Pilot scale demonstration plants of an advanced aqueous amine-based PCC utilizing BASF’s OASE® blue technology

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10th CO₂ GEONET Open Forum
BASF / Linde partnership
Delivers total solutions with confidence

BASF Solvent/Process Expertise
Basic Design Package
Process performance
Emissions performance

Linde Engineering Expertise
Process optimization
Basic/Detailed Engineering
Package/EPC wrap

Founded | 1865
Sales (2014) | €74.3 billion
Employees | 113,292

Founded | 1879
Sales (2014) | €17 billion
Employees | 65,591

13 May 2015 Venice/Italy - 10th CO2 GEONET OPEN FORUM - European-North American Workshop
Technology Development Path with BASF
From Lab to Commercial Scale

**Laboratory**

**Mini Plant**
- 0.015 MW\textsubscript{el}
- 0.01 mt CO\textsubscript{2} / hr

**Solvent screening**
- screening methods

**Proof of concept** under „synthetic“ conditions
- comparision of solvents
- validate simulation models

**Pilot Plant (Niederaussem)**
- 0.45 MW\textsubscript{el}
- 0.3 mt CO\textsubscript{2} / hr

**Litmus test** for new process under real conditions at RWE’s lignite fired power plant

**Pilot Plant (Wilsonville)**
- 1 - 1.5 MW\textsubscript{el}
- 0.8 - 1.2 mt CO\textsubscript{2} / hr

**Advanced design and new materials** aimed at emissions reduction and capex reduction in the large scale

**Demo Plant**
- 25 - 250 MW\textsubscript{el}
- 20 – 200 mt CO\textsubscript{2} / hr

**Test of complete CCS-chain**
- capture, compression, transport, storage/EOR

**Commercial Plant**
- 500 – 1,100 MW\textsubscript{el}
- 340 - 750 mt CO\textsubscript{2} / hr

**Safe, reliable, and economical operation**
in compliance with regional and national regulations
Niederaussem PCC Pilot Plant

Fact Sheet

- Flue gas: 1,550 Nm³/h
- CO₂ product: 7.2 t CO₂/day; capture rate 90%
- Absorber / regenerator packing type and height corresponds to full scale
- Instrumentation: 275 measuring points
- MOC tested at several different locations
- Commissioning and start-up 2009, availability of 97%
- Budget of RWE for phases I/II: 15 Mio. €
- 40% funding by German Federal Ministry of Economics and Technology (0327793 A-I)
Niederaussem PCC Pilot Plant
Flow Sheet

Flue gas cooling, SO₂-prescrubbing

CO₂-capture

Solvent regeneration

Flue gas cooling, SO₂-prescrubbing

Booster fan

Prescrubber

Flue gas (downstream of FGD)

Acid

NaOH solution tank

Drain

NaOH (optional)

Absorber

Condenser

Desorber

Filter

Reboiler

Steam generator

Make-up water

Condenser

Desorber

Dehydration

Make-up water

Solvent tank

Solvent

Drain

CO₂

CO₂ capture

Make-up water

Solvent regeneration

Acid

Booster fan

Prescrubber

Flue gas (downstream of FGD)

NaOH solution tank

Drain

NaOH (optional)

Absorber

Condenser

Desorber

Filter

Reboiler

Steam generator

Make-up water

Solvent tank

Solvent

Drain

CO₂
**Solvent testing**
- MEA & Process
- GUSTAV200
- LUDWIG540

⇒ Selection optimal solvent: **OASE® blue**

**Long-term testing, optimisation**
- Modification of plant components
- Intermediate testing
- Long-term testing (FGD)
- Long-term testing (FGDplus)

**Optimisation, Long-term testing**
- Overall optimum emission mitigation
- Increase of $O_2$-content flue gas
- Variation OASE® blue

⇒ Optimum OASE® blue
- Long-term testing (FGD/FGDplus)
Niederaussem PCC Pilot Plant
Operational experiences and main results

- OASE® blue was tested over 26,000 hours (> 3 years)
- nearly 21,000 t CO2 were captured with OASE® blue

Even after six months of operation, the oxidation rate of OASE® blue was extremely low.

- OASE® blue has a 20% lower specific energy consumption
- OASE® blue has a significant lower solvent circulation rate

A1, A3 – A6: Flanges, tubes, gaskets
A2: Concrete module
B1 – B8: Coupons

Pre-scrubber
Absorber
Desorber
Caustic soda
Drain
Make-up water
Flue gas
CO\textsubscript{2}-lean flue gas
CO\textsubscript{2} from regeneration
Drain
Solvent
Flue gas
Niederaussem PCC Pilot Plant
Emission reduction measures

Variation of Process Configurations:
- FGDplus/pre-scrubbing (w/wo addition of NaOH)
- Number of water wash steps (1 or 2)
- Water wash with double height
- Combination water wash and dry bed
- Combination acid wash and dry bed
- Combination with wet electric precipitator

Variation of Parameters:
- Water wash temperature (40° - 60°C)
- Intercooler temperature
- pH-value acid wash
- Voltage of wet electric precipitator
Niederaussem PCC Pilot Plant
Emission reduction measures – "Dry bed"

Amine traces downstream water wash

Reduction of amine emissions by an order of magnitude:
→ Proprietary process configuration „Dry Bed“
Wilsonville PCC Demonstration Plant
Fact Sheet

Project essentials

- DOE-NETL funded project ($16.2 million funding)
- Total project cost $22.7 million
- Location: 880 MWe Gaston Power plant (operated by Southern Co.) in Wilsonville, AL
- Site of the National Carbon Capture Center
- Capacity: Up to 6,250 Nm³/h flue gas from coal fired power plant (30 t/d CO₂)
- CO₂ purity 99+ vol % (Dry basis)
- Project start: November 2011
- Start-up: January 2015
- Project Duration: 4.5 years
- Partners: Linde LLC, Linde Engineering North America, Linde Engineering Dresden, BASF, DOE-NETL, EPRI, Southern Company (Host site)
Wilsonville PCC Demonstration Plant
Flow sheet - Novel features tested

Advanced emission control system

High capacity structured packing

Optimized Energy Consumption

Gravity Flow Interstage Cooler

Optimized Blower Concept

Higher Desorber pressure

Unique reboiler design

DOE-NETL funding: DE-FE0007453
Wilsonville PCC Demonstration Plant
Construction
Wilsonville PCC Demonstration Plant
Test operation

- CO2 in Flue Gas: 570 tons
- CO2 captured: 501 tons (average of 88% capture rate)

Cumulative CO2 Flow [metric tons]

Date

Wilsonville PCC Demonstration Plant
First results for specific energy consumption

[Graph showing specific energy consumption vs. Circulation Rate with different data points and 90% CO2 Recovery Target]
Linde-BASF PCC technology for large scale
Commercially available

Risk assessment for full scale plant

Solvent
- performance (specific energy consumption, recovery rate, loading, circulation rate) ✓
- impact from real flue gas (foaming, impurities) ✓
- degradation, O₂ stability, emissions → solvent losses ✓
- long term behavior ✓

Equipment
- packings (height, pressure drop) ✓
- wash section (design, performance optimization) ✓
- heat exchanger performance (fouling) ✓
- materials of construction (equipment, piping, seals, gaskets) ✓

Process
- verification of process simulation tools (BASF) ✓
- optimization of process parameters ✓
- verification of online analytics ✓

Risk analysis for a PCC for 1,100 MWₑₑ power plant
Uncertainty detected regarding cost, performance, scale-up
- solvent performance
- absorption column with 18 m diameter
- material of construction

Results from Pilot Plant Niederaussem (& Wilsonville)
Linde-BASF PCC technology for large scale
Commercialization approach

Solvent performance
Equipment design
Process Design
Emissions control
Scale-up
EPC of large scale

- OASE® Blue Technology is ready for commercialization
- continued development for cost reduction required
Summary and conclusions

− Linde and BASF are partnering in the development of an advanced PCC technology incorporating BASF’s novel amine-based process along with Linde's process and engineering innovations

− Performance demonstrated and long term stability validated on a 0.5 MWe lignite fired power plant flue gases (Niederaussem, Germany)

− The next testing campaign will include parametric testing of two new solvents from BASF, followed by a long term test for the most promising solvent

− Nominal 1 MWe pilot plant at the NCCC in Wilsonville, AL commissioned; initial operations & testing have demonstrated stable operation, validation of functional features and initial achievement of several key targets

− The next testing campaign in Wilsonville will include parametric tests aimed at energy optimization, emissions minimization and validation of higher pressure regenerator operation. This will be followed long duration testing (4-6 months) to demonstrate solvent stability.

− Technology is ready for commercialization with continuing efforts on further development to reduce cost of capture.
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Thanks for your attention.
Commercial references
CO₂ capture, compression and purification

CO₂ Capture and injection

- LNG plant Snohwit/Norway with CO₂ capture from natural gas and CO₂ injection offshore

CO₂ Wash Units

- Experience in design and erection of different wash processes for CO₂ removal
  - Linde-Rectisol ®
  - BASF OASE® technology
  - Benfield

CO₂ Food Grade Plants

- Removal of impurities like Hydrocarbons, Heavy metals, O₂, H₂O for food grade CO₂
  - CO₂ plant Leuna
  - CO₂ Plant Rotterdam
  - CO₂ Plant Repcelak
  - CO₂ Plant Al-Jubail

CO₂ Transport and distribution

- Long experience in operation (Linde Gas) of CO₂ plants, CO₂ transport and distribution
  - OCAP pipeline
  - On-site business
**CO₂ Purification and Liquefaction Plant**
Al Jubail/Saudi Arabia

**Process**
Compression and water separation, moisture removal by adsorption, inerts removal, liquefaction and re-evaporation

**Capacity**
- 1,150 t/d CO₂ gaseous and
- 200 t/d CO₂ liquid

**Purity**
- 99.99 vol. % CO₂, food grade

**Scope of work**
- Turnkey plant

**Start-up**
- 2015