Post-Combustion Carbon Capture – Leading Mature Technology for Decarbonization of Fossil Power Generation

Dr. Nicolas Vortmeyer, CTO Power Generation Division
Dr. Rüdiger Schneider, Head of Technology Development Lab
Gernot Schneider, Director Sales and Marketing CCS

Siemens AG, Energy Sector, Power Generation Division
Table of content

- Need for CCS 3
- Competitive Environment 5
- Post Combustion Capture 8
- Power Plant Competitive Capture Technology 10
- Carbon Capture at Gas Fired Plants 12
- Cost Reduction Potential 14
- Conclusion 15
Cooperations

**TNO Cooperation**

**Exclusive Agreement**
Agreement signed June 2009

- Aimed at further advancement of amino acid salt based carbon capture technology
- Targets faster time to market and implementation of full-scale demo plant
- Leverage synergies and optimize resources
- Reduce investment cost and energy demand of capture plant

**Masdar Cooperation**

**Long-term strategic partnership**
Agreement signed March 3rd 2011

Siemens is co-operating together with...
- Masdar City
- Masdar Institute
- Masdar Clean Energy

in the field of **Carbon Capture Utilization and Sequestration (CCUS)** for improved application of CCUS technology in the Middle East region.
In spite of % percentage of fossil decreasing (68% - 61%) CO₂ emissions increase every year in the coming decade.
Competitive Environment

Compensation mechanisms mostly not in place to compensate power plant operation for higher OPEX and CAPEX.

Capture plant is main lever for cost reduction

© Siemens AG 2013 All rights reserved.

*after demonstration phase beyond 2020
CCS is a fully dispatchable, base load capable, low carbon technology with electricity cost comparable to many renewable technologies.
Low-CO$_2$ power plants are required to be operated on mid- to base-load, CO$_2$ certificate price assumed at current, moderate levels.

Fossil Power Plant w/ CCS in optimal operating regime can be more economically than Fossil Power Plant w/o CCS.

Future CCS applications should have priority.
After many years there are still three main options for CCS:

**Pre-Combustion**
- New build, no retrofit possible
- Main application in polygeneration (→ mature technology)
- Large global GT gasifier fleet

**Post Combustion**
- Large reference base for absorption processes in chemical industry
- Retrofitable !!!
- Mature technology

In addition many new ideas……..but need more time, not available before 2020.
Post Combustion Capture

PostCap™ Technology

Validated in unit 5 of E.ON Staudinger steam power plant in Germany

700 MW CCPP in O&G Business

- approx. 1.8 Mio tons of CO₂ reduction per year
- 340 g CO₂/kWh
- 40* g CO₂/kWh

800 MW Steam Power Plant

- approx. 4.0 Mio tons of CO₂ reduction per year
- 730-1000 g CO₂/kWh
- 80* g CO₂/kWh

Other Industrial Processes

- CO₂ concentrations higher, CO₂ quantities lower than in power generation

*90% CO₂ capture rate
© Siemens AG 2013 All rights reserved.
Post Combustion Capture

Post Combustion Process Requirements

- Environmentally friendly
- Low loss of Solvent
- Low specific energy demand
- Minimal effort for power plant retrofit
- Flexible operation (part load / full load)

Cleaned Flue Gas

CO₂ Compression

CO₂ outlet

CO₂ Absorption

CO₂ Desorption

Flue gas inlet (from power plant)

Environmentally friendly

Low loss of Solvent

Low specific energy demand

Minimal effort for power plant retrofit

Flexible operation (part load / full load)
Power Plant Competitive Capture Technology
Siemens Approach for Post Combustion Capture

Ammonia

Amino Acid

Amino Acid Salt

Salts have no vapor pressure
- No thermodynamic solvent emissions
- Non-flammable
- Non-explosive
- Odorless
- No inhalation risk

Negative ion is less sensitive to $O_2$
- Low degradation

Amino acids are naturally present
- Biodegradable
- Nontoxic
- Environmentally friendly

Solvents based on amino acid salts are economic, have low environmental impact and are easy to handle.
## Power Plant Competitive Capture Technology

**PostCap™ Pilot Plant at E.ON Staudinger**

<table>
<thead>
<tr>
<th>Project</th>
<th>Siemens PostCap™ Pilot Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Frankfurt, Germany</td>
</tr>
<tr>
<td>Customer</td>
<td>E.ON (coal-fired power station Staudinger)</td>
</tr>
<tr>
<td>Commissioning</td>
<td>September 2009</td>
</tr>
<tr>
<td>Plant size</td>
<td>Approx. 1 t/d CO₂</td>
</tr>
<tr>
<td>Operating Hours</td>
<td>&gt; 9,000 hours</td>
</tr>
</tbody>
</table>

- Siemens PostCap™-Technology verified
- Simulation tools and scale up-methods validated
- Optimizations and adaptations ongoing
## Carbon Capture at Gas Fired Plants

<table>
<thead>
<tr>
<th></th>
<th>SPP</th>
<th>CCPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ vol-%</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>O₂ vol-%</td>
<td>3</td>
<td>12.5</td>
</tr>
<tr>
<td>Specific Fluegas Flow kg/MW_{el,gross}</td>
<td>1.0</td>
<td>1.6</td>
</tr>
</tbody>
</table>

- **Lower CO₂ content**
- **Higher O₂ content**
- **Lower solvent loadings and driving force**
- **Higher reaction kinetics**
- **Higher solvent degradation**
- **Higher solvent consumption**
- **More flue gas**
- **Larger absorber diameter**

Amino Acid salt has low sensitivity to Oxygen → low degradation

SPP - Steam Power Plant  CCPP - Combined Cycle Power Plant

© Siemens AG 2013 All rights reserved.
Carbon Capture at Gas Fired Plants
Masdar FEED

<table>
<thead>
<tr>
<th>Project</th>
<th>Masdar full-scale CO₂ capture project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>United Arab Emirates</td>
</tr>
<tr>
<td>Customer</td>
<td>Masdar Carbon</td>
</tr>
<tr>
<td>Process</td>
<td>Combined Cycle Power Plant</td>
</tr>
<tr>
<td>Plant size</td>
<td>1.8 Mio tons of CO₂ per year</td>
</tr>
<tr>
<td>Commissioning</td>
<td>tbd</td>
</tr>
</tbody>
</table>

- Overall target for 2030: Capture approx. 30 Mio tons/a for EOR
- Highly advanced CO₂ pipeline network (target 500 km) with excess capacity for growth until 2030
- 1<sup>st</sup> step being implemented: CO₂ from steel manufacturing, approx. 0.8 Mio tons/a CO₂
- Possible 2<sup>nd</sup> step:
  - CO₂ from gas fired power plant (target 1.8 Mio tons/a CO₂): MASDAR-Siemens CCS Collaboration
  - Siemens PostCap™ basis of a FEED executed by Siemens
Carbon Capture at Gas Fired Plants
Full-scale Carbon Capture Mongstad Project

<table>
<thead>
<tr>
<th>Project</th>
<th>Full-Scale Carbon Capture Mongstad (CCM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Mongstad Refinery, Norway</td>
</tr>
<tr>
<td>Customer</td>
<td>Statoil Petroleum AS</td>
</tr>
<tr>
<td>Process</td>
<td>Combined Heat and Power Plant</td>
</tr>
<tr>
<td>Plant size</td>
<td>1.2 Mio tons of CO$_2$ per year</td>
</tr>
<tr>
<td>Status</td>
<td>TQP finalized - project discontinued by Norw. Gov.</td>
</tr>
</tbody>
</table>

Ongoing: Technology Qualification Program (TQP) of CO$_2$ post-combustion capture technologies, divided into three phases:

1. Feasibility study to show that the technology can be used at Mongstad (completed)
2. Demonstrate process operation and specified emissions level/criteria with test-rig and pilot plant (completed)
3. Concept Phase incl. costing for design of full-scale CO$_2$ capture (completed)
Short term cost reduction potential: > 20%, long term > 30% achievable.

- Absorption combined with precipitation
- Innovative cycles / PP integration
- Alternative concepts for direct contact cooling
- Optimization of reclaiming
- Activators
- Target engineering / economy of scale

outstanding cost reduction potential achievable with Siemens PostCap™
Fossil fuels will maintain a big share in global electricity production, CCS is urgently needed to cope with climate change.

LCOE of CCS is lower now than with offshore wind or photovoltaic power generation with further cost reduction potential.

Post-combustion technologies comprises a proprietary chemical absorption process that is mature and retrofitable to coal and gas fired power stations.

Siemens PostCap™ process is very efficient, easy to handle; Power Plant remains Power Plant.

Next challenge is to reduce overall costs of CCS chain and gain acceptance for CO$_2$ Storage. Siemens has identified first potential measures. Demonstration needed.
Disclaimer

This document contains forward-looking statements and information – that is, statements related to future, not past, events. These statements may be identified either orally or in writing by words as “expects”, “anticipates”, “intends”, “plans”, “believes”, “seeks”, “estimates”, “will” or words of similar meaning. Such statements are based on our current expectations and certain assumptions, and are, therefore, subject to certain risks and uncertainties. A variety of factors, many of which are beyond Siemens’ control, affect its operations, performance, business strategy and results and could cause the actual results, performance or achievements of Siemens worldwide to be materially different from any future results, performance or achievements that may be expressed or implied by such forward-looking statements. For us, particular uncertainties arise, among others, from changes in general economic and business conditions, changes in currency exchange rates and interest rates, introduction of competing products or technologies by other companies, lack of acceptance of new products or services by customers targeted by Siemens worldwide, changes in business strategy and various other factors. More detailed information about certain of these factors is contained in Siemens’ filings with the SEC, which are available on the Siemens website, www.siemens.com and on the SEC’s website, www.sec.gov. Should one or more of these risks or uncertainties materialize, or should underlying assumptions prove incorrect, actual results may vary materially from those described in the relevant forward-looking statement as anticipated, believed, estimated, expected, intended, planned or projected. Siemens does not intend or assume any obligation to update or revise these forward-looking statements in light of developments which differ from those anticipated.

Trademarks mentioned in this document are the property of Siemens AG, its affiliates or their respective owners.
Backup
Power Plant Competitive Capture Technology
Siemens Approach for Post Combustion Capture

Solvent Degradation
Solvent deactivation due to degradation (thermal, $O_2$, $NO_x$, $SO_x$, etc...)

Siemens PostCap™ Process
based on: AMINO ACID SALT (AAS) Formulations

- Siemens AAS Solvent - non volatile:
  - Zero Solvent Slip to atmosphere
  - Easy handling
- Effective combination of a power plant and a capture plant as an end-of-pipe solution

Power Plant remains Power Plant

- Chemical reclaiming possible:
  - AAS highly $O_2$ resistant
  - Sellable Sulfur product
  - FGD retrofit can be avoided
  - Small amount of residue

Proprietary reclaiming process available that complements the Siemens PostCap™ Process