Southern Company

Research & Development

Front End Engineering Design of Linde-BASF Advanced Post-Combustion CO2 Capture Technology at a Southern Company Natural Gas-Fired Power Plant

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Landon Lunsford, PI
Southern Company Services

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Project Overview and Objectives

Project Overview:

- Funding: **$7,101,737**
  - DOE: $5,674,533
  - Recipients: $1,427,204
- Work Period: 10/1/2019 - 9/30/2021

Project Objectives:

- Complete a Front-End Engineering and Design (FEED) study for installing the Linde-BASF advanced aqueous amine solvent-based post-combustion CO2 capture technology (PCC) at an existing domestic natural gas-fired combined cycle (NGCC) power plant within Southern Company's portfolio of assets.
- Provide a reference case for a more detailed understanding of CO2 capture costs in a commercial application that will support the development of cost effective, environmentally sound, and high performing technologies for the reduction of CO2 emissions from NGCC plants.

Linde-BASF Post-Combustion Carbon Capture (PCC) Technology

Reduced capital costs / energy costs

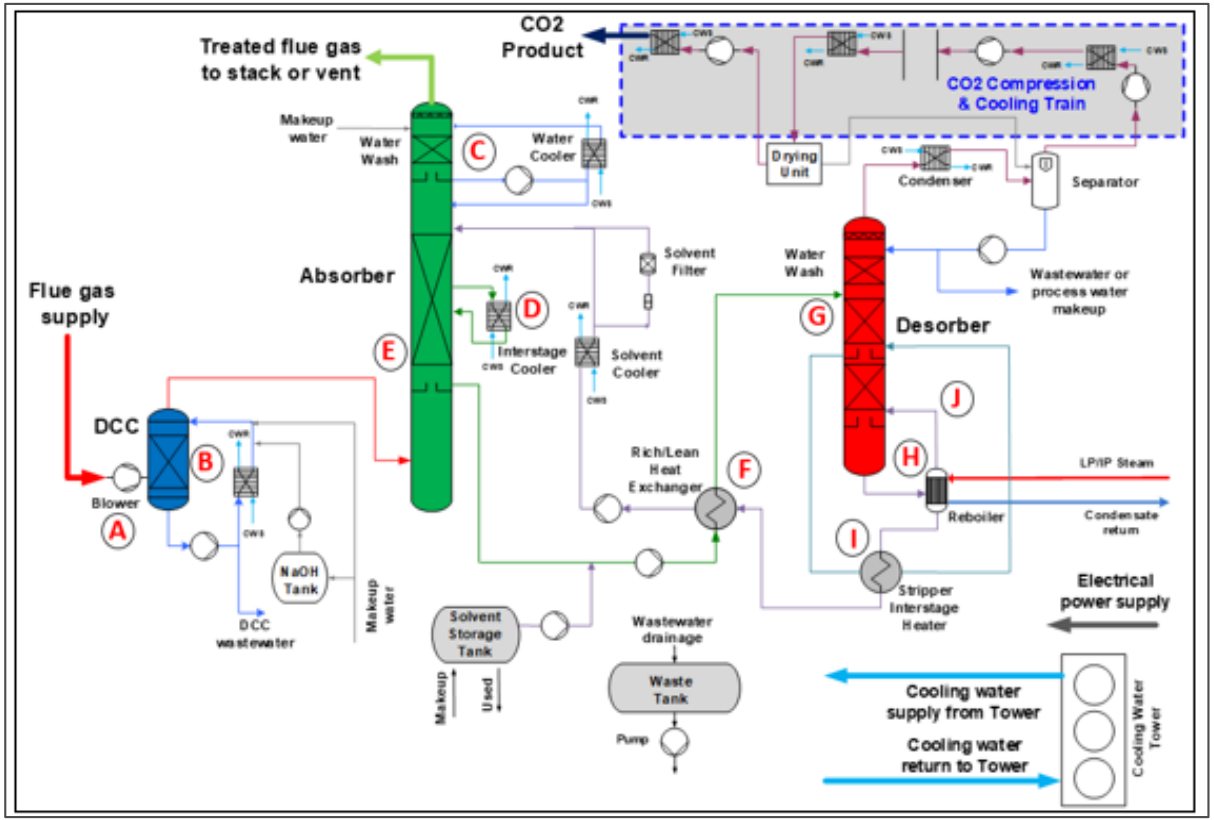
- Optimized BASF OASE® blue solvent
- Efficient CO_2 capture from low-pressure sources
- Longer solvent life (can handle higher O2 conc)
- Lower solvent circulation rate

Notable Linde-BASF process improvements

(C, E) Dry bed water wash design to minimize solvent losses

(G) Stripper regeneration at 3.4 bars reducing CO_2 compressor cost and power consumption

(I) Advanced Stripper Interstage Heater to reduce regenerator steam consumption.



Linde-BASF Post-Combustion Carbon Capture (PCC) Technology

- Technology tested from 2009-2017 in two pilot plants
  - Different flue gas sources
  - Wide range of flue gas compositions and impurities
  - Achieved Technology Readiness Level of 6
  - Multiple process design improvements achieved
- OASE® blue solvent
  - Advanced aqueous amine solvent
  - Favorable kinetics and reduced steam energy requirements
  - Demonstrated solvent stability
  - Lower solvent circulation rate

Prior NGCC CO_2 capture studies conducted in 2011 and 2018 will be leveraged

Project Milestones

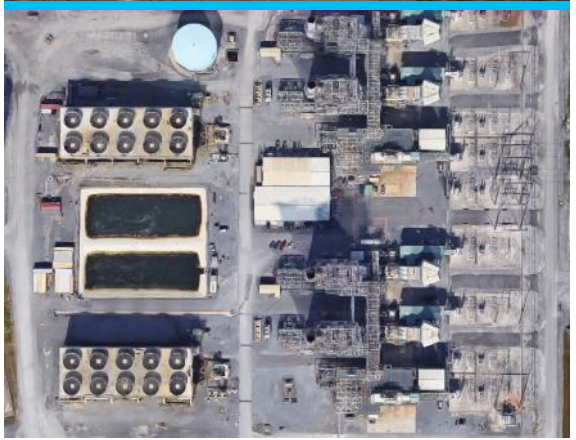
Task/Subtask Number	Milestone Title & Description	Planned Completion Date	Verification Method
1.1	*Project Kickoff Meeting*	*11/22/2019*	*Presentation file*
1.1	*Updated Project Management Plan*	*2/28/2020*	*PMP file*
2.2	*Host site evaluation and selection, including design basis*	*4/29/2020*	*Quarterly Progress Report*
3.2	Basic engineering complete	9/30/2020	Quarterly Progress Report
4.1	HAZOP complete	10/30/2020	Quarterly Progress Report, HAZOP report
4.0	Front-End engineering packages complete	6/30/2021	FEED Study Report
5.3	Finalized cost and schedule analysis	9/30/2021	Topical Report

Success Criteria and Decision Points

Decision Point	Date	Success Criteria
Host site selected	*4/29/2020*	*Letter of confirmation from selected host site; design basis created for that site*
Basic Engineering Completed Successfully	9/30/2020	Solvent system basic design complete. All information required to conduct initial HAZOP complete.
Front-End Engineering Design Complete	6/30/2021	All design packages ready for equipment/material estimation from vendors. HAZOP recommendations reviewed and addressed.
Cost and Schedule Estimate Complete	9/30/2021	Cost and schedule estimate completed and reviewed

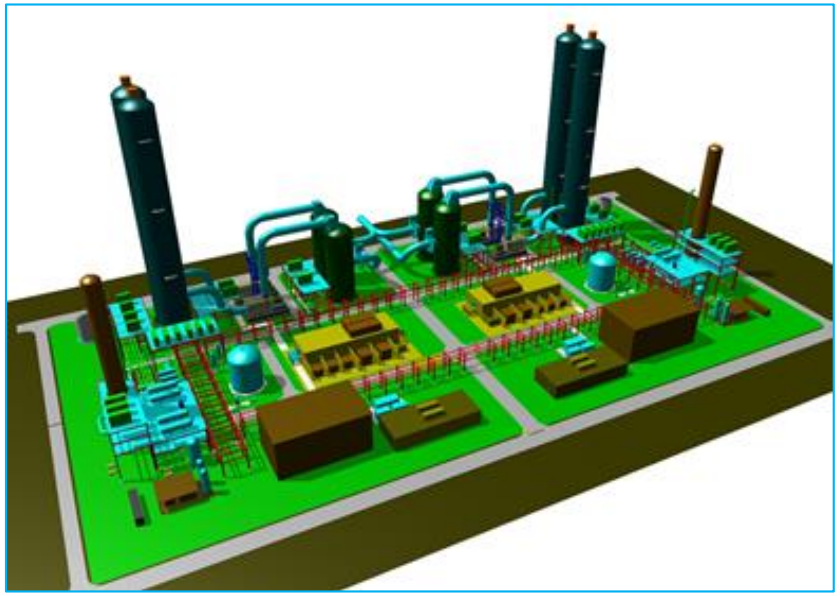
Host Sites for Evaluation

- Alabama Power's Plant Barry Units 6 and 7
  - Located in Bucks, AL
  - Each unit: (2) GE 7FA gas turbines -> (1) Vogt triple pressure HRSG -> (1) GE TC2F D11 steam turbine, 525 MW net
  - Began commercial operation in May 2001
  - Estimated storage costs at $3-4/ton from extensive pre-feasibility geological studies
- Mississippi Power's Plant Daniel Units 3 and 4
  - Located in Moss Point, MS
  - Each unit: (2) GE 7FA gas turbines -> (1) Vogt triple pressure HRSG -> (1) GE TC2F D11 steam turbine, 525 MW net
  - Began commercial operation in May 2001
  - Estimated storage costs at $3-5/ton from pre-feasibility geological studies



Task 2: Requirements Definition and Host Site Evaluation

- Linde and SCS evaluated performance, utility availability, regulatory impacts, and plot space to select Plant Daniel host site
- A basis of design detailing major boundary conditions and operating scenarios was completed
- Developed PCC plant concept:
  - 2 PCC + Compression trains with common utility supply and facilities support infrastructure
  - Each train includes 2 DCC columns, 2 absorbers, and 1 desorber column.
  - Each compression train includes compressor w/ dryer and process condensate handling

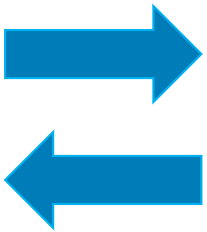


3D design for 550 MW PCC plant based on earlier work

Task 3: Conceptual Design

Linde Scope (ISBL):

- BASF completed basic design based on OASE® blue solvent technology, including preliminary heat and material balances and key equipment sizing
- Linde has progressed basic engineering including development of the first version of PFD, detailed heat & material balances, P&ID, and plot plan.



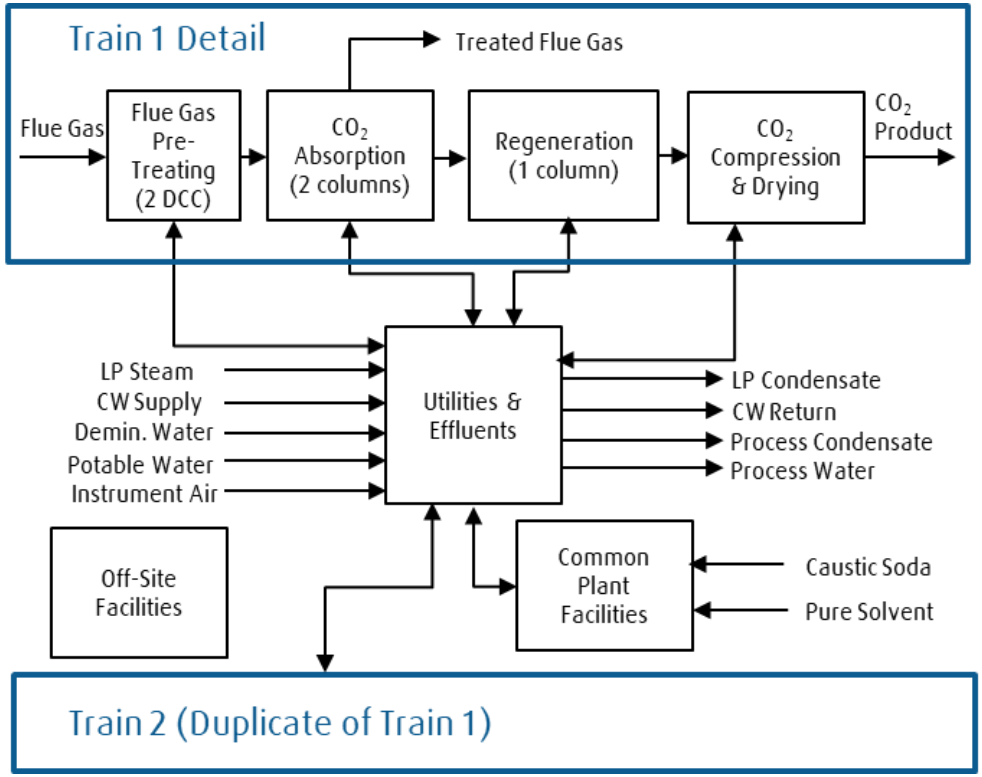
SCS Scope (OSBL):

- Evaluating optimum integration of the steam cycle with the carbon capture system
- Evaluating integration of required utilities, including necessary additions/upgrades
- Evaluating permitting requirements for air and effluents
- Reconciliation between Linde and SCS design standards

Basic Engineering in Development

Key progress:

- Design basis document detailed to summarize quality & quantity of utility requirements and conditions at scope transitions
- Continued Linde-SCS interaction to define utility source points & availability
- Integration aspects related to steam cycle, flue gas duct layout considered



Synergy: DE-FE00031888, Project ECO$_2$S Phase III

- ~$21.9M project, led by Southern States Energy Board (SSEB)
  - Project partners include 16 universities, labs, and private companies
  - *Project remains under negotiation*
- Prepare for a regional CO_2 host site in Kemper County, MS
  - Previous phase identified potential for complex capable of storing 900 million metric tons of CO_2
  - Current efforts will fully characterize the site through additional test well drills
  - CO_2 to be sourced from Plant Ratcliffe (NGCC), Plant Daniel (NGCC), and Plant Miller (Coal)
- Project deliverables
  - Final site geologic characterization
  - CO_2 capture feasibility assessments for proposed host sites
  - UIC Class VI Permit to Construct application

Challenges due to COVID-19:

- Travel restrictions eliminated the possibility of having in-person kickoff and host site visits
  - Team was able to build rapport and select the host site through virtual meetings
- HAZOP scheduled at the end of Task 3 / beginning of Task 4
  - Travel restrictions are expected to still be in place
  - There is a 7-hour time difference between the Linde Engineering team and the SCS engineering team
  - Team is exploring options for rescheduling or executing virtually

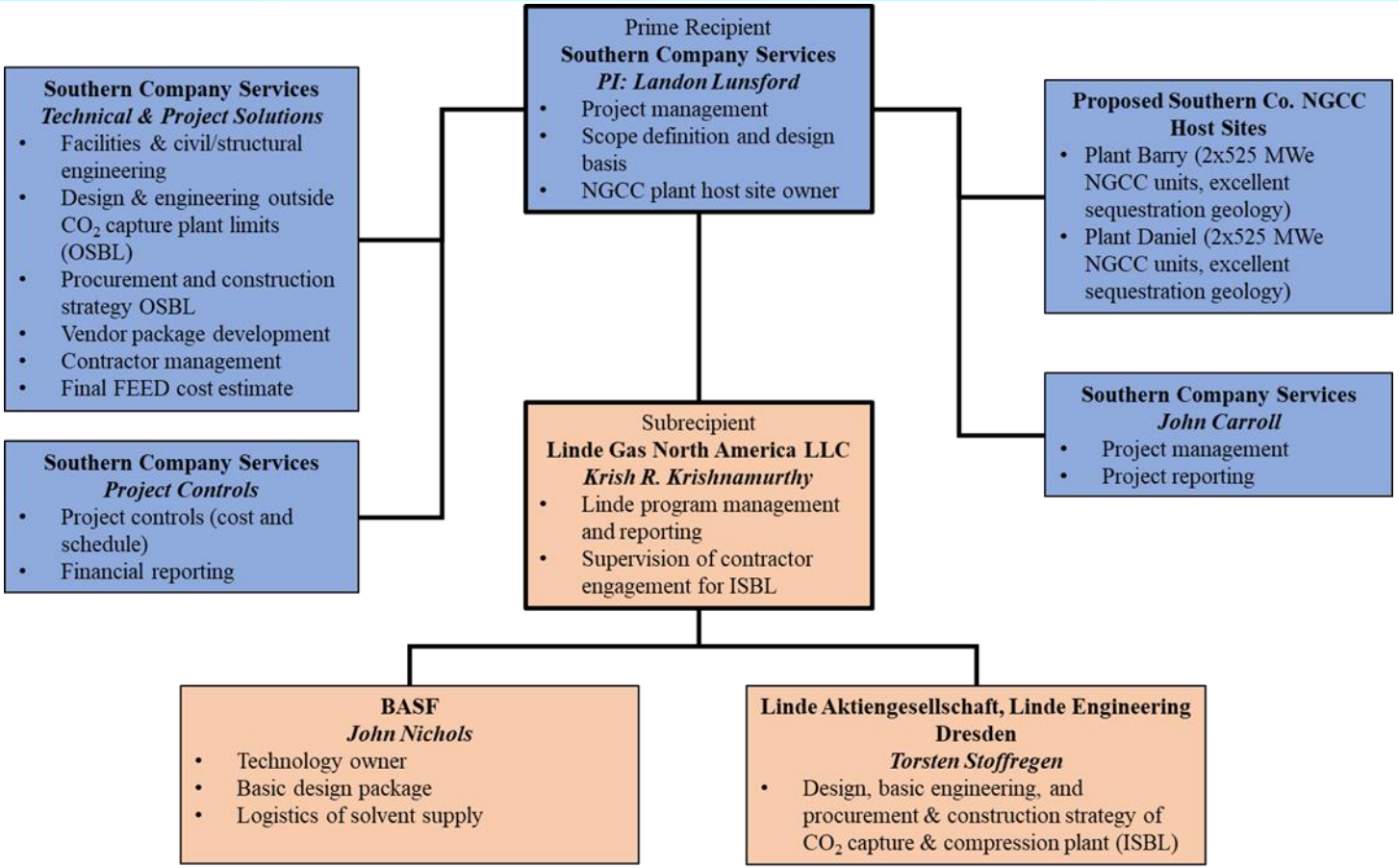
Summary

- Southern Company and Linde assembled a diverse team to develop a FEED study with detailed cost and schedule estimates.
- Despite major changes in work practices and plans due to the COVID-19 pandemic, the project team has adapted and continued the work.
  - No site visits and no in-person team kickoff.
  - Remote working conditions will continue for foreseeable future for many team members.
- The project team is working to complete basic engineering by 3rd quarter.
  - Primary basis of design complete.
  - Initial Process Flow Diagrams complete.
  - Equipment specifications and preliminary P&IDs in development.
- HAZOP will be conducted as basic engineering shifts to detailed design.
  - Virtual options are being considered due to travel restrictions; time zone differences pose a challenge.

Questions?

Appendix

Project Organization Chart



Project Gantt Chart

			Budget Period 1 10/1/19-9/30/2021							
	Start Date	End Date	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Task 1.0 - Project Management & Planning	1/29/2020	9/30/2021								
Subtask 1.1 - Project Management	1/29/2020	9/30/2021								
Subtask 1.2 - Project Administration	1/29/2020	9/30/2021								
Subtask 1.3 - Project Controls	1/29/2020	9/30/2021								
Milestones:										
-Project kickoff meeting			◊							
-Updated Project Management Plan				◊						
Task 2.0 - Scope Definition and Design Basis	1/29/2020	4/29/2020								
Subtask 2.1 - Requirements Definition	1/29/2020	2/29/2020								
Subtask 2.2 - Host Site Evaluation and Selection	3/1/2020	4/29/2020								
Milestones:										
-Host site evaluation and selection including design basis					◊					
Task 3.0 - Conceptual Design	4/15/2020	9/30/2020								
Subtask 3.1 - Basic Design	4/15/2020	5/15/2020								
Subtask 3.2 - Basic Engineering	5/15/2020	9/30/2020								
Milestones:										
-Basic engineering complete						◊				
Task 4. 0 - Front End Engineering Design Study	9/30/2020	6/30/2021								
Subtask 4.1 - Process Engineering	9/30/2020	6/30/2021								
Subtask 4.2 - Mechanical Engineering	9/30/2020	6/30/2021								
Subtask 4.3 - Instrumentation, Controls and Electrical Engingeering	9/30/2020	6/30/2021								
Subtask 4.4 - Civil/Structural Engineering	9/30/2020	6/30/2021								
Subtask 4.5 - Facilities Engineering	9/30/2020	6/30/2021								
Milestones:										
-HAZOP complete							◊			
-Fronte-End Engineering packages complete									◊	
Task 5.0 - Cost and Schedule Estimation	1/1/2021	9/30/2021								
Subtask 5.1 - Procurement and Fabrication Planning	1/1/2021	9/30/2021								
Subtask 5.2 - Construction Management and Planning	1/1/2021	9/30/2021								
Subtask 5.3 - Cost and Schedule Estimation	1/1/2021	9/30/2021								
Milestones:										
-Finalized cost and schedule analysis										◊