



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

Torsten Stoffregen,
Linde Engineering Dresden
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10th CO₂ GEONET Open Forum

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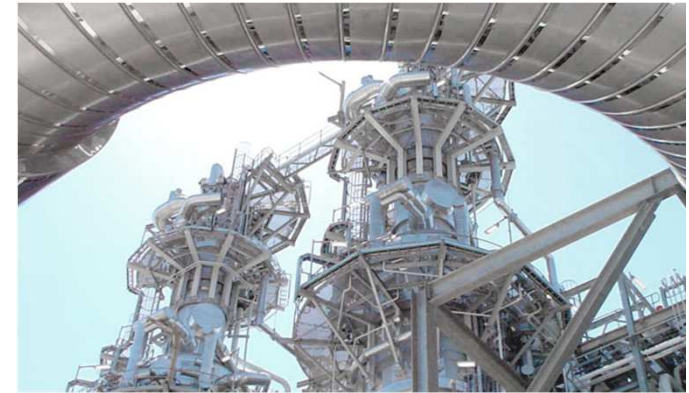
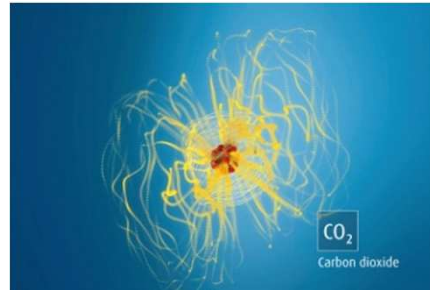
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BASF / Linde partnership

Delivers total solutions with confidence



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



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

PCC capture



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

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

Technology Development Path with BASF

From Lab to Commercial Scale



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Development Path

Laboratory



Solvent screening

- screening methods

Mini Plant

0.015 MW_{el}
0.01 mt CO₂ / hr



Proof of concept under „synthetic“ conditions

- comparison of solvents
- validate simulation models

Pilot Plant (Niederaussem)

0.45 MW_{el}
0.3 mt CO₂ / hr



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

Pilot Plant (Wilsonville)

1 - 1.5 MW_{el}
0.8 - 1.2 mt CO₂ / hr



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

Demo Plant

25 - 250 MW_{el}
20 - 200 mt CO₂ / hr



Test of complete CCS-chain

capture, compression, transport, storage/EOR

Commercial Plant

500 - 1,100 MW_{el}
340 - 750 mt CO₂ / hr



Safe, reliable, and economical operation

in compliance with regional and national regulations

Niederaussem PCC Pilot Plant

Fact Sheet



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- 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



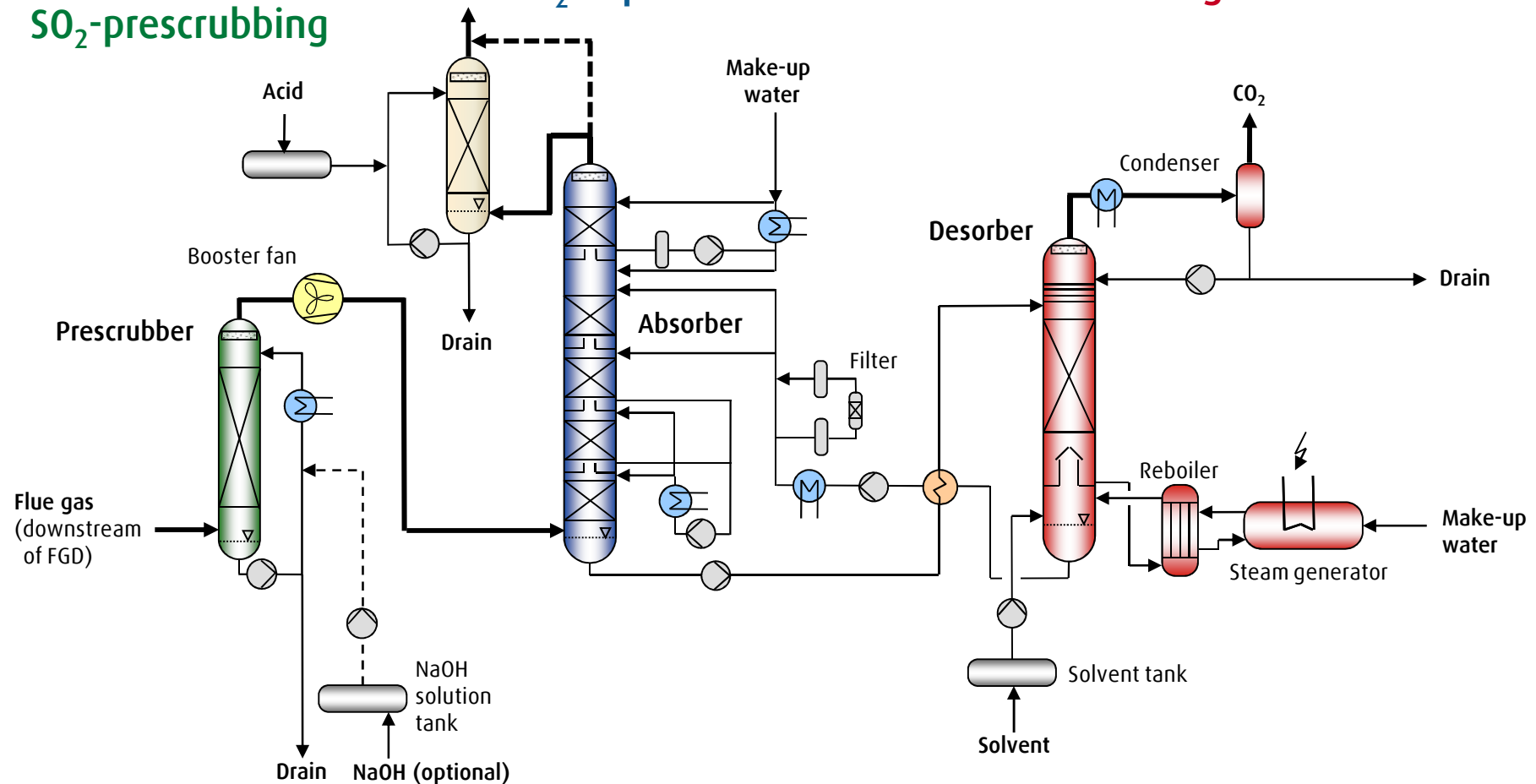
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Flue gas cooling,
 SO_2 -prescrubbing

CO_2 -capture

Solvent regeneration



Niederaussem PCC Pilot Plant Test Campaigns



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Solvent testing

- MEA & Process
- GUSTAV200
- LUDWIG540

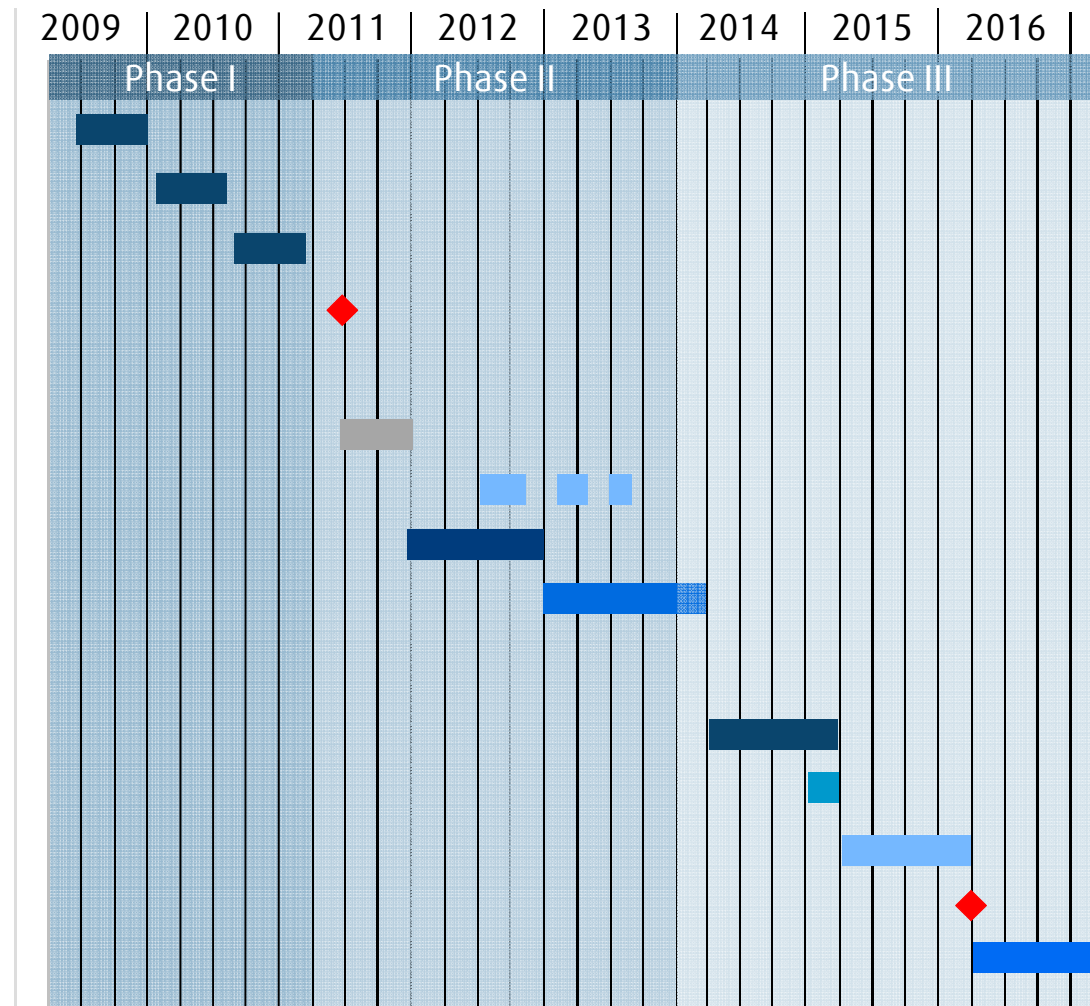
⇒ Selection optimal solvent: OASE[®] blue

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 O₂-content flue gas
- Variation OASE[®] blue
- ⇒ Optimum OASE[®] blue
- Long-term testing (FGD/FGDplus)



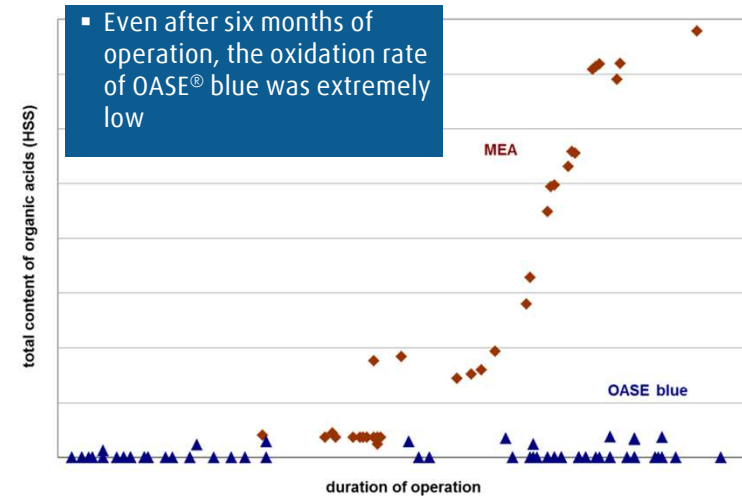
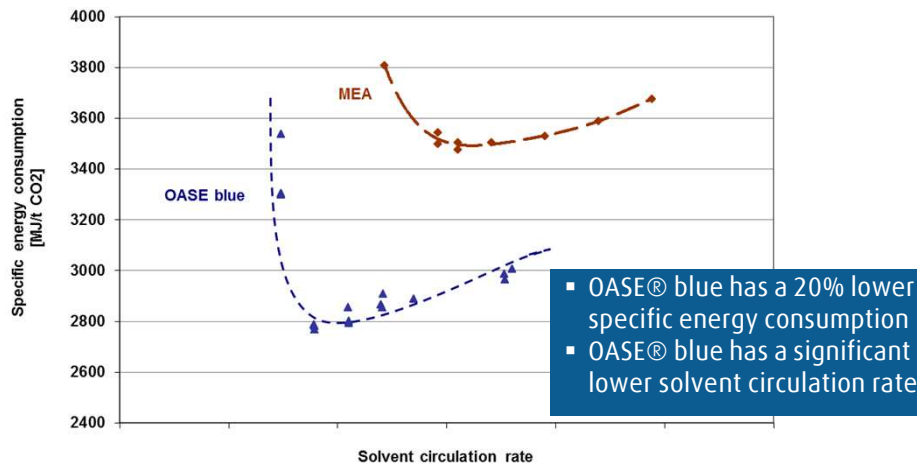
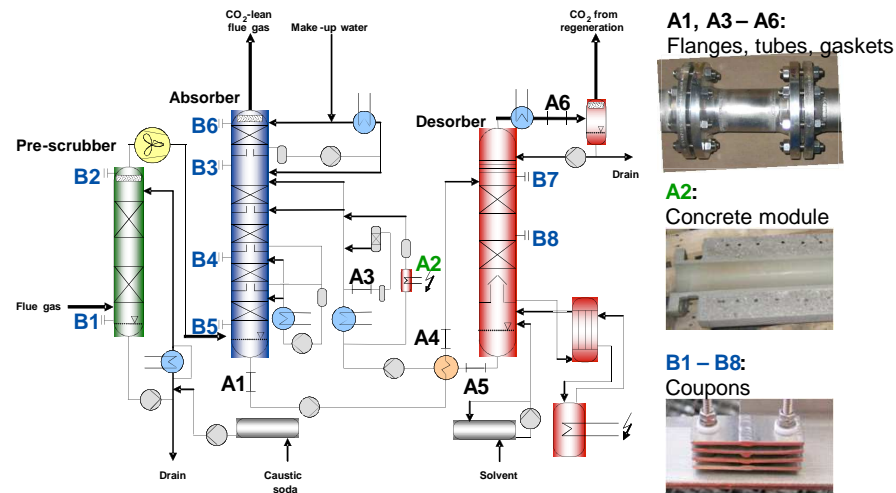
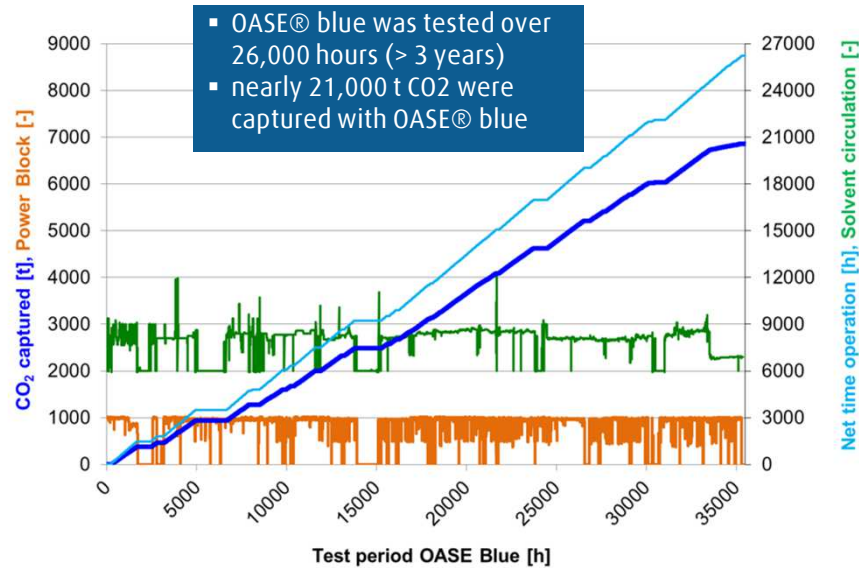
Niederaussem PCC Pilot Plant

Operational experiences and main results

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Niederaussem PCC Pilot Plant

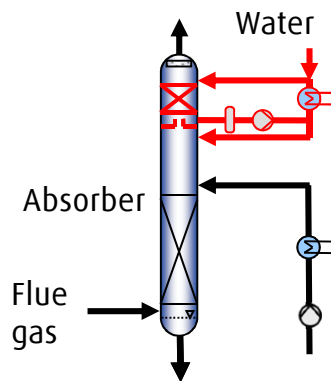
Emission reduction measures



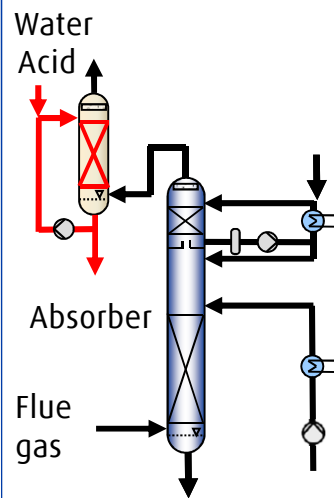
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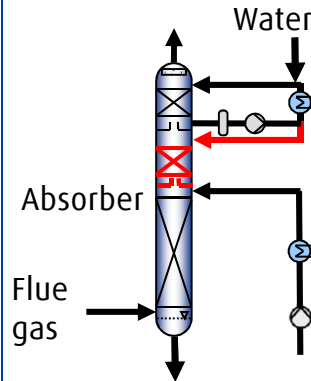
Water Wash



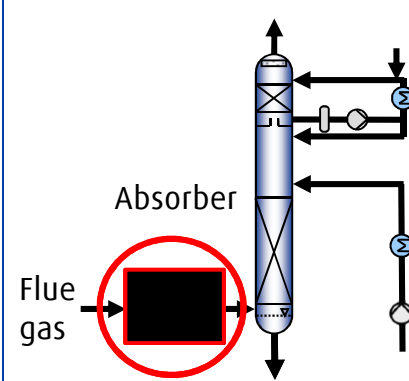
Acid Wash



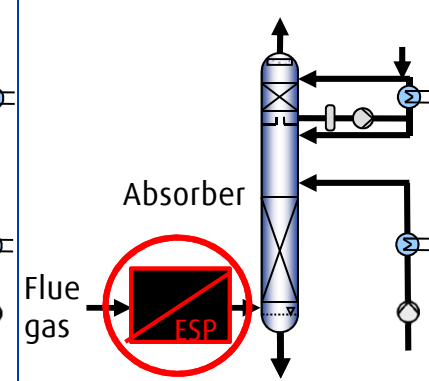
Dry Bed



Flue Gas Pre-Treatment



Wet ESP



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

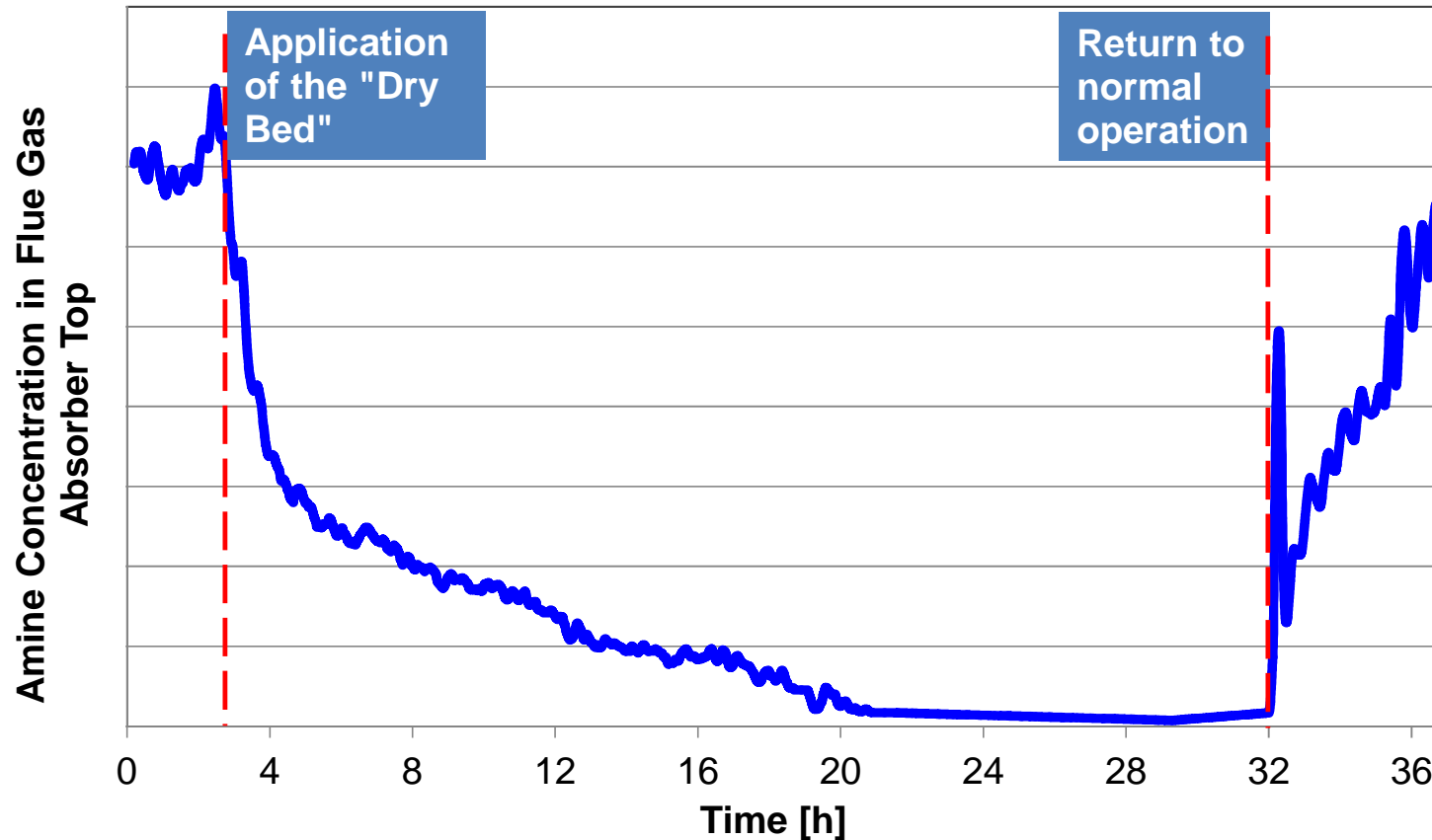
Emission reduction measures – "Dry bed"



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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



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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)



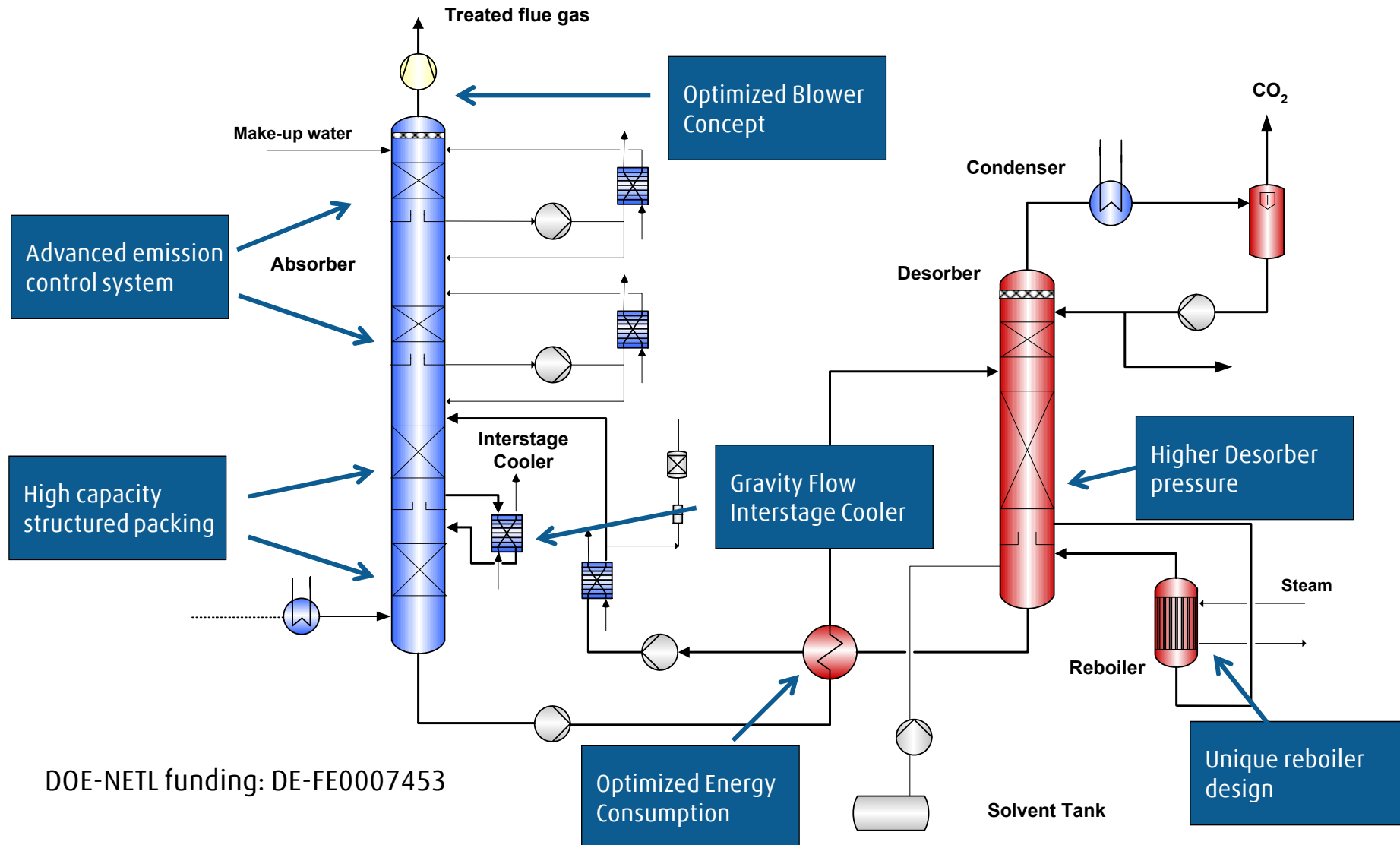
Wilsonville PCC Demonstration Plant

Flow sheet - Novel features tested

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DOE-NETL funding: DE-FE0007453

Wilsonville PCC Demonstration Plant Construction



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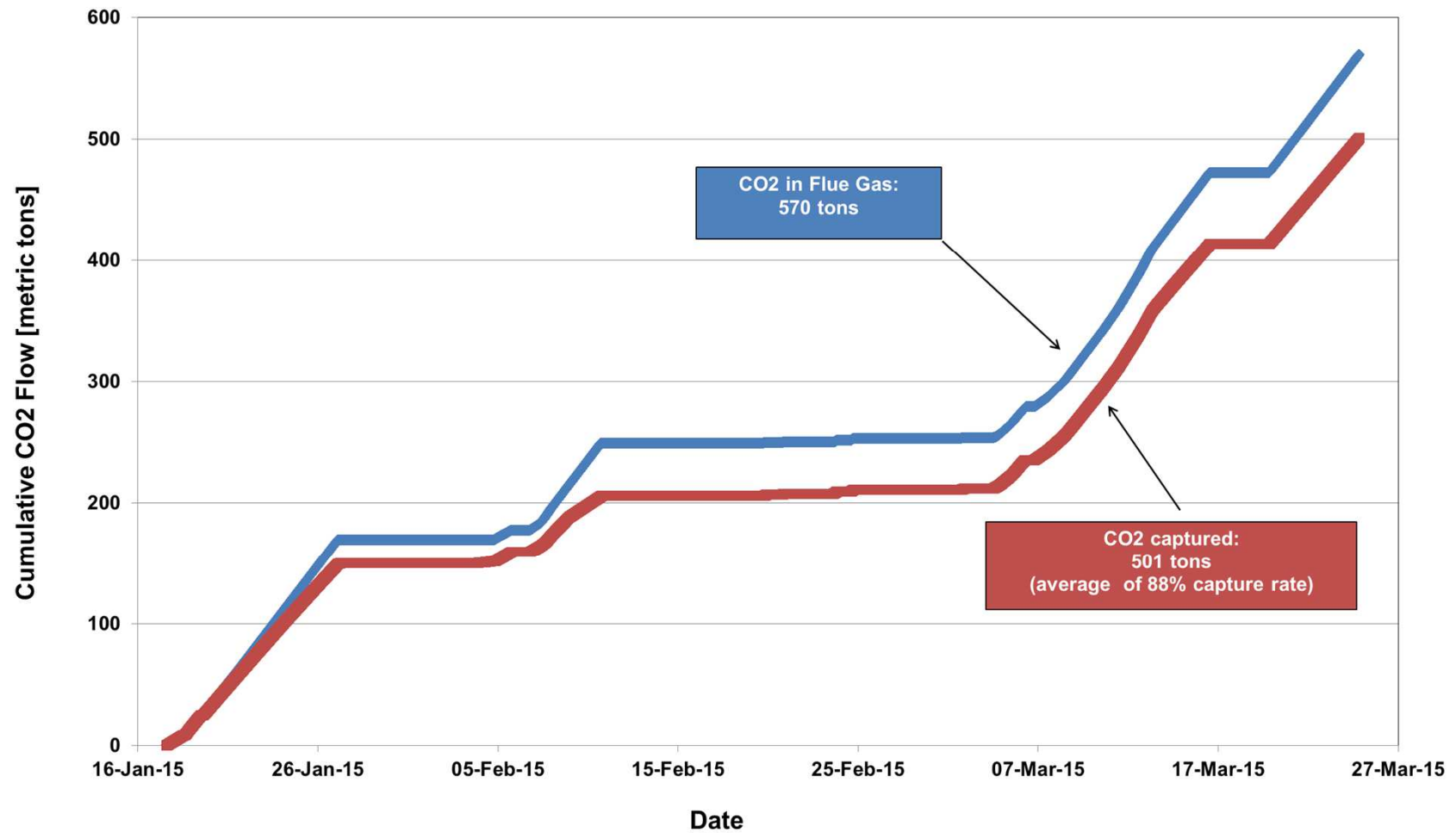


Wilsonville PCC Demonstration Plant

Test operation



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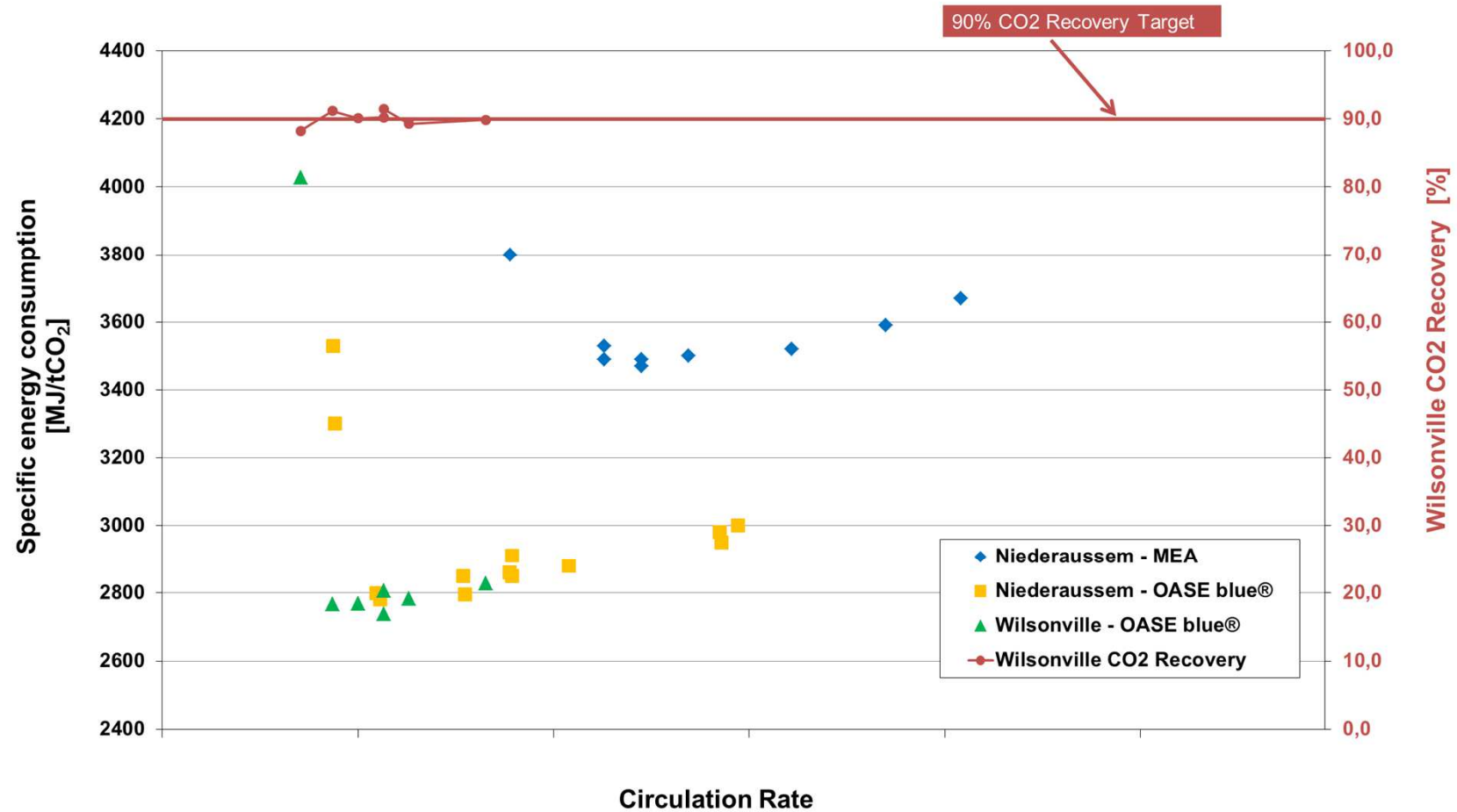


Wilsonville PCC Demonstration Plant

First results for specific energy consumption



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Linde-BASF PCC technology for large scale Commercially available



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Risk assessment for full scale plant

Risikoparameter



Risikofaktor	Kosteneinfluss (Ausrichtungspreis bezogen auf einen Strang)	Einfluss auf Performance (bezogen auf einen Strang)	Stand der Technik (Bedeutung gibt für Wertverlust bzw. spezifisch kein Partner)	Scale-Up Risiko	eigenes Wissen zum Stand der Technik und der Ausrichtung
1	< 100.000 €	kein Einfluss (z.B. Abstand, Anlagengröße, Ausrichtungen im System, Anlage kann trotzdem mit 100% für eine gewisse Zeit weiter betrieben werden)	in zahlreichen Anwendungen eingesetzt (> 50)	keine Unsicherheit durch Scale-Up; Parameter ist nicht größenabhängig (Anordnung wird in gleicher Größe gebaut, wird auch weiterverarbeitet)	Experimentieren
2	< 500.000 €	geringer Einfluss (z.B. Überdimensionierung auf Prozesssicherheit kann vorliegen, Bausatz kann im laufenden Betrieb repariert werden)	in wenigen kommerziellen Anwendungen eingesetzt	Scale-Up Faktor vom Stand der Technik 1 > 2	umfangreiche Kenntnisse
3	< 1 Mio €	Kapazität der Anlage sinkt bei 50% bei Ausfall einer Komponente; Bausatz (z.B. Rohr) kann nicht im laufenden Betrieb repariert werden, Anlage kann aber schon weiter betrieben werden	in Demonstratorn erprobt oder ähnliche Ausrichtungsgrößen eingesetzt	Scale-Up Faktor vom Stand der Technik 2 > 5	gute Kenntnisse
4	< 5 Mio €	Kapazität der Anlage sinkt bei 50% bei Ausfall einer Komponente; Bausatz (z.B. Rohr) kann nicht im laufenden Betrieb repariert werden, Anlage kann aber schon weiter betrieben werden			
5	> 5 Mio €	plötzlicher Totalausfall der Anlage			
6	> 10 Mio €				



Risk analysis for a PCC for 1,100 MW_{el} 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)

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) ✓

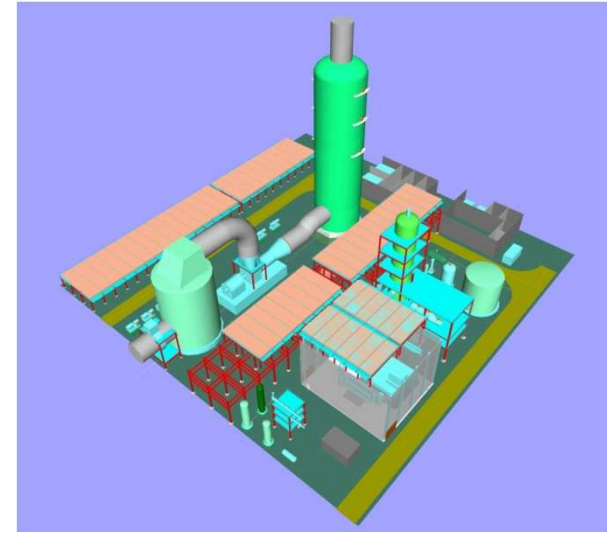
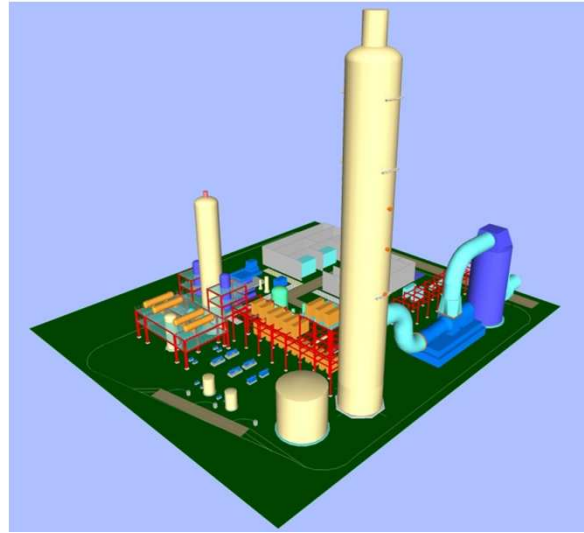
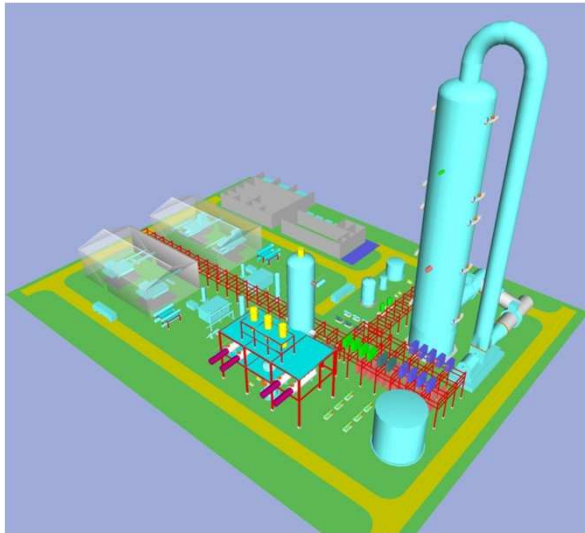
Process

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

Linde-BASF PCC technology for large scale Commercialization approach



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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.

Acknowledgements



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2. Linde: Krish Krishnamurthy, Stevan Jovanovic, Devin Bostick, Annett Kutzschbach and Dieter Mihailowitsch
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4. RWE: Peter Moser, Sandra Schmidt and Georg Wiechers
5. DOE-NETL Project Manager: Andrew Jones
6. SCS/NCCC: Justin Anthony, Frank Morton and Katherine Hofto



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Thanks for your attention.

Commercial references

CO₂ capture, compression and purification

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CO₂ Capture and injection



LNG plant Snohvit/Norway with CO₂ capture from natural gas and CO₂ injection off-shore

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

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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

