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

Project Continuation Request for Initiating Budget Period 2 Tasks

DOE funding award DE-FE0007453

Krish R. Krishnamurthy, Linde LLC
January 14, 2013
Pittsburgh, PA

Purpose and Presentation outline

Purpose: Present the budget period 1 progress and accomplishments and actual status of achievement against success criteria. Present project continuation request and agree with DOE-NETL to proceed to Budget Period 2 tasks.

Presentation Outline:

- Project background
- Project progress and accomplishment in Budget Period 1 (to date)
- Detailed engineering of the 1 MWe pilot plant and the firm cost estimates
- Key Budget Period 1 milestone status
- Actual status of achievement against success criteria for Budget Period 1 tasks
- Project continuation request and agreement with DOE-NETL to proceed to Budget Period 2 tasks

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

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 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	$2,670,773	$9,367,628	$2,754,564	$14,792,365
Cost Share	$667,943	$2,341,907	$688,641	$3,698,091
Total Project	$3,337,716	$11,709,535	$3,443,205	$18,490,456

Cost share commitments:

Linde: $3,107,352

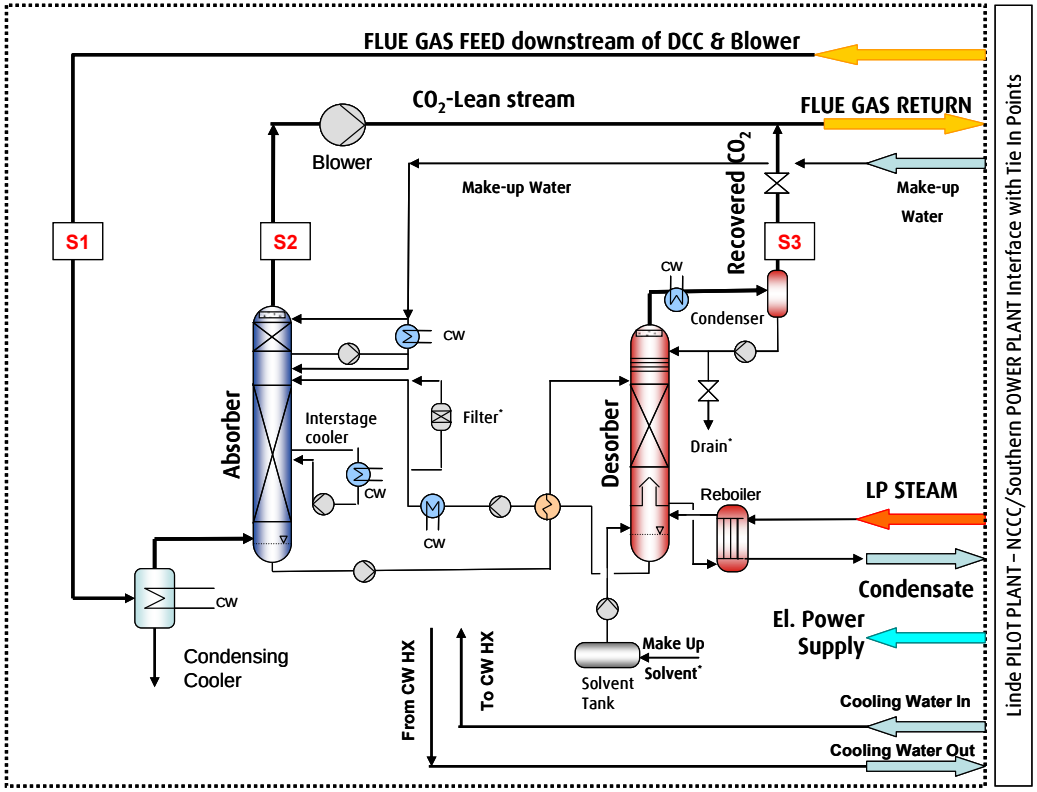
BASF: $ 493,360

EPRI: $ 97,379

Project progress and accomplishments by task (Budget Period 1)

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

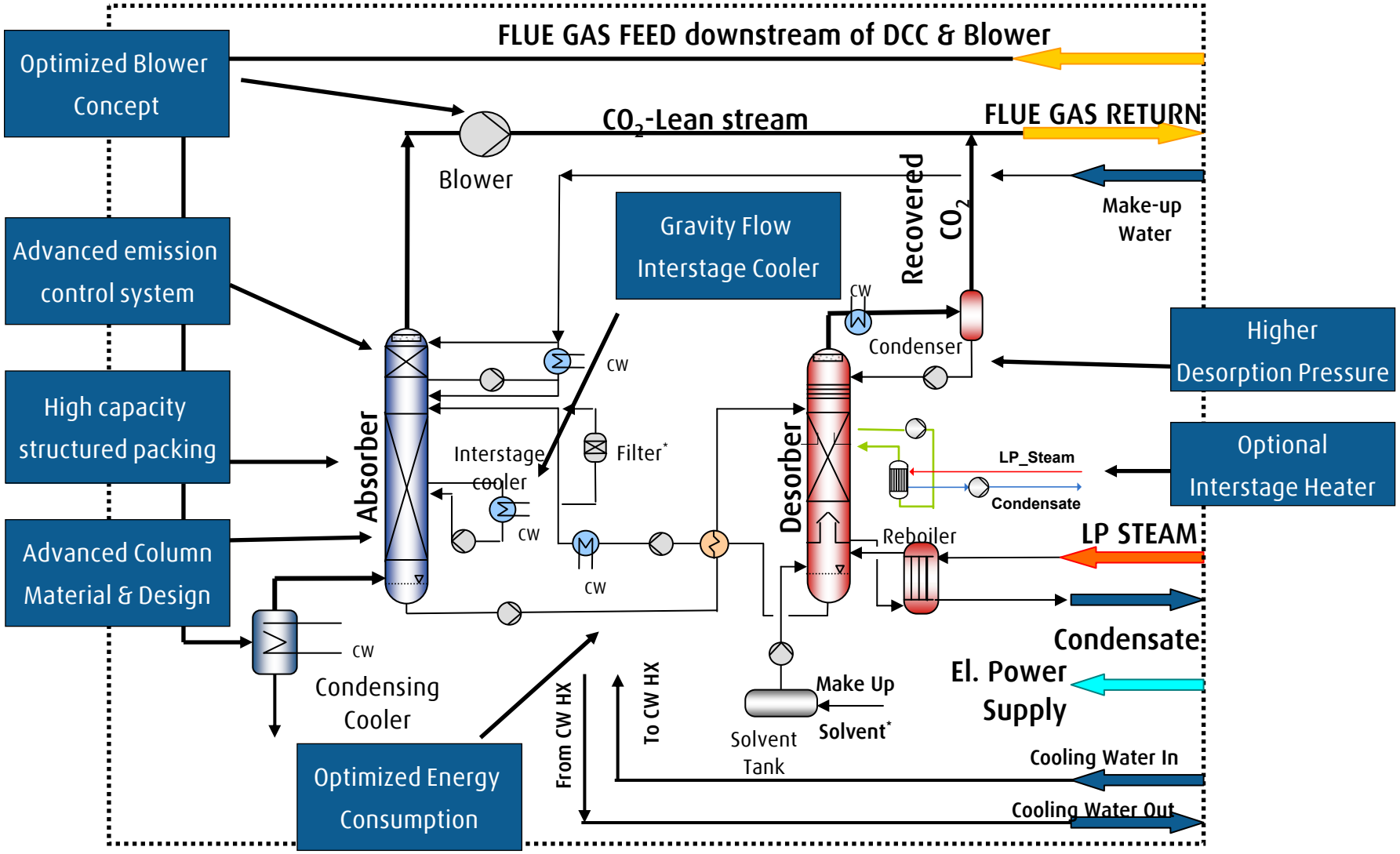
Simplified process flow diagram of the 1MWe pilot plant



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

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

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

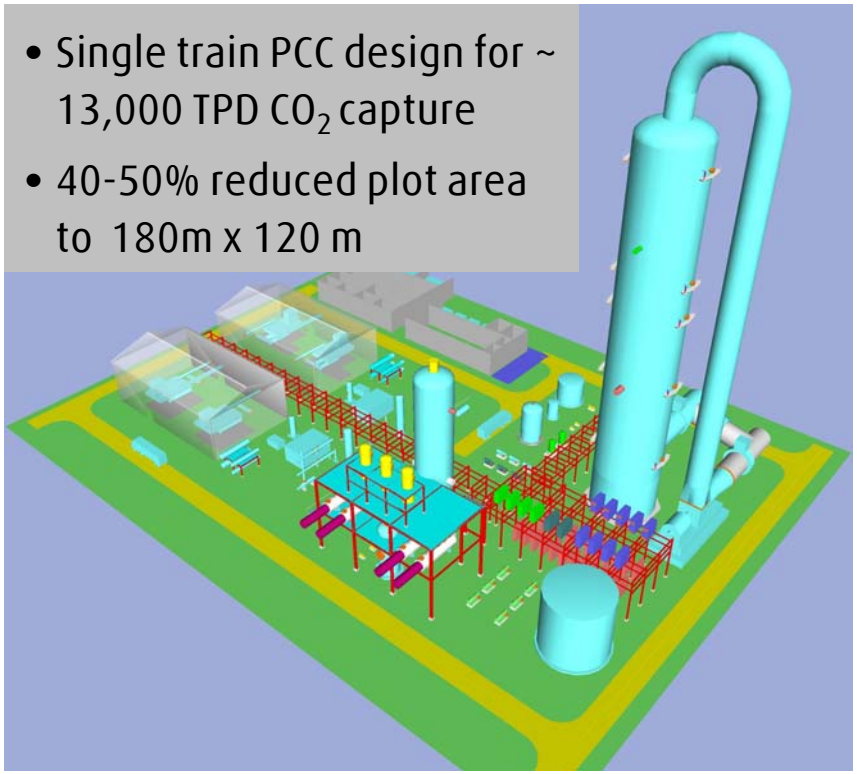
as per DE-FOA-0000403 requirements

- 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

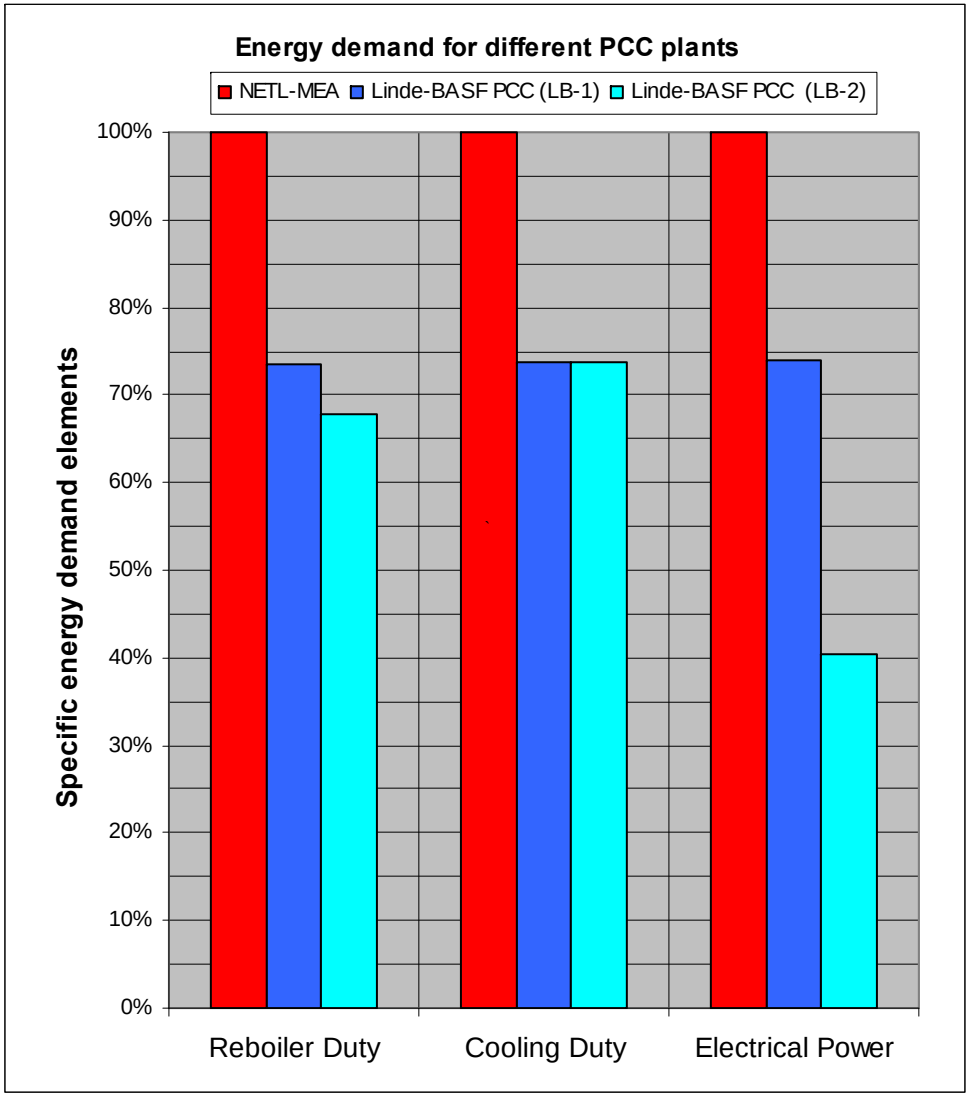
UniSim Design Suite R390, integrated with

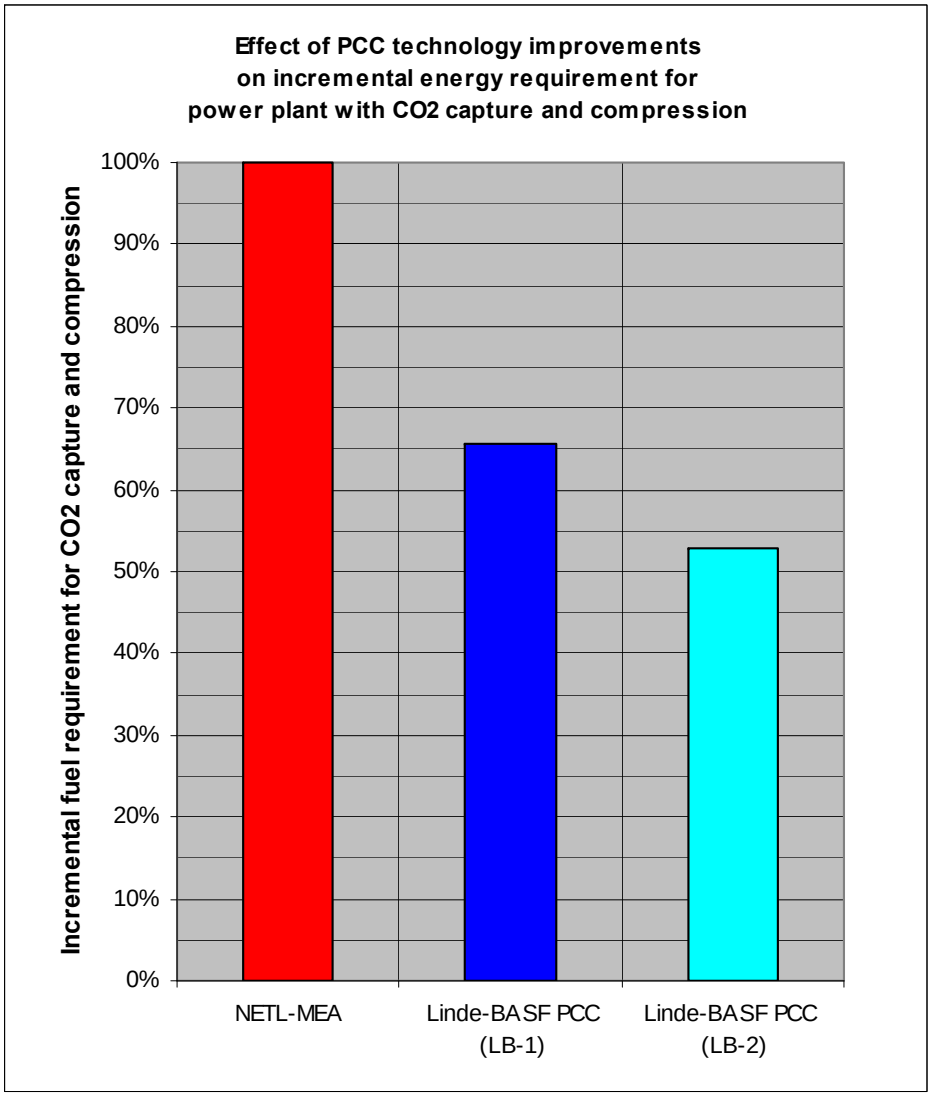
- Brian Research & Engineering ProMax® software for PCC parametric optimization
- BASF's proprietary package for rigorous solvent performance predictions

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



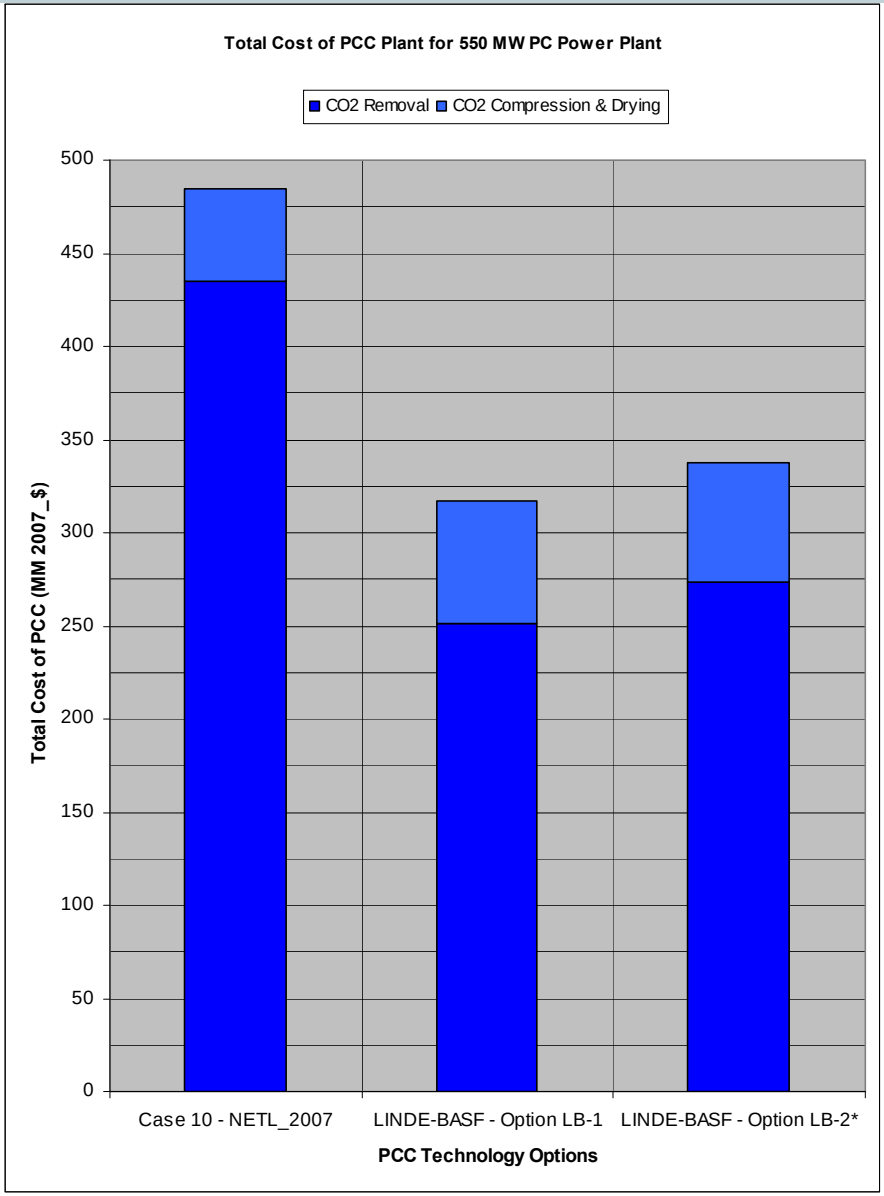
Comparative PCC Performance Results
Linde-BASF vs Reference DOE/NETL Case*





* 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 (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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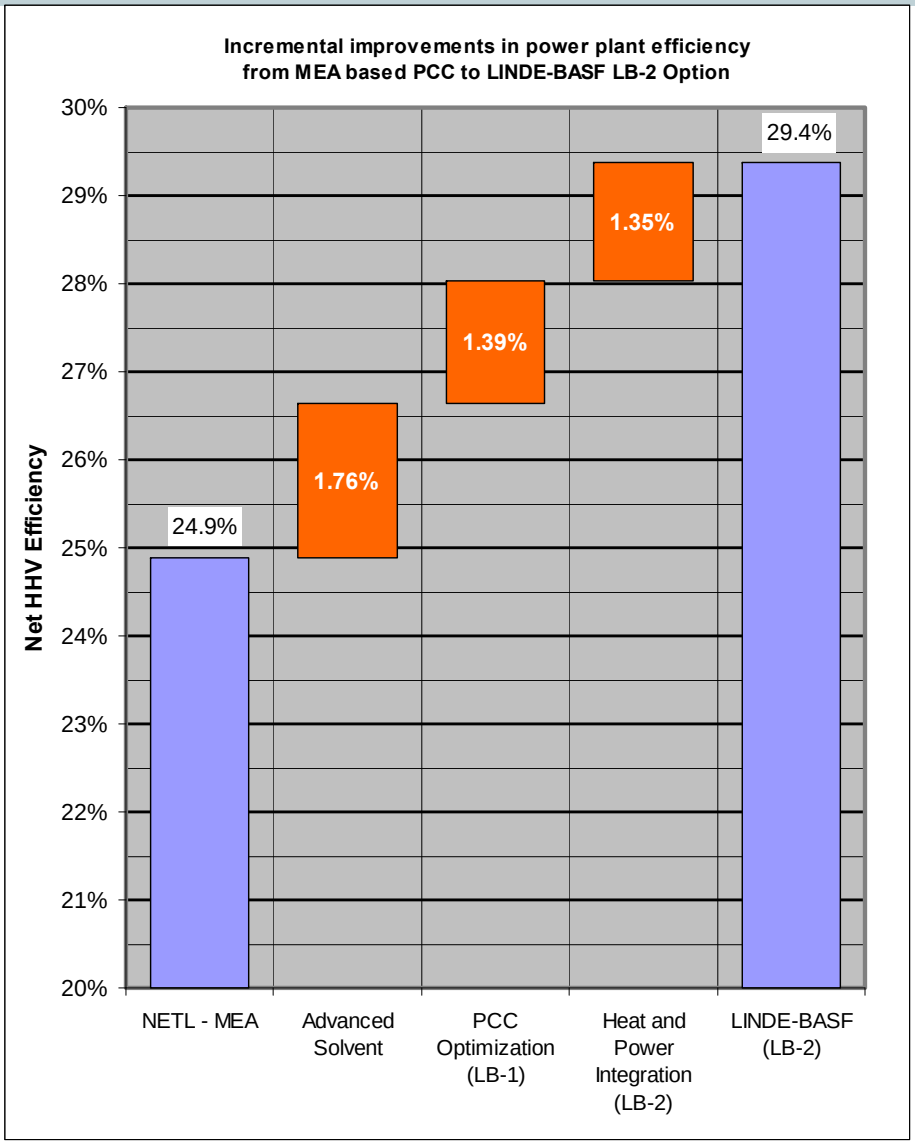
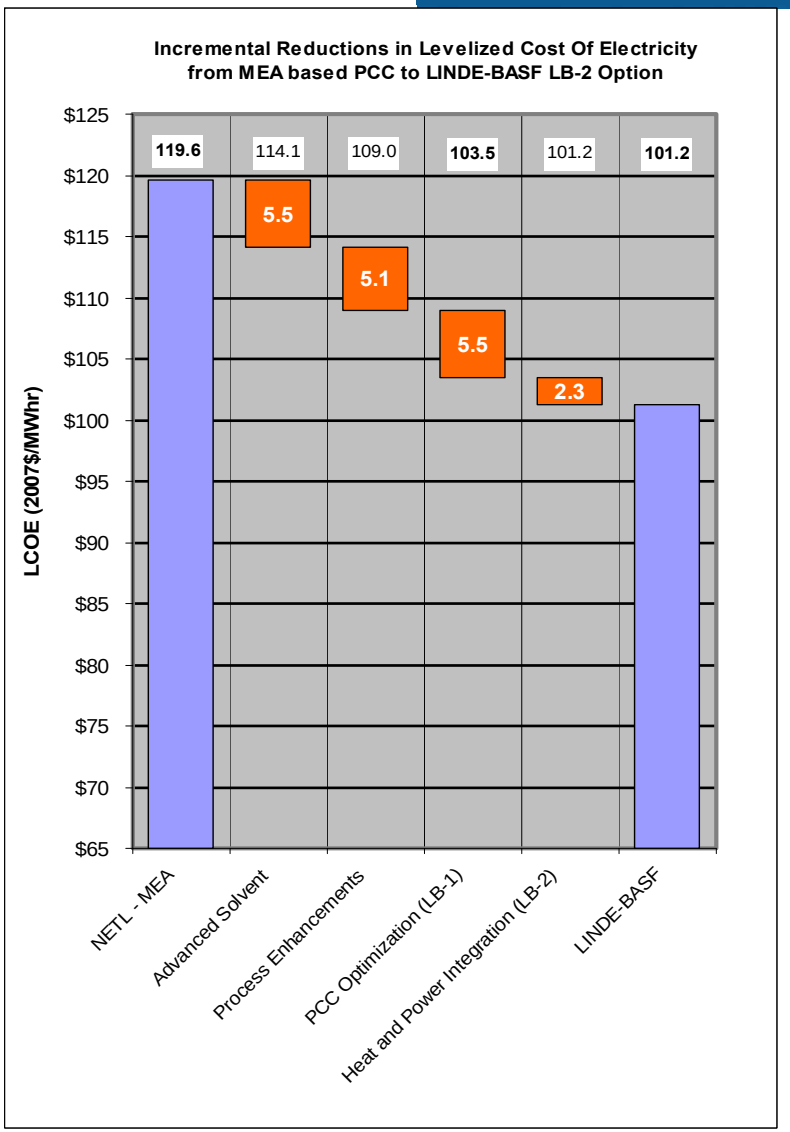
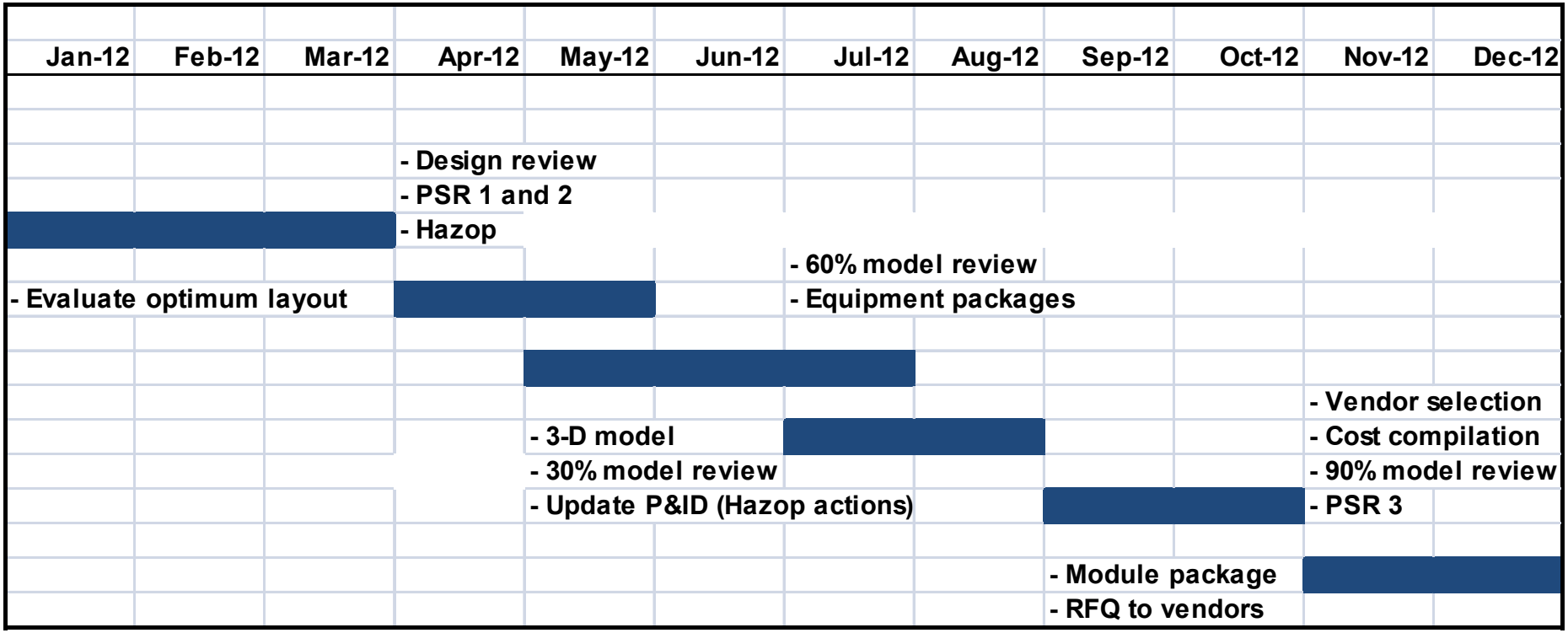




Source: Project DE-FE0007453 Techno-economic analysis of 550 MWe PC power plant with CO2 capture, May 2012.

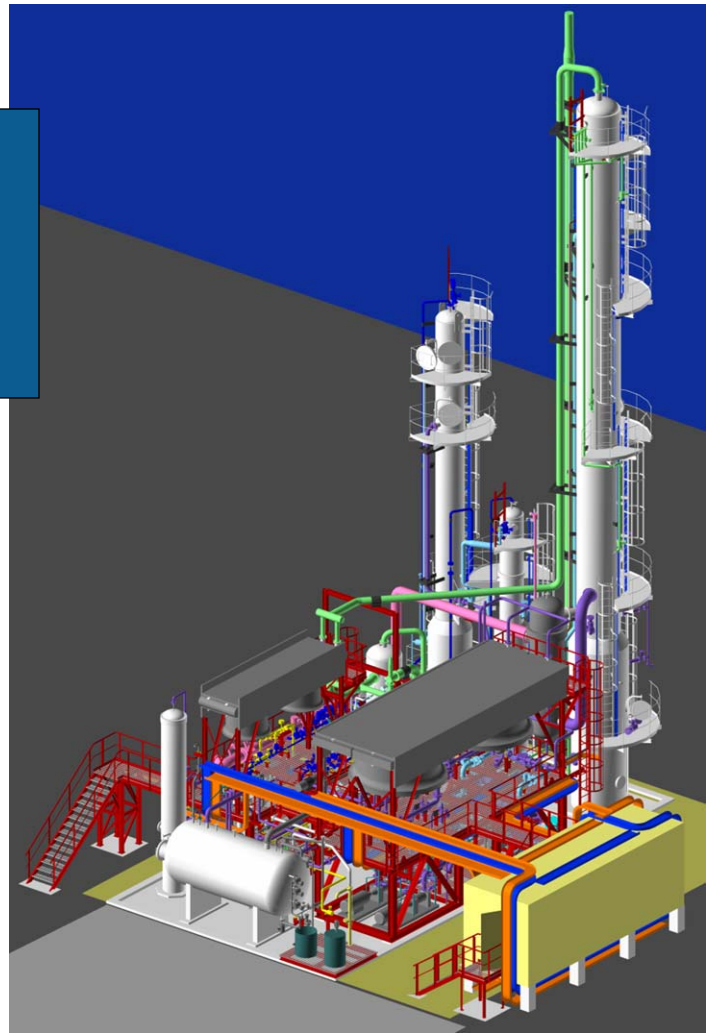
Detailed engineering timeline: Key dates



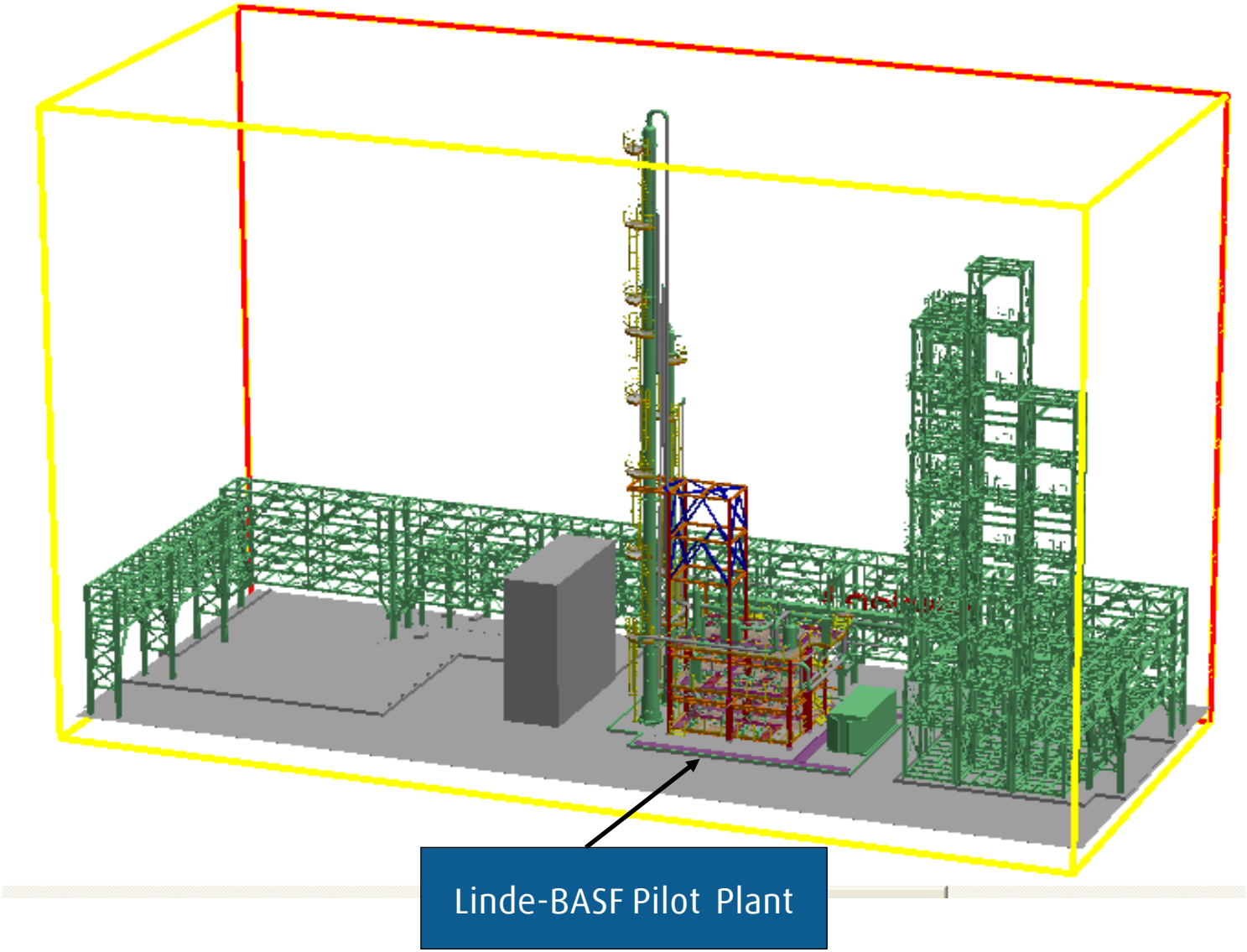
PSR: Process Safety review; P&ID: Process and Instrumentation Diagrams; RFQ: Request for quotes;
Hazop: Hazard and operability study

Task 3: Design Selection
Pilot Plant Layout

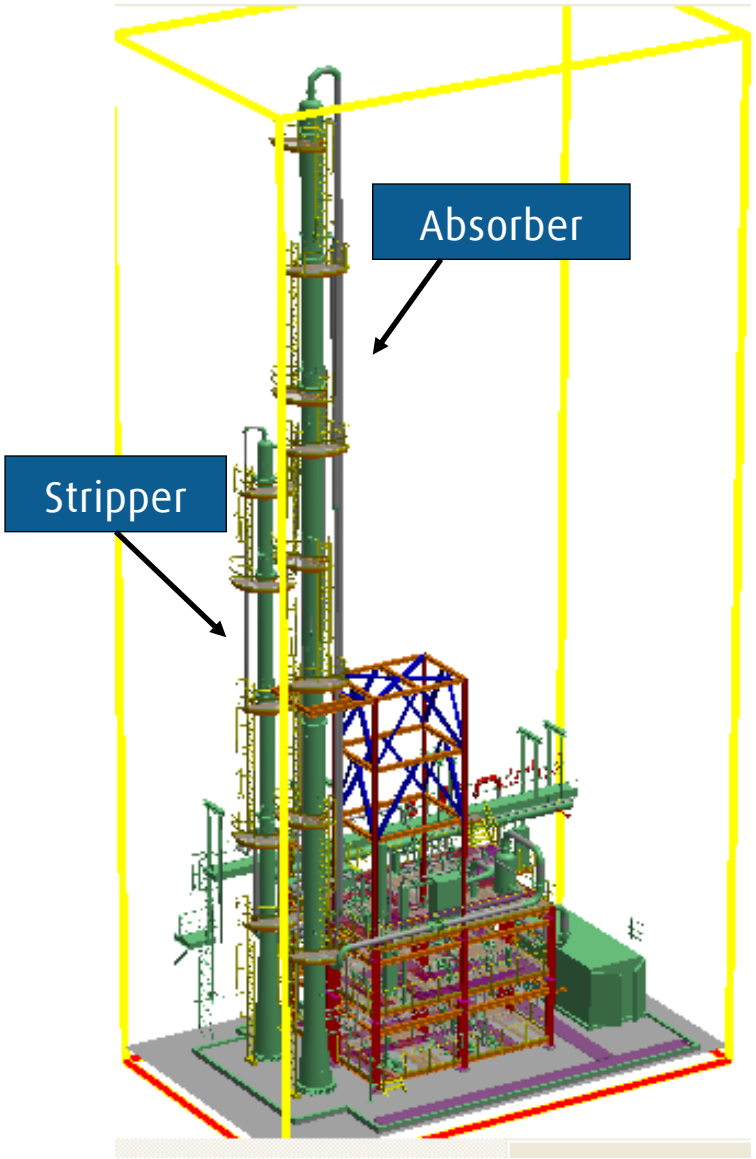
Optimized plant layout
to be investigated

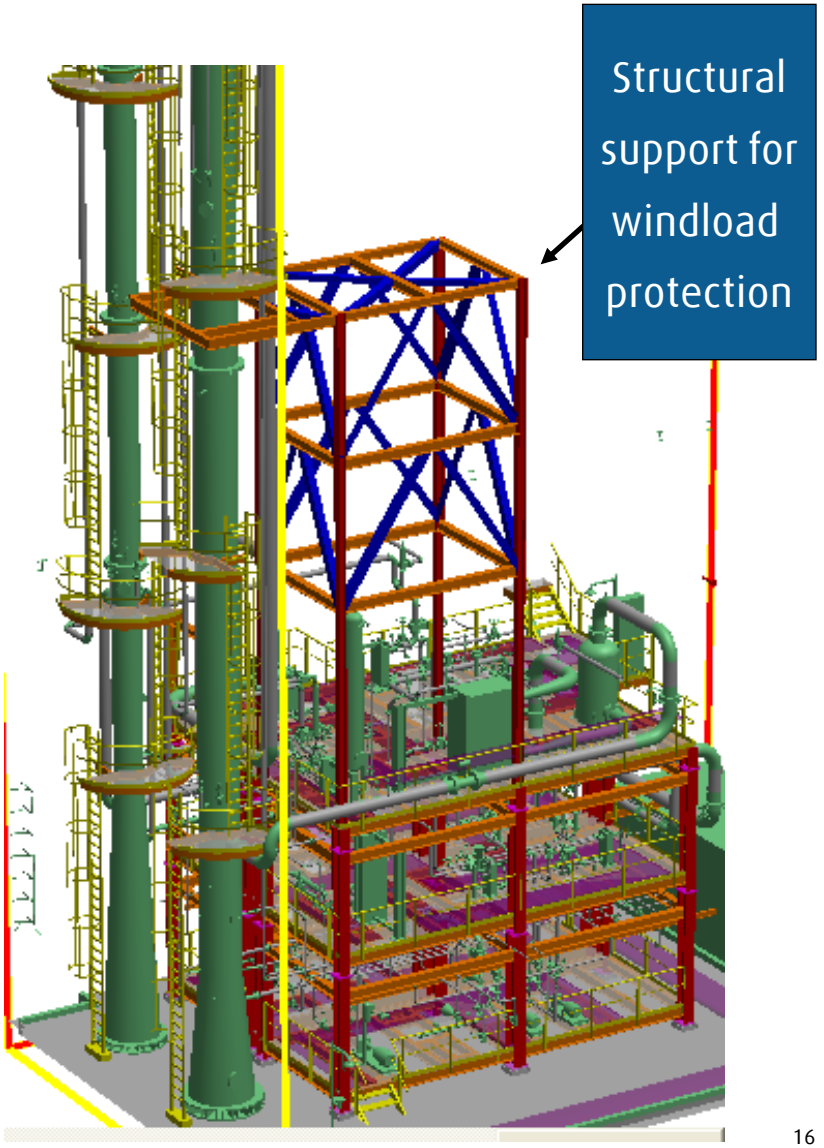


3D Model of NCCC site with Linde-BASF Pilot Plant

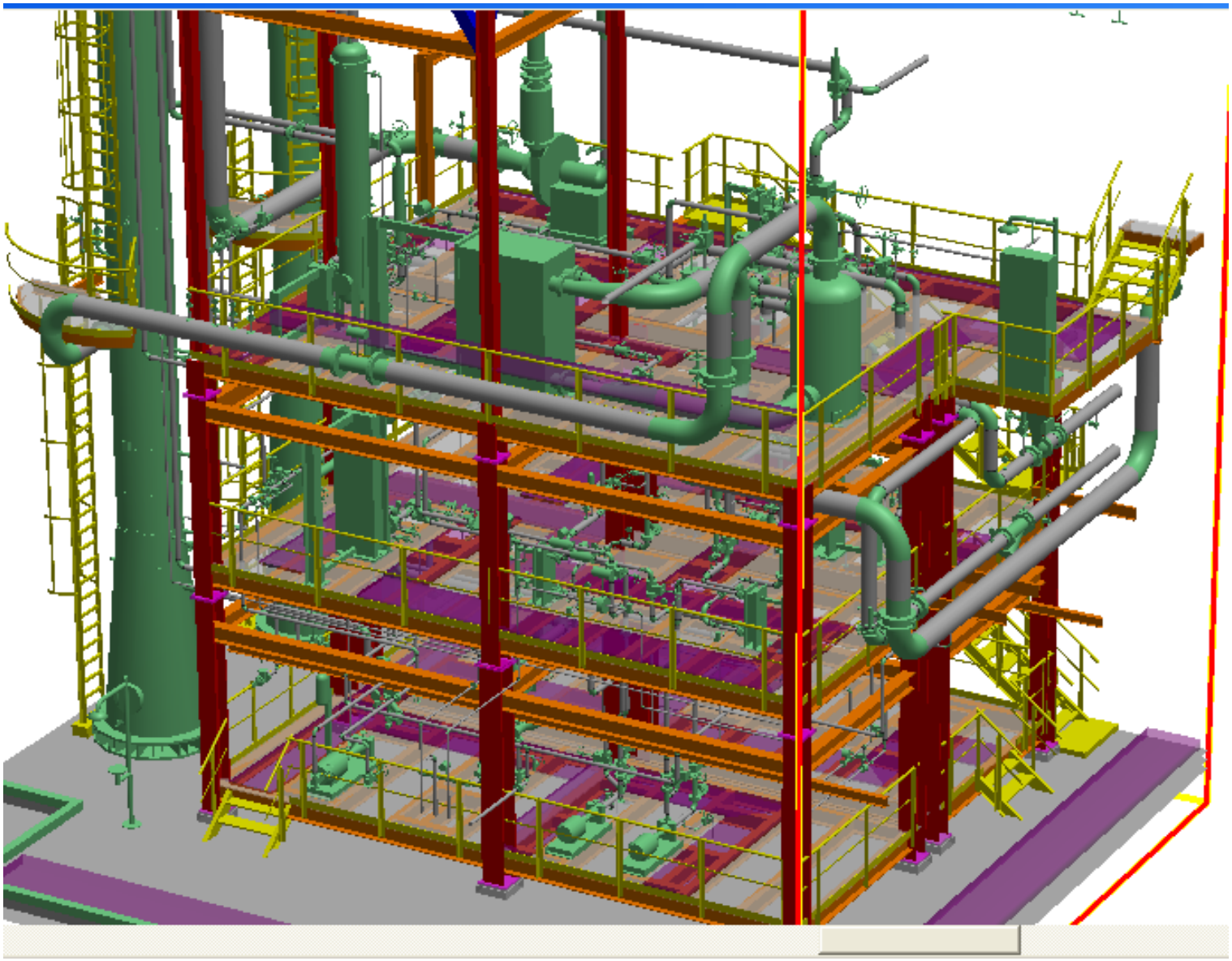


3D Model of Linde-BASF 1 MWe Pilot Plant

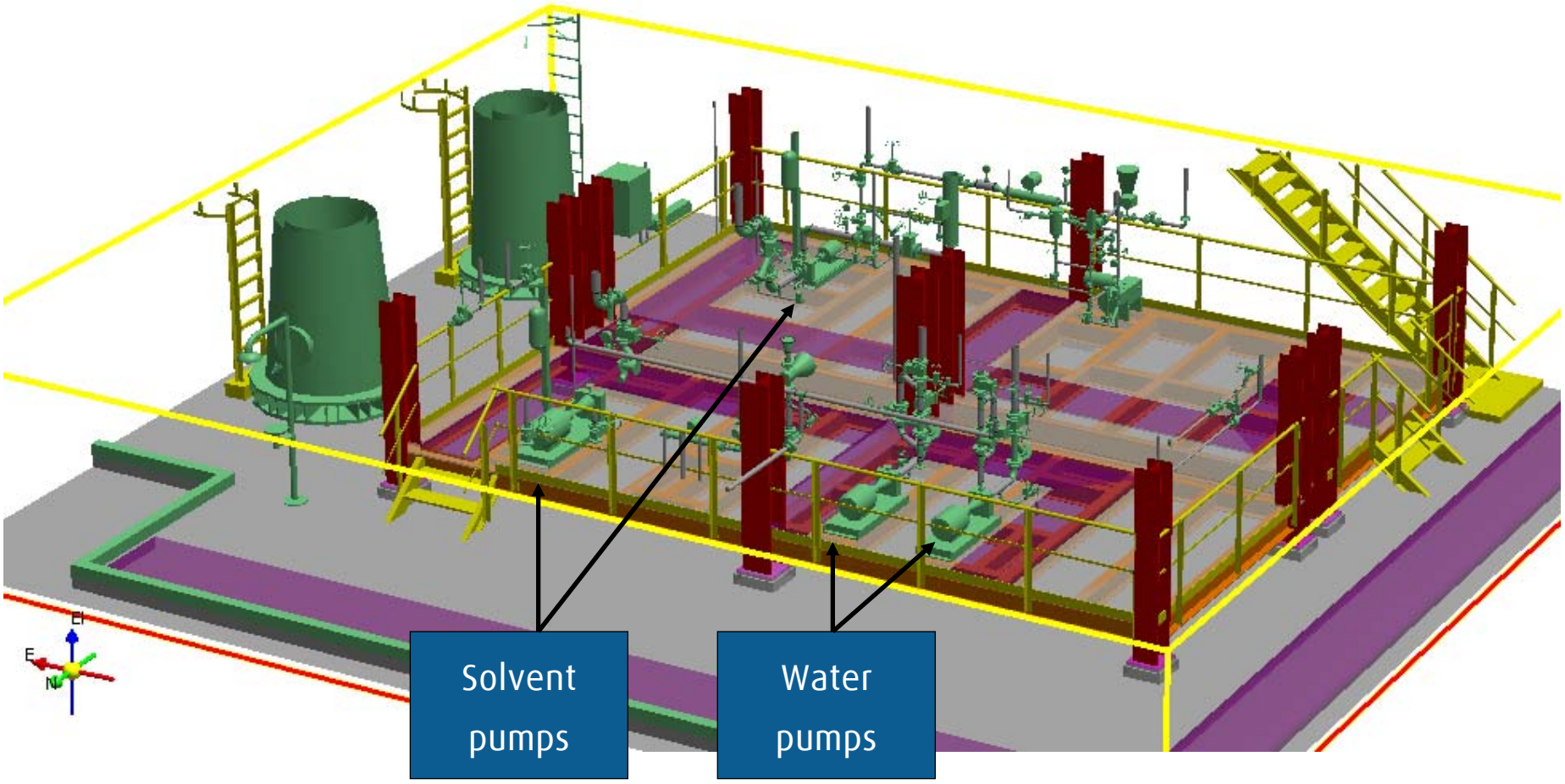




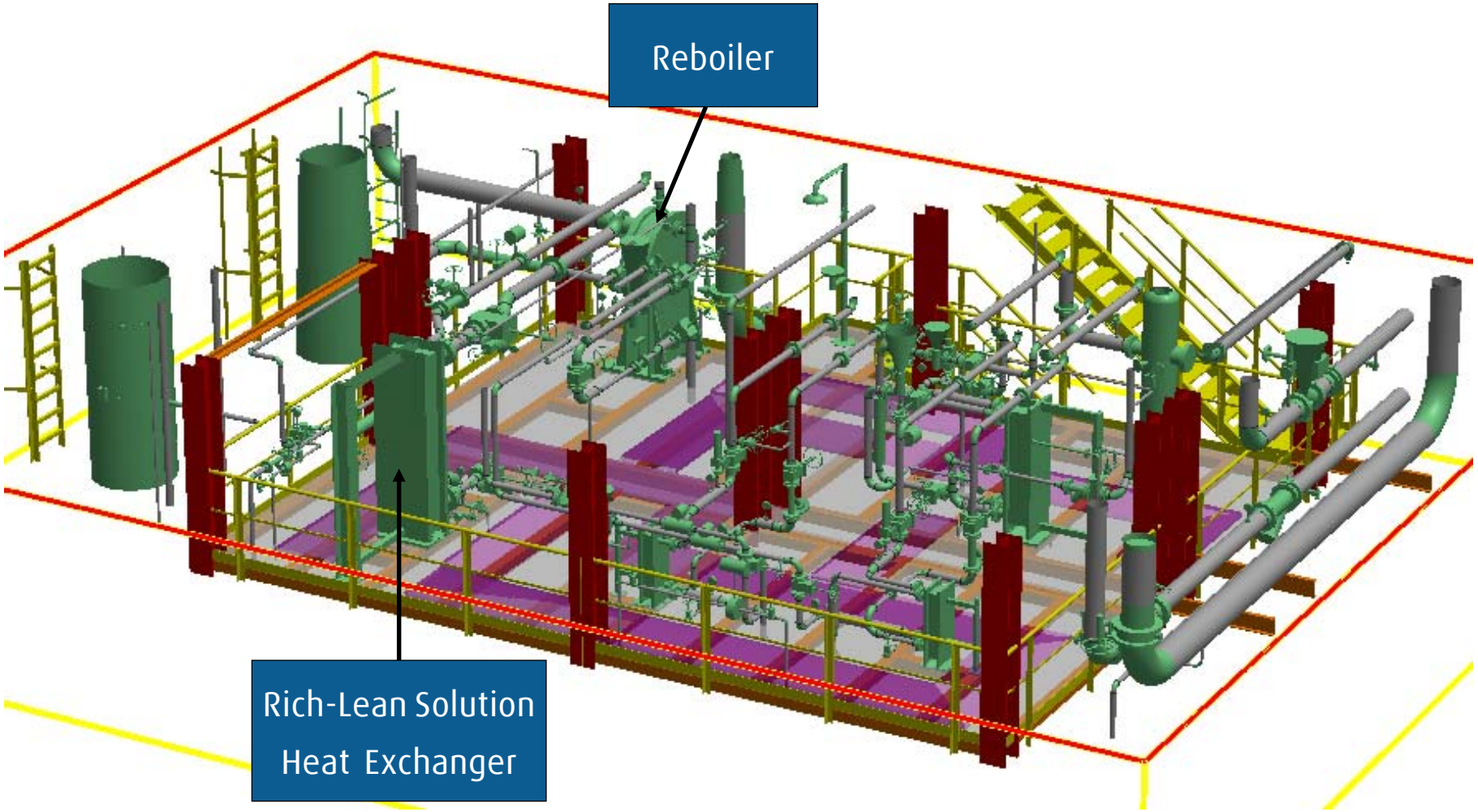
3D Model of Linde-BASF Pilot Plant modular design (3 level structure)



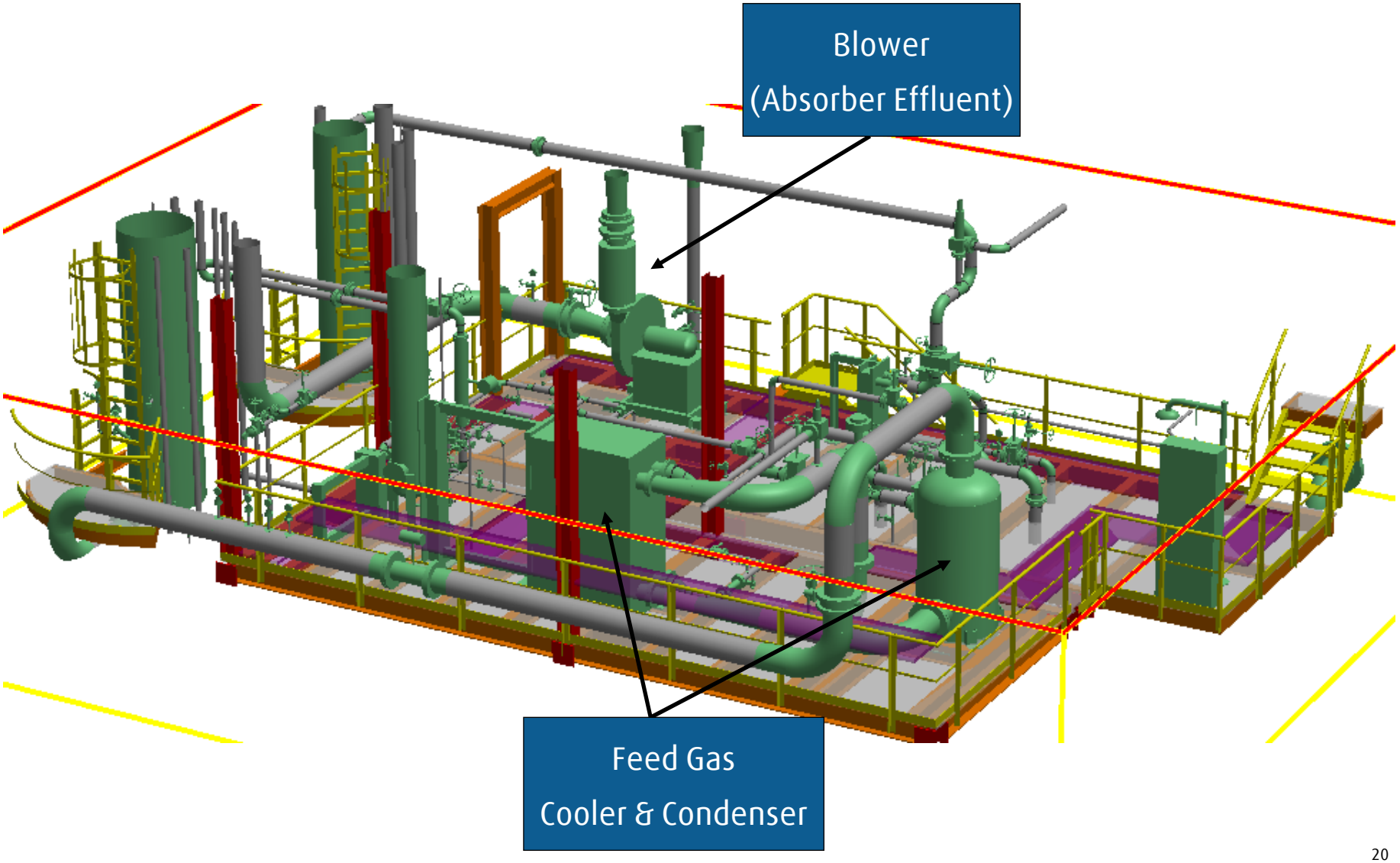
3D Model of Linde-BASF Pilot Plant modules
Level 1 (pumps)



3D Model of Linde-BASF Pilot Plant modules
Level 2 (Reboiler, Heat Exchangers, Eye-wash shower)



3D Model of Linde-BASF Pilot Plant modules
Level 3 (Cooler/Condenser, Blower, Eye-wash shower)



1 MWe Pilot plant firm cost estimates

ITEM	TOTAL COST
Equipment and Modules	
Stripper Column & Absorber Column	$925,539
Stripper & Absorber Column Internals Structured Packing	$166,297
Reflux Drum, Feed Gas Separator, Activated Carbon Filter, & Solution Storage Tank	$181,399
Plate & Frame Heat Exchangers	$190,931
Solution & Wash Water Pumps, Reflux Pumps	$105,612
Analyzer Building with Analyzers, DCS, MCC, UPS	$526,411
Instrumentation, Valves, Gauges, Safety Showers, Fire Alarm System, FRP Piping	$690,381
Total Equipment	**$2,786,570**
Modules	**$3,345,119**
Construction Contracts	
Equipment, Piping, & Analyzer Building Installation, Tie-In Installation	$1,603,475
Installation Assistance for Structured Packings in Columns	$64,980
Field Office	$154,625
Site Construction Manager, HSE Supervisor, QA/QC Supervisor	$464,265
Total Construction	**$2,287,345**
Overall Total	**$8,419,034**

Budget Period 2 Schedule Update

- Original proposal for BP2: 12 months; from March 1, 2013 to February 28, 2014
- BP2 schedule updated based on equipment delivery, module fabrication and construction schedule updates from suppliers
- Critical path: Module fabrication + delivery to site + site installation and tie-in's
- Updated schedule requires BP2 to extend to a 15 month duration: From March 1, 2013 to May 31, 2014
- Attempt will be made to compress schedule by working closely with module fabricator (release engineering early, negotiate schedule improvement etc)
- Request project schedule be updated to change BP2 duration to 15 months.

Key design and engineering features and decisions

- 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

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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

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	This presentation and follow on actions

Project continuation request and agreement to proceed to Budget Period 2 tasks

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- Project team has met all milestones or positioned to complete by end of January 2013
- Proposed technology benefits clearly demonstrated as feasible through techno-economic assessment
- The nominal 1 MWe pilot plant updated firm cost estimates lower than original estimates
- NEPA form completed and DOE-NETL approval obtained
- Host site agreement completed; excellent working relationships established with NCCC team

Project team, therefore, requests:

- Continue project and proceed with Budget Period 2 tasks
- Adjust overall project schedule to increase Budget Period 2 duration by 3 months (from March 1, 2013 to May 31, 2014)
- Update project management plan and SOPO as appropriate

Thank you for your attention!

Project DE-FE0007453
Project continuation request for initiating Budget Period 2 Tasks

Krish R. Krishnamurthy, Linde LLC
January 14, 2013
Pittsburgh, PA