Post-Combustion Capture Development Programme of RWE

A Group-wide Approach to Implementing Technological Breakthroughs
Richard Hotchkiss, Michael Whitehouse, Peter Moser, Sandra Schmidt

12th Meeting of the International Post-Combustion CO₂ Capture Network
29th September - 1st October 2009, Regina, Canada
Boundary Conditions in Germany and UK (2008) Fuel Mix and Domestic Electricity Market

Shares of Primary Energy Sources in Total Electricity Generation Germany/UK

Attractiveness of Coal/Lignite and Gas differs in Germany and the UK. In the UK, the sample curves below change month-to-month.
Electricity Production and Power Plant Fleet 2008

RWE Group Employees: 65,908  External Revenues: Euro 48.9 billion  Customers Electricity: 20 million

Renewables are bundled at RWE Innogy
Capacity 1.3 GW

<table>
<thead>
<tr>
<th></th>
<th>Power plant capacity in MW</th>
<th>Power Produced in TWh</th>
<th>Power plant capacity in MW</th>
<th>Power Produced in TWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite</td>
<td>10,828</td>
<td>73.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>9,513</td>
<td>43.1</td>
<td>4,575</td>
<td>18.0</td>
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<tr>
<td>Nuclear</td>
<td>6,295</td>
<td>49.3</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Gas</td>
<td>3,994</td>
<td>11.5</td>
<td>2,913</td>
<td>18.2</td>
</tr>
<tr>
<td>Renewables</td>
<td>55</td>
<td>0.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pumped storage, oil, other</td>
<td>2,348</td>
<td>1.9</td>
<td>2,657</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>33,033</strong></td>
<td><strong>180.3</strong></td>
<td><strong>10,145</strong></td>
<td><strong>36.7</strong></td>
</tr>
</tbody>
</table>
RWE’s Generation Mix in Germany/UK (2008)

Germany: power produced in 2008 in TWh
- Lignite: 68.3
- Hard coal: 43.6
- Nuclear: 49.3
- Gas: 12.9
- Renewables: 3.1
- Pumped storage, oil, other: 1.9

Total: 179.7 TWh

CO₂ emissions in 2008: 141 million tons

UK: power produced in 2008 in TWh
- Gas: 18.2
- Hard coal: 18.0
- Renewables: 0.9
- Pumped storage, oil, other: 0.5

Total: 37.6 TWh

CO₂ emissions in 2008: 25 million tons

1) Including electricity procured from power plants not owned by RWE that we can deploy at our own discretion on the basis of long-term agreements, totalling 28.6 TWh (hard coal), 0.6 TWh (renewables) and 1.4 TWh (pumped storage, oil, other).

2) Including plant consumption by RWE open-cast mines.
Post Combustion Capture as Part of RWE´s CO₂ Mitigation Strategy for Power Plants

Horizon 1: Modernisation to increase efficiency
- Power plant portfolio: continuous renewal
- Under construction: 5,160 MW capacity Coal-fired

Horizon 2: Further efficiency increase
- WTA lignite pre-drying prototype
- 700 °C test plants
- First dry lignite-fired power plant
- Efficiency >50%
- Nearly CO₂-free
- 700 °C demo plant
- IGCC demo plant
- PCC demo plant

Horizon 3: Nearly CO₂-free
- 450 MW low-CO₂ IGCC power plant incl. storage
- CO₂ scrubbing incl. storage for conventional power plants
- CO₂ scrubbing incl. storage for conventional power plants
CCS Acts and National and EU Funding influences PCC-CCS Development Approach

Germany is not supporting large scale-demonstration projects
- State sees his task of establishing clear legal provisions for the environmentally sound use of CCS, but not more
- No PCC demonstration plant on the short list of EU´s Recovery Plan

UK identified lack of PCC demonstration as barrier for CCS deployment
- “UK Competition” to actively support technology demonstration
- Coal demonstration projects on the short list of EU´s Recovery Plan
- “No new coal without CCS demonstration”

Timelines and Frameworks of the different funding programmes require different approaches and determine widely the content of the projects:
- minimum size of the PCC plant (250 MW or less?)
- availability of the PCC technology (commercial process or under development)
- schedule (off-the-shelf technology or time for development and optimisation)
Key Factors for RWE Power´s and RWE npower´s Definition of RWE´s PCC Development

RWE´s group-wide approach focuses on:

> techno-economical evaluation and optimisation of PCC technology
> testing of most promising PCC technology on pilot plant-scale
> large-scale PCC-CCS demonstration project
> access to best available technology for commercial full-scale application from 2020
> competition between PCC suppliers

Key factors that define the approach and timeline:

> specific boundary conditions in the countries
  market and investment strategy, technical norms, legal and political aspects, public acceptance, funding conditions
> fuel mix (bituminous coal, raw lignite, pre-dried lignite, natural gas)
> target size of PCC plant
  (~800 MW bituminous coal, ~1100 MW pre-dried lignite)
RWE Power and RWE npower defined a Complementary PCC Development Programme

Split of work in the current phase:

> RWE npower is focusing on PCC for bituminous coal-fired power plant
> RWE Power investigates PCC especially for the next generation of lignite fired power plants

Approach guarantees:

> Close examination of fuel related questions
> trace elements in the flue gas, fly ash particles, aerosols and their impact on solvent degradation, corrosion and material selection
> specific power plant related integration concepts, waste heat usage and PCC scale-up issues

> RWE npower and RWE Power entered in this first stage of the development programme with different amine-based solvents, processes and equipment.
PCC Pilot Plant Projects on Amine-Based Processes - Preparing for Demonstration Projects

1. Cooperation of RWE Power, BASF, Linde to develop an advanced amine-based CO$_2$-Scrubbing-Process:

   - Pilot Plant Niederaussem
   - PCC-CCS demonstration, e.g. Eemshaven

2. RWE npower realized the generic test facility at Didcot

   - Didcot Test Rig at CTF
   - Further work

> Assessment of the performance of competitive PCC technologies is not sufficient.

> Pilot plant projects, the optimisation programmes and collaboration with process suppliers is providing knowledge and operational experience for the RWE Group.

> Cooperation and “hands on” experience provide develops a wider knowledge base than simply buying and independently testing “off-the-shelf” plants.
RWE Power Pursues Two PCC Routes

- **Goals for commercial full-scale application from 2020:**
  - PCC-CCS efficiency loss < 10%-points of the power plant efficiency
  - Cost of CO₂ capture & storage < CO₂ certificate price

- **Basic results of our worldwide screening of more than 20 potential PCC-processes and 4 feasibility studies:**
  - Focus on amine-based scrubbing and the new “Chilled Ammonia”-Process
  - Joint and integrated technology development is necessary

**The interdisciplinary approach – key to success:**

- **BASF** – "The Chemical Company": development of new solvents and optimized process design
- **Linde** – “Engineering company”: engineering and construction of the pilot plant, system optimization, scale up
- **RWE Power** – “Power producer and utility”: plant integration, interface optimization, operation
Pilot Plant Niederaussem - Key Figures

- CO₂-capture rate 90 %
- app. 7.2 t per day
- Height: app. 40 m
- Skid mounted design
- Start testing programme: July 2009
- Budget RWE Power: 9 Mio. €
- 40% Funding by the Federal Ministry of Economics and Technology
# RWE Power/BASF/Linde
## Development of a highly efficient amine based PCC Process

### Feasibility Study “PCC Full-Scale”
- Delineation of the pilot plant design
- Solvent Development BASF
- Solvent screening
- Miniplant performance tests

### PCC Pilot Plant Niederaussem
- Engineering, procurement
- Construction
- Operation

### Working Group “Full-Scale/Demo”
- Optimization of the PCC concept
- Scale up for a full-scale plant
- Demo plant design, e.g. Eemshaven

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### Timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Basis of Design</td>
</tr>
<tr>
<td>2008</td>
<td>New solvents</td>
</tr>
<tr>
<td>2009</td>
<td>Basis of Design</td>
</tr>
<tr>
<td>2010</td>
<td>Decision on Demoplant</td>
</tr>
</tbody>
</table>
PCC-CCS Demo Plant as Intermediate Step from Pilot Plant to Commercial Application

<table>
<thead>
<tr>
<th>Today</th>
<th>2010</th>
<th>2015*</th>
<th>2020*</th>
</tr>
</thead>
</table>

- **Pilot Plant**
  - Niederaußem
  - app. 0.5 MW\textsubscript{el, equiv.}
  - \(\approx 2,500\) t/a CO\textsubscript{2}
  - No CO\textsubscript{2} Storage

- **Demo Plant**
  - e.g. Eemshaven
  - app. 140 MW\textsubscript{el, equiv.}
  - \(\approx 0.7\) million t/a CO\textsubscript{2}
  - CO\textsubscript{2} Transportation and Storage - Design, Construction, Commissioning

- **Commercial PCC Plant**
  - 2 trains for a 1,100 MW power plant
  - app. 550 MW\textsubscript{el, equiv.} per train
  - \(\approx 3\) million t/a CO\textsubscript{2} per train

*Timeline depends on development progress and especially project boundary conditions (e.g. permitting).
## Knowledge Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>Understanding and minimising costs and impact on host plant</td>
<td>✓</td>
</tr>
<tr>
<td>Understanding environmental issues (emissions, waste streams)</td>
<td>✓</td>
</tr>
<tr>
<td>Understanding process chemistry, corrosion, solvent degradation</td>
<td>✓</td>
</tr>
<tr>
<td>Process integration and optimisation</td>
<td>✓ Site specific research needed</td>
</tr>
<tr>
<td>Gas cleaning requirements</td>
<td>✓</td>
</tr>
<tr>
<td>Evaluating technologies</td>
<td>✓</td>
</tr>
<tr>
<td>Improvement in process technology / reduction in efficiency penalty</td>
<td>✓</td>
</tr>
<tr>
<td>Developing modelling capability</td>
<td>✓</td>
</tr>
<tr>
<td>Understanding implications for power plant flexibility, grid code and commercial</td>
<td>✓</td>
</tr>
<tr>
<td>Understanding Engineering issues for retrofit</td>
<td>Limited -site specific</td>
</tr>
<tr>
<td>Understanding implications for CCGTs</td>
<td>✓</td>
</tr>
<tr>
<td>Understanding regulatory and legislative requirements</td>
<td>Limited</td>
</tr>
</tbody>
</table>
PCC Impact on Host Power Station

> Reduces efficiency from approx. 45% to approx. 35%
> Requires about half steam from LP turbine
> Energy penalty comprises steam for reboiler 45%, pumps and fans 10% and CO2 compression 45%
> Increased capital cost
> Substantial land area
> Impact on flexibility
> High impact means that even incremental improvements can make a big difference
RWE npower
Schematic of Didcot CTF (Combustion Test Facility)
Post-combustion capture at Didcot

Test programme

> Comparison of energy requirements for range of solvents

> Compatibility with bio-mass

> Testing different flue gas compositions.

> Parametric tests of solvent loading and desorption temperature and pressure.

> Alternative solvents e.g. MDEA, hindered amines

> Validation of baseline process economics and assessment of plant flexibility

Specification

> Treat 33% of 0.5 MW CTF flue gas

> Carbon dioxide removal using MEA of 1 tonne per day (>85%)

> SO₂ and NOₓ pre-treatment
Didcot Amine Test Rig

- 8m column height
- 0.07 MWe (50 kg/h CO$_2$)
- SO$_2$ and NO$_X$ pre-treatment
- Multiple solvent sampling locations
- Provision for corrosion coupons and alternative material test sites
- Trace gas injection
- Continuous analysis

Test programme

- MEA reference tests with heat and material balances and parametric studies
- Alternative solvents e.g. MDEA, hindered amines and blends
- Validation of baseline process economics and assessment of plant flexibility
- Tests on different flue gases and fuels including biomass
ECO-Scrub Concept

> 39 month project funded by EC Research Fund for Coal and Steel, co-ordinated by RWE npower in collaboration with three universities, two research institutes and three utilities from five EU member states

> Enhanced combustion with oxygen and scrubbing

> no recirculation or partial recirculation of flue gas with replacement of some air by oxygen

  - reduces volume of flue gas
  - enhances CO₂ concentration of flue gas

> Several potential benefits

  - potential for net reduction of operating cost due to increased capture efficiency (opex)

  - potential for slight reduction in size of post-combustion capture plant (capex)

  - reduced-cost retrofit option or potential for savings in new plant through advanced combustion optimisation and reduced boiler size

  - may also be able to reduce size of SCR plant

  - no issues with air in-leakage

<table>
<thead>
<tr>
<th>Output of simulations for a lignite-fired power plant</th>
<th>Reference case</th>
<th>Retrofit case (post-combustion)</th>
<th>Retrofit case (oxyfuel)</th>
<th>Retrofit case (ECOS-Scrub)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross electric power MWe</td>
<td>330.67</td>
<td>299.44</td>
<td>357.44</td>
<td>312.19</td>
</tr>
<tr>
<td>Gross electrical efficiency %</td>
<td>42.45</td>
<td>38.44</td>
<td>45.89</td>
<td>40.08</td>
</tr>
<tr>
<td>Net electric power MWe</td>
<td>304.15</td>
<td>243.43</td>
<td>258.62</td>
<td>248.24</td>
</tr>
<tr>
<td>Net electrical efficiency %</td>
<td>39.05</td>
<td>31.25</td>
<td>33.20</td>
<td>31.87</td>
</tr>
<tr>
<td>Pumps (electric) MWe</td>
<td>18.15</td>
<td>18.87</td>
<td>20.16</td>
<td>19.27</td>
</tr>
<tr>
<td>CO₂ compressors (electric) MWe</td>
<td>-</td>
<td>21.24</td>
<td>21.24</td>
<td>21.23</td>
</tr>
<tr>
<td>Fans and compressors (electric) MWe</td>
<td>8.37</td>
<td>15.9</td>
<td>57.42</td>
<td>23.35</td>
</tr>
<tr>
<td>Reboiler duty MWth</td>
<td>-</td>
<td>268</td>
<td>-</td>
<td>256.85</td>
</tr>
<tr>
<td>O₂ in secondary air % vol.</td>
<td>21</td>
<td>21</td>
<td>95</td>
<td>30</td>
</tr>
</tbody>
</table>

Data courtesy of CERTH/ISFTA, National Technical University of Athens
Didcot CTF Burner Inlet (Air and ECO-Scrub firing)
Conclusions

> There is currently no obvious best technology. All need development but amine-based PCC technologies are currently favoured for retrofit.

> In the current phase of RWE´s development programme, RWE Power is focussing on PCC for lignite-fired power plants and RWE npower on bituminous coal-fired power plants.

> The combination of pre-selection of the most promising PCC technologies, individual collaborations with appropriate partners from the technology supply industry and a generic test facility boosts the development.

> Ongoing process optimisation and hands-on experience in the pilot plant projects provides valuable understanding of the technologies and how they interact with power plants.

> Other technology options are being investigated in parallel.

> We believe that this is an excellent basis for the RWE Group to decide on the preferred carbon dioxide capture technology for demonstration plants and commercial application from 2020.
Thank you very much for your attention
### RWE Power’s Development of the Demo Plant

<table>
<thead>
<tr>
<th>Finalization of the preliminary design study of a full scale PCC plant</th>
<th>Continuous optimisation of the integrated PCC concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition of tasks for pilot plant testing to validate the technology and to minimize scale up risks</td>
<td></td>
</tr>
<tr>
<td>Up date of the design of a full scale PCC plant on basis of the pilot plant results</td>
<td></td>
</tr>
<tr>
<td>Definition of tasks for the demo plant testing to validate the optimized technology and to minimize scale up risks</td>
<td></td>
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</tbody>
</table>

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**Demo plant design**

**Boundary conditions from the power plant and the CO₂ transport and storage infrastructure**
Political Framework / Legal Boundary Conditions
Influences Power Plant and PCC Design

Large Combustion Plant Directive: Closure of 13 GW by 2015 (or earlier)

> New emission limits from 2008 for power stations to operate more than 20,000 hours / beyond 2015:

Ordinance on the Implementation of the Federal Immission Control Act (Ordinance on Large Combustion Plants and Gas Turbine Plants)

> Emission limits for power plants with a thermal input of more than 300 MWe:
  - NO\textsubscript{x} 200 mg/m\textsuperscript{3} (from 2013: 100 mg/m\textsuperscript{3})
  - total dust 20 mg/m\textsuperscript{3}; CO 200 mg/m\textsuperscript{3}; SO\textsubscript{x} 200 mg/m\textsuperscript{3} and additionally to the limitation of the mass concentration a rate of desulphurisation of at least 85 per cent must be achieved.
Coal Power Plant Modernisation Programme. Candidates for PCC Retrofit

**Goal of PCC development:**
PCC as a retrofit option and for new-built power plants

**2009**
Lingen
Natural gas
875 MW CCGT

**2011**
Neurath
Lignite
2,100 MW

Hamm
Hard Coal
1,530 MW

**2013**
Eemshaven
Hard Coal/
Biomass
1,530 MW
Minimal Size of the Demo Plant as Result of a Scale-up Risk Analysis for commercial Application

Large Combustion Plant Directive: Closure of 13 GW by 2015 (or earlier)

- PCC design study for a 1,100 MWel pre-dried lignite power plant completed

⇒ 2 PCC trains in parallel, each 550 MWel

- Thorough scale-up risk analysis to define minimal size for a PCC demo plant as a reliable and representative validation for the commercial full-scale application:

⇒ Absorber defines necessary minimal size of the demonstration plant (gas-liquid distribution, mechanical concept, internals, packings, advanced materials)

Result:

The minimal size of a reasonable demonstration plant is app. 140 MWel