



Progress on the developments of an advanced aqueous amine-based post combustion CO₂ capture utilizing BASF's OASE[®] blue technology

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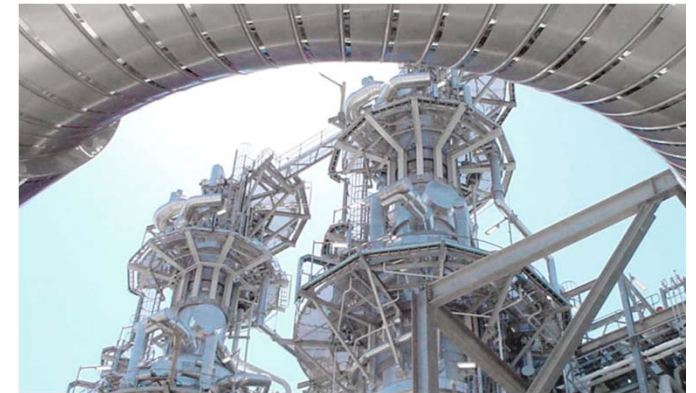
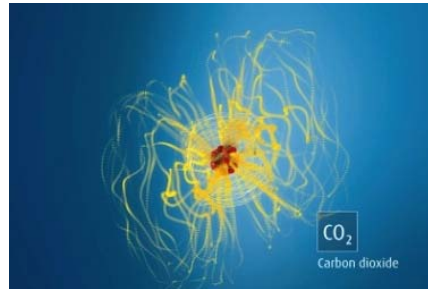


BASF / Linde partnership

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 |

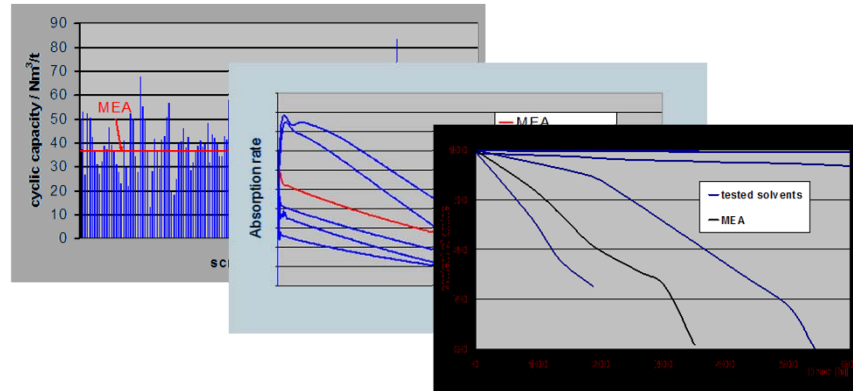
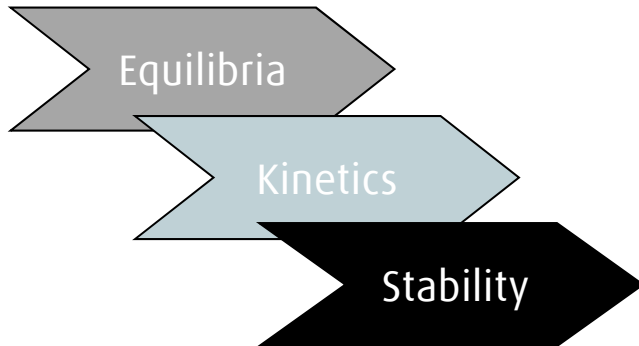
| | |
|---------------------|--------------------|
| Founded | 1879 |
| Sales (2014) | €17 billion |
| Employees | 65,591 |

BASF OASE® blue Technology Development

Adopted and optimized for PCC applications



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Lab scale

- Ludwigshafen, Germany
- Advanced solvent screening, development, optimization

Mini plant

- Ludwigshafen, Germany
- Solvent performance verification



Pilot: 0.45 MWe

- 2009, Niederaussem
- Process opt., materials & emissions testing



Pilot: 1.5 MWe

- 2014, Wilsonville, AL
- Design improvements, emissions confirmation



Niederaussem PCC Pilot Plant: Fact Sheet

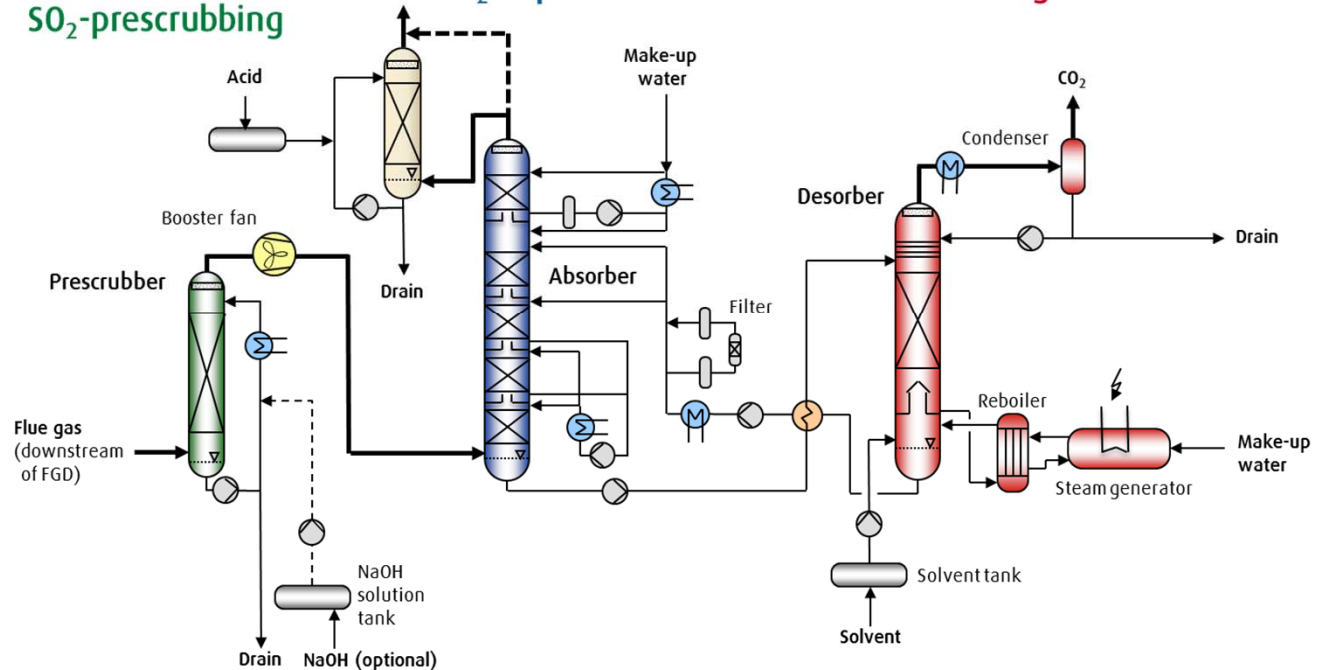


- Flue gas: 1,550 Nm³/h; CO₂ product: 7.2 t CO₂/day; capture rate 90%
- Commissioning and start-up 2009, availability of 97%
- BASF's OASE® blue was tested over 26,000 hours (> 3 years)
- nearly 7,000 t CO₂ were captured with OASE® blue

Flue gas cooling, SO₂-prescrubbing

CO₂-capture

Solvent regeneration



Niederaussem PCC Pilot Plant Test Campaigns



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Solvent testing

- MEA & Process
- GUSTAV200
- LUDWIG540

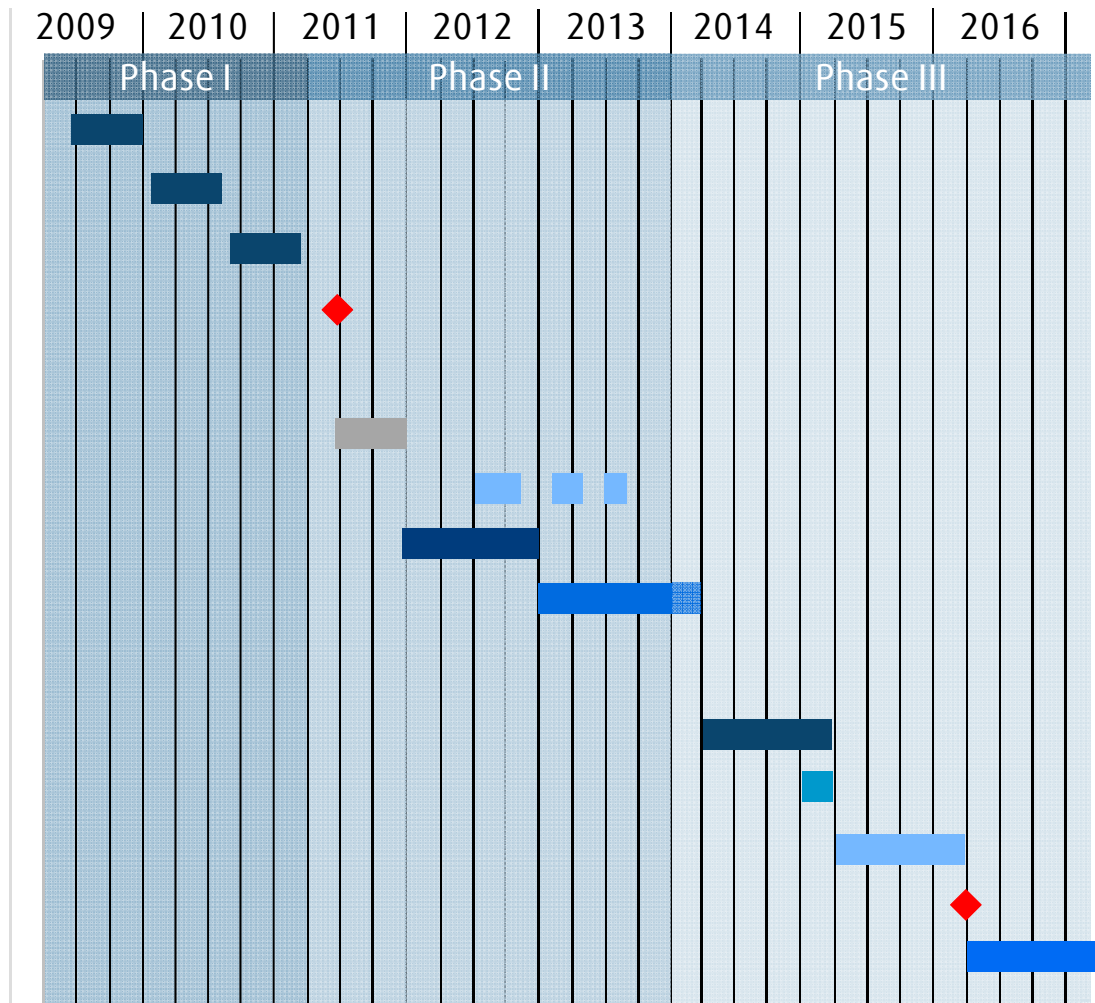
⇒ Selection optimal solvent: OASE® blue

Long-term testing, optimisation

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

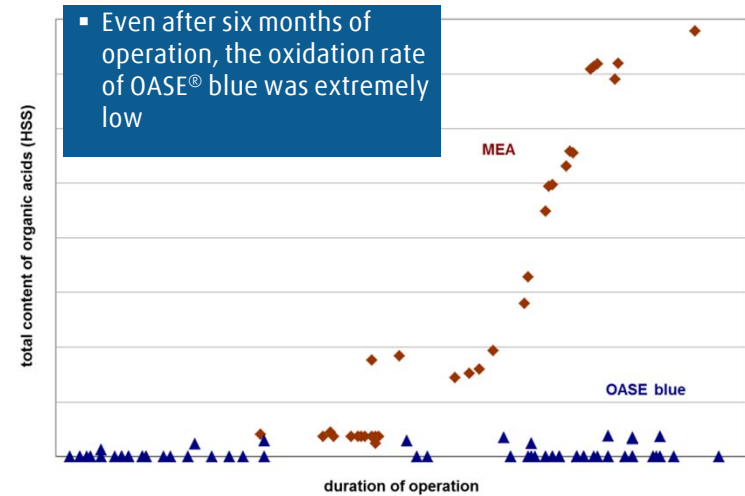
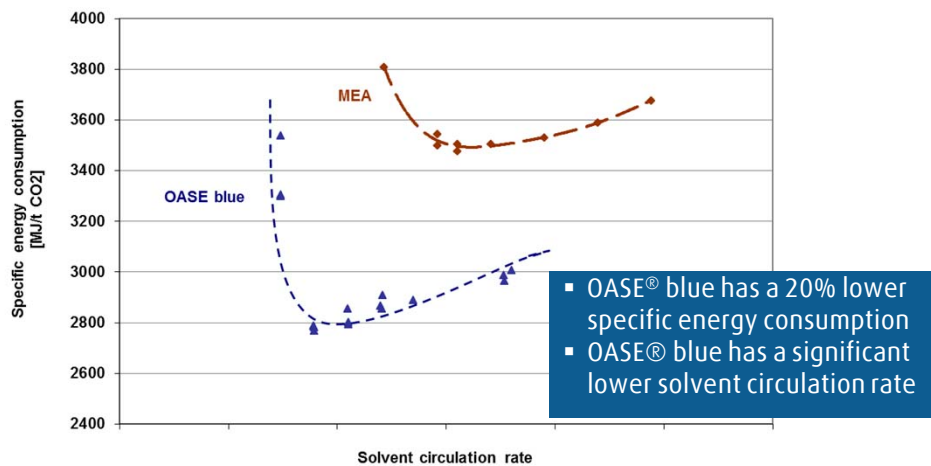
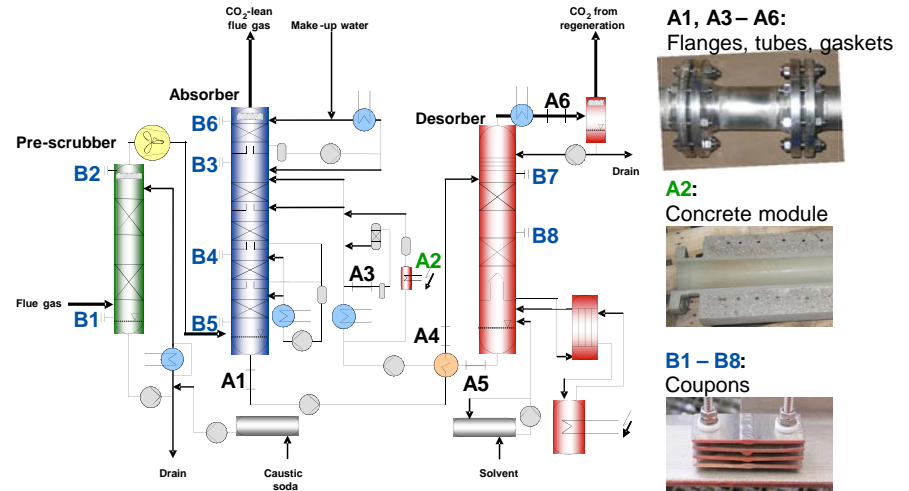
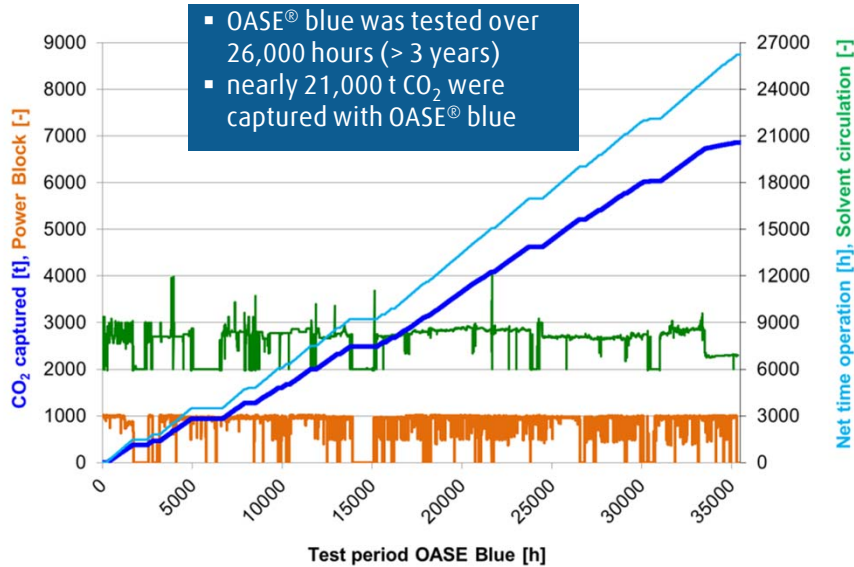
Optimisation, Long-term testing

- 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



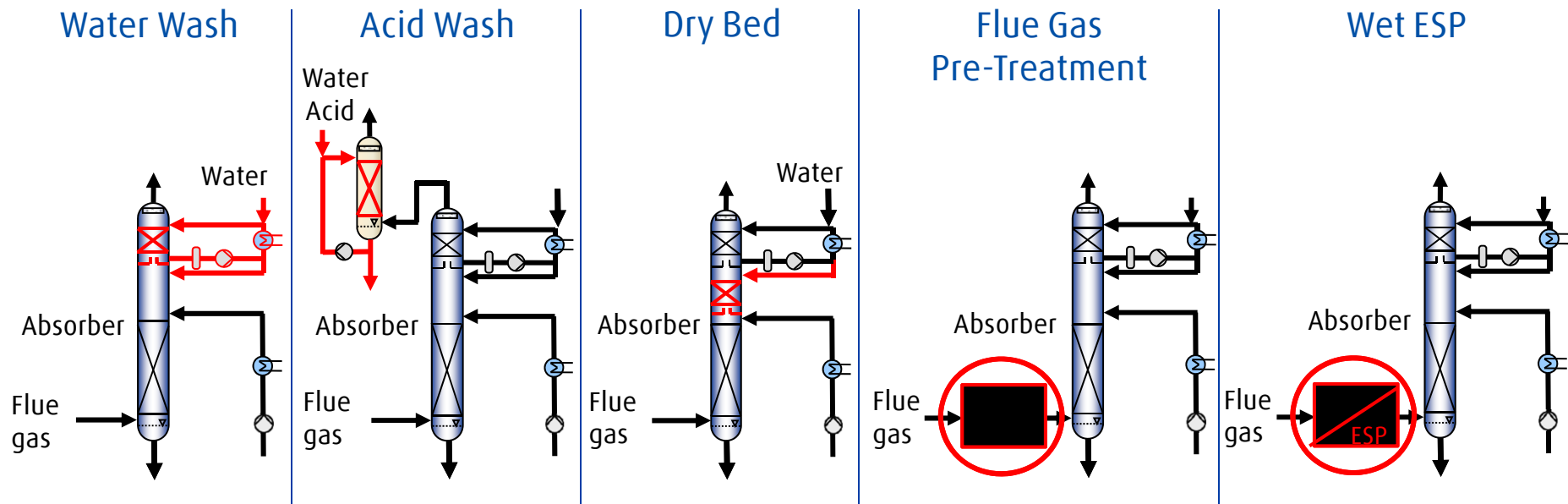
Niederaussem PCC Pilot Plant

Emission reduction measures

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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

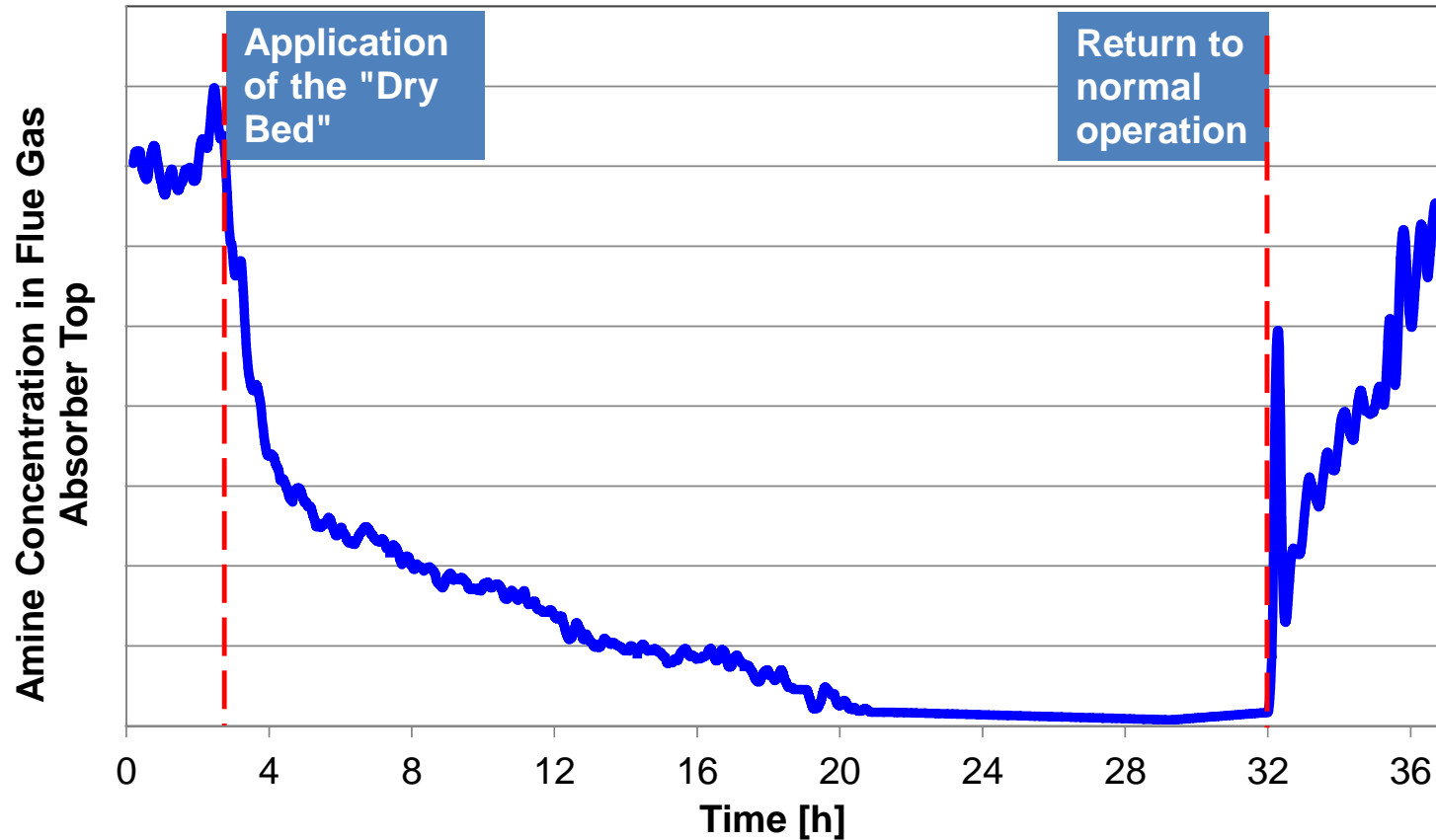
Emission reduction measures – "Dry bed"



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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 Pilot 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); Up to 1.5 MWe
- 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)



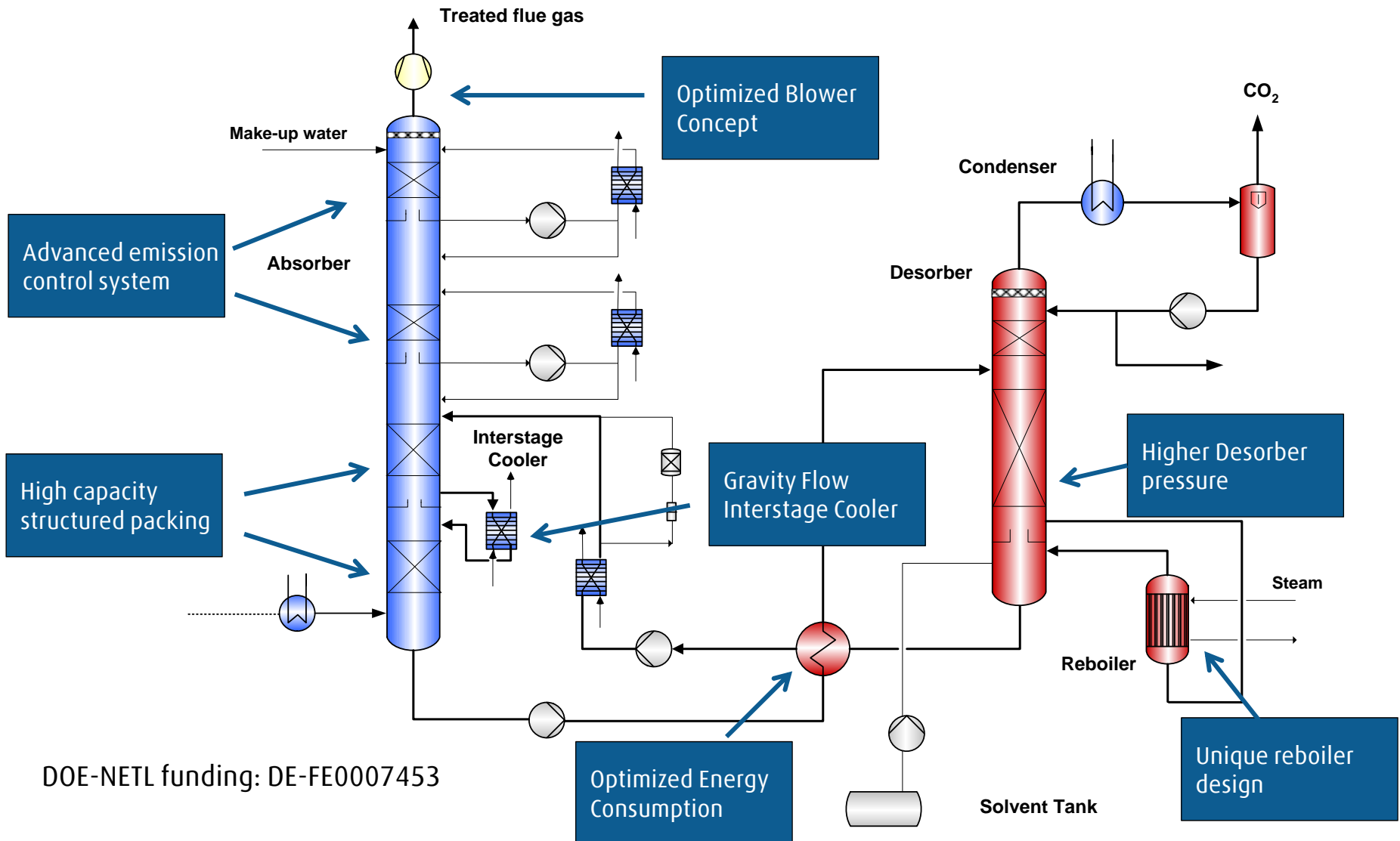
Wilsonville PCC Demonstration Plant

Flow sheet - Novel features tested

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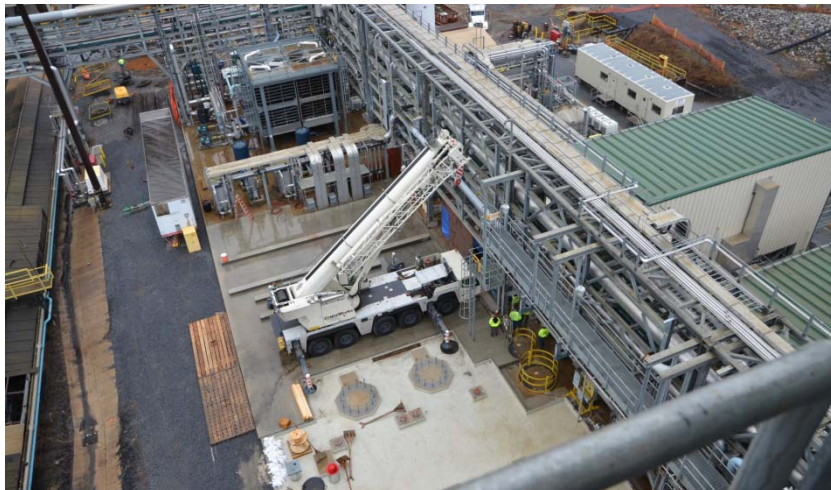


Wilsonville PCC Pilot Plant Construction

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Wilsonville PCC Pilot Plant

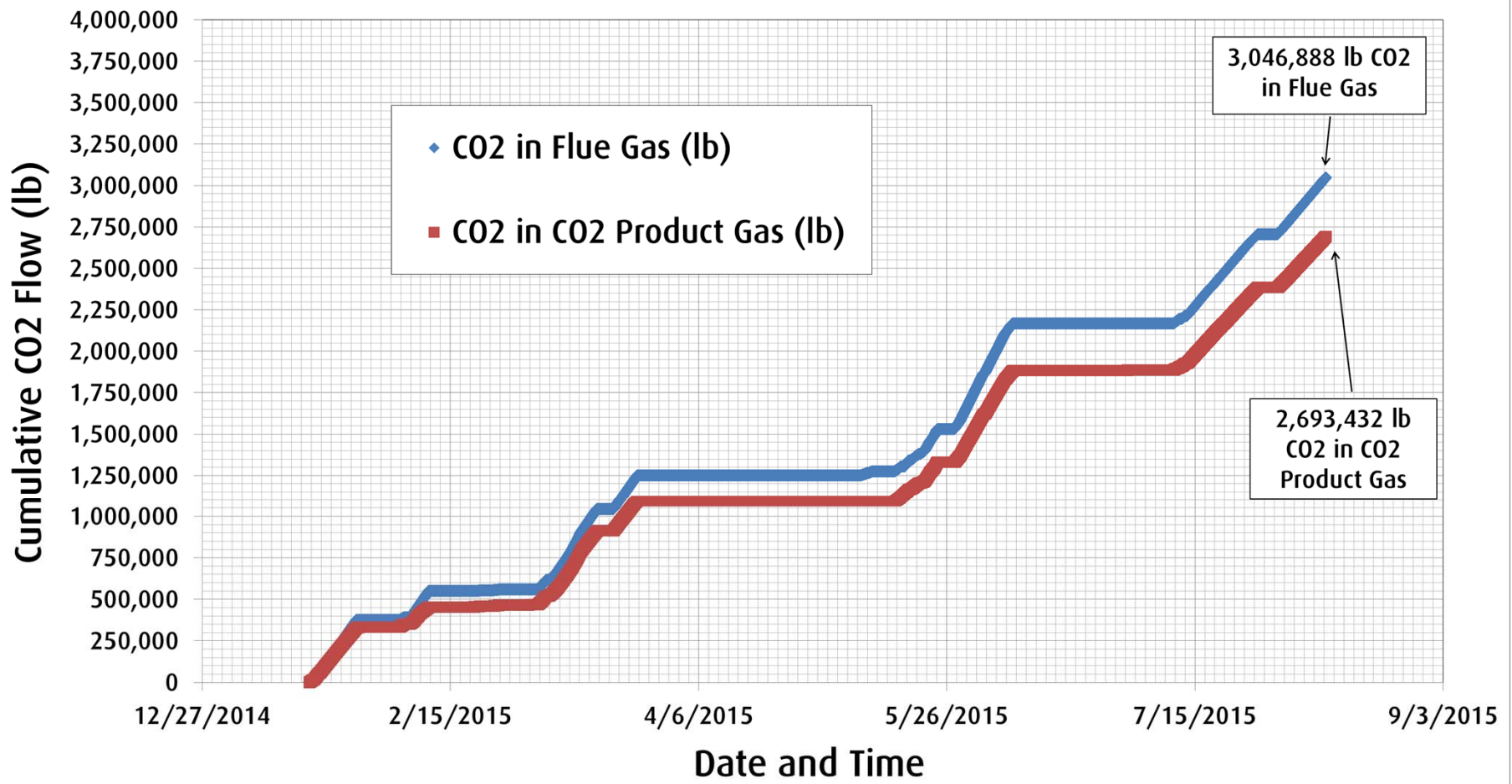
Test operation



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CO2 in Flue Gas and CO2 production - Cumulative Flow (lb)

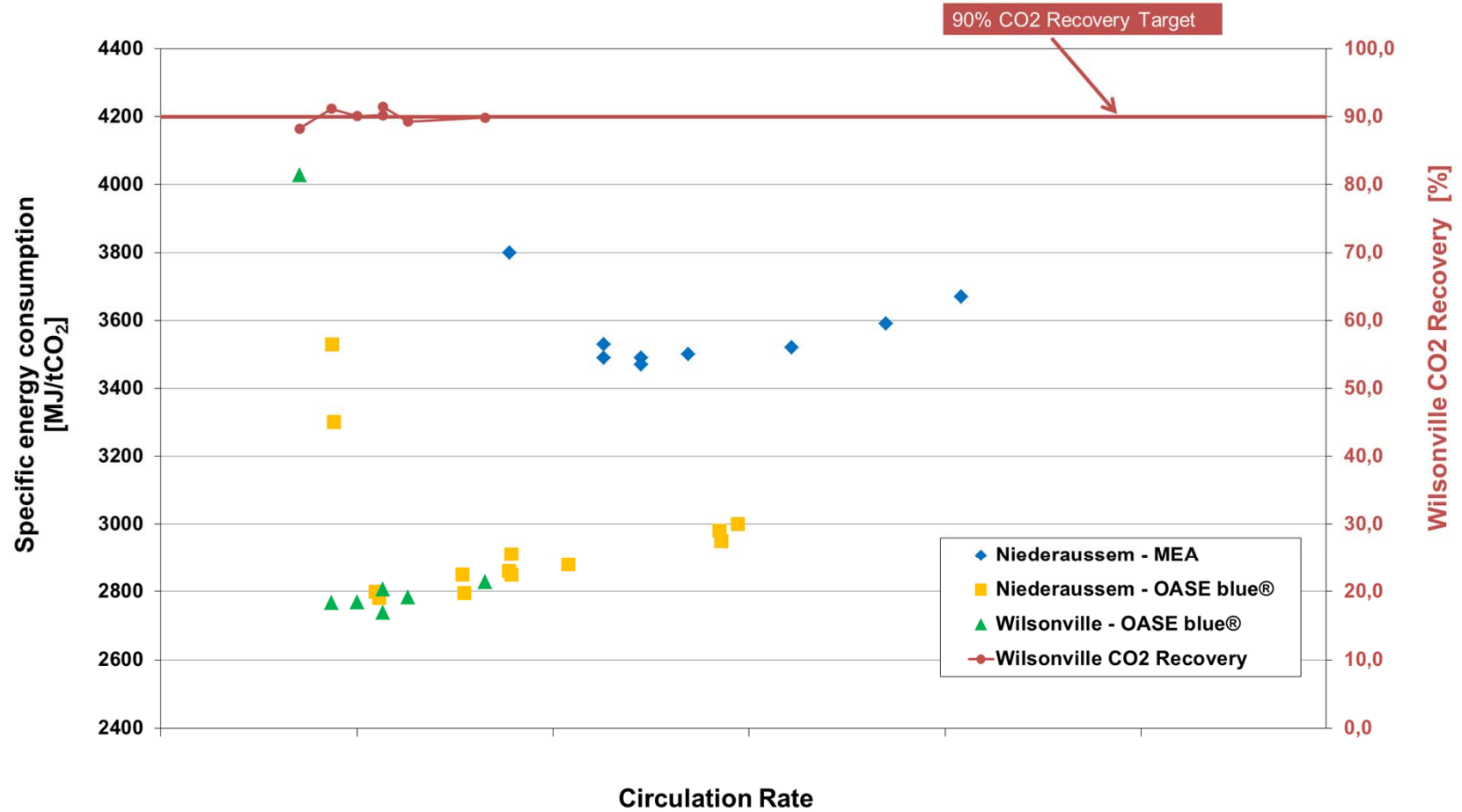


Wilsonville PCC Pilot Plant

Typical result for specific energy consumption



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Wilsonville PCC Pilot Plant

Parametric Testing Performed



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| S.No. | Key variable | Status |
|-------|---------------------------------------|--|
| 1 | Flue gas flow rate | 7,500 to 15,750 lbs/hr |
| 2 | Flue gas temperature to absorber | 86°F to 104°F |
| 3 | Treated gas temperature exit absorber | 86°F to 115°F |
| 4 | Lean solution temperature to absorber | 104°F to 140°F |
| 5 | Inter-stage cooler | On (104°F) /Off |
| 6 | Regeneration pressure | 1.6 to 3.4 bars |
| 7 | Solvent circulation rate | Varied from 80 to 120% |
| 8 | CO ₂ capture rate | 90% typical Varied from 85% to >95% |

Large pilot development at the Abbott Power Plant, University of Illinois, Champaign, IL

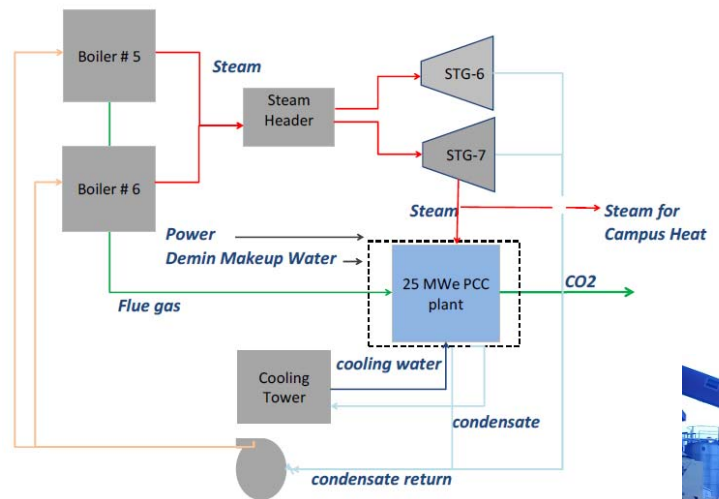
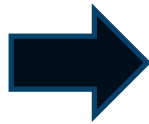


PILOT

- 1.5 MWe coal-fired flue gas (30 TPD CO₂)
- Located at the National Carbon Capture Center, Wilsonville, AL; Host site: Southern Co.'s Alabama Power Gaston plant 880 MWe
- Project period: 2011-2016

- 25 MWe coal-fired flue gas (500 TPD CO₂)
- Located at Abbott Power Plant, Champaign, IL ; Host site: University of Illinois 35 MWe cogen plant
- US DOE funding: \$1 million; Phase 1 Project definition in progress (Q4 2015 - Q3 2016)
- Phase 2 proposal & selection in Q3/Q4 2016

Large Pilot



ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Large pilot development at the Abbott Power Plant, University of Illinois: Deliverables



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Phase 1 (Oct. 1, 2015 – June. 30, 2016)

- Phase 1 Technology engineering and economic analysis report – March 30, 2016
- Phase 1 Technology gap analysis – March 31, 2016
- Phase 1 EH&S study – March 31, 2016
- Phase 1 Topical Report addressing technology, design basis & capabilities, schedule, host site, project participants, updated Phase 2 (detailed design, procurement, construction, operation & decommissioning) costs – March 31, 2016
- Updated project management plan – March 31, 2016
- Phase 2 Environmental Questionnaire – March 31, 2016
- Executed financial and host site agreements – June 30, 2016
- Updated representations and certifications – June 30, 2016

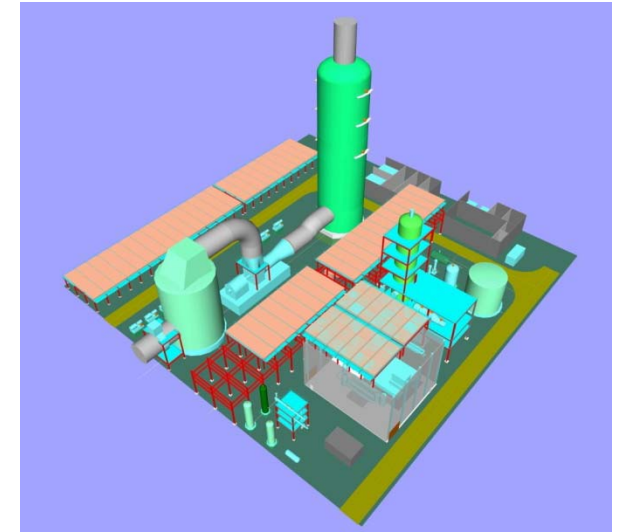
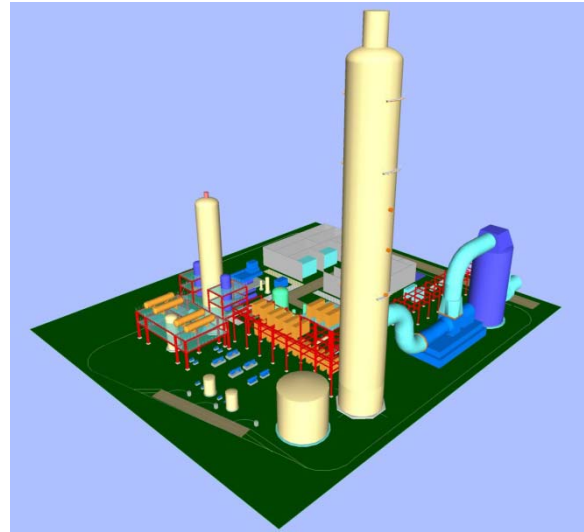
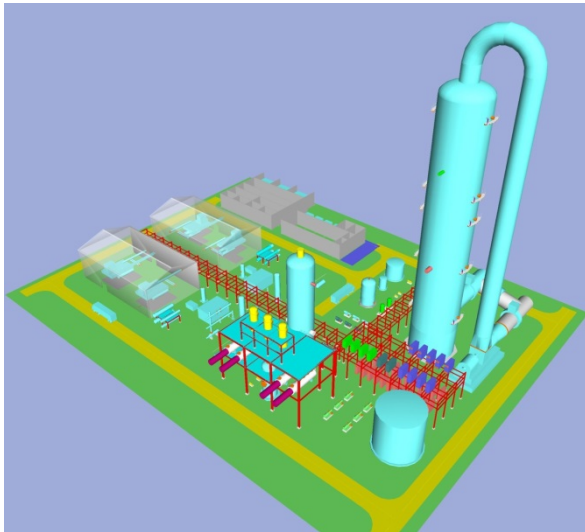
Linde-BASF PCC technology for large scale

Two prong development and commercialization approach

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

- OASE[®] blue Technology is ready for commercialization
- continued development for cost reduction required

Summary and conclusions



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- 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 0.45 MWe lignite fired power plant flue gases (Niederaussem, Germany)
- The current testing campaign includes 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 current testing campaign in Wilsonville is focused on 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.
- Phase 1 design and engineering evaluation for a 25 MWe large pilot implementation at the Abbott Power Plant in University of Illinois, Champaign, IL is in progress.
- Technology is ready for commercialization with continuing efforts on further development to reduce cost of capture.

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Acknowledgements



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3. BASF: Gerald Vorberg and Gustavo Lozano
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Thanks for your attention.