Evaluation of Carbonate Looping

for Post-Combustion CO$_2$-Capture from a Utility's Perspective

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IEA GHG R&D Programme
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Brief portrait
EnBW Energie Baden-Württemberg AG

- Third-largest energy company in Germany
- Business segments: electricity generation and trading, electricity grid and sales, gas, energy and environmental services
- Annual revenue 2010: in excess of € 17 billion
- Customers: some 6 million
- Employees: more than 20,000
Shareholdings in Europe

Wroclaw [Kogeneracja]
Rybnik [ERSA]
Prague [PRE]
Maria Enzendorf [EVN]
Bregenz [VIW]
Sellrain-Silz [TIWAG]
Laufenburg [ED]
Visp [EnAlpin]
Budapest [ELMU]
Miskolc [EMASZ]
Visonta [MATRA]
Istanbul [Borusan EnBW Enerji]
EnBW’s Generation Mix*

As Germany’s third-largest energy company we do take sustainable and responsible action for both the company and the society as a whole.

EnBW generation portfolio electrical output

- Conventional power stations: 2.835 MW
- Nuclear power plants**: 4.856 MW
- Hydrothermal power plants: 259 MW
- Other renewable energies: 7.548 MW

*status quo: Dec 31, 2010
**incl. contracts
Timeline towards Carbon Capture and Storage

First CCS activities

Fossil power plant projects to be CCS-ready

Development of:
- Knowledge
- Capacities
- Experience

Evaluation and analysis of gathered experience

Revision of European Directive


Set-up of CCS Business

Capture

Transport

Storage/Re-use

National/international panels on political, social and regulatory aspects
Relevant Aspects of CO$_2$ Capture

- Overall efficiency of energy conversion process
- Integration of CO$_2$ capture process into power plant
- Flexible operation of coal-fired power plants
- Health, safety and environmental issues
- By-product and waste management
CCS R&D Roadmap
CO₂ - Capture

Post-combustion
- Amine-based solvents and optimised process design
- Chilled Ammonia
- Solid sorbents

Oxyfuel
- Air separation
- Power plant components/process layout
- Process integration

Pre-combustion
- Gasification
- Gas treatment
- Hydrogen gas turbine

Process validation plants in pilot-scale
Process development plants in lab-scale
Test rigs and pilot plants

Research & development

short-term | medium-term | long-term
Focus 'Post-combustion Capture'

Post-combustion capture
Why focus of EnBW?

› Retrofit of existing coal-fired power plants
› Retain proven power plant technology
› CO₂ capture technology closest to commercial availability

New built power plant RDK8

› Bituminous coal
› Pulverised coal furnace
› 900 MW, 600/620°C, >46 %
› Capture-ready
EnBW's CO₂-Capture Test Plants

**Amine scrubbing test plant**

@ Coal-fired Heat and Power Plant Heilbronn  
Treated flue gas flow: 1.150 Nm³/h  
CO₂ capture rate: 90 %  
Captured CO₂ mass flow: 300 kg CO₂/h

Pre-scrubber and absorber, H = 40 m,  
Polypropylene/GRP  
Desorber, H = 25 m, stainless steel (1.4571)

**Carbonate Looping test plant**

@ Universität Stuttgart (IFK)  
Treated flue gas flow: 250 Nm³/h  
CO₂ capture rate: > 85 %  
Captured CO₂ mass flow: 120 kg CO₂/h

Dual fluidised bed (DFB) system for CO₂ absorption/desorption (blue/red, H = 10 m)  
+ FB combustor for flue gas provision (yellow)
Calcium-based CO$_2$ Capture Process Scheme

1. **CO$_2$-Adsorption (Carbonator)**
   - Flue gas from power plant
   - Process temperature: 600 – 700 °C
   - Reaction: CaO + CO$_2$ $\rightarrow$ CaCO$_3$

2. **CO$_2$-Desorption (Calciner)**
   - CO$_2$-lean flue gas
   - Process temperature: 850 – 920 °C
   - Reaction: CaCO$_3$ $\rightarrow$ CaO + CO$_2$
   - Inputs: Lime, Coal, Oxygen
   - Outputs: Limestone, CO$_2$
### Calcium-based CO₂ Capture Process

#### Technical Evaluation

<table>
<thead>
<tr>
<th></th>
<th>Study 1¹)</th>
<th>Study 2²)</th>
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<tbody>
<tr>
<td><strong>Reference coal-fired power plant</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net power (MWₑ)</td>
<td>1052</td>
<td>500</td>
</tr>
<tr>
<td>Net efficiency (%)</td>
<td>45.6</td>
<td>40.3</td>
</tr>
</tbody>
</table>

### Power Plant with CO₂ Capture

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<tr>
<td>Net power (MWₑ)</td>
<td>1452</td>
<td>700</td>
</tr>
<tr>
<td>Net efficiency (%)</td>
<td>39.2 ³)</td>
<td>35.6 ⁴)⁵)</td>
</tr>
<tr>
<td>Efficiency penalty (%)</td>
<td>6.4</td>
<td>4.7⁵)</td>
</tr>
<tr>
<td>CO₂ capture rate (%)</td>
<td>82.8</td>
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</tbody>
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¹) Feasibility study Carbonate Looping, TU Darmstadt/ University Stuttgart, 2008; Unterberger et al., PowerGen 2009

²) Romeo et al., Chem. Eng. J., 2009

³) Including CO₂ compression up to 110 bar

⁴) Including CO₂ compression up to 120 bar

⁵) Own calculations
Technical Evaluation of Carbonate Looping Benefits and Drawbacks

Benefits

› Retrofit option for existing power plants/
  Host power plant remains unmodified
› Builds on commercially available power plant technology
› Sorbent material well known/originating from competitive supply market
› If necessary, application of well-proven emission abatement technologies (DeNOx, DeSOx, DeDust)
› Potential purge stream utilisation in cement industry and/or flue gas desulphurisation

Drawbacks

› Behaviour and deactivation of limestone not fully understood
› Possibly further CO₂ treatment necessary (CO₂ quality)
› 2nd/3rd generation capture process
Carbonate Looping Technology Development Road Map

**Objectives**
- Laboratory Investigations
  - Sorbents
  - Attrition
  - Cyclic Capacity
  - Process concept

- Ongoing Work Achievements
  - Natural limestones
  - TGA analyses
  - Attrition testing
  - Carbonation model
  - Cold models

- Sintering
- Partitioning
- Microscopy
- Model validation

**Bench-Scale Test**
- Process design
- Single process components
- Coupled process in bench-scale
- Coupled process
- Reactor/process models
- Design data for larger test plants
- Sorbent testing
- Treated natural and engineered sorbents

**Test Plants**
- Process demonstr. under realistic conditions
- Scale-up tools
- First test plants operational
- Parametric testing
- Operational aspects
- Energy requirem., CO₂ capture rate
- Scale-up
- CAPEX/OPEX

**Intermediate benchmarking and validation step**
- Assessment and confirmation of existing process performance data
- Decision upon EnBW's further process development steps
Open Tasks/ Future Work

Process related issues

› Process layout and reactor concepts
  › Process layout study regarding reactor coupling
  › Systematic screening and assessment of reactor concepts

› Process control and monitoring concepts
  › Conceptual study regarding measurement techniques and control strategies

› Water-steam cycle design for Carbonate Looping Plant

› CO₂-quality und –purification
  › Theoretical study on CO₂-purification system based on achievable CO₂ composition from test plants

› Calcination
  › Alternative fuels for oxyfuel calcination, e.g. natural gas, biomass
  › Alternatives to oxyfuel combustion
Open Tasks/ Future Work

Sorbent related issues

› Limestone behaviour and demand
  › Lifetime estimations of natural limestones
  › Performance of different limestones under real conditions

› Potential of engineered sorbents
  › Pre-treated natural limestones and engineered sorbents
  › Theoretical evaluation of potential of engineered sorbents

› Evaluation of purge utilisation in cement industry or desulphurisation

Power plant interaction

› Carbonate Looping process integration into power plant
  › Screening and assessment for new-build and retrofit cases

› Effects on power plant flexibility and load following capability
Conclusions and Outlook

- Benefits for operator of coal-fired power plants
  - Retain existing power plant technology
  - Retrofit option
  - Sorbent is known in power plant processes
  - No release of further pollutants

- Comparably low parasitic power demand

- Competitive with other capture technologies

- 2nd/3rd generation post-combustion capture technology

- Needs further R, D & D activities

- Confirmation of promising process characteristics outstanding

- Next step should be process demonstration in pilot plant scale (5 - 20 MWth)
Back-up Slides
Our locations in Germany

1 EnBW operates some 80 hydro-electric power stations and numerous other renewable energy facilities. We have therefore only presented some of the major locations.

2 Operations ceased on 11 May 2005 as a result of the nuclear energy agreement.
Calcium-based CO$_2$ Capture Process
Power Plant 1052 MW$_{e,\text{net}}$, 45.6 % el. eff., 335 t/h coal

Flue gas from power plant
$\text{CO}_2$: 815 t/h

**CO$_2$-Adsorption (Carbonator)**
600 – 700 °C
- Heat release: 1268 MW$_{th}$
- Gross power output: 633 MW$_{e,\text{gross}}$
- Net power output: 400 MW$_{e,\text{net}}$

$\text{CO}_2$: 163 t/h (to stack)

Lime
- Make up: 55 t/h
- CO$_2$: 1154 t/h (to compression)

4420 t CaO/h

CaCO$_3$

**CO$_2$-Desorption (Calciner)**
850 – 920 °C
- Coal: 200 t/h
- Oxygen: 438 t/h

Coal: 200 t/h
Calcium-based CO₂ Capture Process
Integration with Coal Power Plant

Coal-fired power plant 1100 MWₐₜ, gross

Steam cycle 1

Coal-fired power plant

Flue gas cleaning (DeNOₓ, DeDust, DeSO₂)

Air Coal

Carbonator (650°C)

CaO + CO₂ → CaCO₃

Flue gas cleaning

CaCO₃

Calciner (900°C)

CaCO₃ → CaCO + CO₂

Oxygen Coal

CO₂-Conditioning

CO₂ to transport & storage

Make-up

Purge

CO₂ capture plant 633 MWₐₜ, gross

Q₁, Q₂, Q₃, Q₄

CO₂-lean flue gas

Steam cycle 2