Slipstream pilot plant demonstration of an amine-based post-combustion capture technology for CO_2 capture from coal-fired power plant flue gas

DOE funding award DE-FE0007453

2012 NETL CO_2 Capture Technology Meeting

Krish R. Krishnamurthy, Linde LLC

July 9-12, 2012

Pittsburgh, PA

The Linde Group Overview and Carbon Capture Expertise

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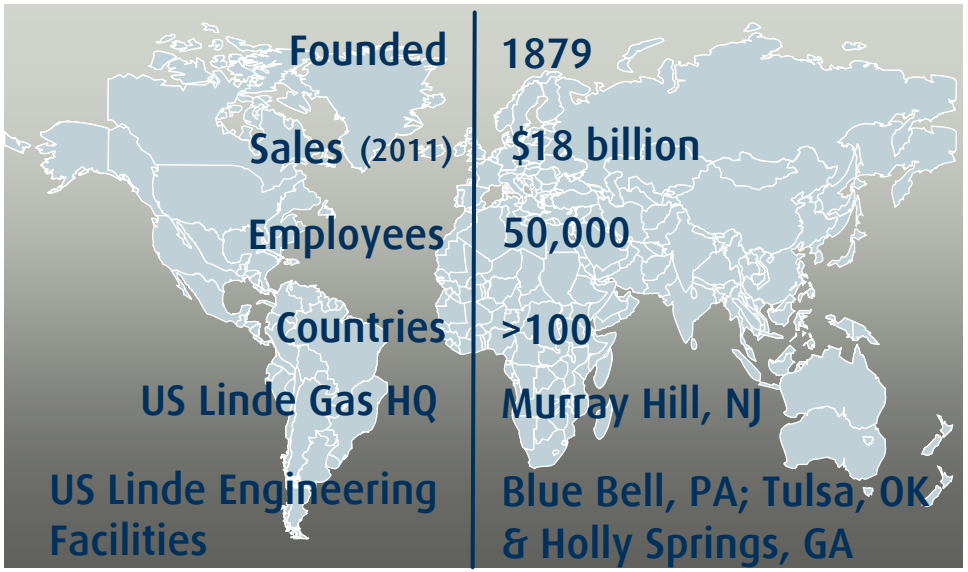
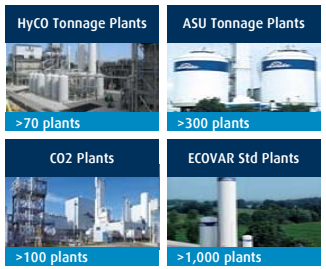


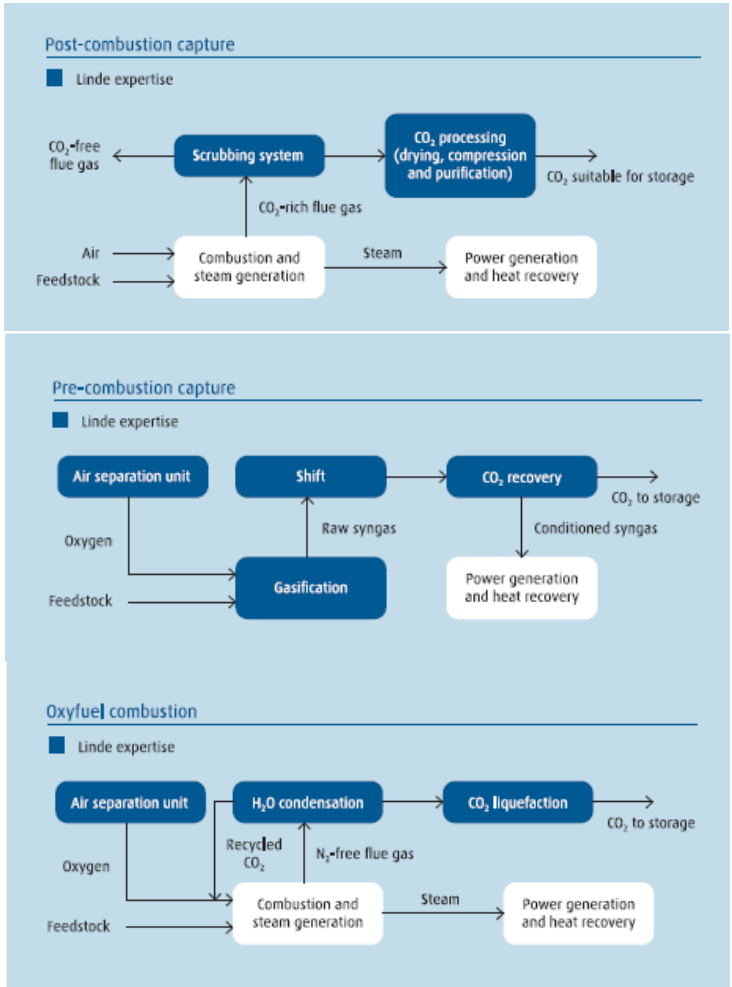
Linde Engineering
Technology-focused

Leveraging Synergies

Linde Gas - Tonnage
World-class operations



Linde pursues technology development and solution offer in all three CC pathways



Project Participants

Partner/ Organization	Lead contact(s)	Key Role(s)
DOE-NETL	Andrew P. Jones, Project Manager	-Funding & Sponsorship
Linde LLC	Krish Krishnamurthy, PI Stevan Jovanovic, Technical Lead	-Prime contract -Overall program management -Operations and testing
BASF	Iven Clausen (BASF SE) Sean Rigby (BASF Corp)	-OASE® blue technology owner -Basic design -Solvent supply and analysis
EPRI	Richard Rhudy	-Techno-economics review -Independent validation of test analysis and results
Southern Co./NCCC	Frank Morton Michael England	-NCCC Host site (Wilsonville, AL) -Infrastructure and utilities for pilot plant build and operations
Linde Engineering, Dresden	Torsten Stoffregen Harald Kober	-Basic engineering -Support for commissioning -Operations and testing
SFPC (Linde Eng)	Lazar Kogan	-Detailed engineering -Procurement and installation

Project Objectives

Overall Objective

— Demonstrate Linde-BASF post combustion capture technology by incorporating BASF's amine-based solvent process in a 1 MWel slipstream pilot plant and achieving at least 90% capture from a coal-derived flue gas while demonstrating significant progress toward achievement of DOE target of less than 35% increase in levelized cost of electricity (LCOE)

Specific Objectives

— Complete a techno-economic assessment of a 550 MWel power plant incorporating the Linde-BASF post-combustion CO_2 capture technology to illustrate the benefits

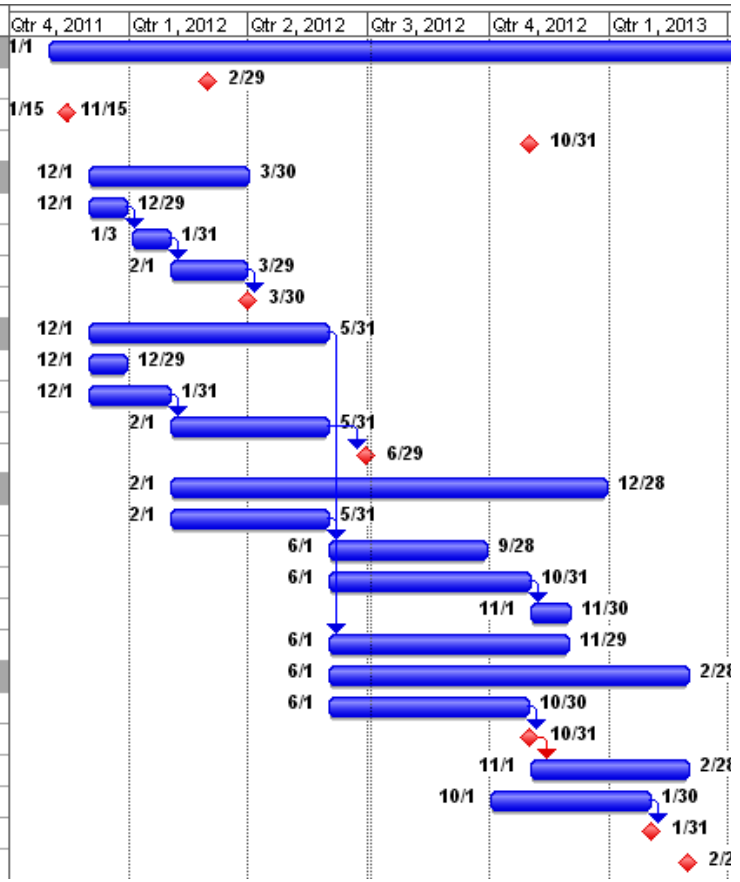
— Design, build and operate the 1MWel pilot plant at a coal-fired power plant host site providing the flue gas as a slipstream

— Implement parametric tests to demonstrate the achievement of target performance using data analysis

— Implement long duration tests to demonstrate solvent stability and obtain critical data for scale-up and commercial application

Project schedule and milestones: Budget Period 1

ID	Task Name
1	**1. Project management and planning**
2	**a. Submit project management plan**
3	**b. Conduct kick-off meeting**
4	**e. Host site agreement executed**
5	**2 Techno-economic evaluation on a 550 Mwel power plant**
6	2.1 Basis and scope for power plant with CO2 capture and compression
7	2.2 Detailed design of the power plant
8	2.3 Economic analysis of the power plant with CO2 capture and compression
9	**c. Complete initial techno-economics analysis on a 550 MWe power plant**
10	**3 Pilot plant design optimization & basic design**
11	3.1 Solvent selection and basic amine process design
12	3.2 Parametric design optimization and confirmation of design basis
13	3.3 Basic design package of the pilot plant
14	**d. Complete basic design and engineering of the 1 MWe pilot plant to be tested at the NCCC**
15	**4. Pilot plant system design and engineering**
16	4.1 Preliminary engineering studies
17	4.2 Process design review and HazOP
18	4.3 Detailed design and engineering
19	4.4 Development of equipment packages
20	4.5 Site design, engineering and foundations specification
21	**5. Pilot plant cost and safety analysis**
22	5.1 Preliminary pilot plant ES&H assessment
23	**f. Complete initial EH&S Assessment**
24	5.2 Transportation and lifting study
25	5.3 Cost estimation and updated pilot plant cost build up
26	**g. Complete pilot plant engineering and cost analysis for the 1 MWe unit to be tested at NCCC**
27	**Go - No Go decision to build pilot plant**



Budget Period 2: March 2013 to February 2014 (Pilot plant procurement, fabrication and installation)

Budget Period 3: March 2014 to November 2015 (Pilot plant operations, parametric and long-duration testing)

Project Budget: DOE funding and cost share

Source	Budget Period 1 Dec 2011 – Feb 2013	Budget Period 2 Mar 2013 – Feb 2014	Budget Period 3 Mar 2014 – Nov 2015	Total
DOE Funding	$2,215,352	$9,822,449	$2,754,564	$14,792,365
Cost Share	$553,838	$2,455,612	$688,641	$3,698,091
Total Project	$2,769,190	$12,278,061	$3,443,205	$18,490,456

Cost share commitments:

Linde: $3,107,352

BASF: $ 493,360

EPRI: $ 97,379

Key Project Milestones (Budget Period 1)

Budget Period 1 (Dec. 1, 2011 – Feb. 28, 2013)

- Submit project management plan (03/09/2012) √
- Conduct kick-off meeting with DOE-NETL (11/15/2011) √
- Complete initial techno-economic analysis on a 550 MWel power plant (05/04/2012) √
- Complete basic design and engineering of a 1 MWe pilot plant to be tested at NCCC (06/20/2012) √
- Execute host site agreement (10/31/2012)
- Complete initial EH&S assessment (10/31/2012)
- Complete detailed pilot plant engineering and cost analyis for the 1 MWe pilot plant to be tested at NCCC (01/31/2013)

Key Project Milestones (Budget Periods 2 and 3)

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Budget Period 2 (Mar. 1, 2013 – Feb. 28, 2014)

- Complete purchase orders and fabrication contracts for the 1 MWe pilot plant (03/29/2013)
- Complete shop fabrication of equipment and modules and associated engineering checks (07/31/2013)
- Complete site preparation and foundation installations at NCCC to receive pilot plant (08/15/2013)
- Complete installation of the 1 MWe pilot plant at NCCC (11/30/2013)
- Mechanical completion of 1 MWe pilot plant at NCCC (02/28/2014)

Budget Period 3 (Mar. 1, 2014 – Nov. 30, 2015)

- Complete pilot plant start up and demonstrate plant operation at steady state (05/31/2014)
- Develop pilot-scale parametric test plan (06/30/2014)
- Complete 1 MWe pilot-scale parametric tests (11/30/2014)
- Develop pilot-scale long duration test plan (12/31/2014)
- Complete 1 MWe pilot-scale long duration tests (08/31/2015)
- Complete updated techno-economic analysis (10/31/2015)
- Complete updated EH&S assessment (11/30/2015)

Linde-BASF experience in large scale carbon capture

CO_2 capture in natural gas processing: Re-injection Project - Hammerfest

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World's first industrial project to deliver CO_2 separated onshore from the well-stream back offshore for re-injection into a reservoir

— Partnership with StatoilHydro Petroleum

— Melkoya island near the town of Hammerfest, Norway

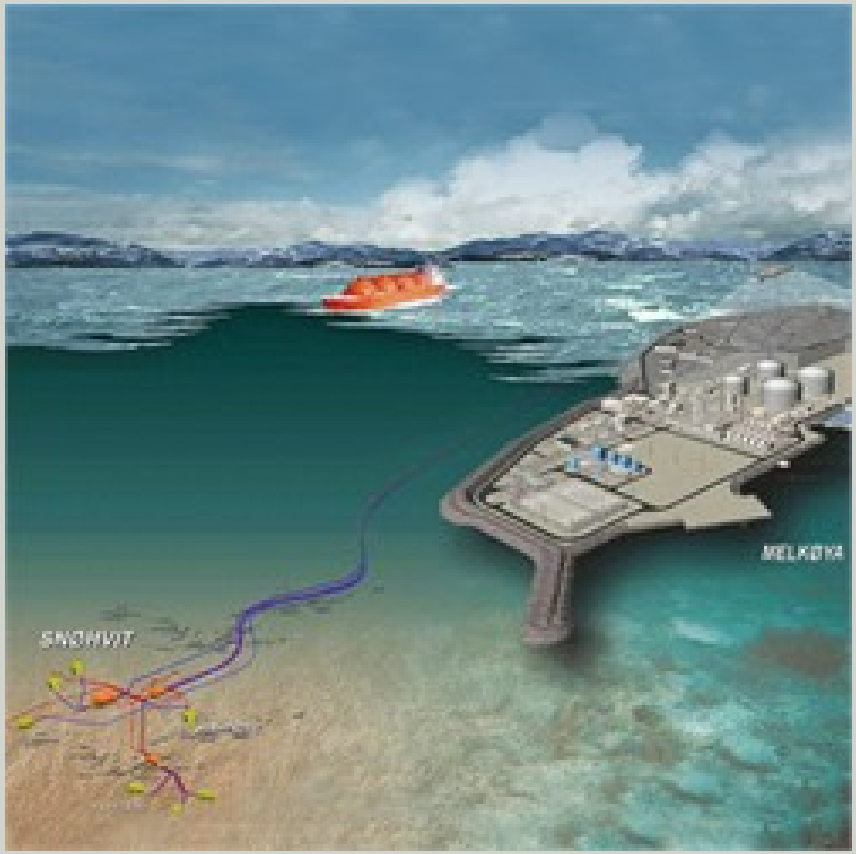
— CO_2 sequestration and re-injection integral part of the Hammerfest LNG project. **Linde performed design, EPC and commissioning**

— One dedicated well for CO_2 storage in a sandstone formation sealed by shale cap.

— Re-injection started in April 2008

— **BASF's OASE® purple process used in CO_2 capture**

700,000 tpa CO_2 capture and re-injection (part of world scale LNG project, Snøhvit, Norway)



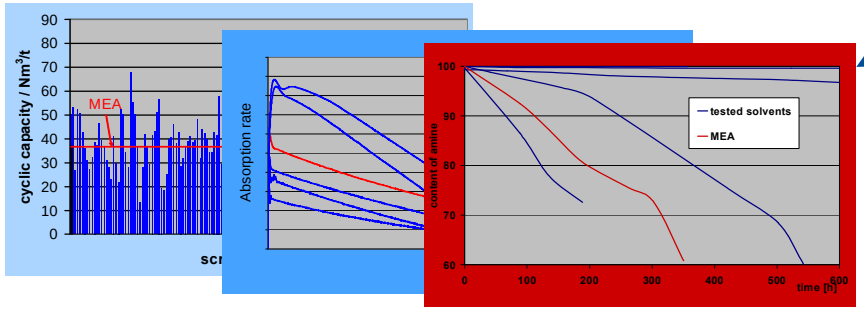
Post combustion CO_2 capture: Challenges compared to CO_2 removal in NG/LNG plants

	NG/LNG	Flue gas
Pressure	50 – 100 bars	1 bara
CO_2 partial pressure	1 – 40 bars	30 – 150 mbars
Flowrate	up to 60 mio scf/hr	up to 120 mio scf/hr
Gas composition	CH_4, C_2H_6, …, CO_2, H_2S, COS, C_xH_y,S, H_2O	N_2, O_2, H_2O, CO_2, (SO_x) NO_x
Treated gas specification	50 ppm – 2 % CO_2 S < 4 – 10 ppm	CO_2 removal rate (90 %) low amine emissions
Energy efficiency	not a key issue	of highest priority $\eta \searrow$ 7-10% points

- ❑ large volume flows @ low pressure
- ❑ solvent stability
- ❑ emissions of solvent
- ❑ overall power plant efficiency losses

BASF OASE® blue Technology Development Designed for PCC Applications

Equilibr Kinetics Stability

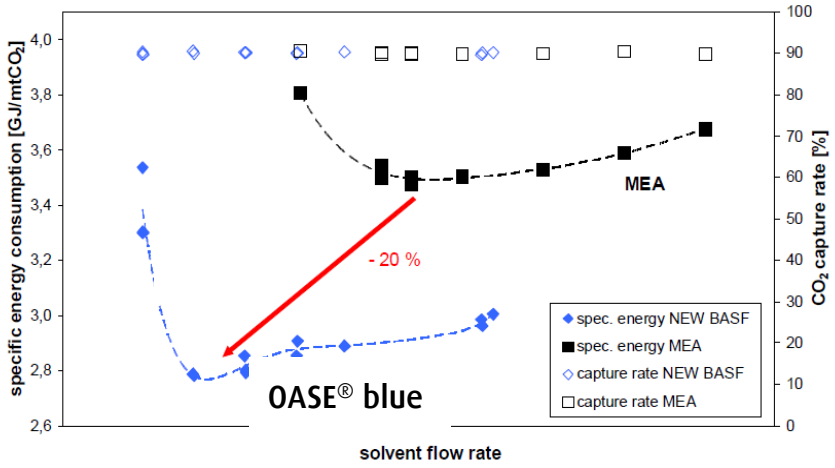


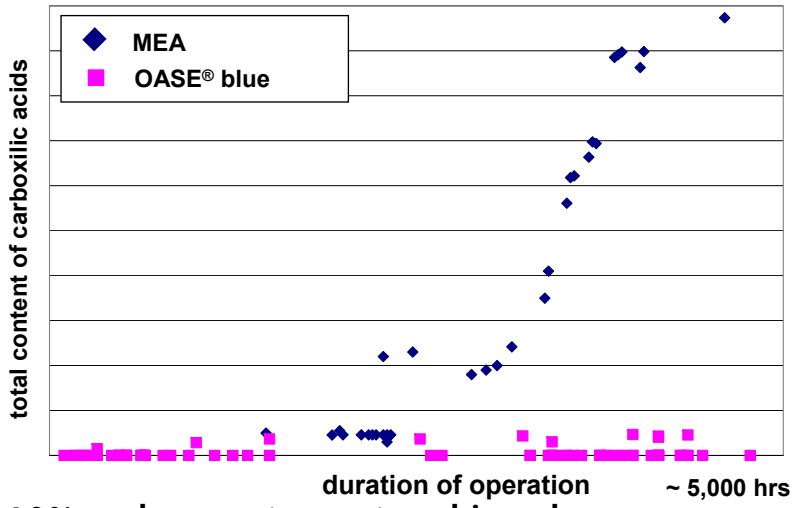
Fundamental Lab Scale R&D: Advanced Solvents Screening, Development, Optimization

BASF Miniplant, Ludwigshafen, Germany: Solvent Performance Verification

0.45 MWe PCC Pilot, Niederaussem, Germany: Preliminary Process Optimization

Niederaussem* pilot plant key results





>90% carbon capture rate achieved

>20% improvement in specific energy compared to MEA

New BASF solvent is very stable compared to MEA

Acknowledgement: * Pilot project partner RWE

Solutions for Large Scale PCC Plant (1100 Mw_{el} Power) Design challenges

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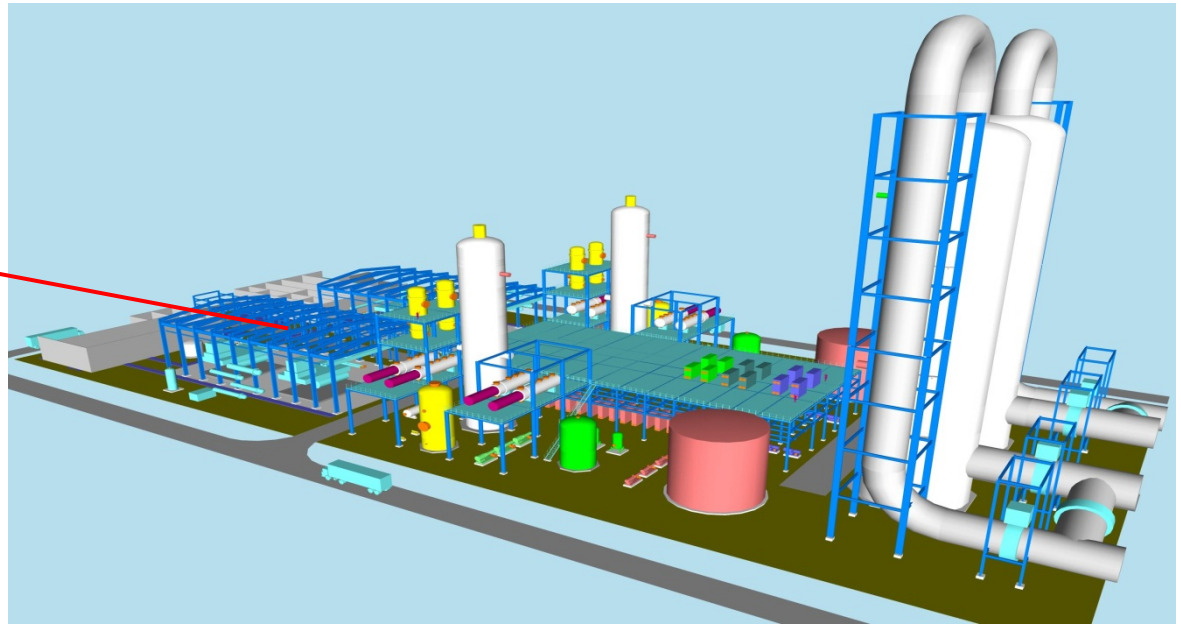
Optimizing CAPEX by reduced number of trains to handle 18,000 tpd CO_2

- 2 process trains selected
- reduced plot space

Compressor section
two lines per train

→flexible turn down operation



Lower number of trains results in bigger size of components, e.g.

- Absorption column: diameter ca.18 m, height ca. 75 m → on site fabrication required
- Pipes ducts and valves: diameters up to 7 meters
- Plot : ca. 100 m x 260 m

Concepts for a Large Scale PCC Plant
Key elements of plant costs

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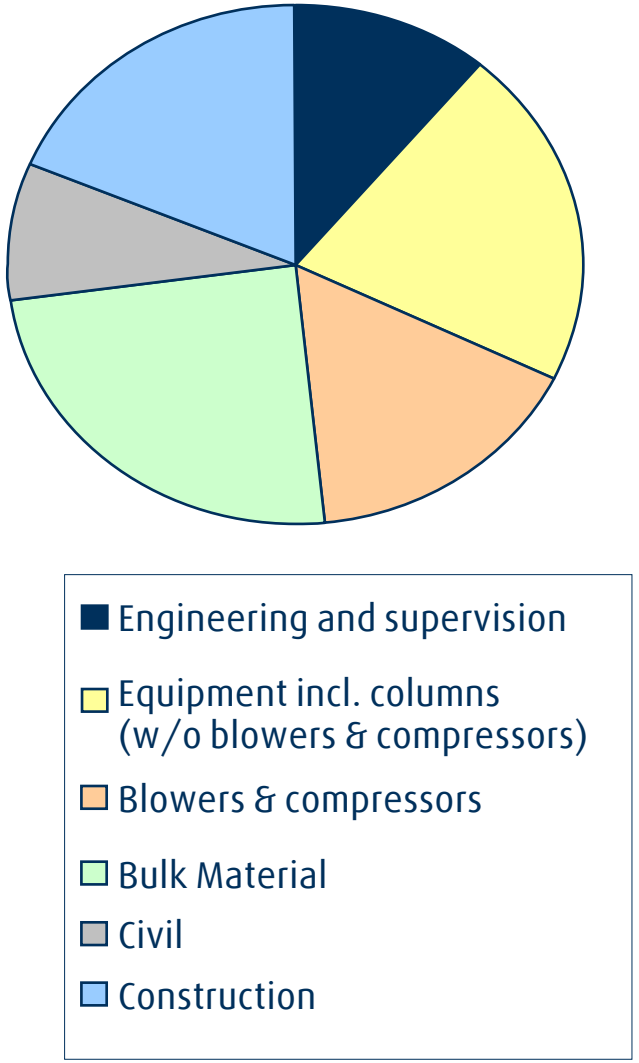
Main challenges

- Large equipment size requires new concepts
- Required plot area is very significant
- Alternative materials need to be assessed
- New equipment arrangements needed
- FIeld fabrication
- Large pipe and duct

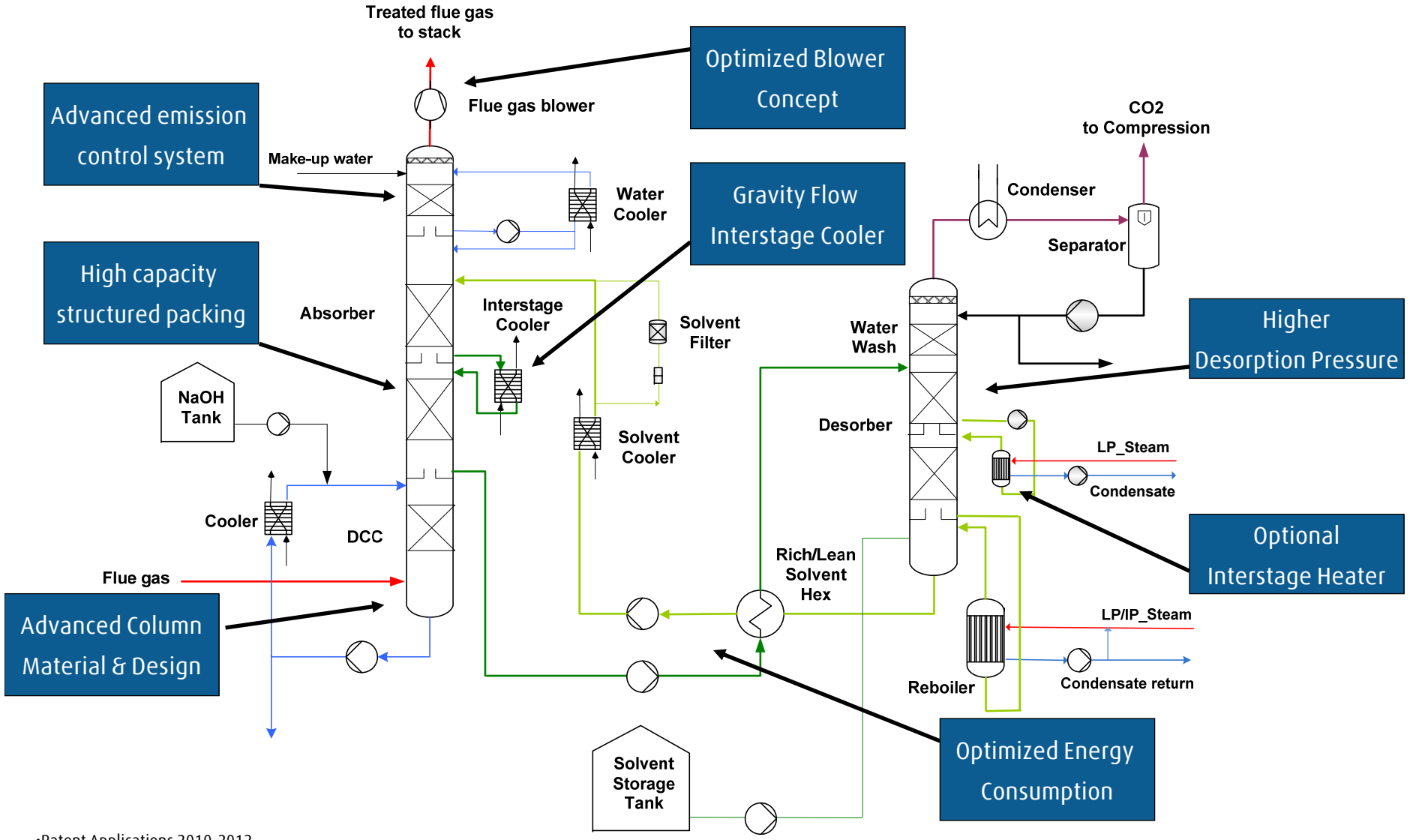
Linde studies to address challenges

- Scaling to a very large single train
- Optimize equipment arrangement (flue gas blower, pre-cooler, absorption columns sump etc)
- Develop new column construction materials
- Optimize machinery options

Total plant cost distribution



Linde-BASF advanced PCC plant design*



•Patent Applications 2010-2012

Source: Project DE-FE0007453 Techno-economic analysis of 550 MWe PC power plant with CO2 capture, May 2012.

Project progress and accomplishments

Task#	Task Description	Key Objectives	Accomplishments
1	Program Management	Complete project management plan and implement to agreed cost and schedule.	- Project kick-off meeting held - Updated project management plan completed
2	Techno-economic evaluation	Complete techno-economic analysis on a 550 MWe coal-fired power plant incorporating Linde-BASF PCC technology.	- Techno-economic assessment completed and presented to DOE-NETL
3	Pilot plant optimization and basic design	Define pilot plant design basis and the key features incorporated. Complete basic design and engineering.	-Design basis document completed and pilot plant features selected. - Basic design and engineering completed.
4	Pilot plant system design and engineering	Complete detailed design and engineering of the pilot plant (ready to build).	-Preliminary 3-D model developed - Detailed engineering in progress (30% model)
5	Pilot plant cost and safety analysis	Complete preliminary environment, health and safety assessment for the pilot plant	- Preliminary NEPA document completed. - Hazop review completed and design updates incorporated.

Basis for techno-economic assessment for 550 MW_e power plant with 90% CO_2 capture

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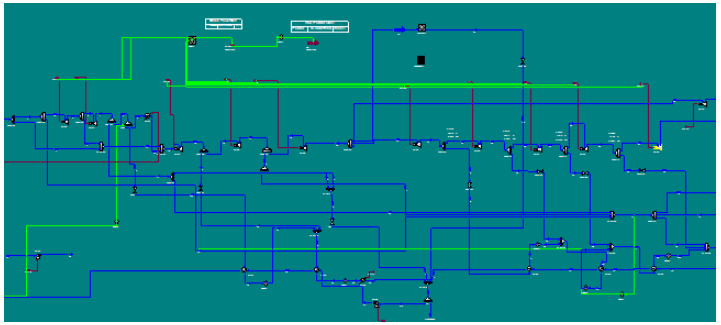
Specifications and Design Basis

identical to DOE/NETL Report 2007/1281

as per DE-FOA-0000403 requirements

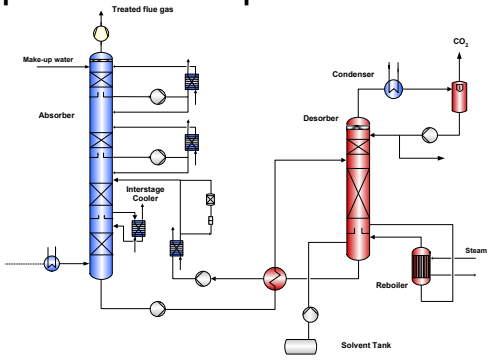
- Bituminous Illinois #6 Coal Characteristics
- Site Characteristics and Ambient Conditions
- Pulverized Coal Boiler Design
- Subcritical Steam Turbine Design
- Steam Cycle Conditions
- Environmental Controls and Performance
- Balance of Plant
- Economic Assumptions and Methodology

Computational Platform

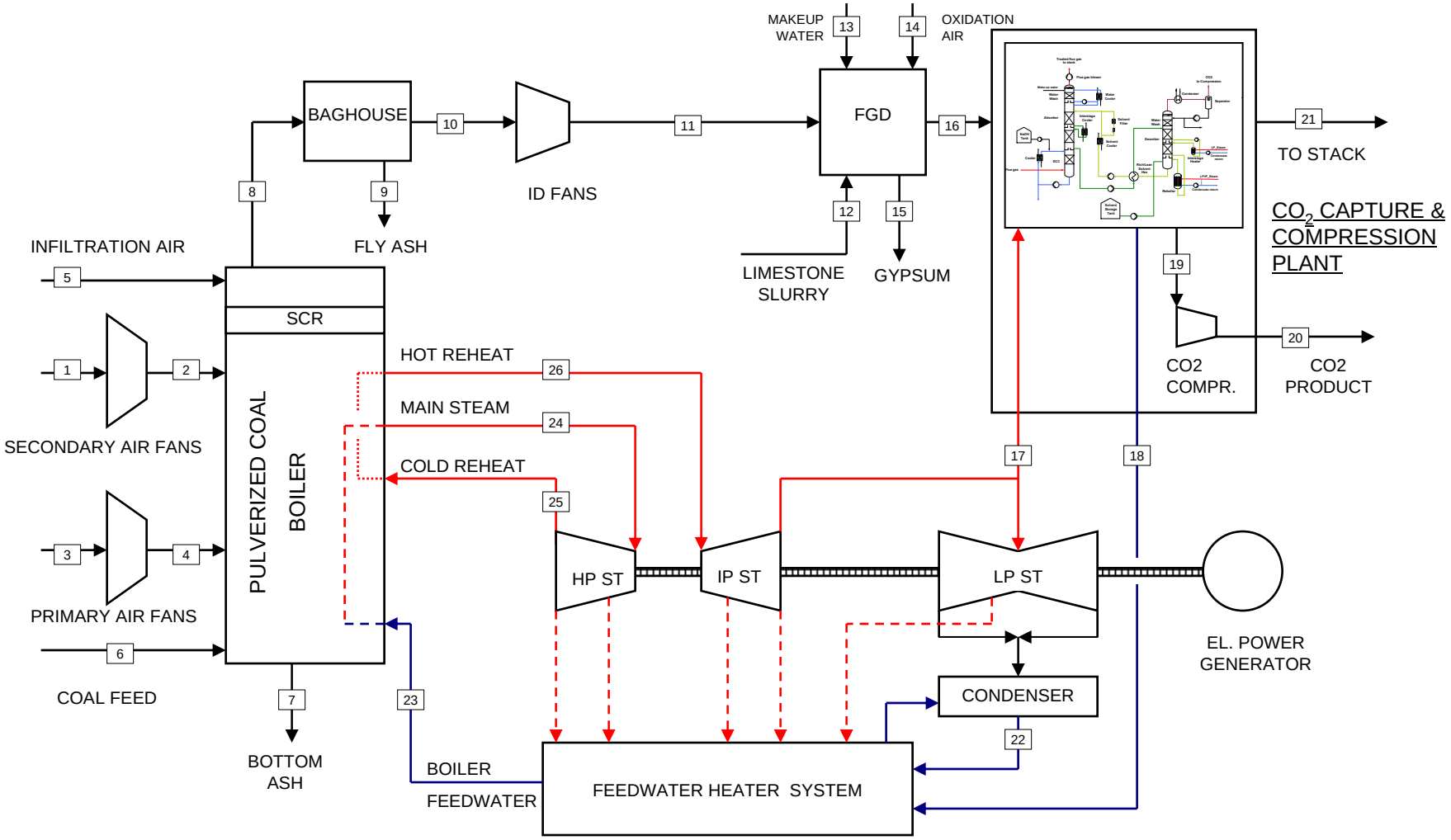


UniSim Design Suite R390, integrated with

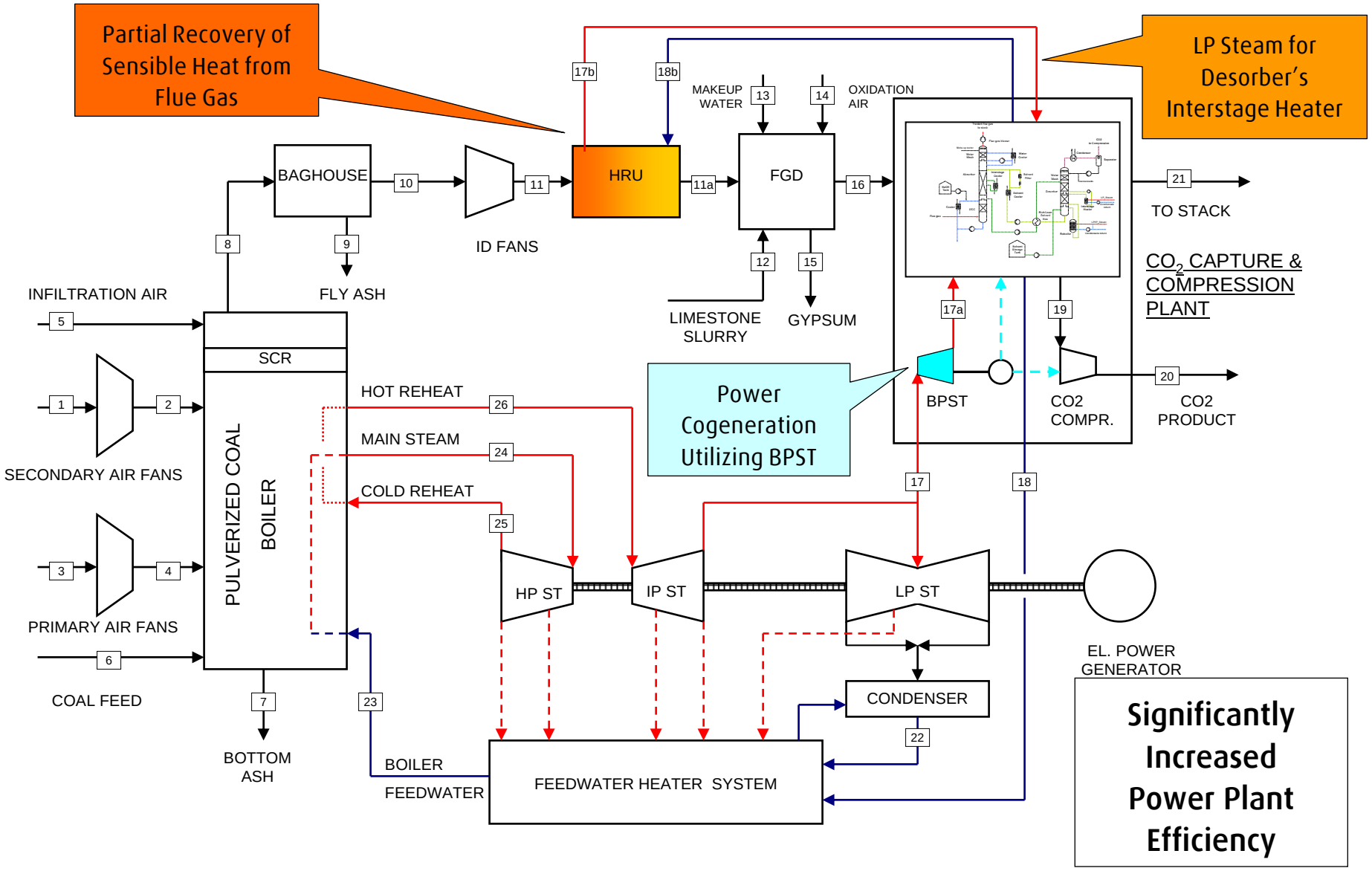
- Brian Research & Engineering ProMax® software for PCC parametric optimization
- BASF's proprietary package for rigorous solvent performance predictions



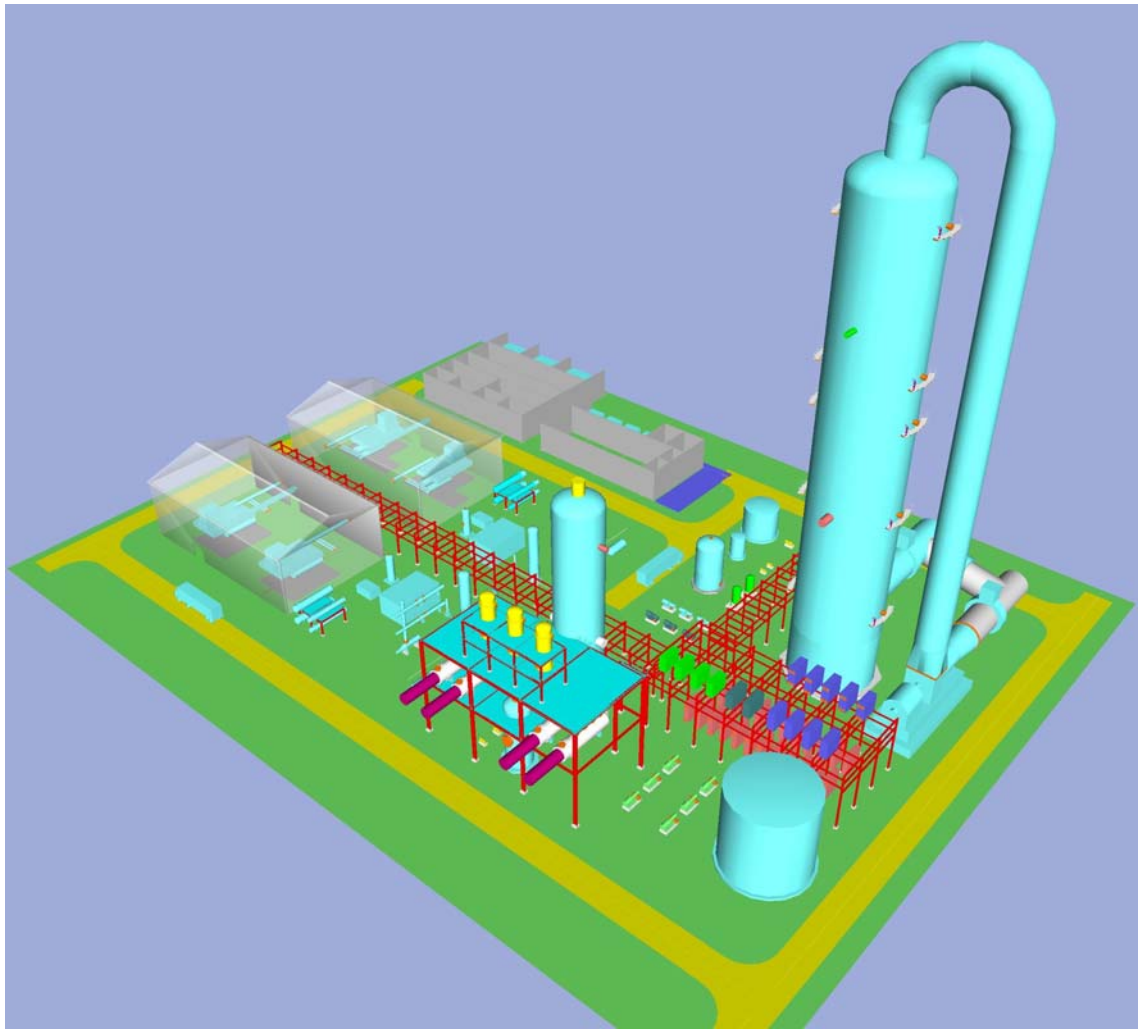
PCC – Power Plant
Typical Process Integration Option (LB-1)



PCC – Power Plant
Advanced Process Integration Option (LB-2)

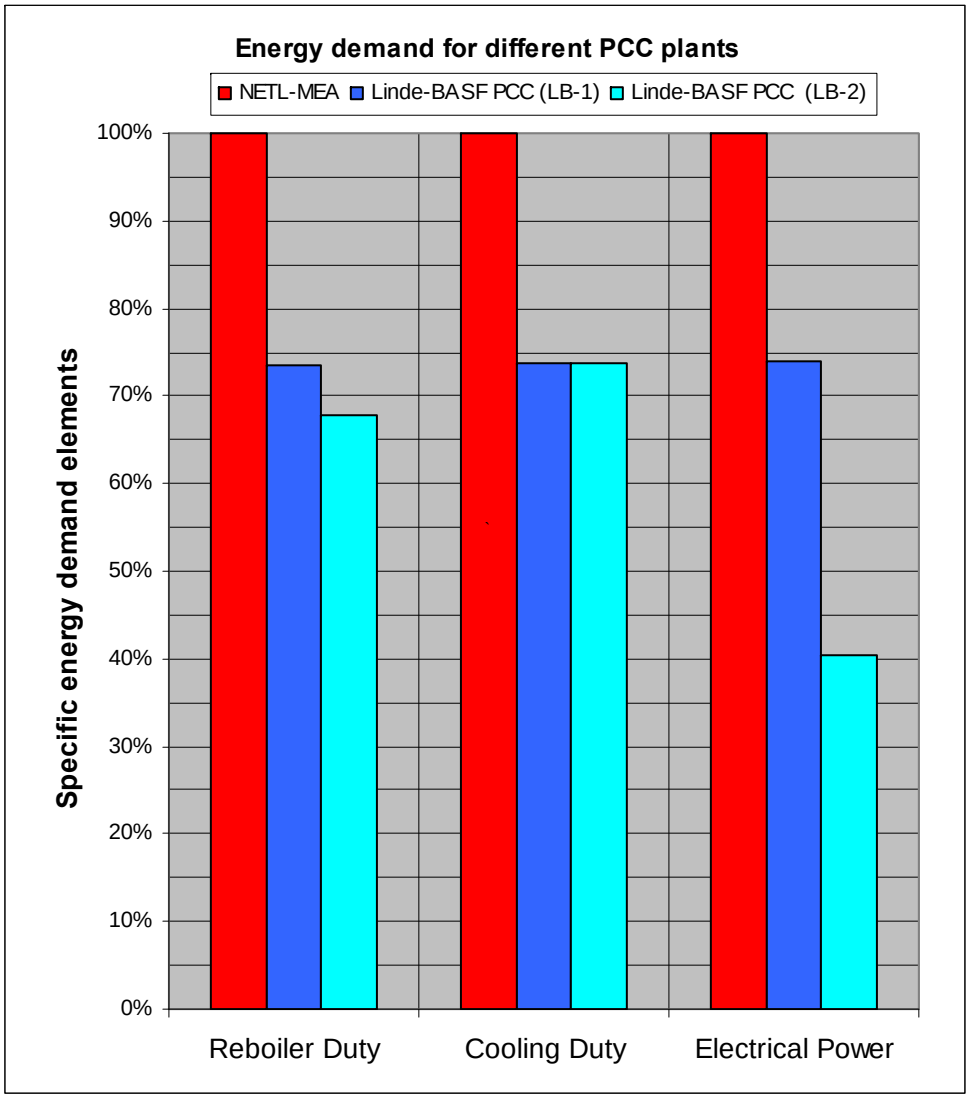


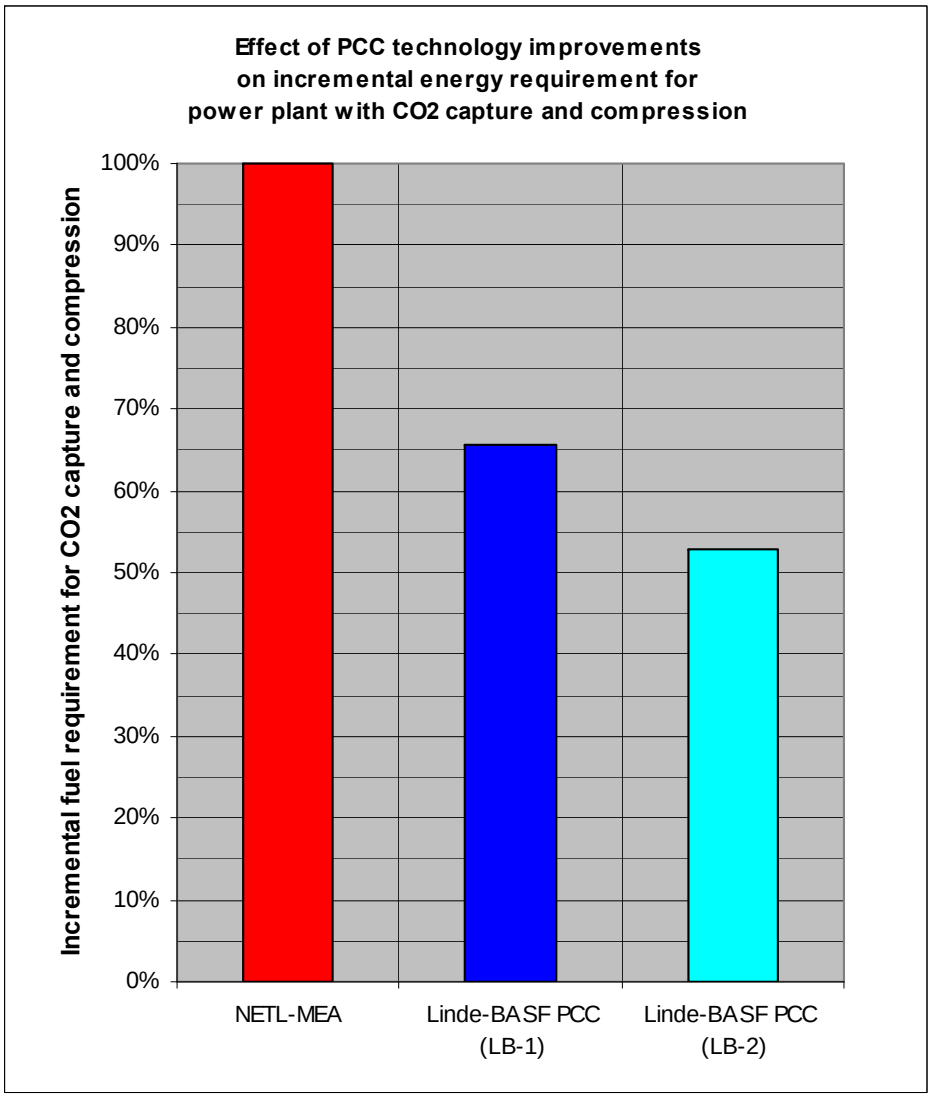
Linde-BASF PCC Plant Design for 550 MWe PC Power Plant



- Single train PCC design for ~ 13,000 TPD CO_2 capture
- 40-50% reduced plot area to 180m x 120 m

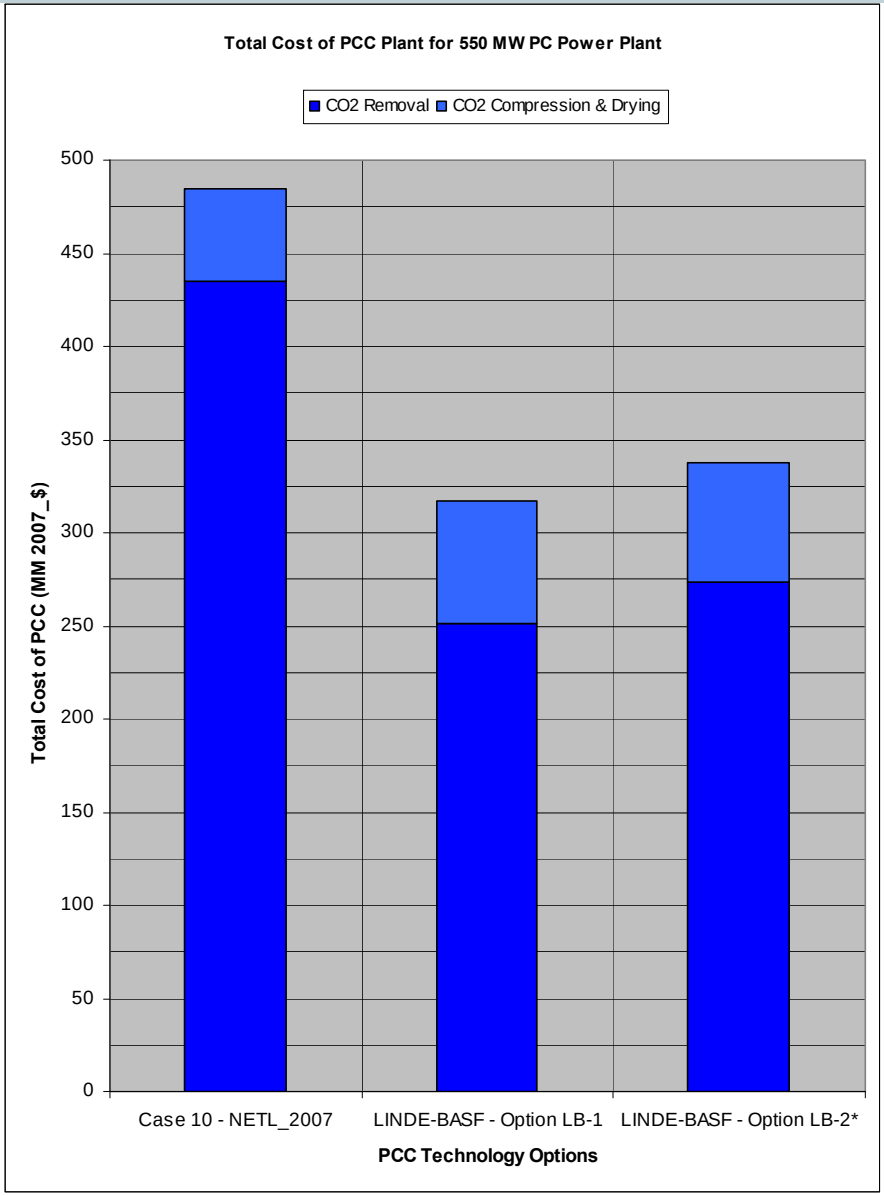
Comparative PCC Performance Results
Linde-BASF vs Reference DOE/NETL Case*





* Reference Case # 10 of DOE-NETL 2007/1281 Report

Total PCC Plant Cost



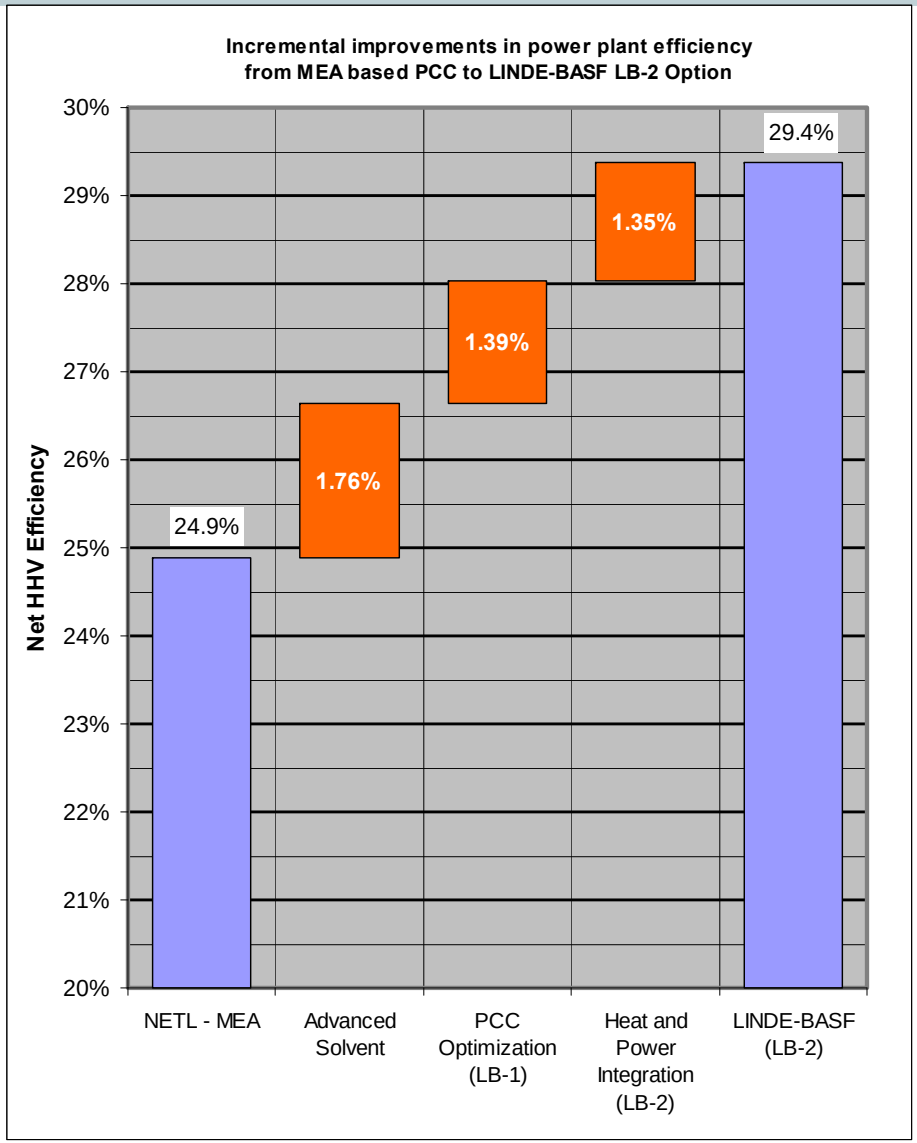
Significantly reduced total PCC plant Cost relative to DOE/NETL 2007 Reference Case #10 due to

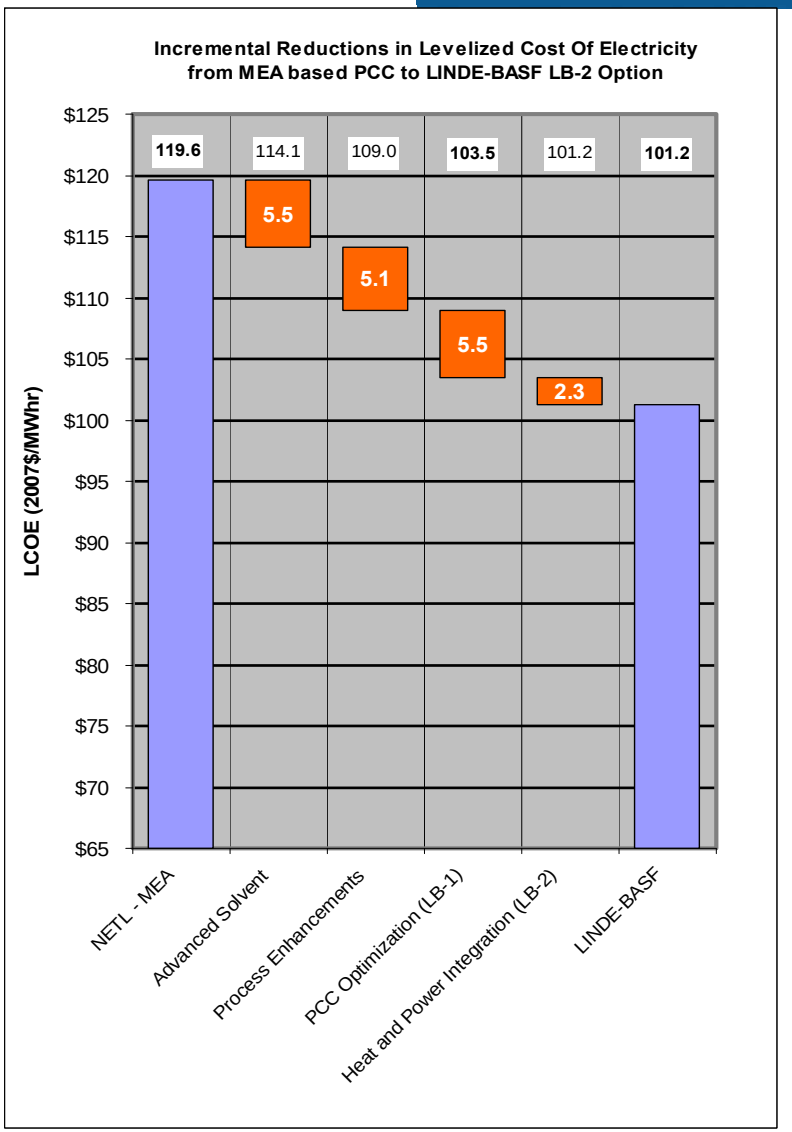
1. Reduced coal combustion (CO2 production) for 11.1% (LB-1) or 15.2% (LB-2)

2. Single train PCC design

3. Optimized PCC plant design

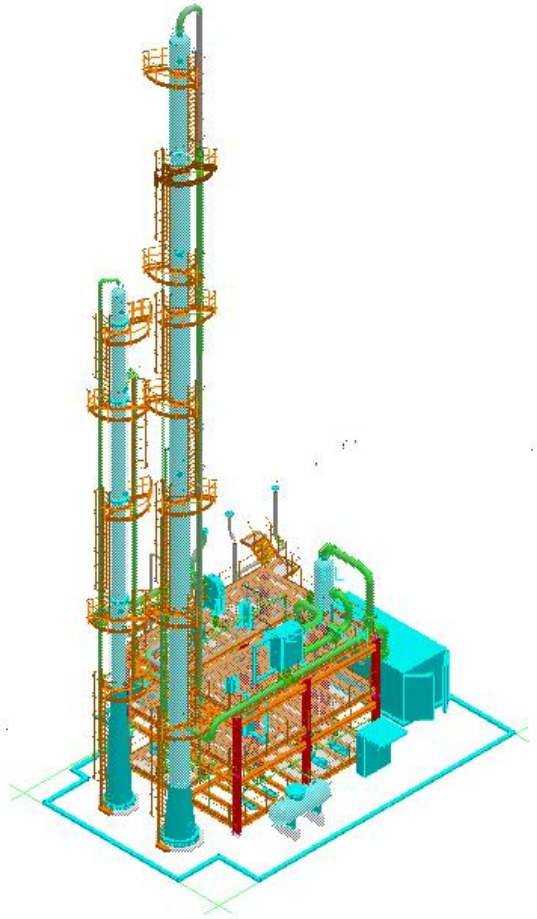
Power plant efficiency improvements and LCOE reductions with Linde-BASF PCC technology

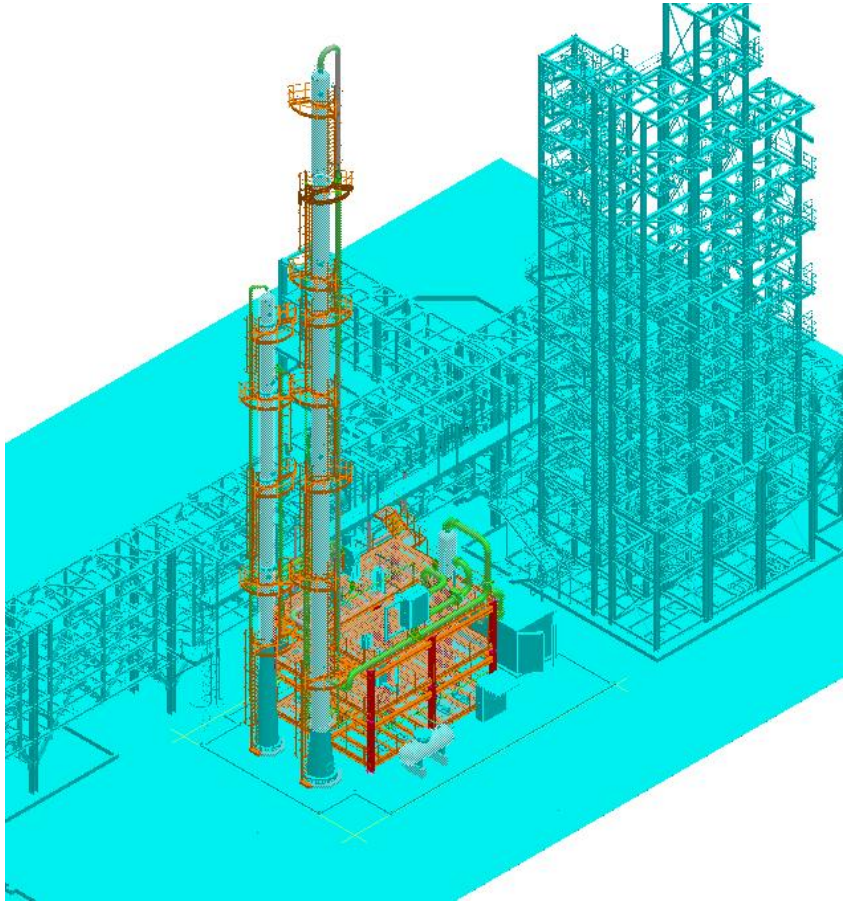




Source: Project DE-FE0007453 Techno-economic analysis of 550 MWe PC power plant with CO2 capture, May 2012.

Detailed Engineering Model of Pilot Plant





- Free-standing absorber and stripper
- Equipment modules containing pumps, blower, HX etc

Pilot plant located in NCCC site with the exisiting 0.5 MWe pilot and piperack in the background

Summary and Next Steps

- Linde and project partners are designing and building a 1 MWe post-combustion capture pilot plant to be installed and tested at the National Carbon Capture Center in Wilsonville, AL.
- The plant will incorporate BASF's OASE® blue solvent technology and Linde-BASF process enhancements and demonstrate that target performance can be achieved.
- Techno-economic assessment on a 550 MWe coal-fired power plant has confirmed the significant energy and capex savings compared to a reference MEA PCC plant, thereby, driving down the levelized cost of electricity.
- Critical next steps for the project:
  - Complete detailed engineering of the pilot plant and firm cost estimates and reach "Go" decision to proceed pilot plant procurement and build (Budget Period 1)
  - Procure, fabricate and install pilot plant at the NCCC and achieve mechanical completion (Budget Period 2)
  - Perform parametric and long duration tests and confirm achievement of target performance. (Budget Period 3)

Acknowledgement and Disclaimer

Acknowledgement: This presentation is based on work supported by the Department of Energy under Award Number DE-FE0007453.

Thank you for your attention!

Project DE-FE0007453
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Krish R. Krishnamurthy, Linde LLC
July 9-12, 2012
Pittsburgh, PA