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 3 Tasks

DOE funding award DE-FE0007453

Krish R. Krishnamurthy, Linde LLC, Murray Hill, NJ
Keith Christian, Linde Engineering North America (LENA), Blue Bell, PA
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June 9, 2014
Pittsburgh, PA

Purpose and Presentation outline

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Purpose: Present the Budget Period 2 (BP2) progress and accomplishments and actual status of achievement against success criteria. Present project continuation request and agree with DOE-NETL to proceed to BP3 tasks.

Presentation Outline:

- Project background including BP1 milestones accomplished
- Project progress and accomplishment in BP2 (to date)
- Procurement of equipment and site installation of the 1 MWe pilot plant at the NCCC
- Key BP2 milestone status
- BP2 and BP3 schedule and costs
- Actual status of achievement against success criteria for BP2 tasks
- Project continuation request and agreement with DOE-NETL to proceed to BP3 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	Sean Rigby (BASF Corp) Gerald Vorberg (BASF SE)	-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 (LENA)	Lazar Kogan Keith Christian	-Detailed engineering -Procurement and installation

Project Budget: DOE funding and cost share (Amended Feb 2014)

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Source	Budget Period 1 Dec 2011 – Feb 2013	Budget Period 2 Mar 2013 – Aug 2014	Budget Period 3 Sep 2014 – May 2017	Total
DOE Funding	$2,670,173	$10,441,507	$3,107,167	$16,218,847
Cost Share	$667,543	$3,237,450	$776,792	$4,681,785
Total Project	$3,337,716	$13,678,957	$3,883,959	$20,900,633

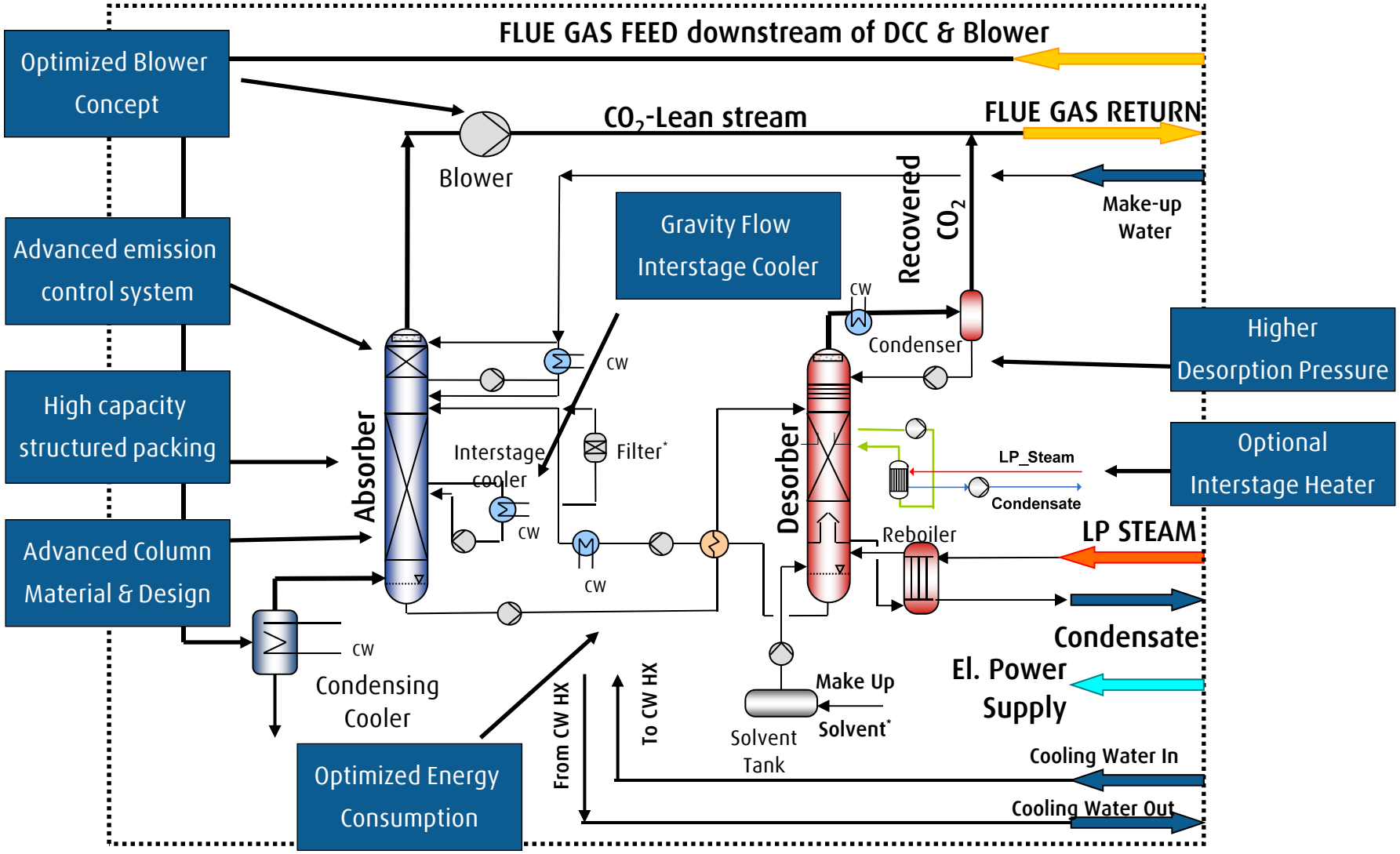
Cost share commitments:

Linde: $4,091,046

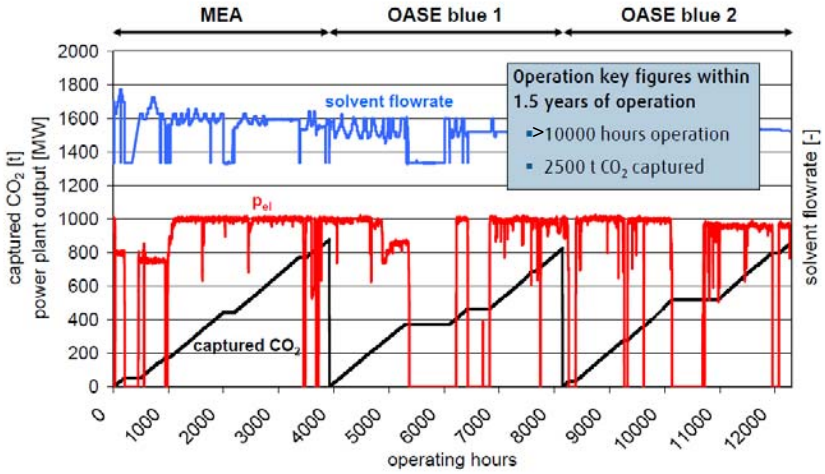
BASF: $ 493,360

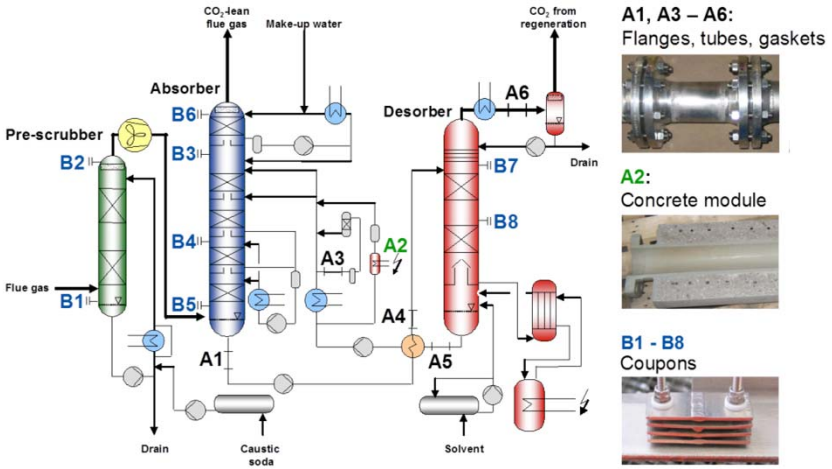
EPRI: $ 97,379

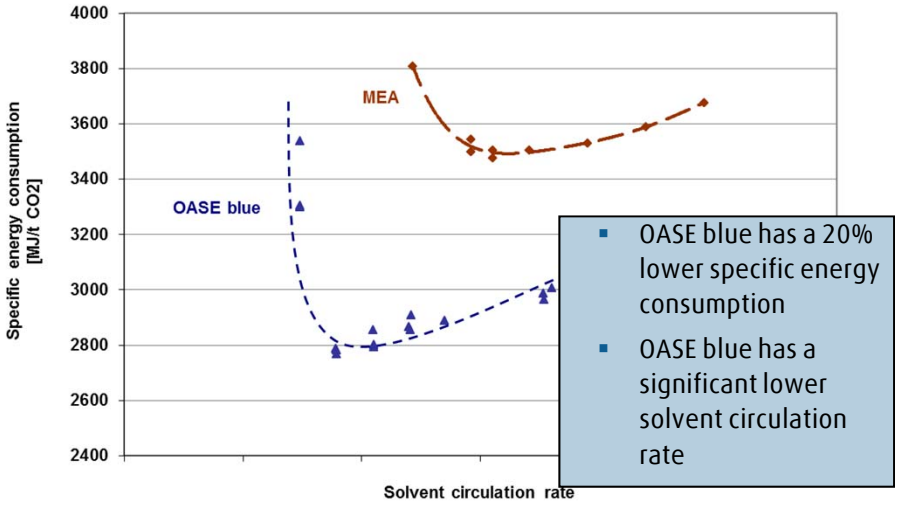
Linde-BASF advanced PCC plant design*

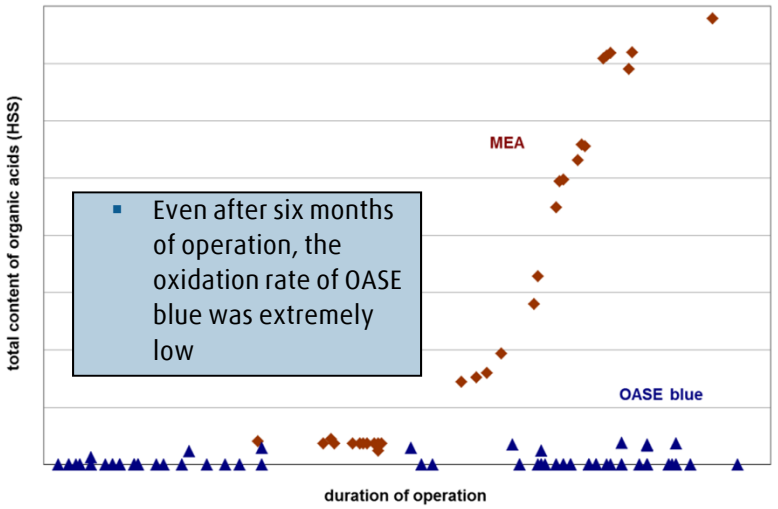


Niederaussem Pilot Plant: Main results of Phase I









Pilot Plant Niederaussem Test run history

Phase 2 focus: Long term testing evaluating materials, solvent degradation and emissions reduction

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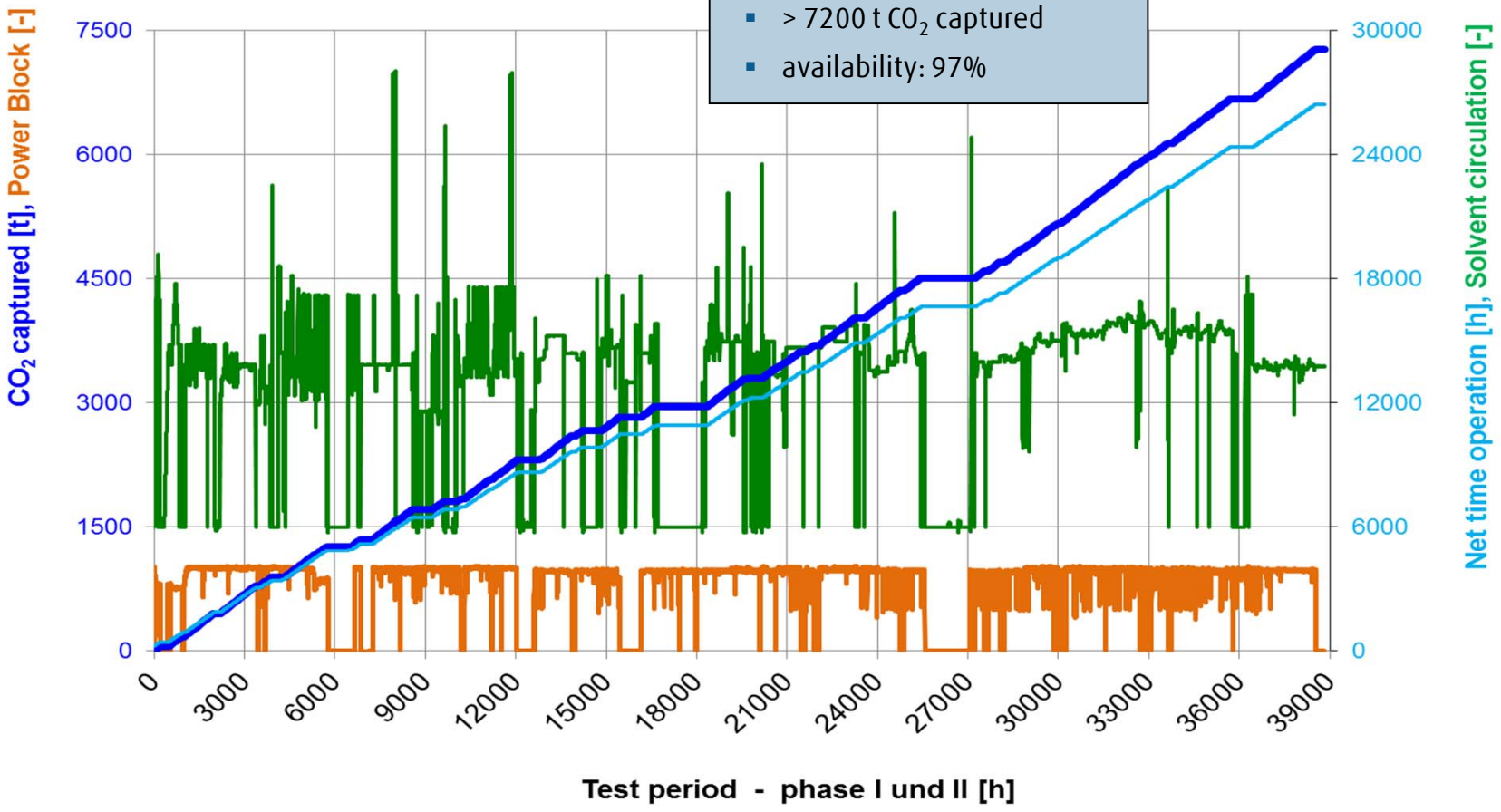
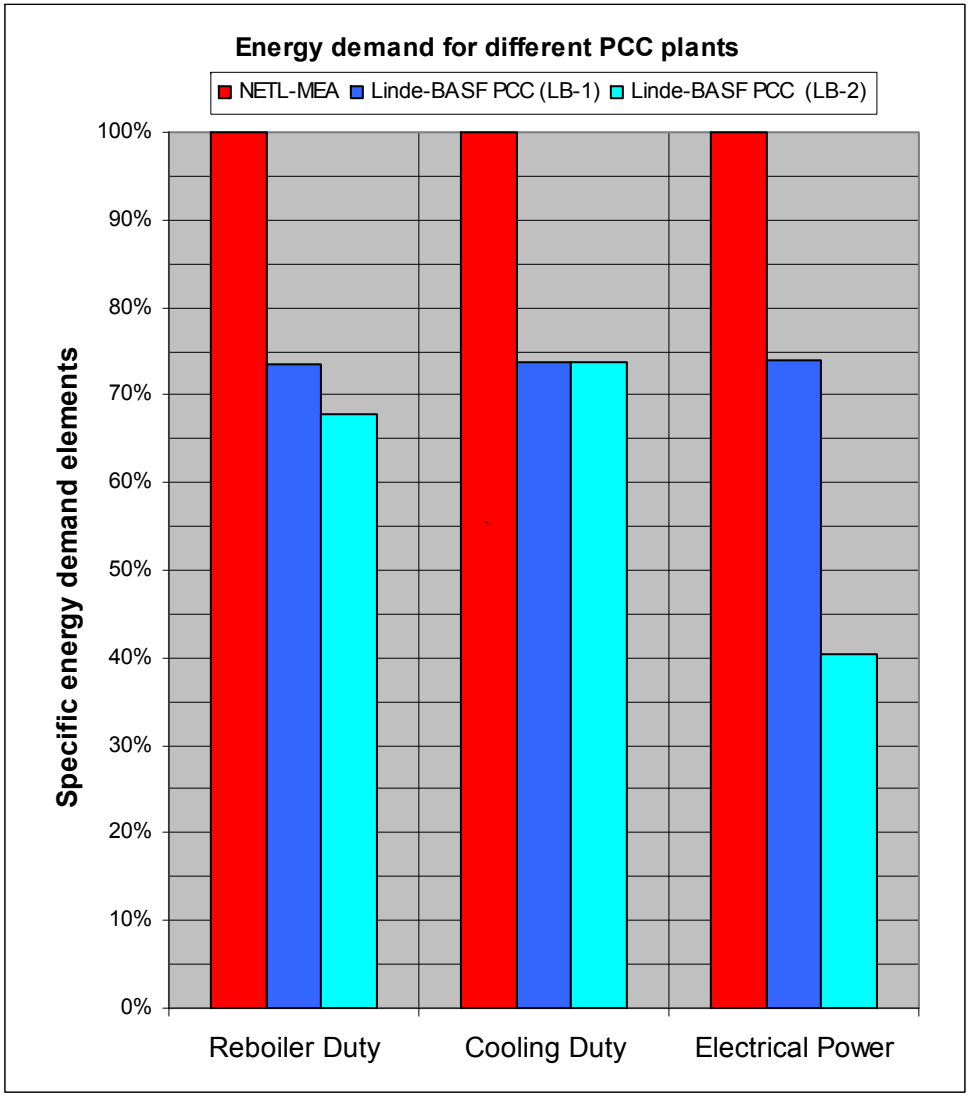
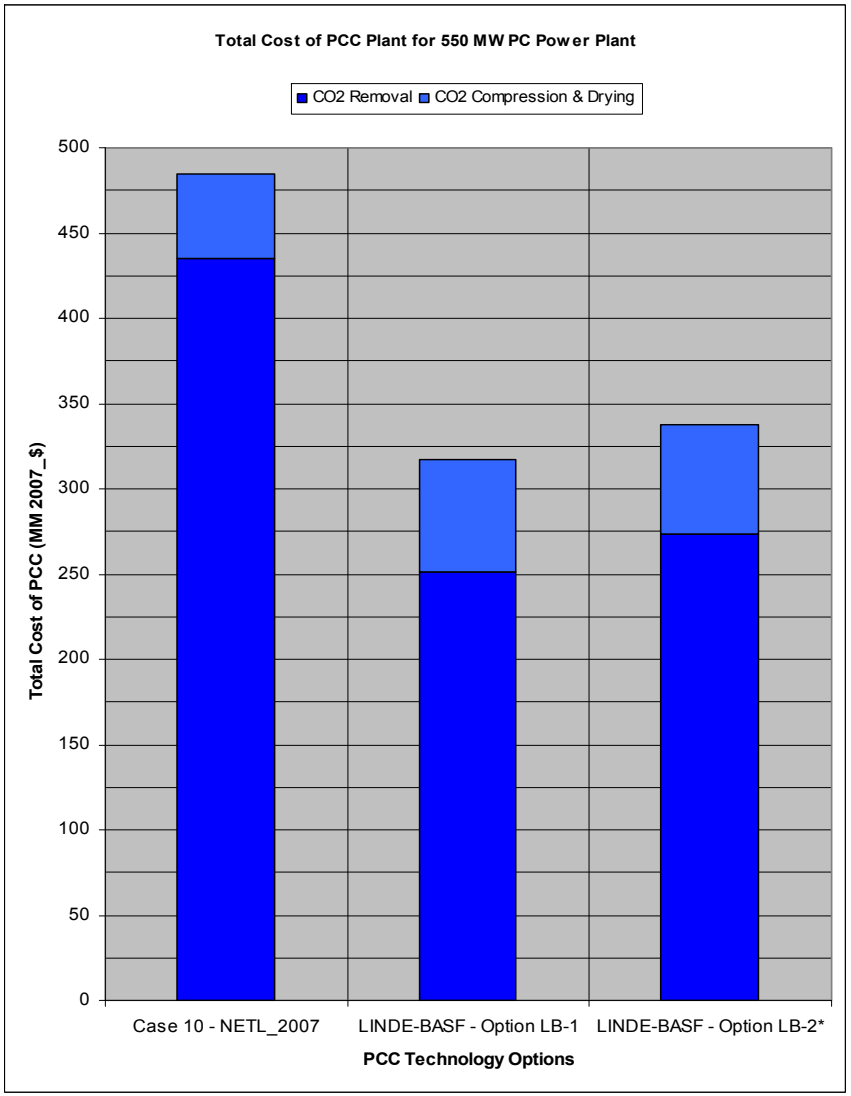
Status: Phase I and II (Dec 2013)

- > 26,000 hours operation
- > 7200 t CO_2 captured
- availability: 97%

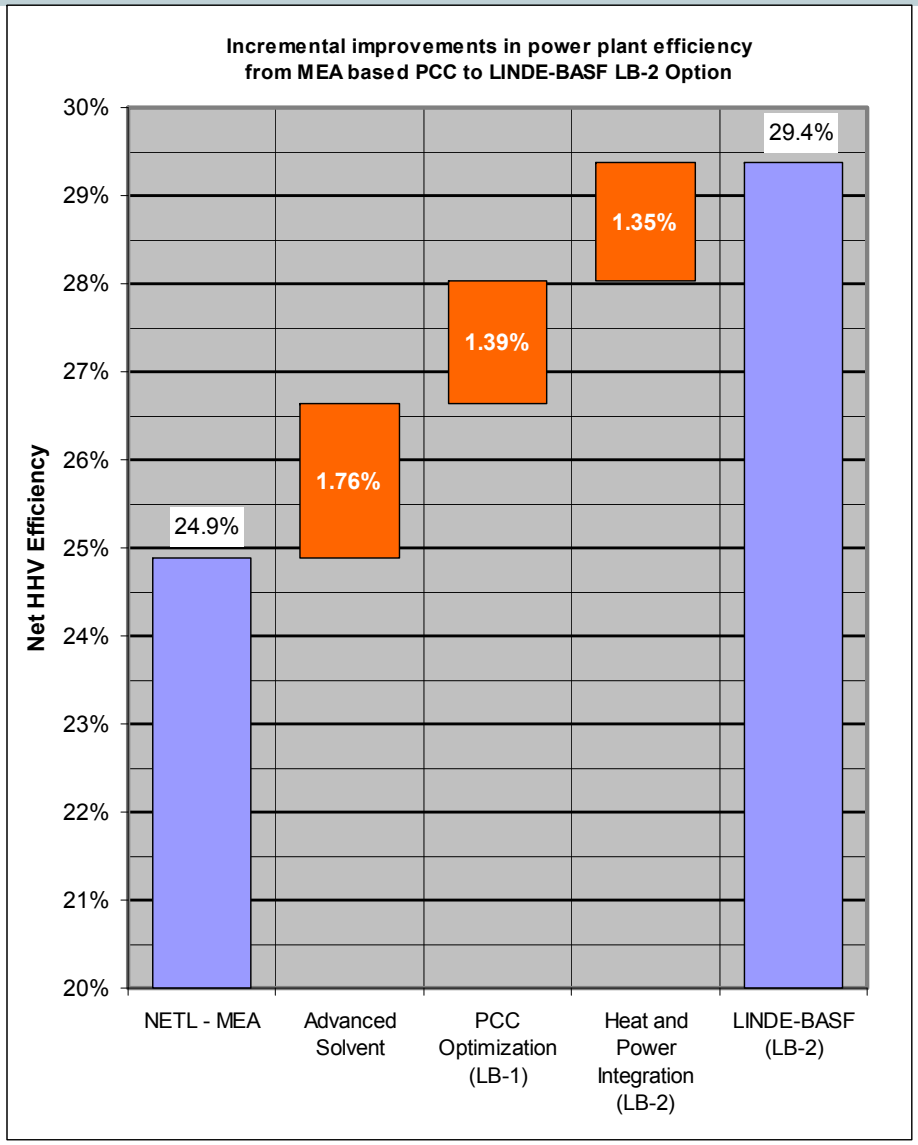


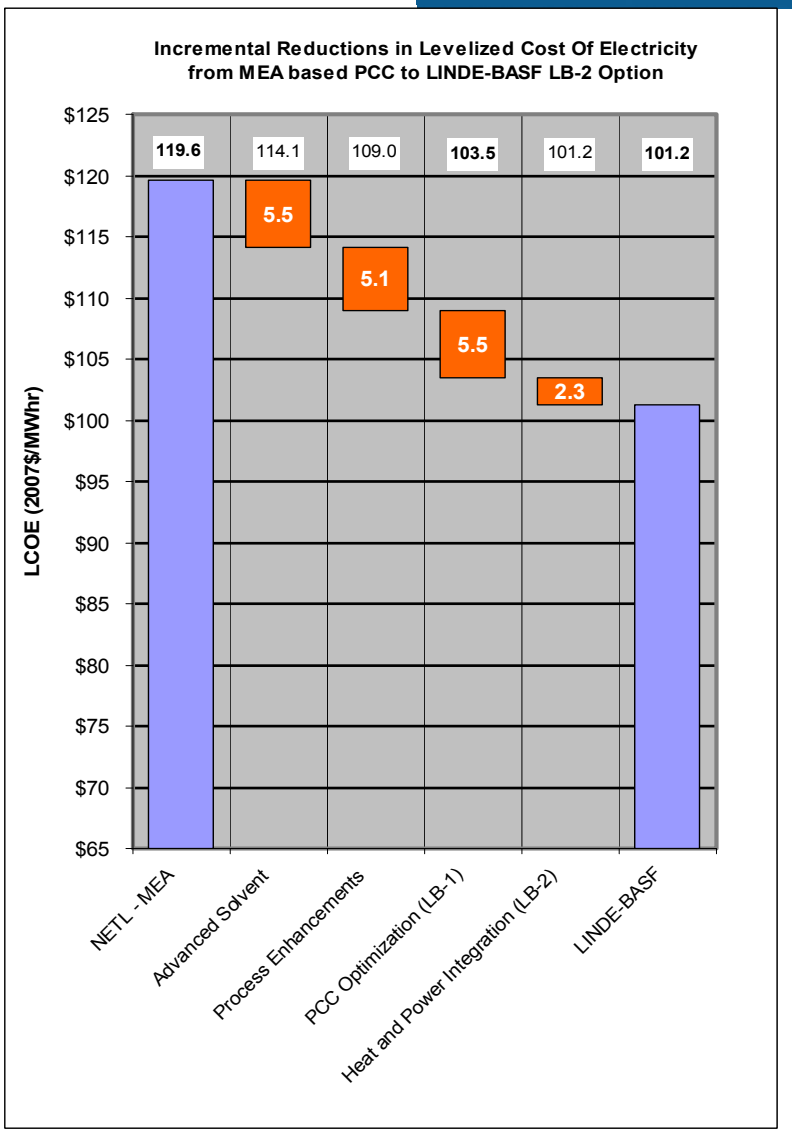
Comparative PCC Performance Results (Energy and Capex) Linde-BASF vs Reference DOE/NETL Case*





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





Key Budget Period 1 Project Milestones

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BP1 (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) - Completed 02/15/2013 √

Project progress and accomplishments by task (BP2 initiated in March 2013 and in progress)

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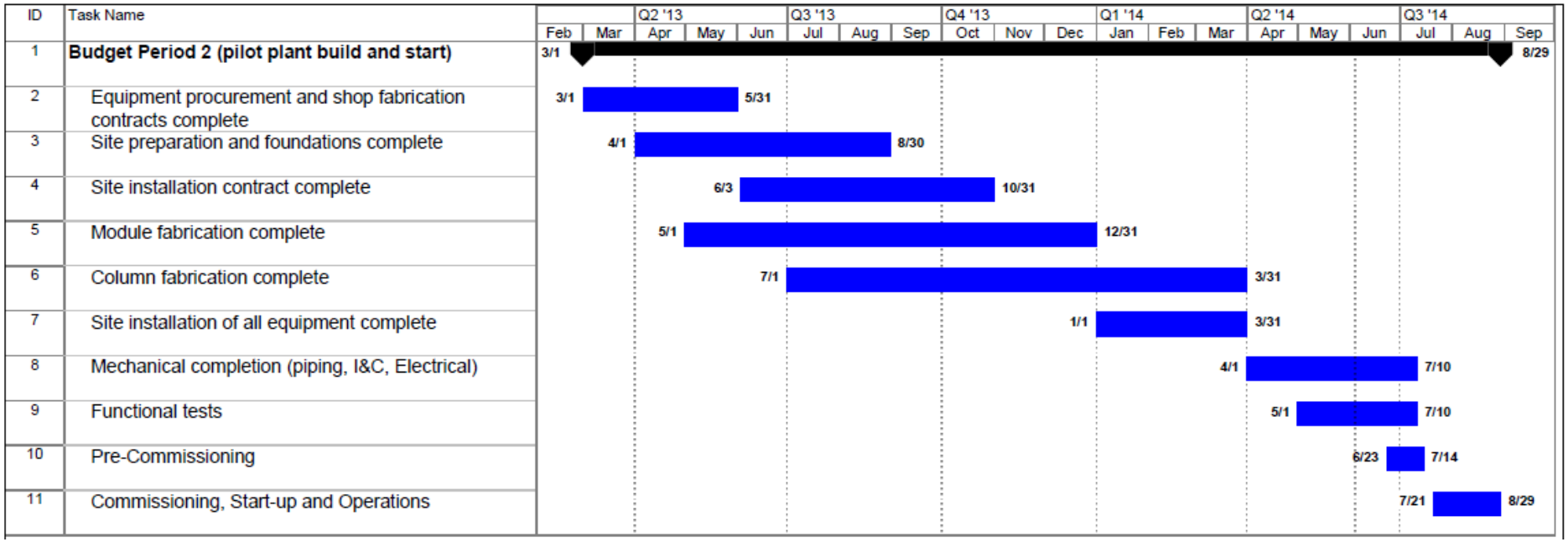
Task#	Task Description	Key Objectives	Accomplishments
6	Supply of plant equipment	- Complete the equipment and modules purchases (including fabrication shop installation) and have them transported to the NCCC site - Prepare the site (civils and utilities) for pilot plant installation	- **Completed purchase orders and fabrication contracts (June 2013)** - **Completed site preparation and foundations installation to receive pilot plant at NCCC (Jan. 2014)** - **Completed shop fabrication of equipment and modules and associated engineering checks (Dec 2013)** - **Shop fabrication of absorber/stripper columns completed and shipped to NCCC site in March 2014**
7	Plant construction and commissioning	- Complete the installation of the pilot plant at site - Enable mechanical completion of the pilot plant	- **All modules, columns and equipment (analytical container, solution storage tank) have been installed at site** - Piping installation 95% complete; Electrical installation 98% complete; Instrumentation & Controls near 100% complete - Water flushing, pressure testing, I&C loop checking significantly progressed - Preparation for pre-commissioning (demin. water and potash flush); Commissioning plan developed.

BP2 project schedule: Key dates



ID	Task Name	Start	Finish
1	**Budget Period 2 (pilot plant build and start)**	3/1	8/29
2	Equipment procurement and shop fabrication contracts complete	3/1	5/31
3	Site preparation and foundations complete	4/1	8/30
4	Site installation contract complete	6/3	10/31
5	Module fabrication complete	5/1	12/31
6	Column fabrication complete	7/1	3/31
7	Site installation of all equipment complete	1/1	3/31
8	Mechanical completion (piping, I&C, Electrical)	4/1	7/10
9	Functional tests	5/1	7/10
10	Pre-Commissioning	6/23	7/14
11	Commissioning, Start-up and Operations	7/21	8/29

- Construction process safety review (PSR4) completed Dec. 9, 2013
- Hazop actions review and updates on actions: Dec 9, 2014 & May 30, 2014
- NCCC site orientation and training for construction personnel: Dec 2013-Jan 2014
- Linde HSE site for project: Initiated Jan 2014/ongoing reporting

Key BP2 Project Milestones and Status

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BP2 (Mar. 1, 2013 – Aug. 31, 2014)

- Complete purchase orders and fabrication contracts for the 1 MWe pilot plant (06/30/2013) √
- Complete shop fabrication of equipment and modules and associated engineering checks (12/15/2013) – Completed 12/20/2013√
- Complete site preparation and foundation installations at NCCC to receive pilot plant (11/15/2013) – Completed 1/3/2014 √
- Complete installation of the 1 MWe pilot plant at NCCC (02/28/2014) – Completed 3/28/2014√
- Mechanical completion of 1 MWe pilot plant at NCCC (05/28/2014) – Expected completion 7/11/2014

Key Process Equipment for the Pilot Plant

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Heat Exchangers (Plate and Frame)

- Vendor: Tranter
- Tested & inspected at vendor site
- Installed on modules
- Provision to add plates for additional heat transfer area

Plate frame Heat Exchangers

Process and Cooling Water Pumps

- Vendors: Sulzer, Milton Roy, Easley
- All pumps except reflux pump are centrifugal
- Tested & inspected at vendor site
- Installed on modules
- Spares: 3 spare internals for use in all pumps + one spare reflux pump

Process Pumps

Module fabrication and installation in shop (Roeslein, Red Bud, IL)

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Steel structures in shop fabrication

Module installation & Assembly

Module design:

1. Six equipment modules (approximately 30 ft x 13 ft x 9 ft).
2. Arranged in three levels, two side by side at each level.
3. Design was to maximize shop fabrication. Off module piping produced by module fabricator.
4. Steel structure above the top module to support absorber (prevent swaying, 90 miles/hr wind design basis)

Columns fabrication in the shop in Decatur, Alabama

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Absorber section in fabrication and assembly

Stripper section in fabrication and assembly

- Stripper column fabrication and internals assembly completed. Shipment to site as one piece: March 9, 2014
- Absorber columns section fabrication and internals assembly completed. Shipment to site in three sections: March 17-26, 2014.
- Absorber column packing and internals for the bottom two sections installed at site. Completed March 28, 2014.

NCCC site preparation to accept pilot plant

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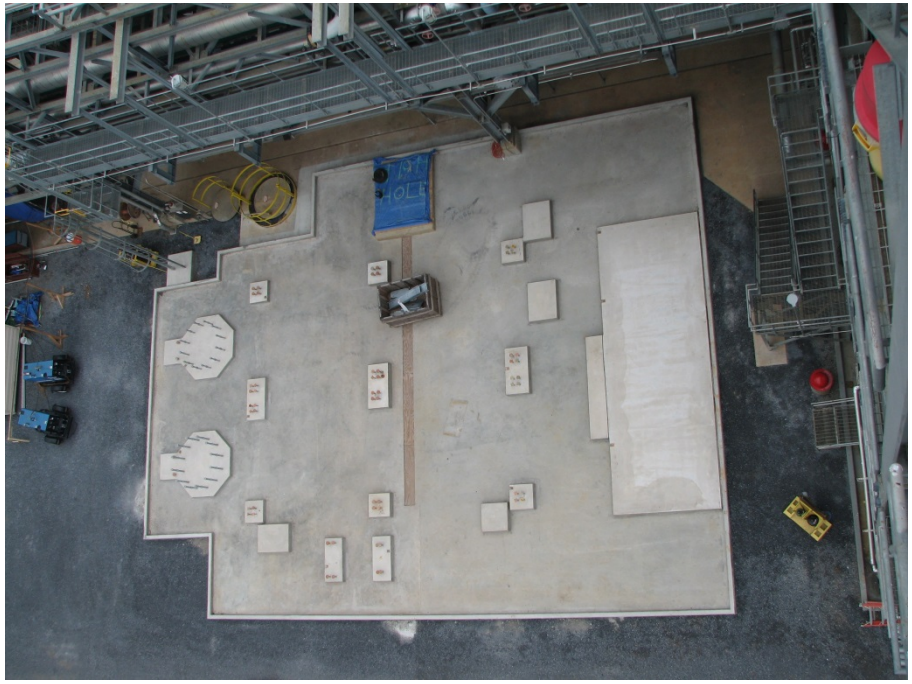
Rebar Placement

Foundations and Slab Complete



SCS/ NCCC scope and accomplishments:

1. Civil design completed. Micro-pile installation, form and pouring foundation completed.
2. FRP flue gas header designed & installed.
3. Sump pump, flue gas blower, pre-scrubber packing and internals purchased and installed.
4. Pre-scrubber modifications completed for increased flue gas capacity.
5. Pure solvent storage system modifications completed. Demin. water pump impeller replacement.

Construction Status & Progress

Item	Accomplishments to Date	Activity Planned for Completion
Off-Module Piping Installation	95% Completed (incl. hydrotests)	June 14th
Off-Module Piping Heat Tracing	Areas 1 & 4 Completed June 6th	June 6th
Off-Module Piping Insulation	Started June 2nd	June 24th
Loop Checks	50% Completed	June 18th
Functional Testing of DCS	Plan to Start June 18th	June 24th
Cleaning & Flushing	Plan to Start June 17th	July 7th
Mechanical Completion		July 11th
Pre-Commissioning Completed		July 18th

Site prepared and ready to install equipment and modules (Jan 10, 2014)

Module 5 lifted into place

Installation of one of the modules at site (6 of 6 modules)

Steel structure for wind load protection (absorber) lifted into position

Analytical container set in place (left) and module installation completed (right)

Solution storage tank set in place in front of modules

Analytical container fabricated in shop and installed at site

- Pilot plant incorporates significant instrumentation and online analytical measurements
- Batch analysis in conjunction with online measurements allow redundancy checks for mass and energy balances
- Batch sampling and offsite analysis for solvent stability measurements
- Corrosion coupons incorporated to assess effect on materials over the testing duration

Analyzer and controls container

Analyzer and sampling panels

Stripper column delivery and installation at site

Absorber bottom section ready for installation

Absorber bottom section set in place (left); view of the installed solution storage tank

Absorber second section installation

Top section of the absorber lifted into position (left); Column installation complete (right)

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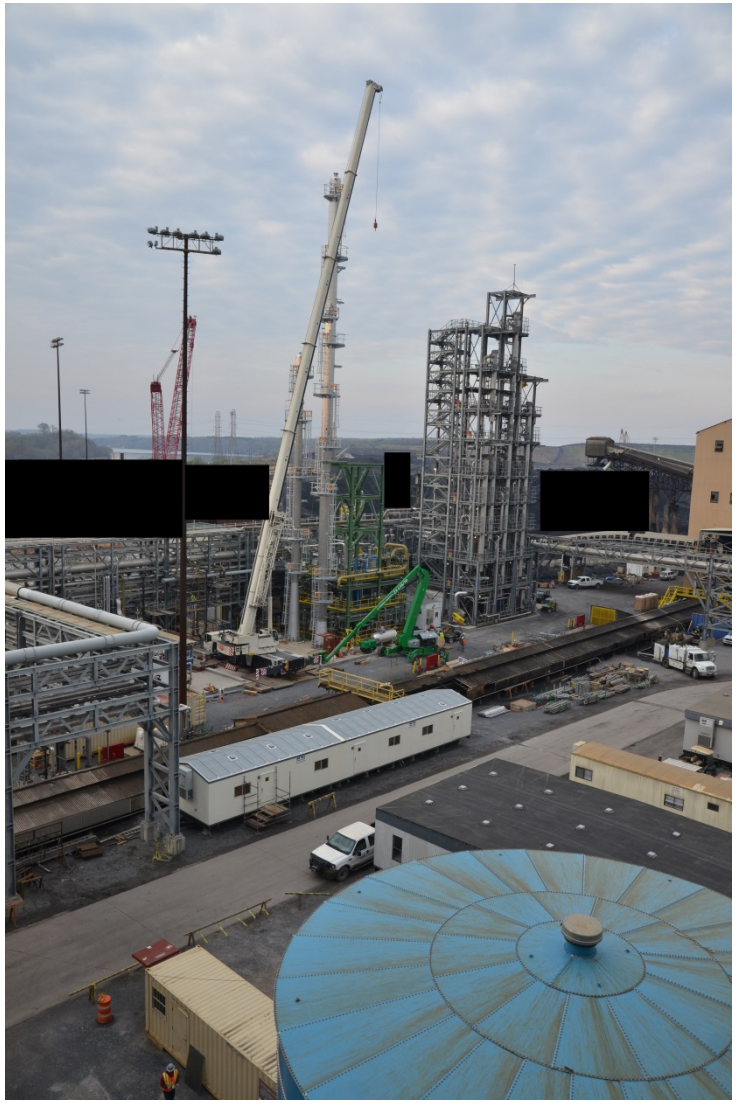

Absorber and stripper column scaffolding to install piping, pipe supports, insulation and heat tracing.

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Based on safety assessment, decision made by contractor to scaffold the columns for installation of piping, pipe supports, insulation, heat tracing, and insulation. Original intent was to use man-lift.

BP3 Project Schedule (Continuous availability of site and utilities)

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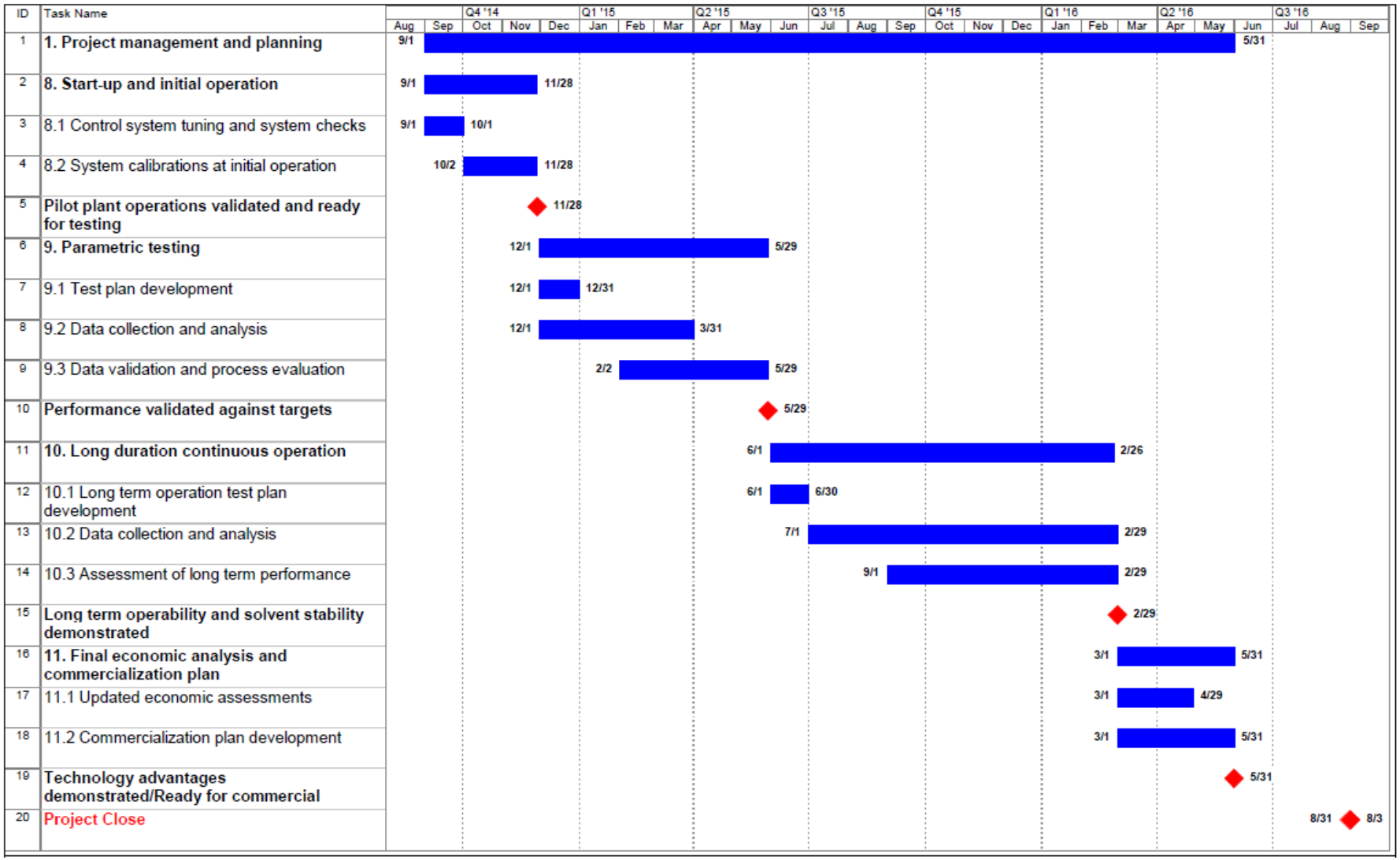

BP3 scope & budget proposal

Category	BP3 Budget (Feb 2013)
Linde LLC costs including personnel, travel	$1,477,635
Supplies and other	$77,000
Subcontractor	
BASF Corp.	$226,360
EPRI	$420,057
LEDD	$749,165
LENA	$933,742
Subcontractor/Consultant Total	$2,329,324
TOTAL BUDGET PERIOD 3 COSTS	$3,883,959

- BP3 Tasks as per original proposal:
  - Task 8: Start-up and initial operation
  - Task 9: Parametric testing
  - Task 10: Long duration continuous operation
  - Task 11: Final TEA and commercialization plan

- Project team interested in testing also diluted flue gas during Task 10.

- BP3 projected costs are the same as agreed in Feb 2013 amended (end of BP1)

- LENA budget of $933,742 is for removal of pilot plant at the end of testing. Recent estimate received at $1,190,635 but scrap value assumed to lower to budget value.

Challenges with Procurement & Construction

- Numerous engineering changes to columns – lengthened drawing review process
- Column Internals late to column supplier (high capacity packing damaged in shipment – had to be replaced)
- Field Technician for assisting column supplier with installing column internals delayed 3 days (columns on critical path)
- Columns delivered late to site (by approx. 5 weeks compared to intended schedule)
- Some pipe supports late to site (lengthened time for completing off-module piping installation)
- Change to scaffolding (from man lift) of absorber & stripper for installation piping, pipe supports, insulation and heat tracing based on safety review
- Construction company having difficulty with keeping proper number of welders, instrument tech's and pipe fitters at site (lengthened time for completing off-module piping installation)

Project cost summary: Feb 2013, Amended Feb 2014 and current estimate to BP2 completion

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Category	Project Costs	DOE-NETL funding	Participant Cost Share	DOE-NETL funding (%)	Participant Cost Share (%)
Budget Period 1 (Feb 2013)	$3,337,716	$2,670,173	$667,543	80	20
Budget Period 2 (Feb 2013)	$11,268,781	$9,015,025	$2,253,756	80	20
Budget Period 3 (Feb 2013)	$3,883,959	$3,107,167	$776,792	80	20
Total project (Original)	$18,490,456	$14,792,365	$3,698,091	80	20
Budget period 2 (Amended, Feb 2014)	$13,678,957	$10,441,507	$3,237,450	76	24
Total project (Amended, Feb 2014)	$20,900,633	$16,218,847	$4,681,785	78	22

- BP2 project cost update to BP2 completion is in progress. Additional site installation costs are projected due to the challenges outlined.

Concluding Remarks

- BP1 successfully completed in Feb 2013 and decision jointly made with DOE-NETL to proceed to pilot plant build
- BP2 initiated in March 2013 and has focused on equipment procurement, finalization of shop fabrication and site installation contracts and fabrication & site installation of modules and columns
- The project partners (Linde entities, SCS/NCCC and BASF) have continued to work closely to successfully progress the tasks with strong support for the project from DOE-NETL
- Significant emphasis on safety processes and implementation of safety procedures during shop fabrication and site installation work
- The project progress is tracking the revised schedule and mechanical completion is expected on July 11, 2014 with commissioning and start-up activities beginning soon after
- Major challenges in equipment procurement/delivery, shop fabrication and site construction has resulted in delays to critical path items and significant impact on cost

Status against BP2 decision point success criteria

Decision Point	Basis for Decision/Success Criteria	Status
Completion of BP2	Successful completion of all work proposed in BP2	On track
	Implementation of EH&S processes: - SCS/NCCC Site Safety Processes - Linde HSE sign-off for construction phase	Full compliance No incident, first aid or lost time
	Process safety review (PSR) during construction phase completed	Completed Jan. 2014
	Mechanical completion of pilot plant achieved	On track for July 11,2014
	Preliminary test matrix for the parametric testing	Prepared
	Environmental questionnaire for operational site and operational permits	NEPA form completed with NCCC. All required structural drawings reviewed by Alabama PE
	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 BP3 tasks

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- Project team has successfully completed all agreed milestones except mechanical completion (MC), now targeted for July 11, 2014.
- Functional testing of pilot plant sub-systems (mechanical & structural, rotating equipment, electrical, instrumental & controls) in progress and will be completed in conjunction with MC.
- The pilot plant is expected to be ready for commissioning and start up by July 14, 2014. Final safety review is planned week of July 14, 2014 to enable proceeding to commissioning & start-up.
- Challenges in equipment delivery and site contracts have resulted in significant cost escalation; budget amendment in Feb 2014 has helped immensely but still significant gap in funding (estimated vs amended budget)
- BP3 timeline and cost estimates similar to original plan

Project team, therefore, requests:

- Discussion and resolution on Budget Period 2 funding gap
- Continuation to BP3 (operations and testing phase) once the remaining planned tasks for BP2 are successfully completed.
- Agreement on BP3 schedule to reflect NCCC site availability and expected implications on the overall project duration
- Update project management plan.

Thank you for your attention!

Project DE-FE0007453
Project continuation request for initiating Budget Period 3 Tasks

June 9, 2014
Pittsburgh, PA