Linde Briefing for USEA

Update on DOE Post-Combustion Capture project & CCUS activities

Leading.

THE LINDE GROUP

January 2013

THE LINDE GROUP

Linde Overview & Focus on CCUS Pathways

PCC Technology & Update on DOE Project

Current CCUS Activities & Focus Areas

The Linde Group Overview

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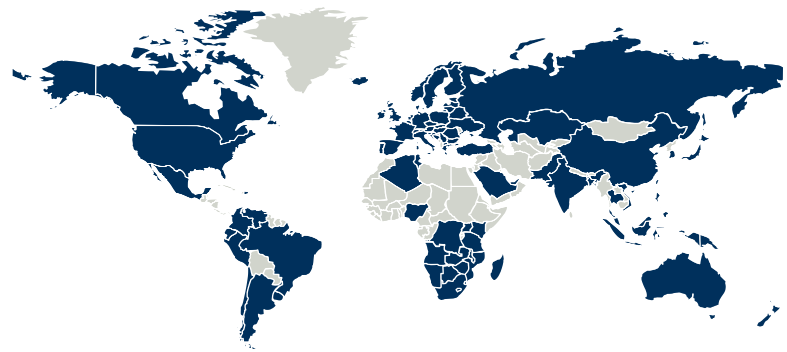
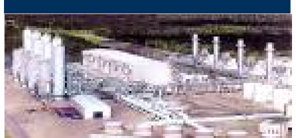
Founded	1879
Sales	~$20 billion
Employees	~62,000
Countries	>100



Linde Engineering

Technology-focused

Air Separation

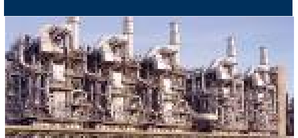


Global #1

Hydrogen/Syn Gas

Global #2

Olefins



Global #2

Natural Gas

Global #3

Leveraging Synergies

Linde Gas - Tonnage

World-class operations

HyCO Tonnage Plants

>70 plants

ASU Tonnage Plants

>300 plants

CO2 Plants

>100 plants

ECOVAR Std Plants

>1,000 plants

Growth opportunities
Product portfolio serving mega trends

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Growth markets

Clean energy

Healthcare

Leveraging Gases & Engineering business synergies

Linde pursuing all three CCS pathways

Technology Development & Solution Offering

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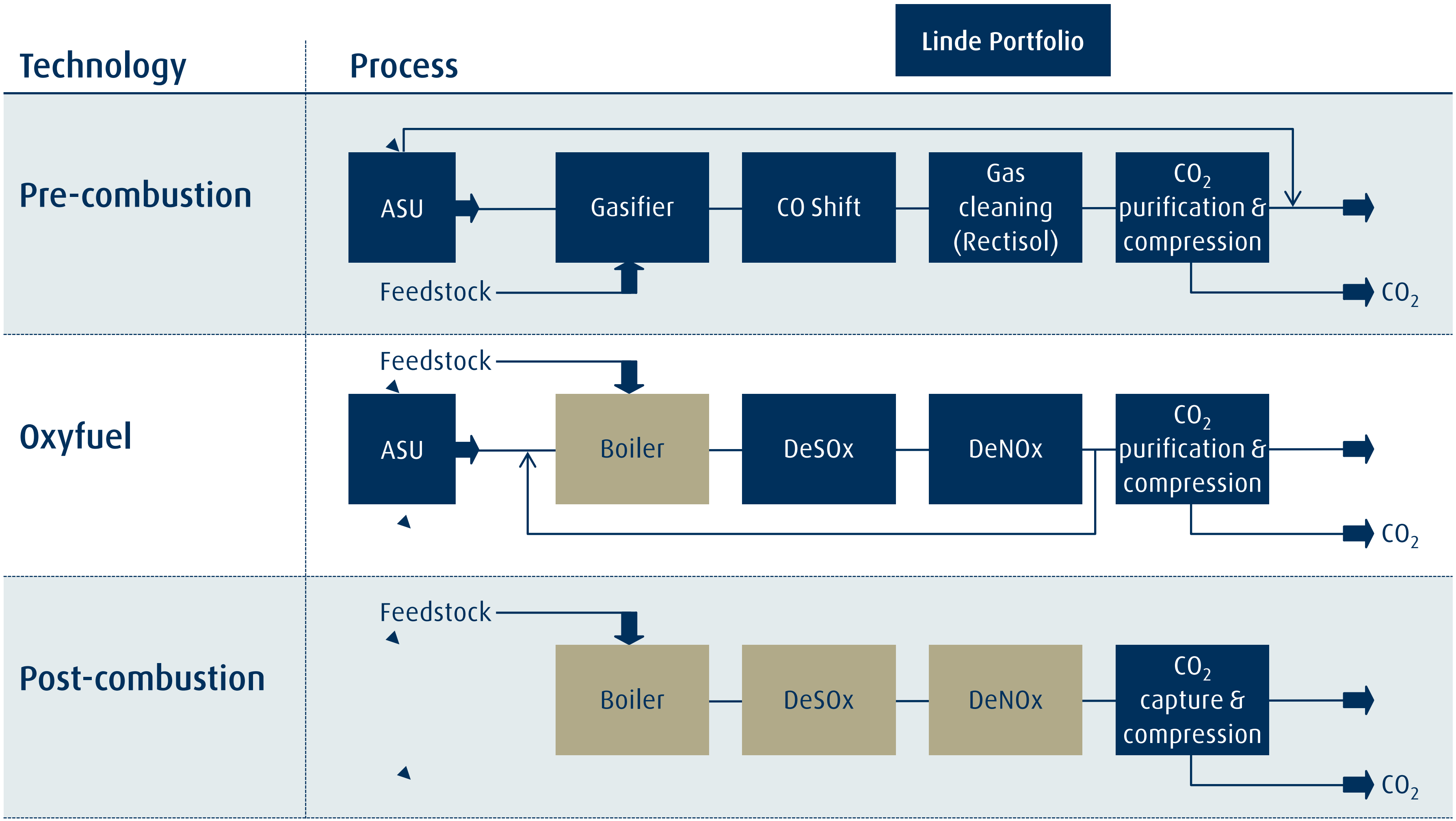

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Project Objectives

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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

DE-FE0007453 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 Keith Christian	-Detailed engineering -Procurement and installation

Project schedule by budget period and task

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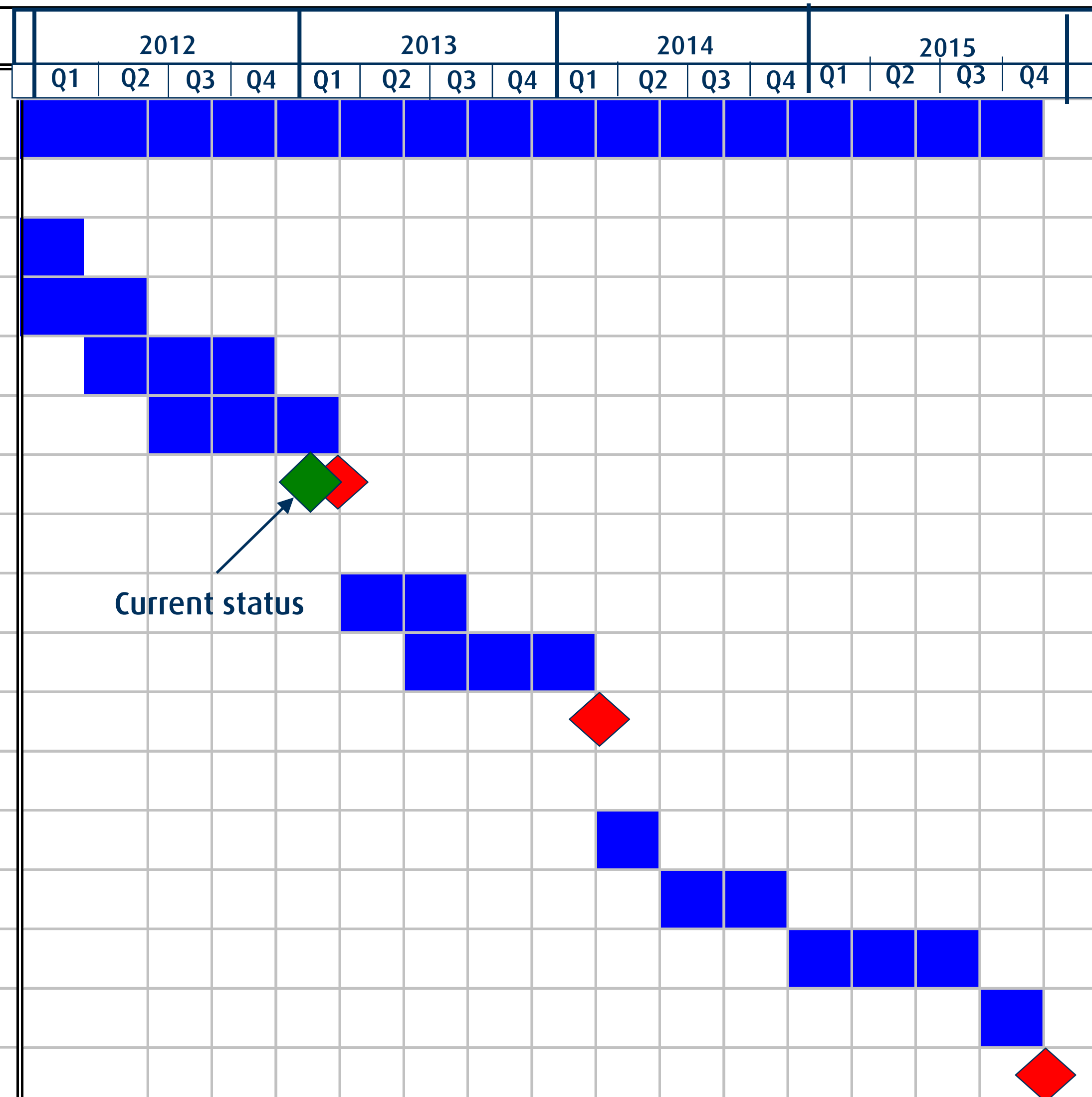
Task #	TITLE
1	Program Management
Budget Period 1	
2	Techno-Economic Evaluation
3	Pilot plant optimization and basic design
4	Pilot plant system design and engineering
5	Pilot plant cost and safety analysis
	Go - No Go DECISION
Budget Period 2	
6	Supply of plant equipment and materials
7	Plant construction and commissioning
	Mechanical completion of pilot plant
Budget Period 3	
8	Start-up and initial operation
9	Parametric testing
10	Long duration continuous operation
11	Final economic analysis and commercialization plan
	Project Closeout



Project progress and accomplishments by task (Budget Period 1)

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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 - Benefits of technology demonstrated
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 design and engineering	Complete detailed design and engineering of the pilot plant.	- Detailed engineering nearing completion (90% model)
5	Pilot plant cost and safety analysis	Complete preliminary environment, health and safety assessment for the pilot plant	- NEPA document completed with NCCC and DOE-NETL approval obtained -Preliminary EH&S topical report completed - Vendor packages developed and firm cost estimates obtained

Linde-BASF experience in large scale carbon capture

CO_2 capture in NG processing: Re-injection Project - Hammerfest

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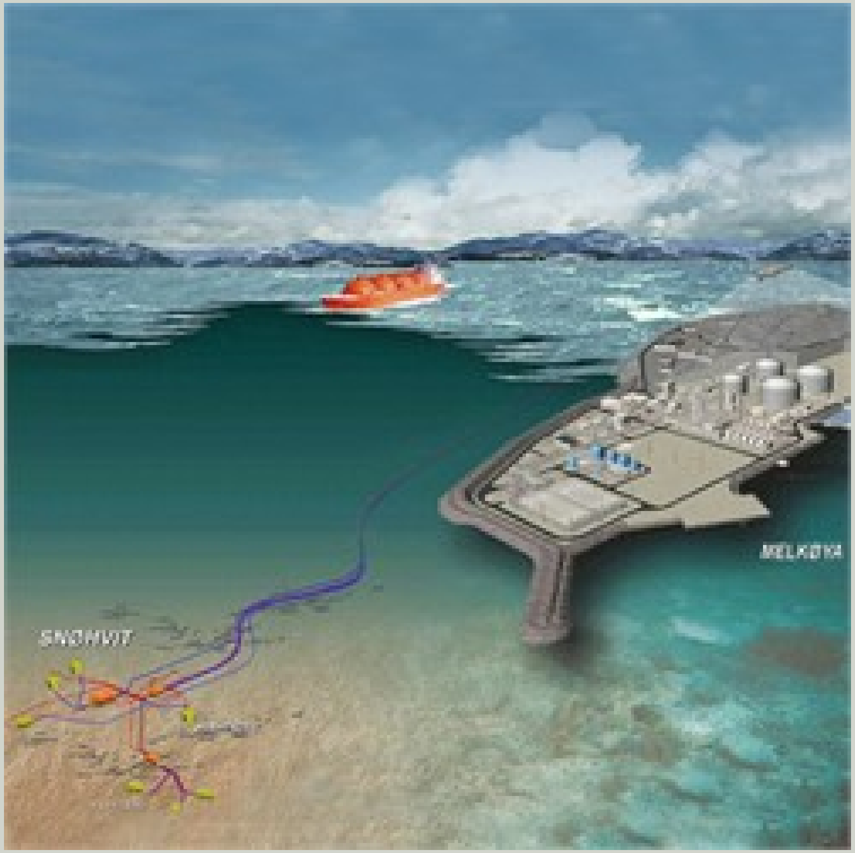
World's first industrial project to deliver CO_2 separated onshore from the well-stream back offshore for re-injection into a reservoir

- 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)



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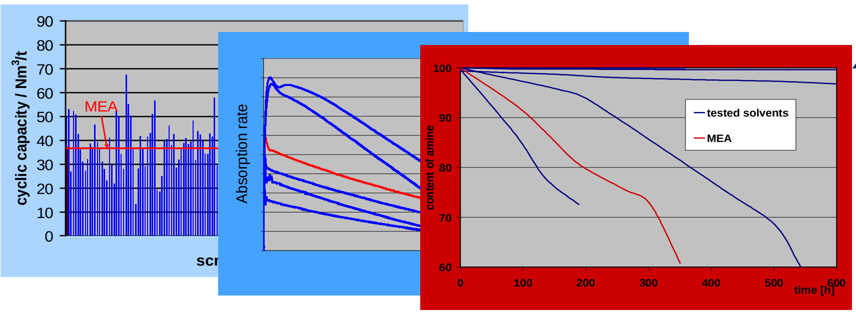
Post combustion CO_2 capture: Challenges compared to CO_2 removal in NG/LNG plants

	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 η ↘ 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

Equilibria → Kinetics → Stability

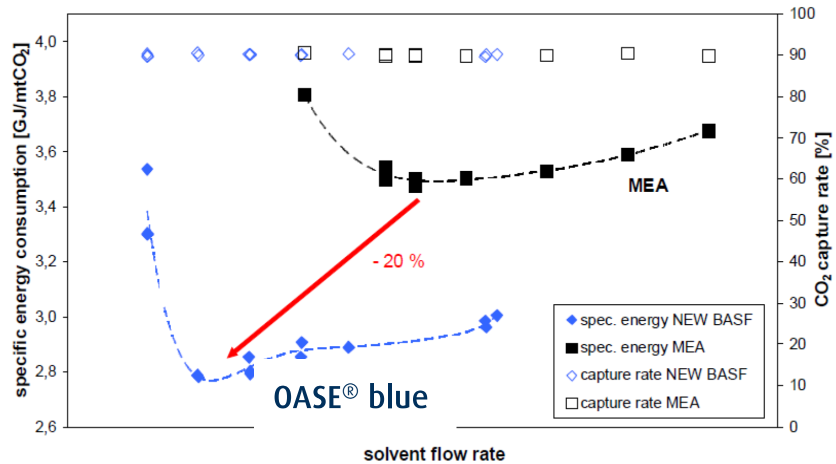


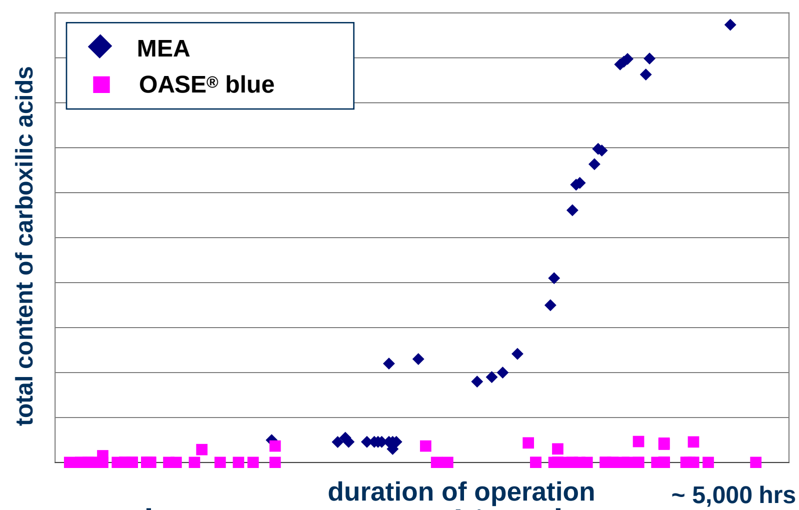
Fundamental Lab Scale R&D: Advanced Solvents Screening, Development, Optimization

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

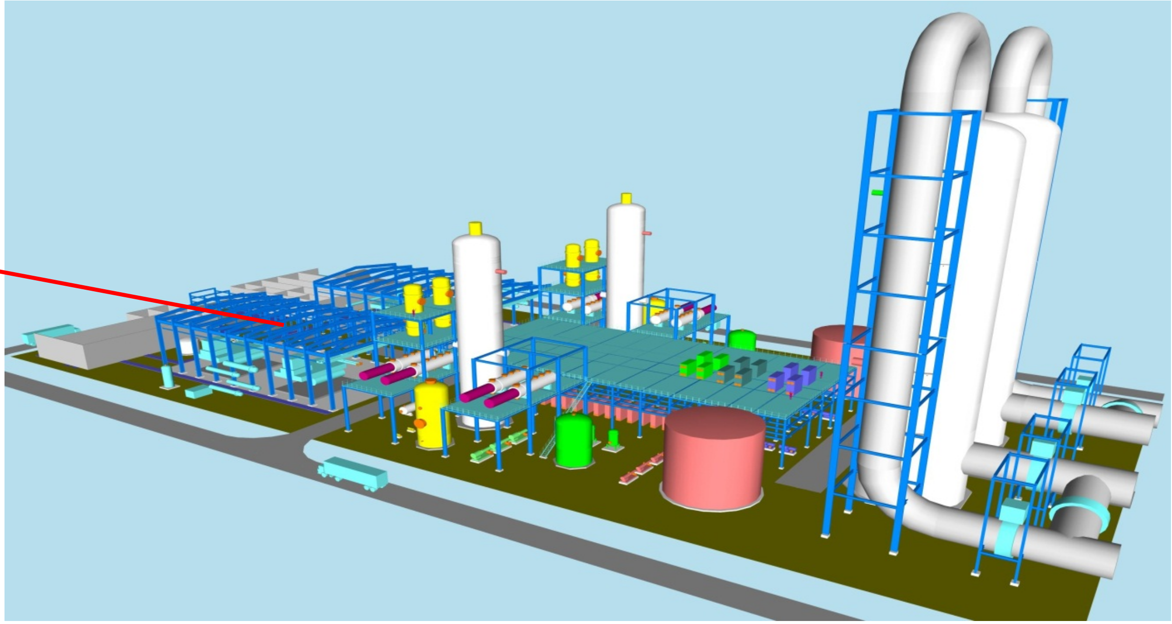
New BASF solvent is very stable compared to MEA

Acknowledgement: * Pilot project partner RWE

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

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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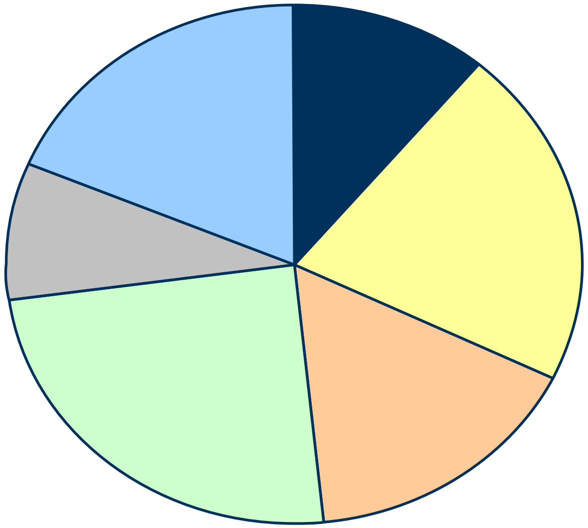
Main challenges

- 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



Simplified process flow diagram of the 1MWe pilot plant

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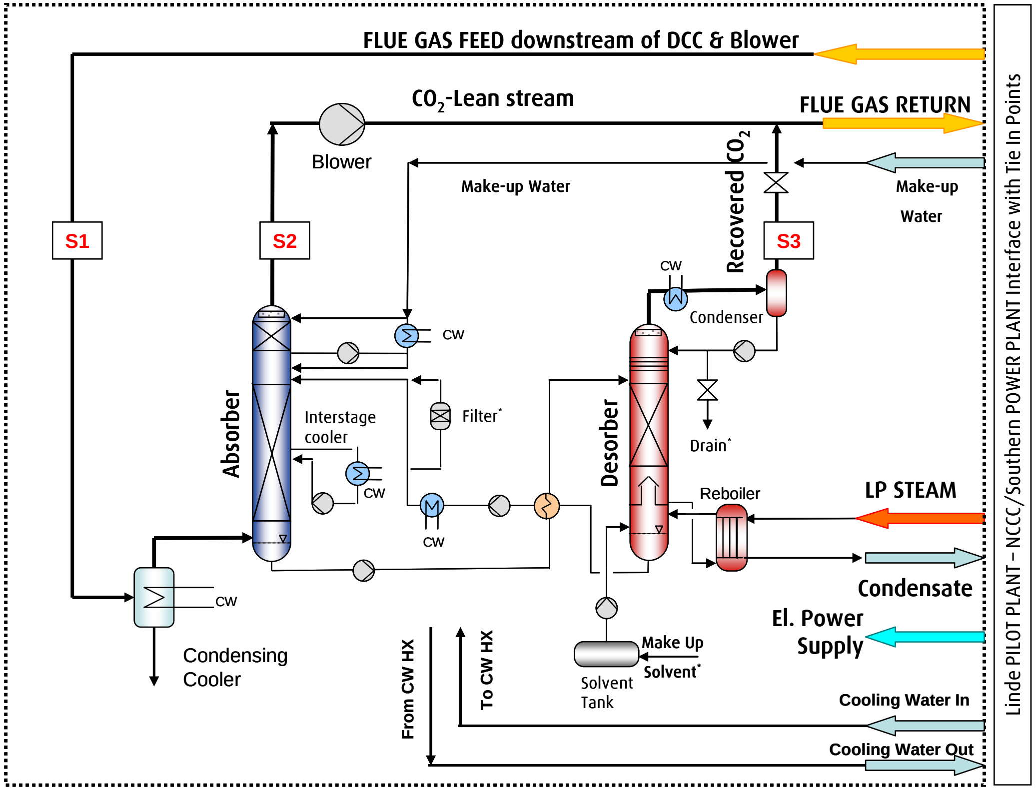
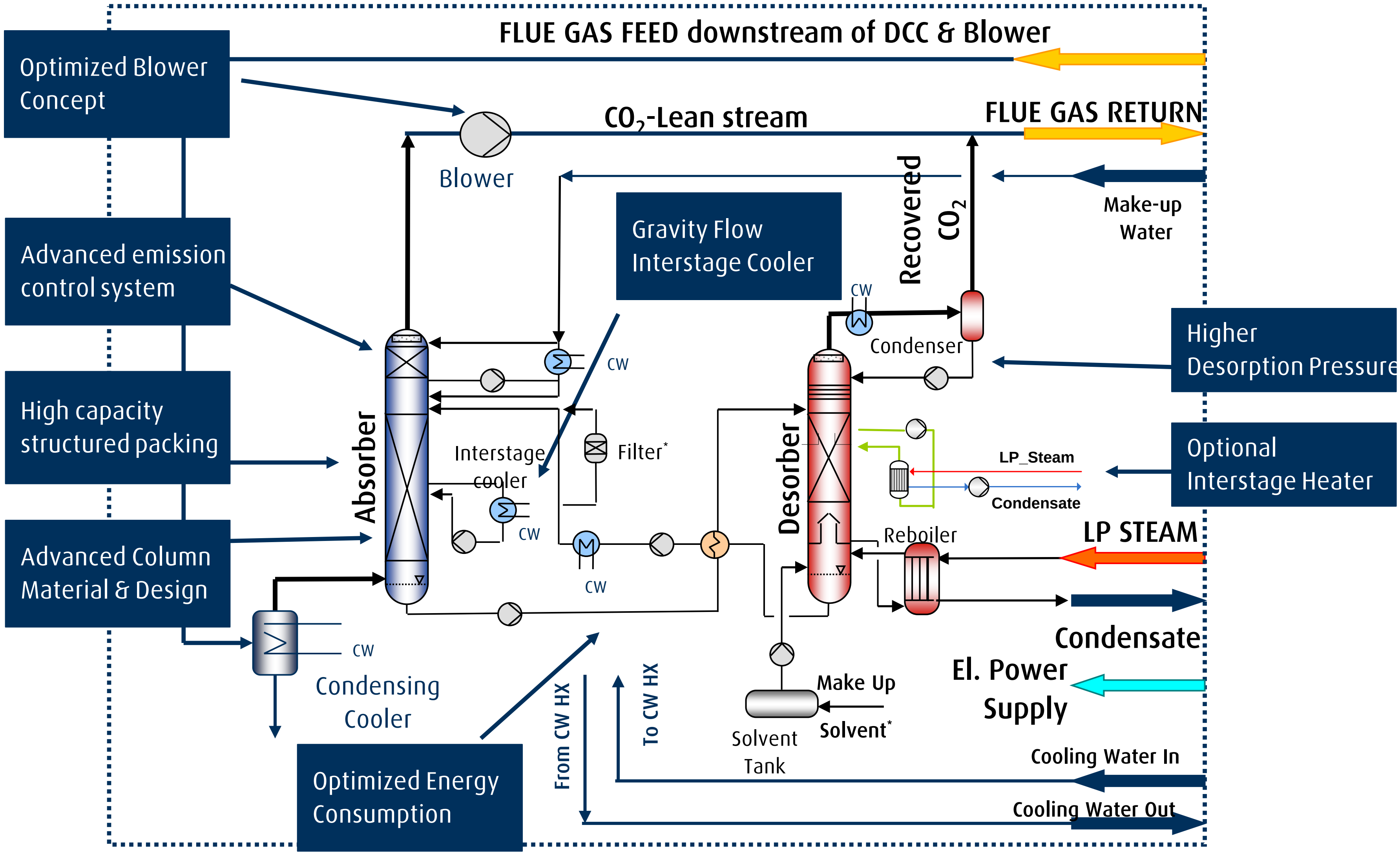


Stream		S1	S2	S3
		Feed gas	CO2 Lean	CO2 Rich
Temperature	F	123.8	114.1	104.0
Pressure	psia	14.9	13.8	47.9
H2O	vol%	13.30	9.49	2.31
CO2	vol%	12.14	1.45	97.67
CO	vol%	0.00	0.00	0.00
N2	vol%	69.36	82.85	0.01
O2	vol%	5.20	6.21	0.00
Flow rate (total)	mscf/hr	217.4	182.0	24.3
Flow rate (total)	lb/hr	16,517	13,209	2,782
CO2 Recovered	TPD			30.0

Utilities for 30_TPD Pilot Plant		
LP Steam	lb/hr	3,600
El. Power	kW	190
Cooling Water	GPM	570
Makeup water	GPM	0.3

Linde-BASF advanced PCC plant design*



Techno-Economic Assessment: Linde-BASF PCC Plant Design for 550 MWe PC Power Plant

BASF The Chemical Company

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Specifications and Design Basis

identical to DOE/NETL Report 2007/1281

as per DE-FOA-0000403 requirements

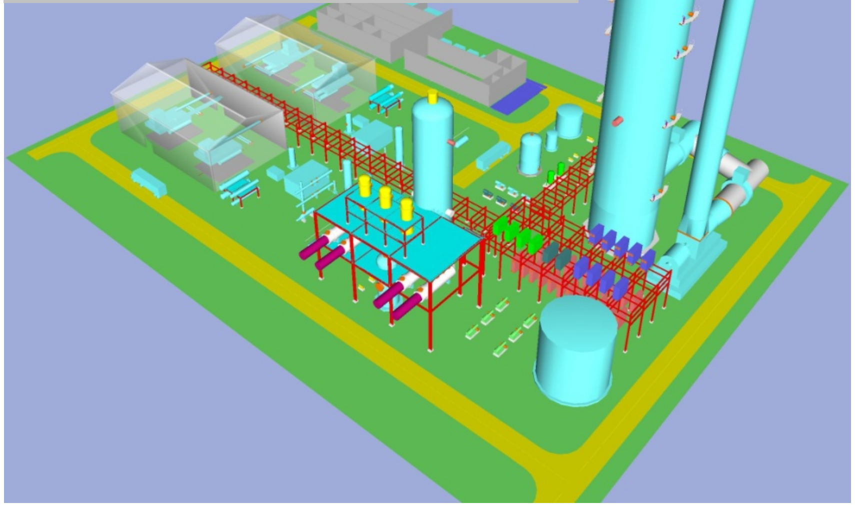
— Bituminous Illinois #6 Coal Characteristics
— Site Characteristics and Ambient Conditions
— Pulverized Coal Boiler Design
— Subcritical Steam Turbine Design
— Steam Cycle Conditions
— Environmental Controls and Performance
— Balance of Plant
— Economic Assumptions and Methodology

UniSim Design Suite R390, integrated with

— Brian Research & Engineering ProMax® software for PCC parametric optimization

— BASF's proprietary package for rigorous solvent performance predictions

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



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

BASF The Chemical Company

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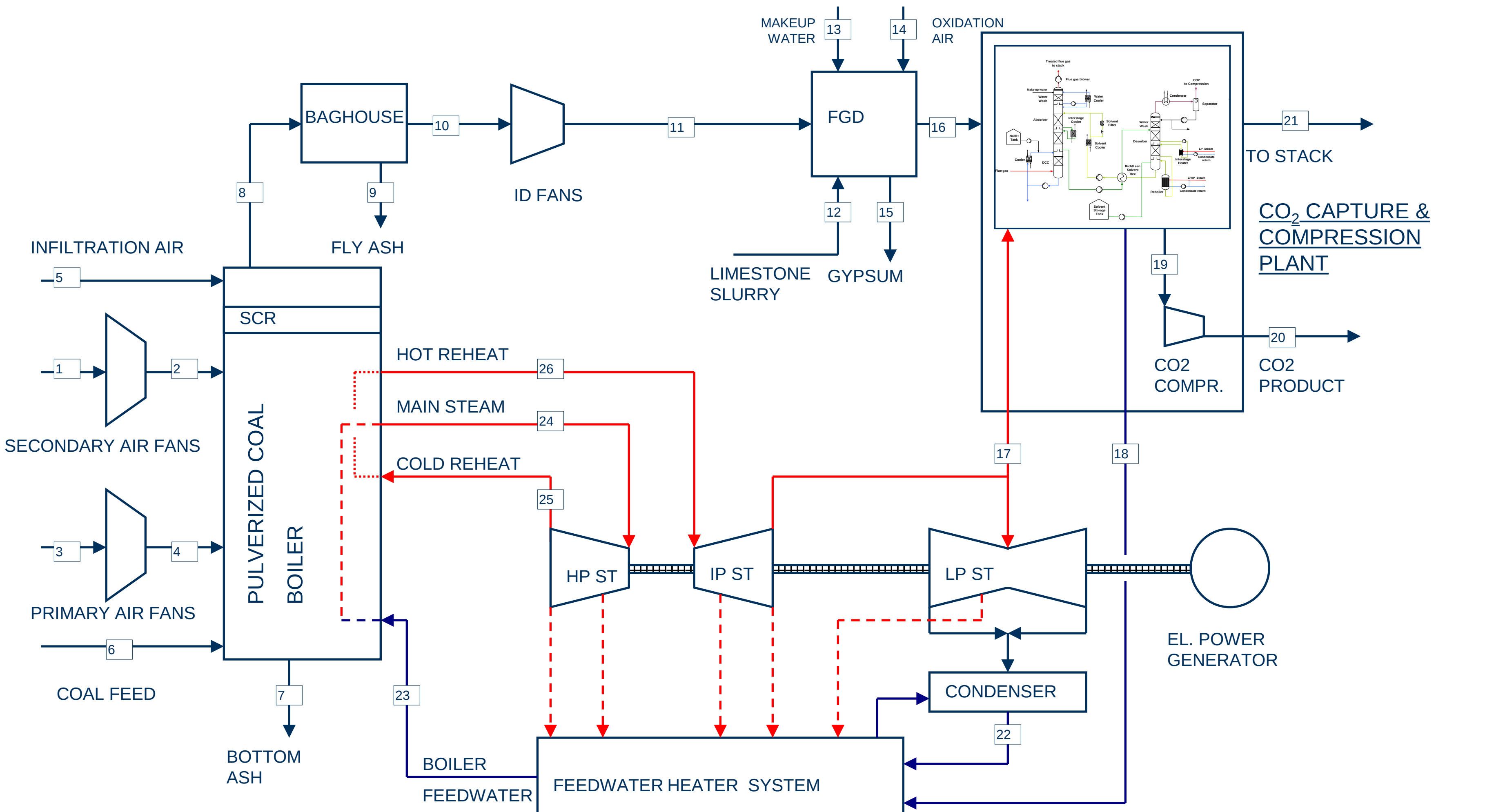

PCC – Power Plant
Advanced Process Integration Option (LB-2)

BASF The Chemical Company

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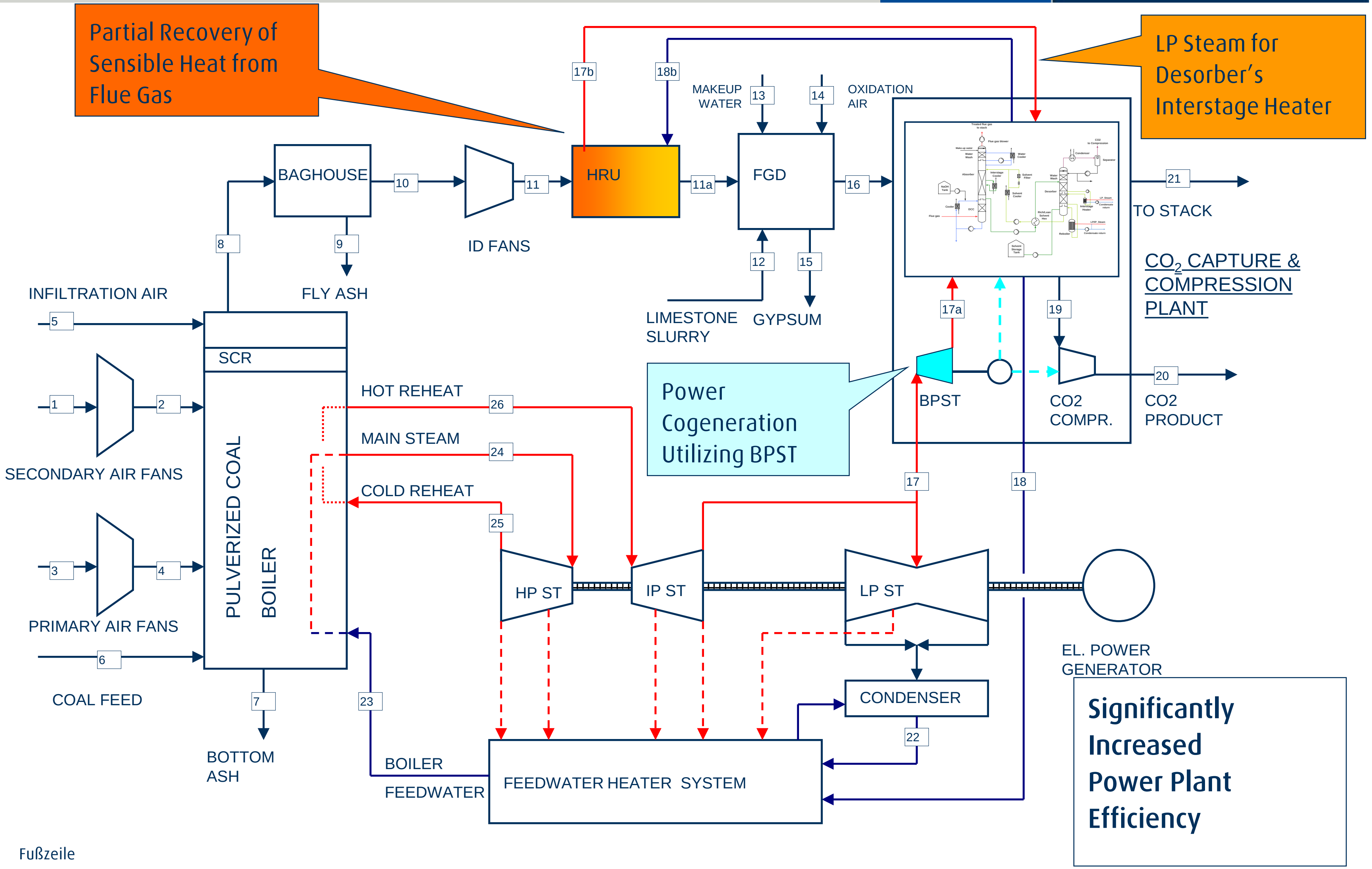

Significantly Increased Power Plant Efficiency

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

BASF The Chemical Company

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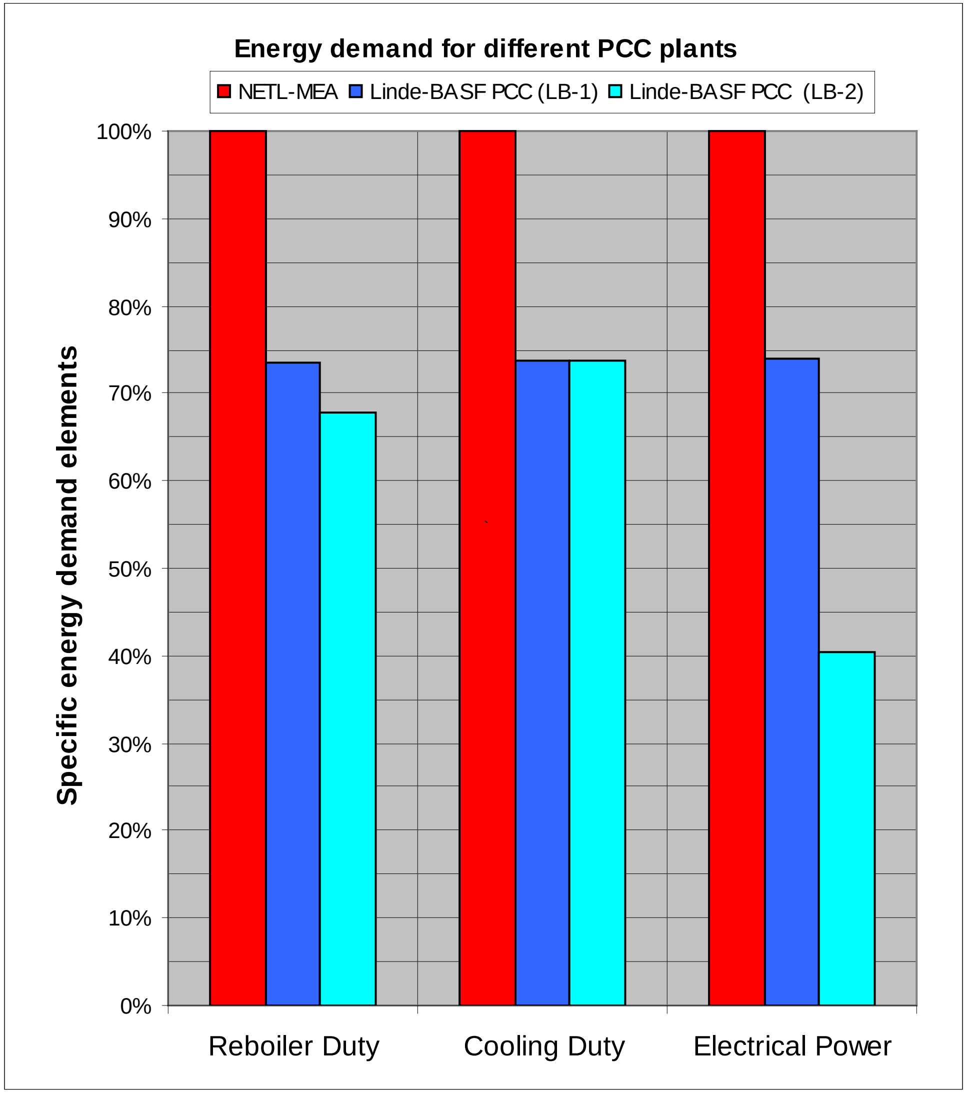

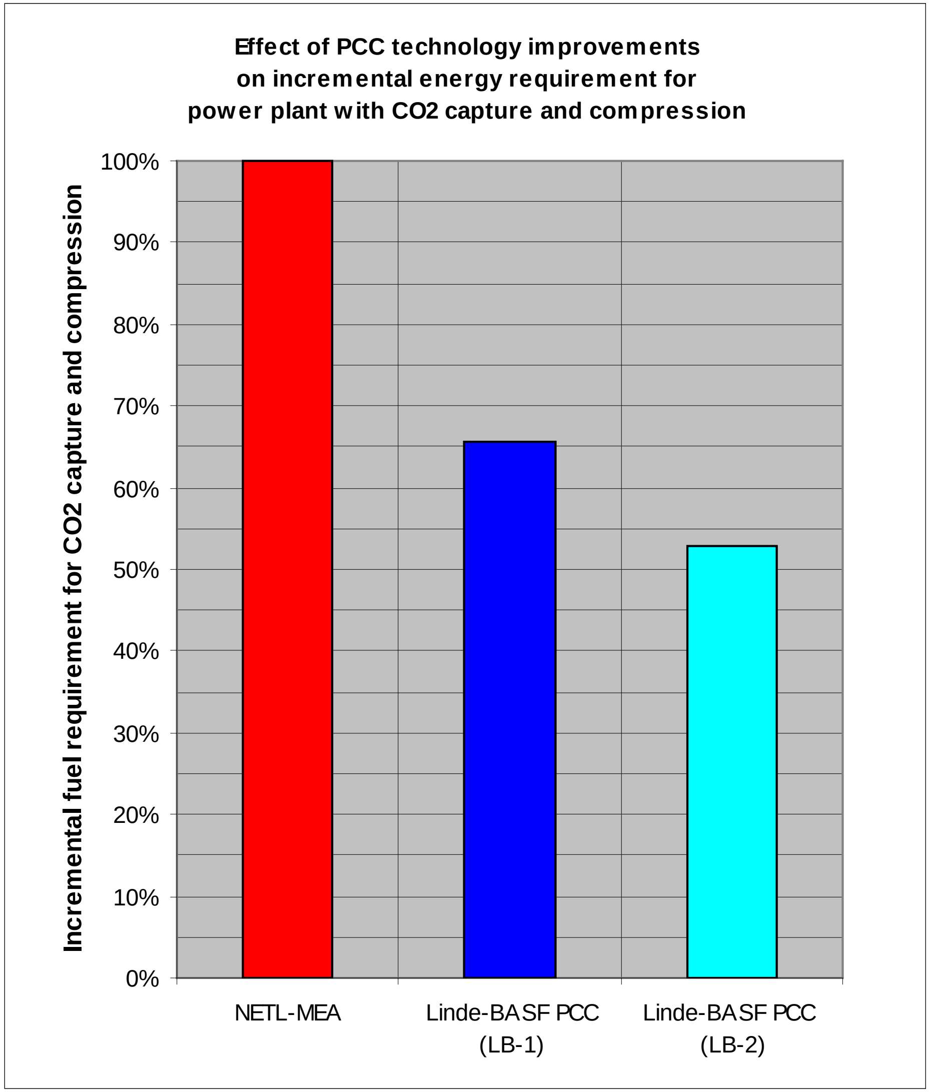

* Reference Case # 10 of DOE-NETL 2007/1281 Report

Total PCC Plant Cost

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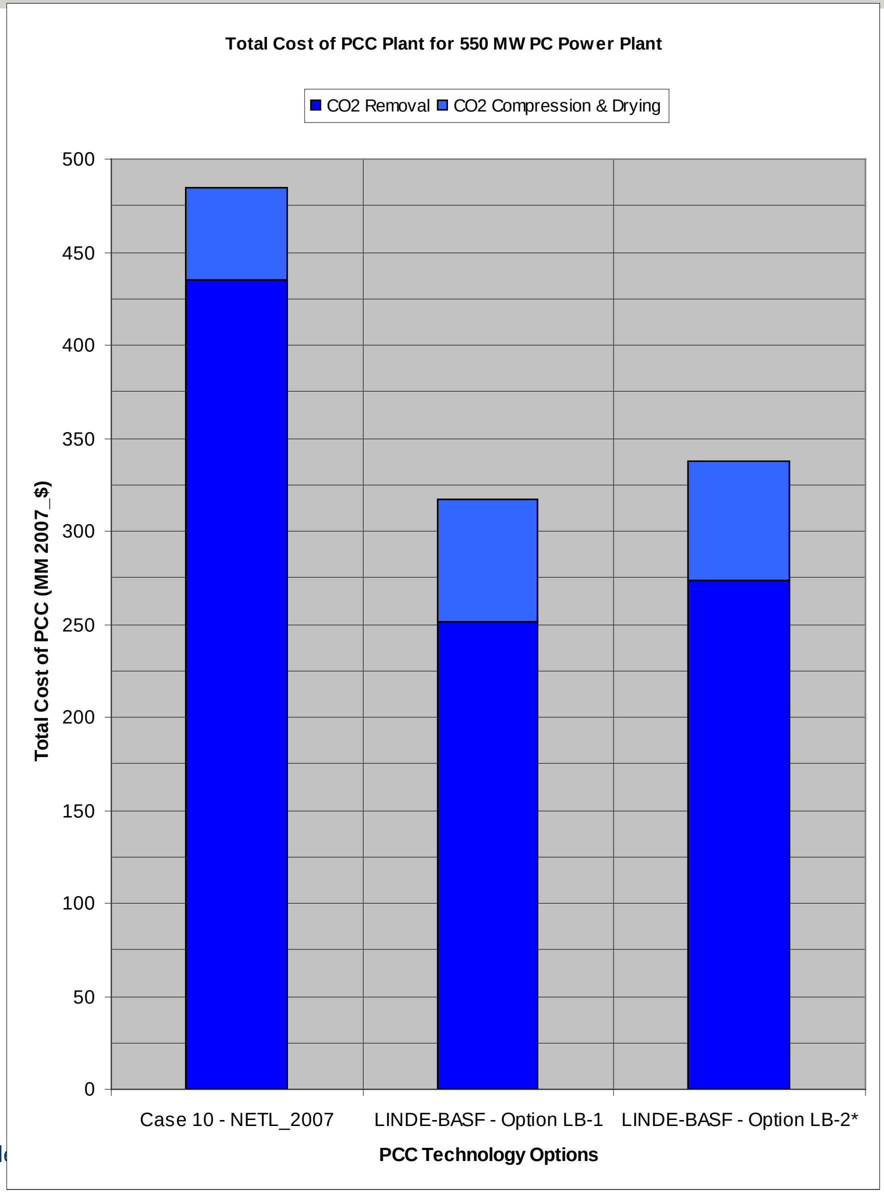

Significantly reduced total PCC plant Cost relative to DOE/NETL 2007 Reference Case #10 due to

1. Reduced coal combustion (CO_2 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

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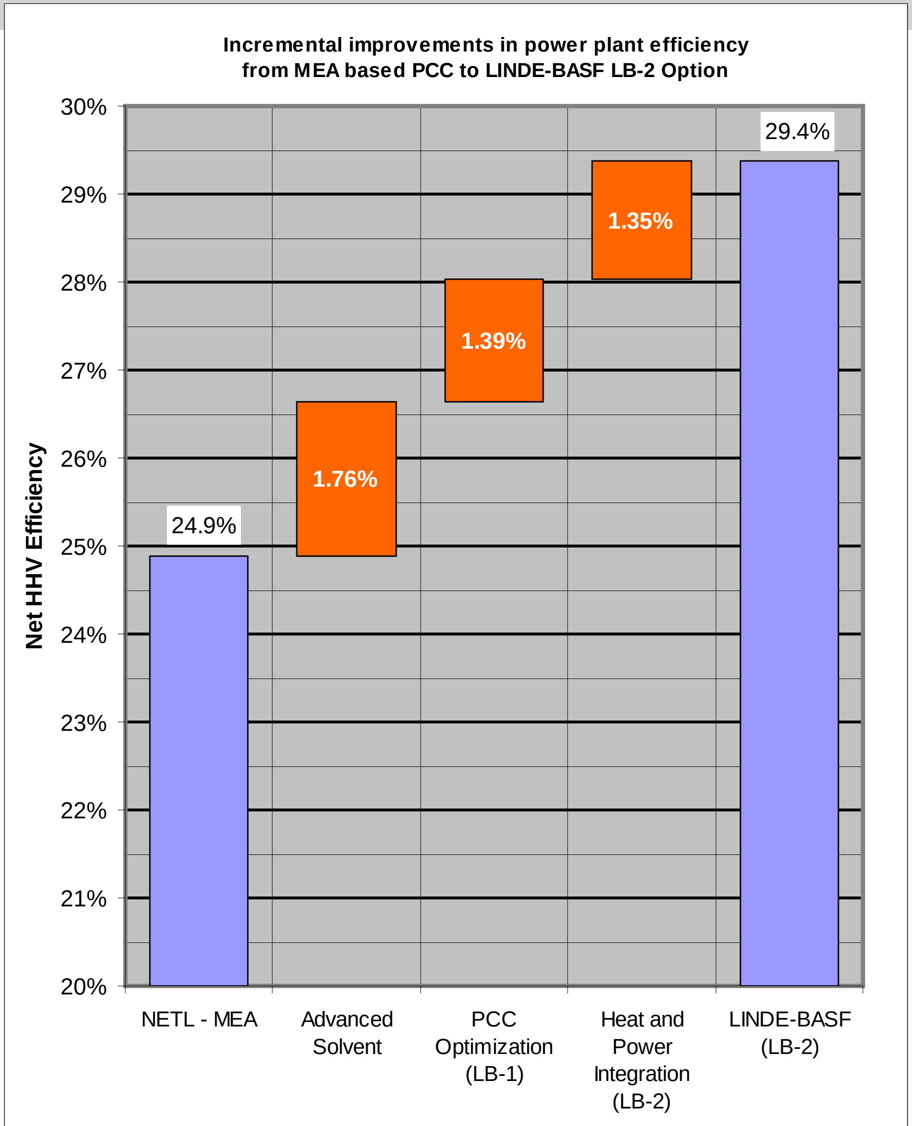

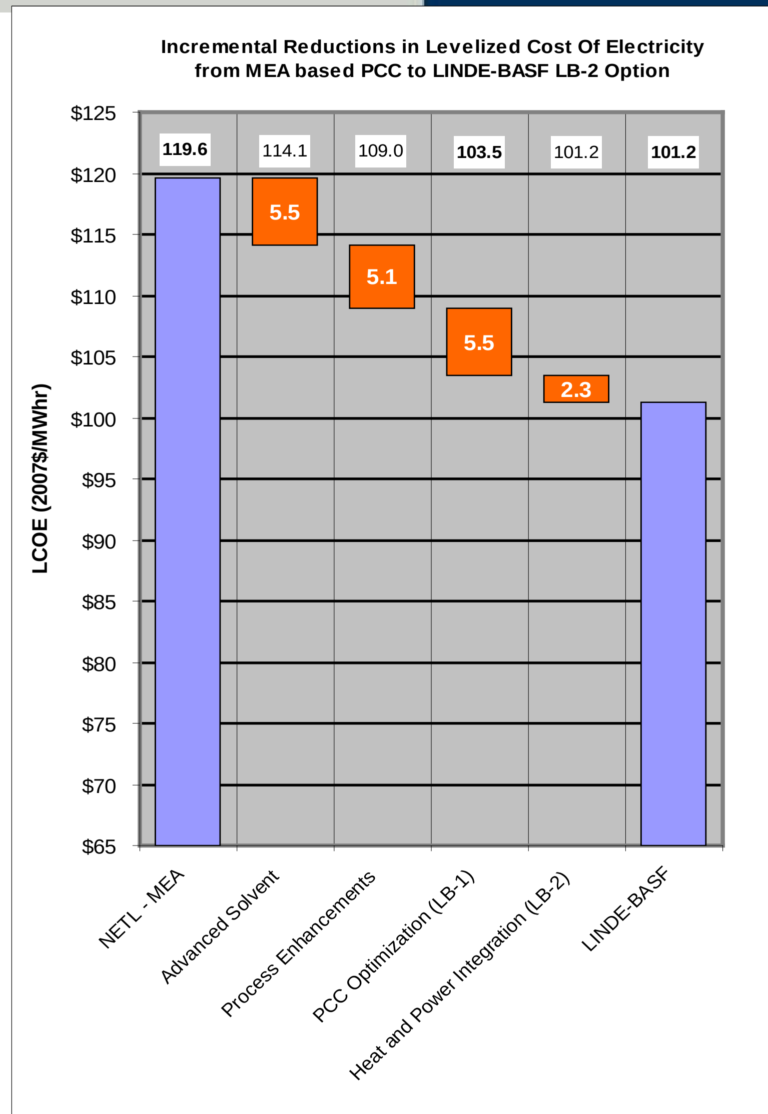

Source: Project DE-FE0007453 Techno-economic analysis of 550 MWe PC power plant with CO2 capture, May 2012.

Detailed engineering timeline: Key dates

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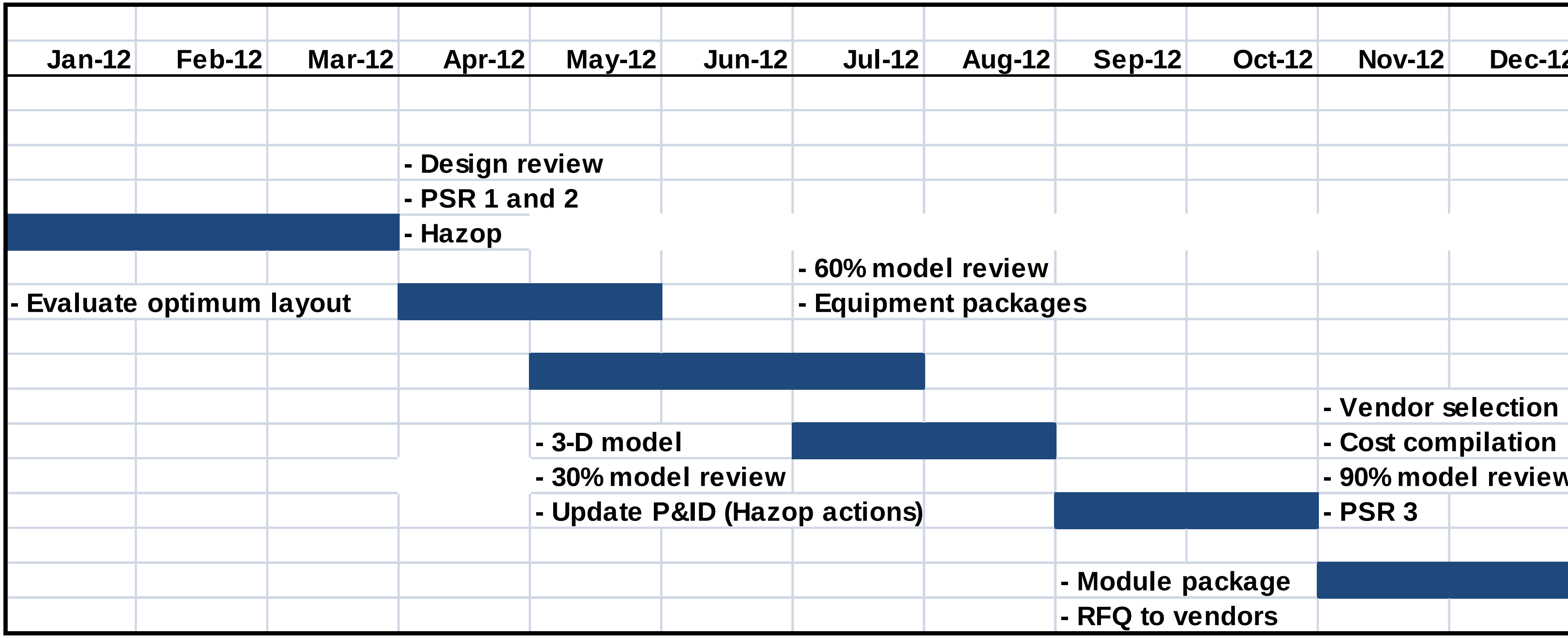

PSR: Process Safety review; P&ID: Process and Instrumentation Diagrams; RFQ: Request for quotes;
Hazop: Hazard and operability study

Task 3: Design Selection
Pilot Plant Layout

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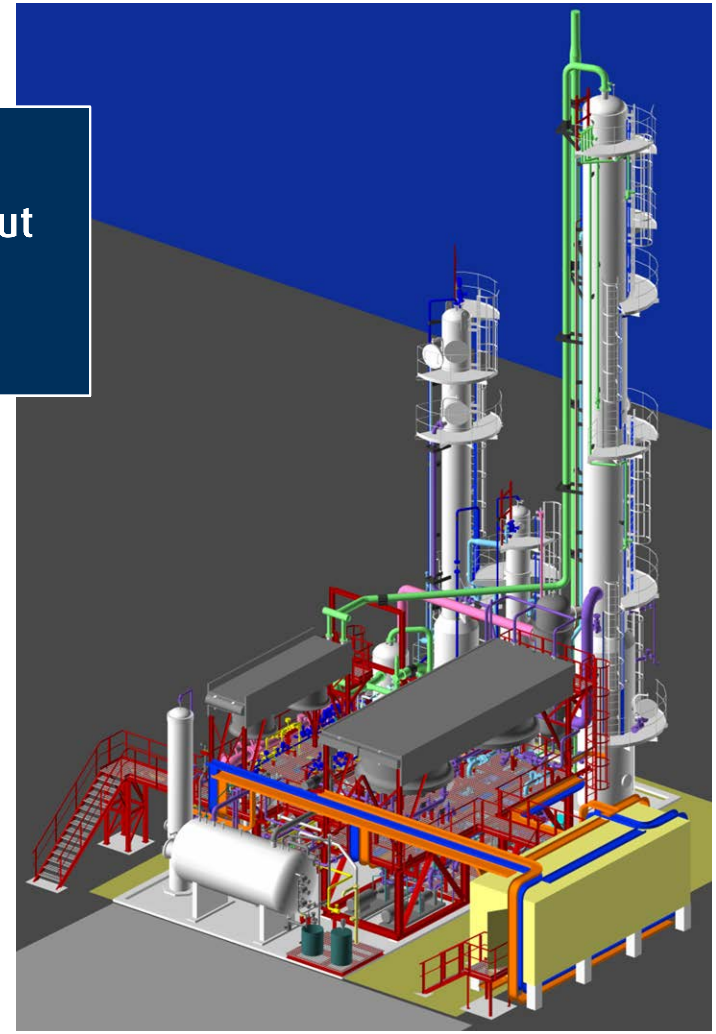
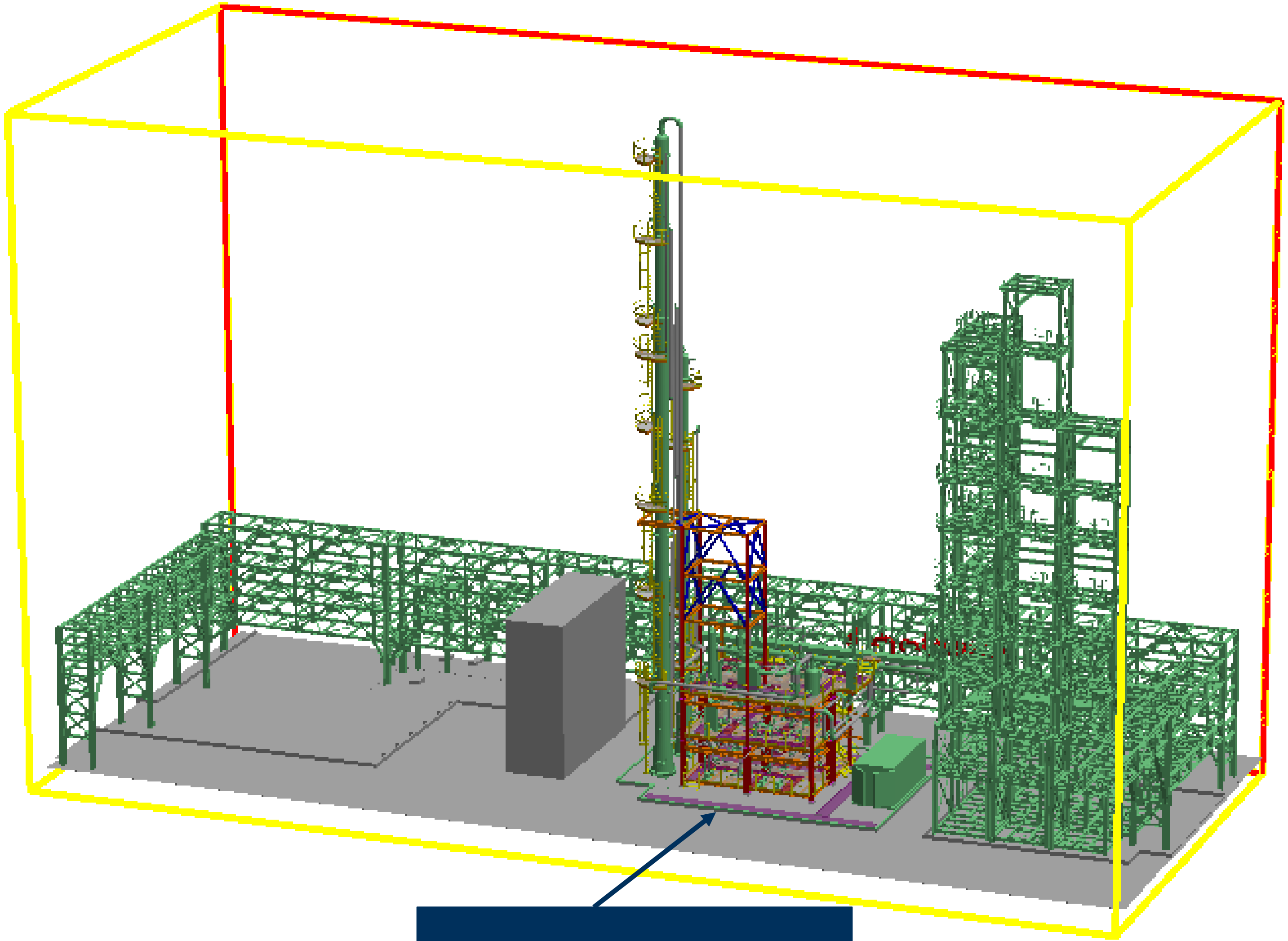
Optimized plant layout
to be investigated



3D Model of NCCC site with Linde-BASF Pilot Plant



Linde-BASF Pilot Plant

3D Model of Linde-BASF 1 MWe Pilot Plant

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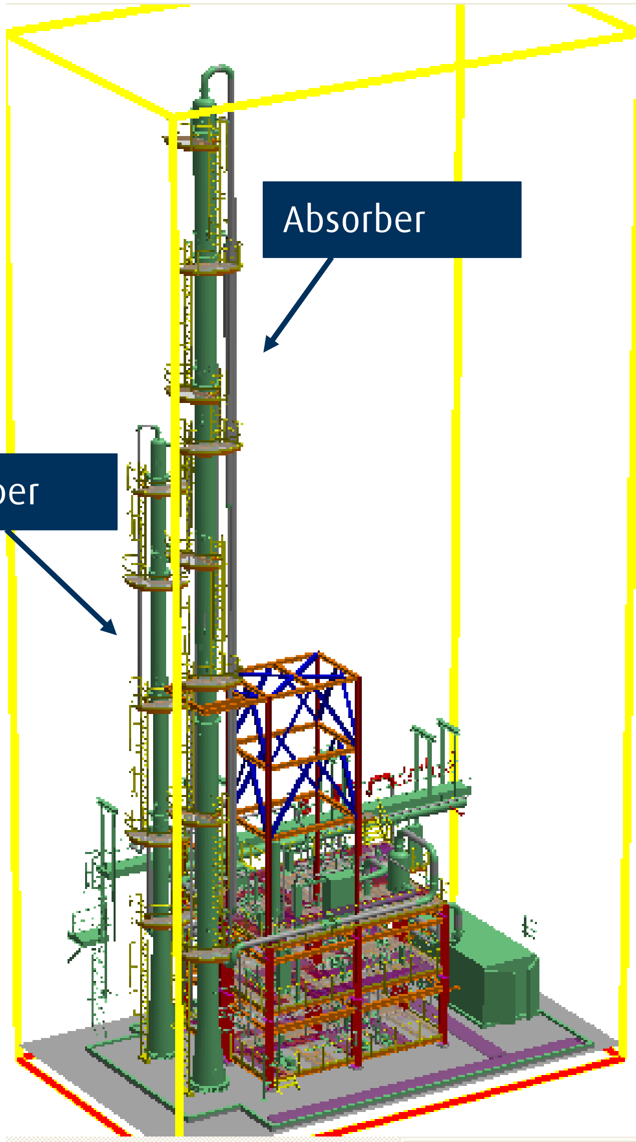

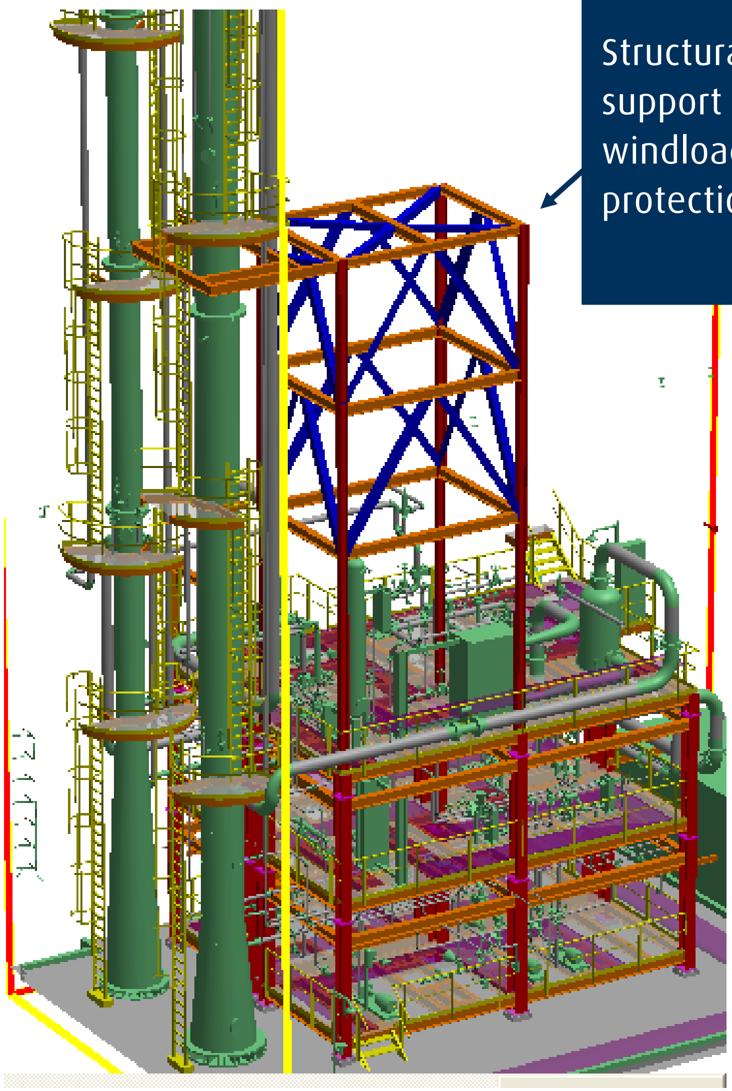

3D Model of Linde-BASF Pilot Plant modular design (3 level structure)

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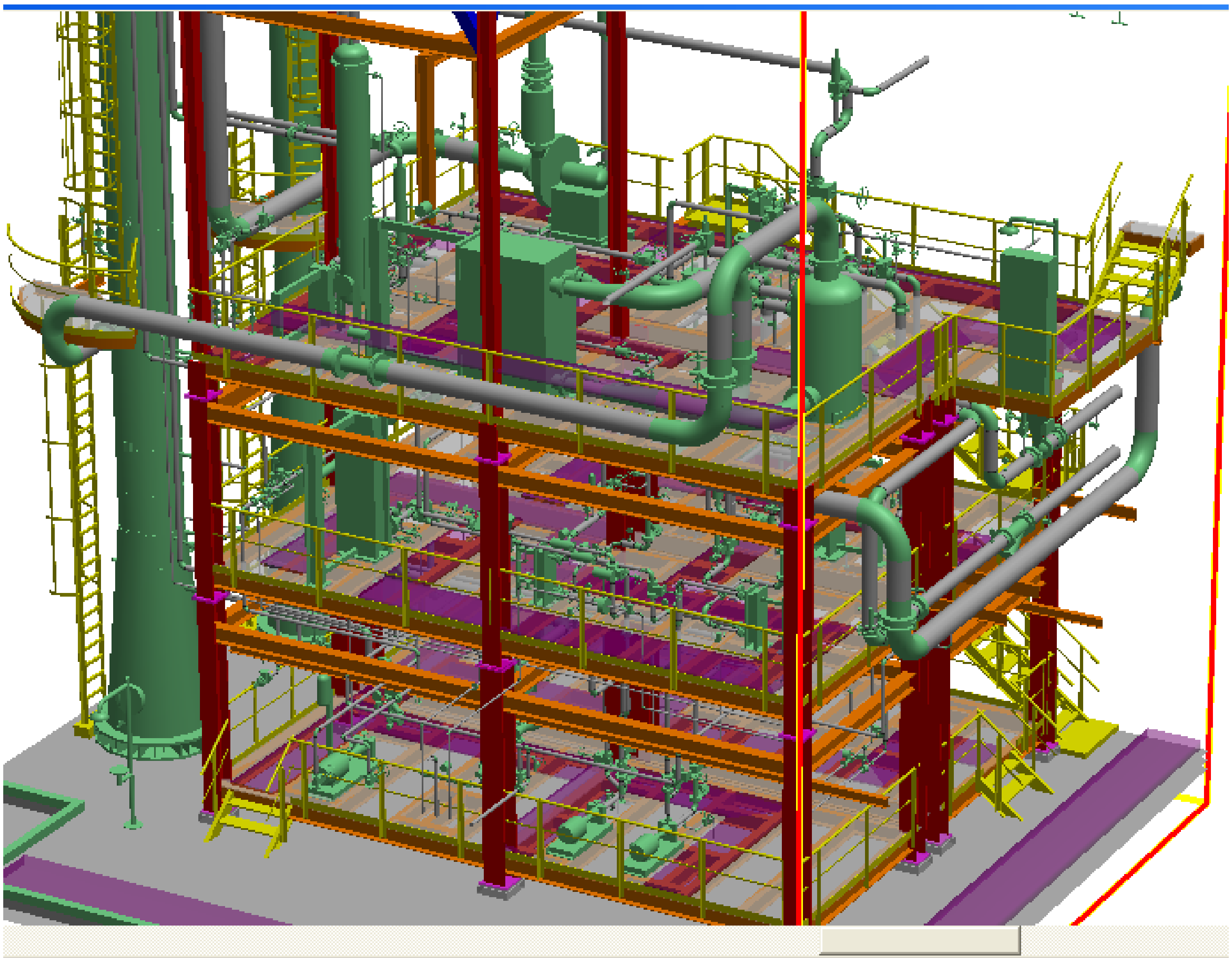

Key design and engineering features and decisions

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- Joint design basis development (Linde and SCS/NCCC) for the nominal 1 MWe pilot plant
- Leveraged Niederaussem pilot plant experience for early design selection decision on target solvent, pilot plant preliminary sizing, process control and analytical sampling and measurement
- Targeted 1 m absorber diameter size, leading to testing capability to 30 TPD CO2 or 1.5 MWe equivalent – confirmed utility availability with upside margins
- Integrated modeling approach for detailed engineering – start with the existing NCCC facility model with tie-in points defined and integrated into pilot plant model to avoid conflicts in build phase
- Equipment and module packages sent to multiple vendors and vendor selection performed based on cost, capability and eagerness for involvement in project
- Concrete column sections evaluated but determined to impact project timeline significantly – currently allowing for swapping the SS bottom section of absorber with concrete section.
- Concrete column section engineering design to be completed in BP2 and cost proposal made during the continuation request for BP3.
- Current pilot plant equipment procurement and build schedule (BP2) requires BP2 timeframe extension by 3-months. Will explore improving the schedule.

Project progress: Key Project Milestones (Budget Period 1) Status

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) – completed 01/09/2013 √
- Complete initial EH&S assessment (10/31/2012) – Completed 12/14/2012 √
- Complete detailed pilot plant engineering and cost analyis for the 1 MWe pilot plant to be tested at NCCC (01/31/2013) Planned for completion by 01/31/2013

Status against Budget Period 1 decision point success criteria

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Decision Point	Basis for Decision/Success Criteria	Status
Completion of Budget Period 1	Successful completion of all work proposed in Budget Period 1	On track
	Demonstrate a 10% reduction in capital costs with Linde-BASF CO2 capture process	30.5 to 34.7% for PCC and 16.6 to 17.3% for integrated power plant
	Demonstrate a LCOE increase of less than 65% over the baseline	62.2% and 58.8% for 2 options considered
	Submission of an Executed Host Site Agreement	Completed
	Submission of a Topical Report – Initial Techno-Economic Analysis	Completed
	Submission of a Topical Report – Initial EH&S Assessment	Submitted
	Submission of a Topical Report – Detailed Pilot Plant Engineering and Cost Analysis	By 1/31/2013
	Submission and approval of a Continuation Application in accordance with the terms and conditions of the award	Presentation to DOE-NETL on Jan 14, 2013

Acknowledgement and Disclaimer

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

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PCC Technology & Update on DOE Project

CCUS Activities & Focus Areas

Linde Focus Areas

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Key Goal

- Develop repeatable commercial-scale projects
- Continue focus on technology advancement

Challenges

- Carbon value, lack of planning certainty
- Risk-sharing & value-sharing of emitter, capturer, user

Technology Development

- **Pre-Combustion:** Rectisol advancements, improved integration
- **Post-Combustion:** commercial-scale demo, 3rd gen technology
- **Oxy-Fuel:** Advanced HP oxy-fuel

Industry & Government Collaboration

- Coal Utilization Research Council (**CURC**)
- National Enhanced Oil Recovery Initiative (**NEORI**)

Project Activities

- **Summit's Texas Clean Energy Project (TCEP) –** Odessa, TX
- **UK DECC Projects:** including oxy-fuel & pre-combustion
- Various **EOR-driven** opportunities in US and abroad including NG-based CCUS

Commercial Areas of Focus

- "Bankable" arrangements
- Risk-sharing models

CCUS – It can be done!!

< 20% of people attempting to climb Mount Everest are successful in reaching the summit

… but some do!

How can we get CCUS projects over the finish line with today's "carbon valuation"??

Continued technology advancement, creative business models & rational risk-sharing