geological time scale, current changes are happening at a very fast pace.

A Global solution with long term commitments is needed.

ZEP takes an active role to accelerate governments and global institutions towards practical solutions.
Future Role of Fossil Fuels in the Global Energy Mix

Global net power generation in billion MWh

- Coal will remain vital to energy supply in the future.

Global Electricity Generation by Fuel - IEA Scenarios 2003-2050
(Source: IEA, June 2006)

Important role for CCS and strong growth in the shares for renewables and nuclear.

A Three Phase Argumentation

- Reducing emissions and increasing efficiency in ecologically and economically optimised steps
  - Modernisation of existing plants: \(\text{SO}_2, \text{NO}_x\), dust, retrofit
  - Construction of new state-of-the-art power plants

- Development of high-efficiency power stations with the aim to minimise consumption of resources and reduce specific emissions, particularly those of \(\text{CO}_2\)

- New Technologies for \(\text{CO}_2\) capture and storage
Current Efforts to Increase Power Plant Efficiency

- COMTES 700: material and component test for 700 °C technology (joint project of VGB, generators, equipment suppliers and EU)
  
  \[ + 4 \% \] (compared to 600/620 °C, 275 bar live steam)

- Fluidised-bed drying process for lignite (RWE Power)

  \[ + 4 \% \] (43 → 47 % - net)

- CCGT-Project Irsching to increase net efficiency up to 60 % (Siemens, E.ON)

  \[ + 1.5-2 \% \] (58 → 60 % - net)

- Efficiency improvements by replacement of existing steam turbines by new turbines with 3D-designed blades (retrofitting)

  Depending on individual case

- Further increasing of net efficiency of PC-boilers by development of materials for live steam parameters of 750 °C and more (COORETEC, BMWI)

  \[ + 5 \% \] (≤ 55% - net)

Objectives: Efficiencies of more than 50 % for steam power plants and above 60 % for gas turbine plants

EC-Projects on the Way to 50% Coal Fired Power Plant (Source: E.ON)

<table>
<thead>
<tr>
<th>COMTES700</th>
<th>NRWPP700</th>
</tr>
</thead>
<tbody>
<tr>
<td>• EC-funded project managed by VGB to test nickel-based components (joint project of generators and equipment suppliers)</td>
<td>• Pre-Engineering study from 09/2006-07/2008 for a 700°C demonstration plant with &gt;400 MW</td>
</tr>
<tr>
<td>• Pilot plant in Scholven with 40 MWth</td>
<td>• EC-funded project managed by VGB</td>
</tr>
<tr>
<td>• Operation 2005 - 2009</td>
<td>• Basic and detail design for boiler, turbine and connecting pipework</td>
</tr>
</tbody>
</table>
Efficiency enhancement as a fundamental way to CO₂ reduction
(Source: RWE)

Development goal: dry lignite-fired PP
Offsets lignite's drawbacks compared to hard coal; application from 2014
η₀ + 4 % points → η > 47%

WTA technology permits drying heat recovery through recondensation of the evaporated water.

Development goal: 700°C PP for L/HC
Novel materials permit steam parameters of 350 bar/700 °C; application from 2018
η₀ + 4 % points → η > 50%

Together, both measures bring up the efficiency of lignite-fired power plants to > 50 %

Main Technology Options for CO₂ Capture from Power Plants

Three technologies seem capable to fulfil the primary target to 2020
• All largely contain known technology and components
• All need optimization, scale up and process integration
• Power process efficiency increase is always a supporting activity

Post-combustion CO₂ capture (steam power plants)
Conventional power plant with CO₂ scrubber
1,000 m³/s, 13 vol-% CO₂
Coal → Convent. steam PP → Flue gas cleaning → CO₂ capture → CO₂

Oxy-fuel process
Coal → O₂ → Boiler → Flue gas cleaning → CO₂ / H₂O → CO₂

Pre-combustion CO₂ capture (IGCC power plants)
IGCC process
Coal → Gasi- fication → Gas cleaning → CO₂ capture → CCGT with H₂ turbine → CO₂
10 m³/s, 45 vol-% CO₂
Power Generation Cost for Large Scale Power Plants in 2020 (Source: ZEP – WG1)

Avoidance Cost for Large Scale Power Plants in 2020 (Source: ETP ZEP – WG1)
Pilot and Demo Projects

**Post-Combustion**
- Shell/Statoil, NO, 860 MW, NG-CC, EOR (Draugen, Heidrun), 2010
- RWE, coal, retrofit, Tilbury/UK, 2016

**Pre-Combustion**
- BP/S&SE/GE, UK, 350 MW, NG-CC, EOR (Miller), 2010
- RWE, D, 450 MW, coal, IGCC, 2014
- E.ON/UK, Killingholme, 450 MW, 2011
- GE, PL, 900 MW, coal, IGCC, 2011

**Oxy-fuel**
- Vattenfall, Schwarze Pumpe/D, 30 MWth, coal, 2008
- Total, Lacq/F, 30 MW, liquid fuel, retrofit, 2008

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**Share of Fossil Fuels in German Power Plant Capacity 31.12.2005**

<table>
<thead>
<tr>
<th>Fuel</th>
<th>GW</th>
<th>RWE</th>
<th>E.ON</th>
<th>Vattenfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard coal</td>
<td>9,6</td>
<td>7,5</td>
<td>0,5</td>
<td></td>
</tr>
<tr>
<td>Lignite</td>
<td>10,1</td>
<td>1,3</td>
<td>7,4</td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>3,7</td>
<td>3,8</td>
<td>1,0</td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>-</td>
<td>1,1</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td><strong>Fossil Fuel</strong></td>
<td><strong>23,4</strong></td>
<td><strong>13,7</strong></td>
<td><strong>8,9</strong></td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td>5,5</td>
<td>8,5</td>
<td>1,5</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>2,9</td>
<td>3,4</td>
<td>2,9</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31,8</strong></td>
<td><strong>25,6</strong></td>
<td><strong>13,3</strong></td>
<td></td>
</tr>
</tbody>
</table>
Quantum leap in power plant technology  
(Source: E.ON, 31.10.2006)

... 50plus by using new materials

<table>
<thead>
<tr>
<th>Location</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>50 %</td>
</tr>
<tr>
<td>Capacity</td>
<td>&gt; 400 MWel</td>
</tr>
<tr>
<td>Investment</td>
<td>&gt; 600 Mio. €</td>
</tr>
<tr>
<td>Start of operation</td>
<td>2014</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>2008</th>
<th>2010</th>
<th>2014</th>
</tr>
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<tr>
<td>Preliminary planning</td>
<td>Material development</td>
<td>Construction</td>
</tr>
<tr>
<td>Search for location</td>
<td>Request for proposal</td>
<td>Start of operation</td>
</tr>
</tbody>
</table>

2008
Preliminary planning
Search for location
2008
Material development
Request for proposal
2014
Construction
Start of operation

IGCC with CCS Project at Killingholme
(Source: E.ON)

- Single coal-based IGCC module with CCS, nominally 450MW, net output ~350 MW, CO2-storage in gas field of southern north sea
- Built on or close to the existing Killingholme site in Lincolnshire
- Feasibility Study completed at end Sept, now moving into project development:
  > Consent applications in 2007
  > Detailed engineering and tendering 2008
  > Investment decision end 2008
  > Commissioning 2011/12

Overview

Picture shows existing 900MW CCGT in the foreground with a possible IGCC layout behind
The Vattenfall Project of a CO$_2$-free Oxyfuel Pilot Plant
(Source: Vattenfall)

Thermal Capacity: 30 MW
Coal Demand: 5.2 t/h
Oxygen Demand: 10 t/h
CO$_2$ (liq.) Production: 9 t/h

Advantages of oxyfuel technology
(Source: Vattenfall)

- Power plant process with high efficiency potential
- High CO$_2$-separation potential
- Comparable to conventional steam power plant process
- Investment and operation cost good assessable based on conventional power plant technology
Development of the oxyfuel power plant (Source: Vattenfall)

- **Incineration tests**
  - 0.05 MWth

- **Test facility**
  - 0.5 MWth

- **Pilot plant**
  - 30 MWth

- **Demo plant**
  - 300-600 MW

- **Commercial plant**
  - 1,000 MW

Basics of incineration behaviour
- 2004 / 2005

Basics of flue gas recirculation
- 2005 / 2006

Test of complete technology chain
- 2008

Realisation of CO2 storage / proof of economics
- 2015

Competitive power plant
- 2020

- **TU Dresden**
  - ADECOS (Joint project)

- **BTU Cottbus**
  - CEBRA (Joint Project)

- **KW Schw. Pumpe**
  - Vattenfall

The RWE Project of a Zero-CO₂ 450 MW Power Plant with CO₂ Storage (IGCC-CCS) (Source: RWE)

- Basic technology: IGCC
- El. capacity: 450 MWgross / 360 MWnet
- Net efficiency: 40%
- CO₂ storage: 2.3 mill. t/a in depleted gas reservoir or saline aquifer
- Commissioning: 2014
- RWE budget: approx. € 1 billion
IGCC Offers Excellent Product Flexibility

**Fuel flexibility**
- Natural gas
- Coal
- Biomass
- Residues

**Product flexibility**
- CO₂
- CO₂ capture
- CCGT
- Power
- Heat
- H₂
- Synthesis gas (CO + H₂)
- SNG (nat. gas)
- Methanol
- Motor fuels (ctl)

Advantages of IGCC technology
(Source: RWE)

- Fuel and product flexibility
- Only technology that can already be implemented on a large scale today
- Components tested in large scale, own RWE know-how
- Power plant process with highest efficiency potential, efficient operation also without CO₂ capture
Main Activities of German Utilities towards CO₂ Reduction

E.ON:
- 700 °C demo plant > 400 MW 2014
- IGCC with CCS at Killingholme/UK
- Participation in FutureGen Alliance in USA for 275 MW-coal-fired IGCC with CCS

Vattenfall:
- Development of oxyfuel technology, pilot plant 2008, demo plant 2015

RWE:
- Zero-CO2 450 MW-coal-fired IGCC 2014
- CO2-scrubbing for lignite and hard coal for advanced conventional power plant technology and as a retrofit option
- Feasibility study for clean coal 1000 MW hard coal fired power plant at Tilbury/UK
Expected Support of EC/Politics (1)

- Clear commitment to coal as important part of the future energy mix
- Clear commitment to CCS as instrument for CO₂ mitigation to stop climate change
- Support of efficiency increase to minimise consumption of resources and as pre-requisite of ZEP
- Create legal framework for geological storage of CO₂: amendment of EU waste and water framework directive and amendment of national mining law

Expected Support of EC/Politics (2)

- Support and active cooperation in public relations to get the acceptance for ZEP
- Sufficient financial support of the ZEP recommendations within SRA and SDD to allow for the necessary R&D and to set out for 10 - 12 demo projects
- No preference for renewable energies within the European FP7
- Close collaboration in ETP-ZEP and in continuation of German COORETEC initiative
Towards Zero CO₂ Power Generation

**CO₂ capture**
- post-combustion at conventional plants
- pre-combustion at gasification plants
- oxy-fuel combustion

**CO₂ storage**
- deep saline aquifers
- depleted oil and gas fields
- unmineable coal seams
- mineralisation

Some technologies are well-proven, others need significant R&D. All require demonstration with monitoring & verification of storage sites. An information campaign for public acceptance is needed.

**Research in both areas is necessary with the same effort.**
There will be no acceptance for a zero emission power station without CO₂ storage possibilities.

**Summary**
- Coal will remain its worldwide importance for electricity generation.
- Coal has to be used even more efficient and environmental friendly.
- Precondition is the large scale test of efficiency increasing technologies like integrated coal drying and raised steam parameters as well as CO₂ capture and storage.
- The necessary time-frame is about 10 to 15 years. Joint development projects make it easier to be successful.
- The joint generators activities and the cooperation within the ZEP technology platform confirm these considerations.
- CO₂ capture and storage is a promising option to secure the future of power generation based on fossil fuels. It doesn’t reduce, however, the necessity of CO₂ avoidance through further efficiency increases.
- The technical feasibility of ZEP technologies is beyond dispute.
- The economic efficiency will depend on the political frame-conditions.
Thank you for your attention