CO₂ Capture Utilization and Sequestration (CCUS)
Drivers of CCUS – Development

Global electricity market: demand for (fossil) electricity still growing. CO₂ emissions will increase without CCUS

Enhanced Oil Recovery with CO₂ is well-proven technology employed in USA. Demand of CO₂ is increasing

Power generation mix worldwide, in TWh

Source: Siemens
**CO₂ abatement scenario according to IEA in the 450 Scenario**

CCUS indispensable to achieve GHG emission reduction targets.

The 450 Scenario (i.e. max. 450ppm CO₂ concentration in ambient air) describes how technologies may be transformed to limit the average global temperature increase to 2 °C.

Source: IEA Technology Roadmap CCS 2013
Siemens Energy Sector –
Clean electricity for the world

Top performance in four Divisions

<table>
<thead>
<tr>
<th>Division</th>
<th>Performance Highlights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Generation (E P)</td>
<td>World record 60.75% efficiency for combined cycle power plants</td>
</tr>
<tr>
<td>Wind Power (E W)</td>
<td>Deep-sea capable 36 kV Seabed power distribution at depths of up to 3,000 m</td>
</tr>
<tr>
<td>Energy Service (E S)</td>
<td>New performance dimensions 6 MW for wind turbines</td>
</tr>
<tr>
<td>Power Transmission (E T)</td>
<td>Additional 200 MW through modernization in 2011</td>
</tr>
<tr>
<td></td>
<td>World record 800 kV for direct current transmission</td>
</tr>
</tbody>
</table>
Chemical Engineering of Siemens in Industrial Park Höchst Frankfurt

IP Höchst
Area: 4.6 km²
Employees: 22,000
Companies: > 90

Proprietary Post Combustion Carbon Capture technology (Siemens PostCap™), developed in Industrial Park Höchst, now ready for large scale demonstration projects.
CO₂ Reduction Potential through Siemens’ PostCap™ Technology

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
✓ 40* g CO₂/kWh
340 g CO₂/kWh

800 MW Steam Power Plant
approx. 4,0 Mio tons of CO₂ reduction per year
✓ 80* g CO₂/kWh
730-1000 g CO₂/kWh

Other Industrial Processes
CO₂ concentrations higher, CO₂ quantities lower than in power generation

*90% CO₂ capture rate
Siemens Post-Combustion Carbon Capture for Fossil Fuel fired Power Plants

**CO₂ Absorption - Desorption**

- Proven technology in chemical processing and oil & gas industry...
- ...but special considerations for fossil power plant environment, e.g.
  - Flue gas release to atmosphere
  - High content of oxygen
  - Easy-to-handle for power plant personnel

**Siemens PostCap™ Process**

- Based on: AMINO ACID SALT Formulations
  - "Scalable" market introduction (from pilot to demonstration plant)
  - Retrofitable to existing power plants as well as applicable to new plants

Post Combustion is preferred solution for CCUS demonstration projects
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.

Source: Masdar
Siemens PostCap™ Process

**CO₂ Absorption**
- high absorption rate
- low degradation

**Flue gas inlet**
(from power plant)

Amino-based capture processes have volatile solvent in exhaust gas; additional washing units required. SIEMENS does not require it!

**CO₂ Compression**
- (concentration > 99%)

**CO₂ Desorption**
- heating up solvent
- desorption of CO₂
- 2.7 GJ per ton of CO₂ captured

**Cleaned flue gas released to atmosphere, Nearly zero solvent slip**

Amino Acid salt has low sensitivity towards Oxygen → low degradation

Siemens PostCap™ process based on amino acid salts is economic, has low environmental impact and easy to handle.

Steam, @ approx. 120° C
Siemens’ Reclaimer Technology
Proprietary Know-How

Solvent degradation

Solvent deactivation due to degradation (thermal, O₂, NOx, SOx, etc...)

✓ High amount of solvent can be recycled
✓ Sellable Sulfur product
✓ FGD retrofit can be avoided
✓ Small amount of residue

Proprietary PostCap™ reclaimer

deactivated solvent → Sulfur Recovery → Solvent slip-stream

Sulfur Product (sellable) → AAS Recovery

reactivated solvent → residue

back to capture process
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
## Feasibility Study for ROAD Maasvlakte

<table>
<thead>
<tr>
<th>Project</th>
<th>ROAD Maasvlakte Feasibility Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Process</td>
<td>1000 MW coal fired power plant (900 TPH flue gas with 21%wt CO2)</td>
</tr>
<tr>
<td>Plant size</td>
<td>250 MW flue gas slipstream (1,400,000 TPA of CO2 @ 100 bar)</td>
</tr>
<tr>
<td>Status</td>
<td>Design finalized for 1 train PostCap™ Plant</td>
</tr>
</tbody>
</table>

![Image of the project location on a map]

![Image of the project setup]

![Diagram of the project setup]
## Contract Study for Statkraft Norway Combined-Cycle Power Plant with PostCap

<table>
<thead>
<tr>
<th>Project</th>
<th>Contract Study for CCPP in Norway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Norway</td>
</tr>
<tr>
<td>Customer</td>
<td>Statkraft</td>
</tr>
<tr>
<td>Process</td>
<td>Combined Cycle Power Plant</td>
</tr>
<tr>
<td>Plant size</td>
<td>1.2 Mio tons of CO₂ per year</td>
</tr>
</tbody>
</table>

### TASK 1
Adaptation and optimization of Siemens PostCap™ process for CCPP

### TASK 2
Definition of capture ready CCPP and PP performance evaluation

### TASK 3
Evaluation of load change behavior of CCUS-CCPP
Masdar full-scale CO₂ Capture Project

<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 2030: Capture 30 Mio tons/a for EOR
- Highly advanced CO₂ pipeline network (target 500 km) with excess capacity for growth until 2030
- 1st step: CO₂ from steel manufacturing, approx. 0.8 Mio tons/a CO₂ (detailed engineering commenced)
- Possible 2nd step:
  - CO₂ from gas fired power plant (target 1.8 Mio tons/a CO₂): MÅSDAR-Siemens CCUS Collaboration
  - Siemens PostCap™ selected: FEED for PostCap™ CO₂ Capture plant finalized by Siemens
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)
Capture Ready Design for SPP: Basis: 800-900 MWel / Internat’l Coal
Capture Ready Requirements for Steam Power Plant: technical aspects to be considered

- Consider capacity extension in column design
- Exhaust ducts considering \( \Delta p \) from CO\(_2\) absorption unit later flue gas connection to capture unit (T-branch)
- Flue gas fan upgradeable design or additional space for installation of second fan downstream of FGD
- Steam turbines extraction of approx. 40% of LP steam; turbine table needs to be designed for additional load
- Steam turbine building sufficient space/foundation for: modification of turbines, steam and condensate pipes
- Electrical auxiliary load sufficient space for: additional auxiliary transformer(s), switchyard, cable routes
- Condensate system, sufficient space for: heat exchangers for low grade heat utilization, additional piping routes with supporting structure / racks
- Cooling system sufficient space for: additional circulation pumps, service water system, sufficient cooling capacity of cooling tower
- Raw water & cooling water supply / Waste water treatment sufficient space for enlargement, secure water utilization rights
- Plant area for capture plant sufficient space/foundation for capture plant: approx. 25,000 m\(^2\)
Capture Ready Requirements for Combined Cycle Power Plant: technical aspects to be considered

Stack:
Consider later flue gas connection to capture unit and flue gas flow switch devices

Gas turbine plant:
1. Air intake
2. Compressor
3. Gas turbine
4. Heat recovery steam generator
5. Generator
6. Transformer

Steam turbine plant:
7. Steam turbine
8. Condenser
9. Feeding pump
10. Generator
11. Transformer
12. Circulating pump

Turbine building:
Sufficient space for modification of turbines, retrofit of steam extraction and condensate return lines

Steam turbines / Reheating:
Adaptability for steam extraction; options for modification of turbines depend on required operating modes.

Turbine building:
Sufficient space for modification of turbines, retrofit of steam extraction and condensate return lines

Auxiliary electric supply:
Sufficient space for additional auxiliary transformer(s), switchgear and cable routes

Cooling system:
Sufficient space for additional circulation pumps and service water system, sufficient space for extension of cooling capacity

Cooling tower

Water supply / Waste water treatment:
Sufficient space for corresponding retrofit measures; Provision of additional water utilization rights

Capture Ready Requirements for Combined Cycle Power Plant: technical aspects to be considered

Stack:
Consider later flue gas connection to capture unit and flue gas flow switch devices

Gas turbine plant:
1. Air intake
2. Compressor
3. Gas turbine
4. Heat recovery steam generator
5. Generator
6. Transformer

Steam turbine plant:
7. Steam turbine
8. Condenser
9. Feeding pump
10. Generator
11. Transformer
12. Circulating pump

Turbine building:
Sufficient space for modification of turbines, retrofit of steam extraction and condensate return lines

Steam turbines / Reheating:
Adaptability for steam extraction; options for modification of turbines depend on required operating modes.

Auxiliary electric supply:
Sufficient space for additional auxiliary transformer(s), switchgear and cable routes

Cooling system:
Sufficient space for additional circulation pumps and service water system, sufficient space for extension of cooling capacity

Cooling tower

Water supply / Waste water treatment:
Sufficient space for corresponding retrofit measures; Provision of additional water utilization rights

Elaboration of capture ready measures requires insight into an appropriate capture process
Siemens supplies License Package for Core CO₂ Capture Island and reclaimer package unit → Implementation by EPC Partner!
Siemens Power Plant and CCUS Solutions – Partner from process development to project implementation

Siemens Experience

- Good environmental performance
- Process is “easy-to-handle”
- Intelligent two-step reclamer, sellable sulfur product
- Low operating costs (OPEX)
- Optimized power plant integration
- Optimized electricity generation costs
- Optimized cost of CO\textsubscript{2} captured

Process Development + License Package

- Process and Model Development
- Piloting & Optimization
- FEED / Basic Eng.
- Licensing

Project Implementation with EPC - partner

- Detail Eng.
- Construction & Installation
- Comissioning
- Plant support

E P MO CCS © Siemens AG 2014 All rights reserved.
Summary

Fossil fuels will maintain a big share in global electricity production, CCS is urgently needed.

Enhanced Oil Recovery is providing additional revenue streams (CCUS).

Siemens PostCap™ based on amino acid salt is very efficient and has good environmental rating.

Siemens post-combustion CO₂-capture technology successfully verified in pilot plant.

Large-scale applicability of PostCap™ demonstrated in several engineering projects globally.

Siemens offers License Package for PostCap™ incl. delivery of reclaimers package unit for large-scale scale projects.
“Many thanks for your kind attention”

Contacts

Marketing, Sales and Communication for CCS:
Gernot Schneider, +49 9131-18 82281, gernot.schneider@siemens.com

Sales Manager for CCS:
Oliver Reimuth, +49 9131-18 5923, oliver.reimuth@siemens.com
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.