



# LARGE PILOT SCALE TESTING OF LINDE/BASF POST- COMBUSTION CO<sub>2</sub> CAPTURE TECHNOLOGY AT THE ABBOTT COAL-FIRED POWER PLANT

*Phase I Kick-off Meeting  
December 10, 2015*



# Objectives

- Design and install a carbon capture system of nominal 25 MWe
  - Integrate with the Abbott Power Plant flue gas system
  - Demonstrate the viability of continuous operation under realistic conditions with high efficiency and capacity
  - Optimize the process at this scale and to gather performance data to enable a robust design of large commercial size plants
- Provide a guideline for the retrofit of other existing plants within the coal fleet
  - Enable future knowledge sharing with other utilities in order to encourage and facilitate the retrofit process
- Illustrate a path forward for the utilization of the captured CO<sub>2</sub>

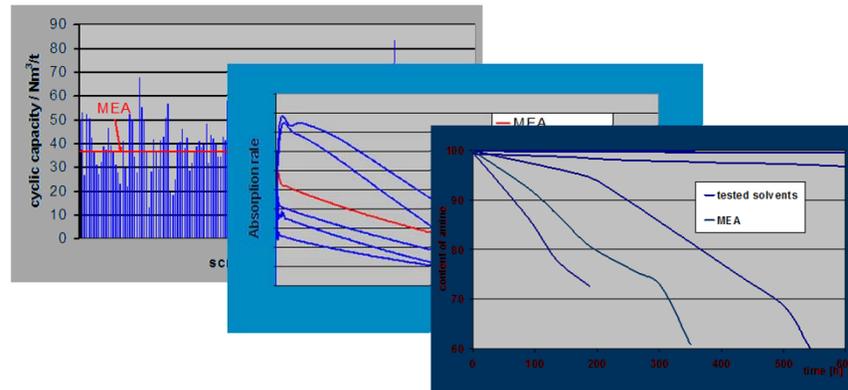
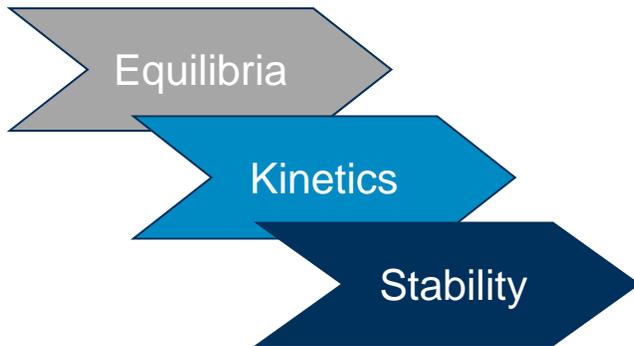


# TECHNOLOGY DESCRIPTION



# BASF OASE<sup>®</sup> blue technology development

*Linde adopted and optimized for PCC applications*



## Mini plant

- 2001, Ludwigshafen
- Solvent performance verification



## Pilot: 0.5MWe

- 2009, Niederaussem
- Process optimization, materials testing



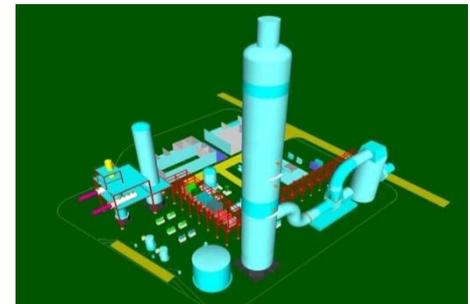
## Pilot: 1.5 MWe

- 2014, Wilsonville, AL
- Design improvements, emissions confirmation



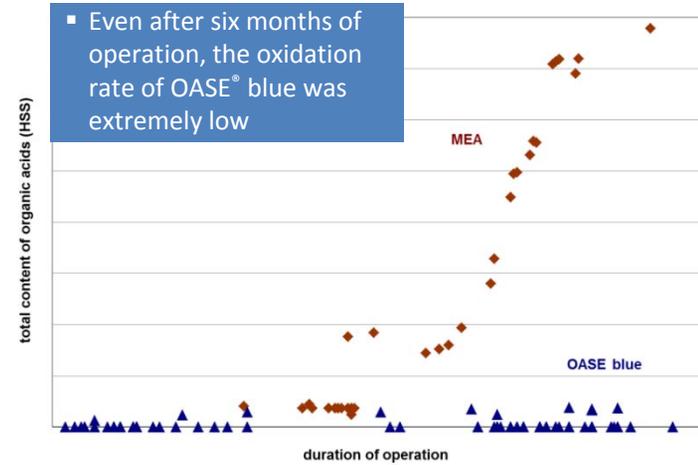
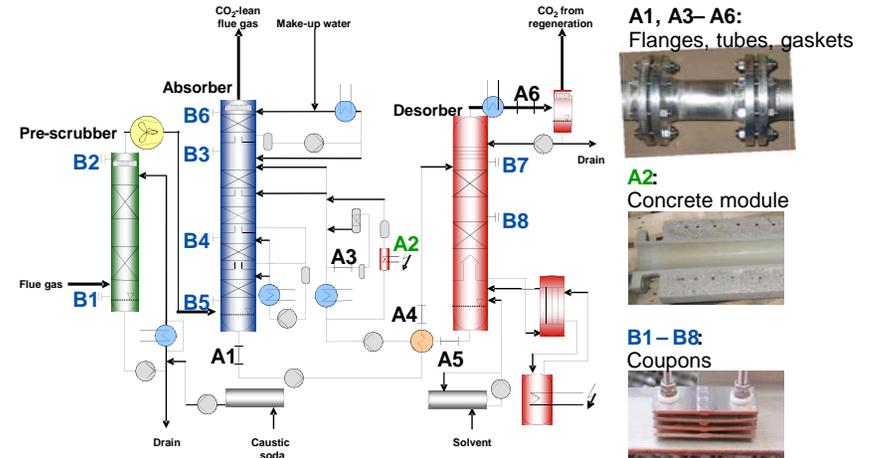
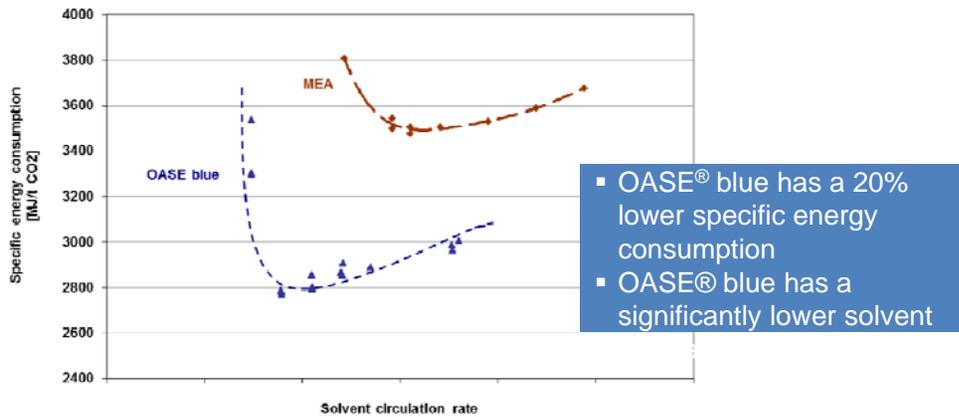
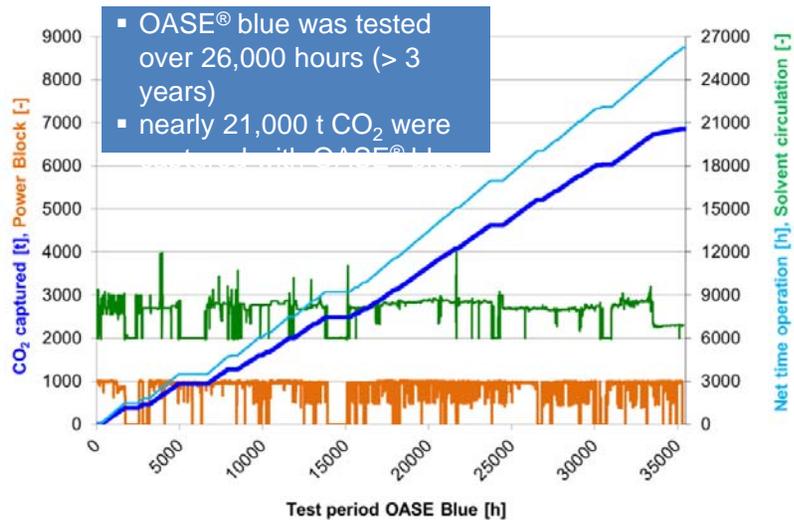
## Large Pilot: 25 MWe

- 2017/18, proposed
- PCC plant cost reduction
- Full value chain



# Niederaussem PCC Pilot Plant

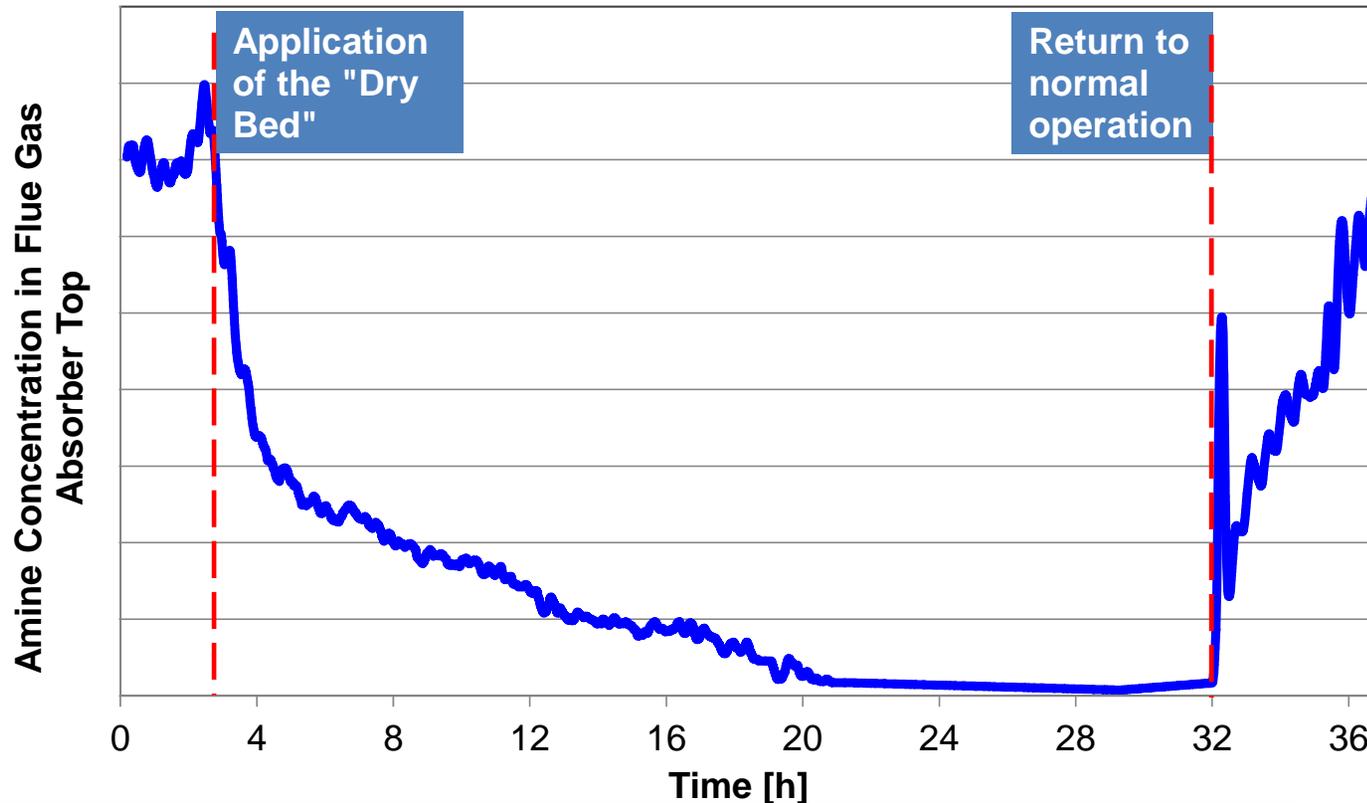
## Operational experiences and main results



# Niederaussem PCC Pilot Plant

*Emission reduction measures – "Dry bed"*

Amine traces downstream water wash



Reduction of amine emissions by an order of magnitude:

→ Proprietary process configuration „Dry Bed“



# Wilsonville PCC Pilot Plant

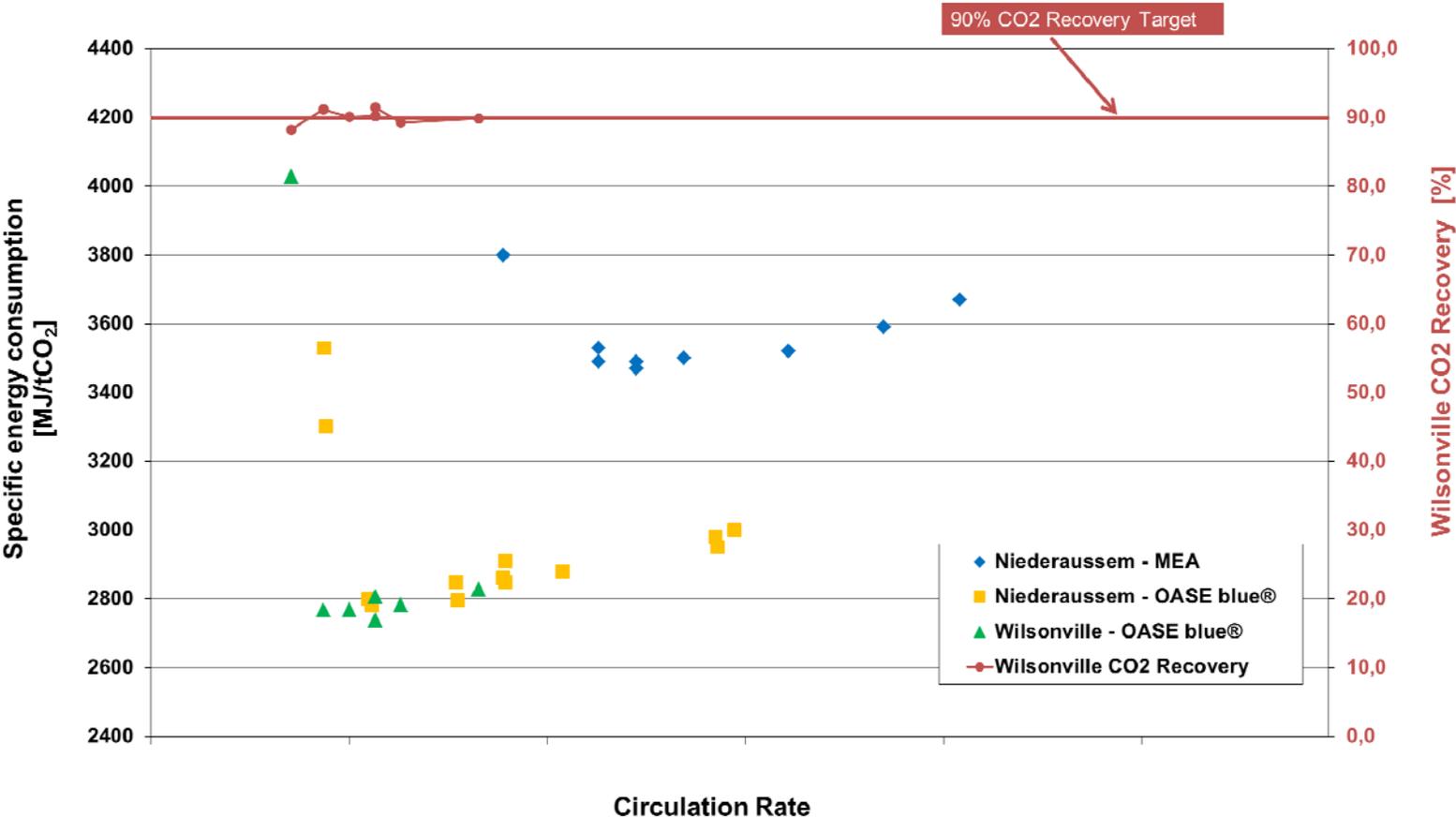
## *Project essentials*

- DOE-NETL funded project (\$16.2 million funding)
- Total project cost \$22.7 million
- Location: 880 MWe Gaston Power plant (operated by Southern Co.) in Wilsonville, AL
- Site of the National Carbon Capture Center
- Capacity: Up to 6,250 Nm<sup>3</sup>/h flue gas from coal fired power plant (30 t/d CO<sub>2</sub>); Up to 1.5 MWe
- CO<sub>2</sub> purity 99+ vol % (Dry basis)
- Project start: November 2011
- Start-up: January 2015
- Project Duration: 4.5 years
- Partners: Linde LLC, Linde Engineering North America, Linde Engineering Dresden, BASF, DOE-NETL, EPRI, Southern Company (Host site)



# Wilsonville PCC Pilot Plant

Typical result for specific energy consumption



# Wilsonville PCC Pilot Plant

## *Plant performance against targets*

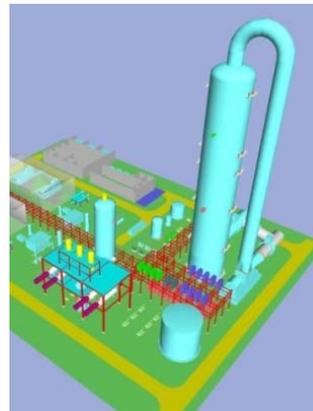
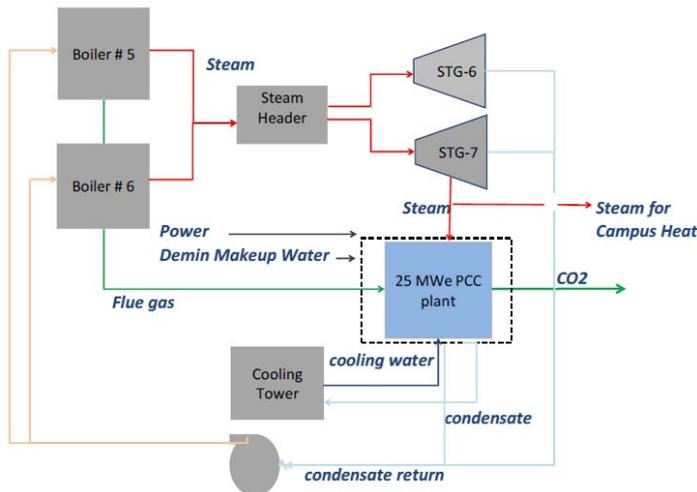
Performance Attribute	Current achievement against target	Remarks
1. CO2 capture rate	>90% per target	Achieved. Optimized for specific energy.
2. CO2 purity	99.9% dry basis per target	Achieved. Low O2 impurity level for EOR applications demonstrated.
3. Plant capacity	> 1.5 MWe per design target (>15,500 lbs/hr flue gas)	Achieved. Higher capacity testing performed ~10 days in May-June and repeated in Nov 2015
4. Regenerator steam consumption	~ 2.8 GJ/tonne CO2 (same as Niederaussem consumption)	Energy optimization continued.
5. Emissions control validation	Validation of dry bed (BASF patented) operation per design	Emissions control optimization performed with special isokinetic sampling & analysis.
6. Regenerator operating pressure	Testing performed up to 3.4 bars and higher pressure performance validated	Parametric tests to compare optimum performance at different pressures from 1.6 to 3.4 bars in progress
7. Validation of unique features	(i) high capacity packing, (ii) gravity driven intercooler, (iii) blower downstream of abs. (iv) unique reboiler design.	Optimization of lean-rich heat exchanger for energy reduction during next campaign

# Large pilot development at University of Illinois

## Project essentials

### LARGE PILOT

- 25 MWe coal-fired flue gas (500 TPD CO<sub>2</sub>)
- Located at Abbott Power Plant, Champaign, IL ; Host site: University of Illinois 35 MWe cogen plant
- US DOE funding: \$1 million; Phase 1 Project definition in progress (Q4 2015 – Q3 2016)
- Phase 2 proposal & selection in Q3/Q4 2016



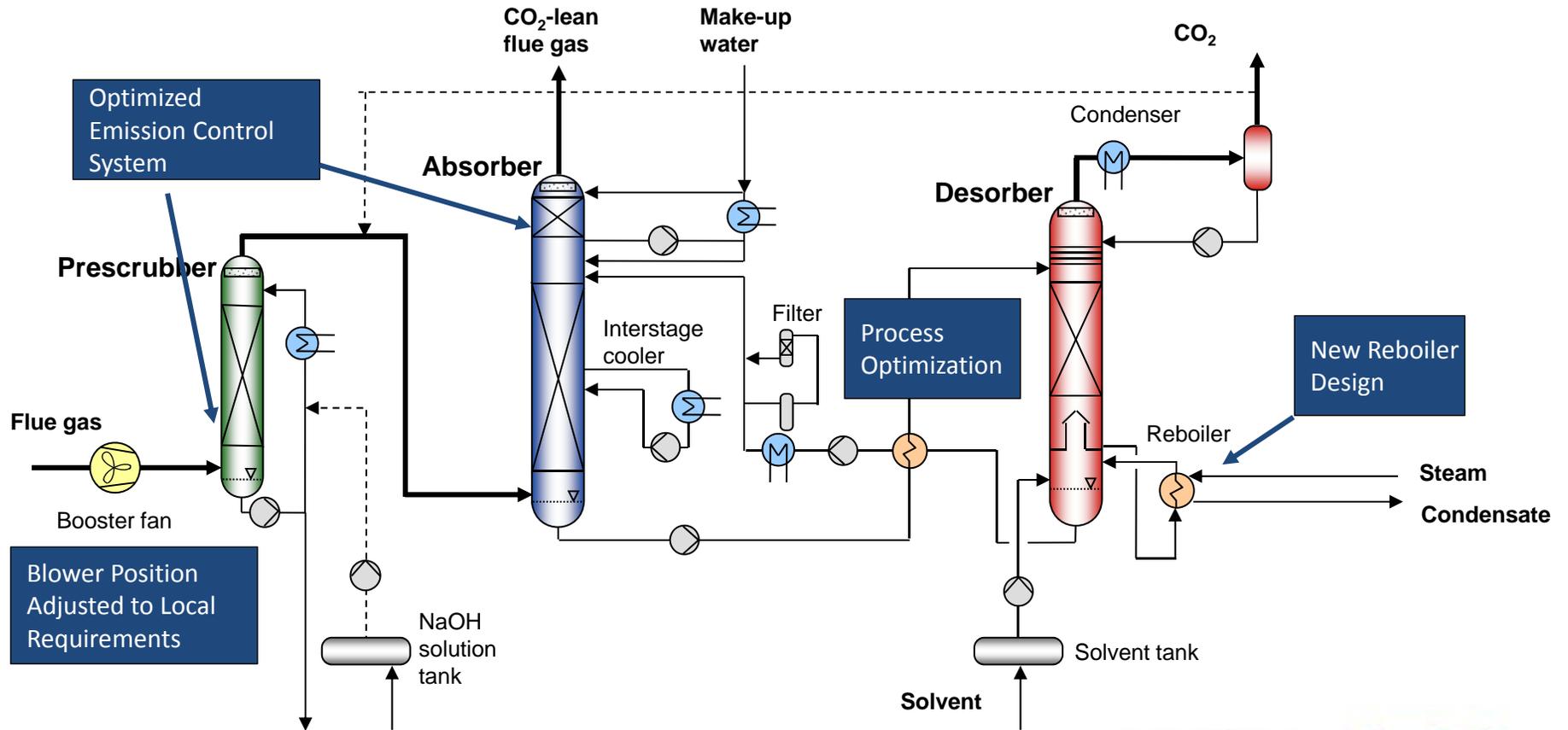
# Illinois PCC Large Pilot Plant

## Technology features

### Flue gas cooling, SO<sub>2</sub>-pre scrubbing

### CO<sub>2</sub>-capture

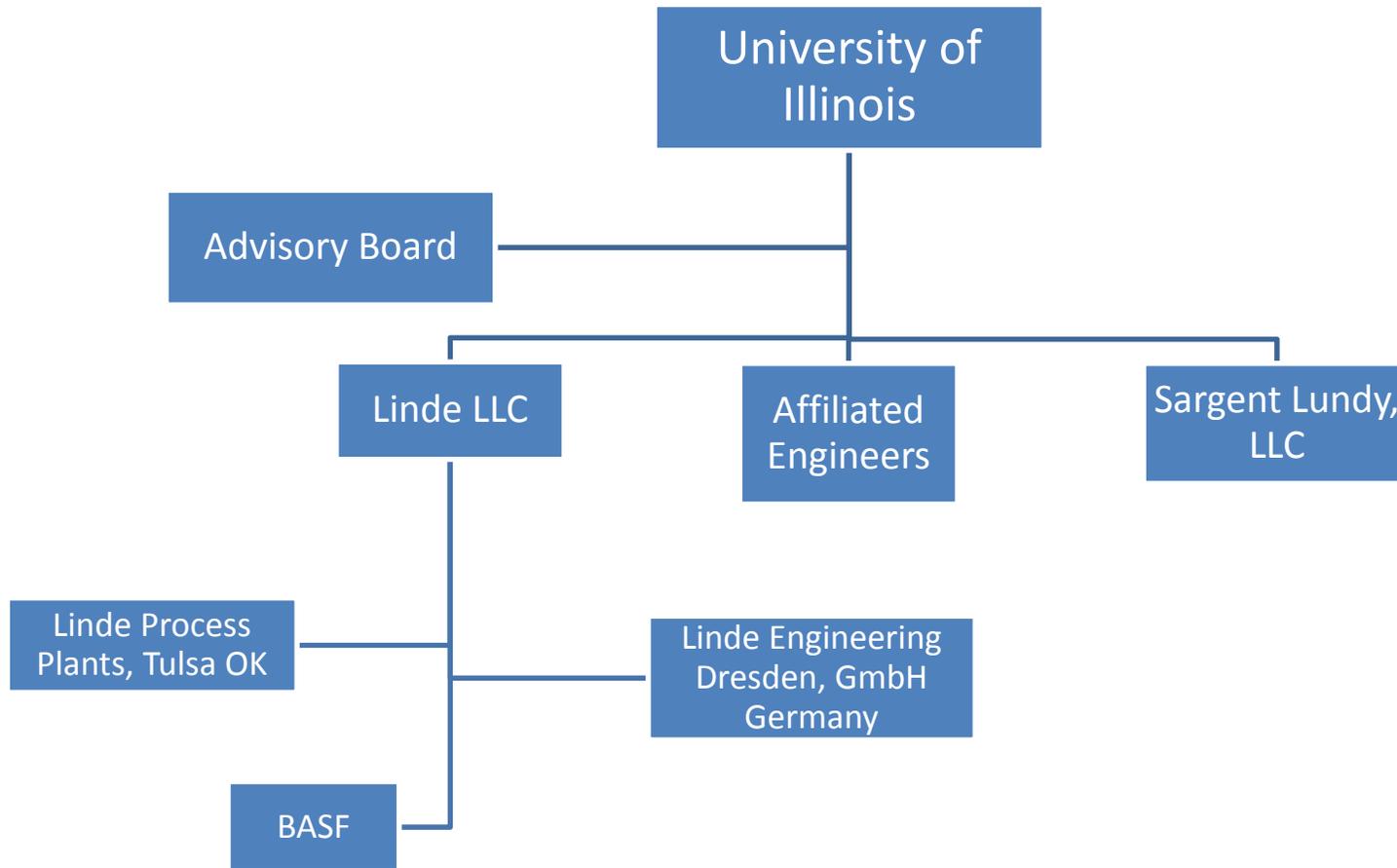
### Solvent regeneration



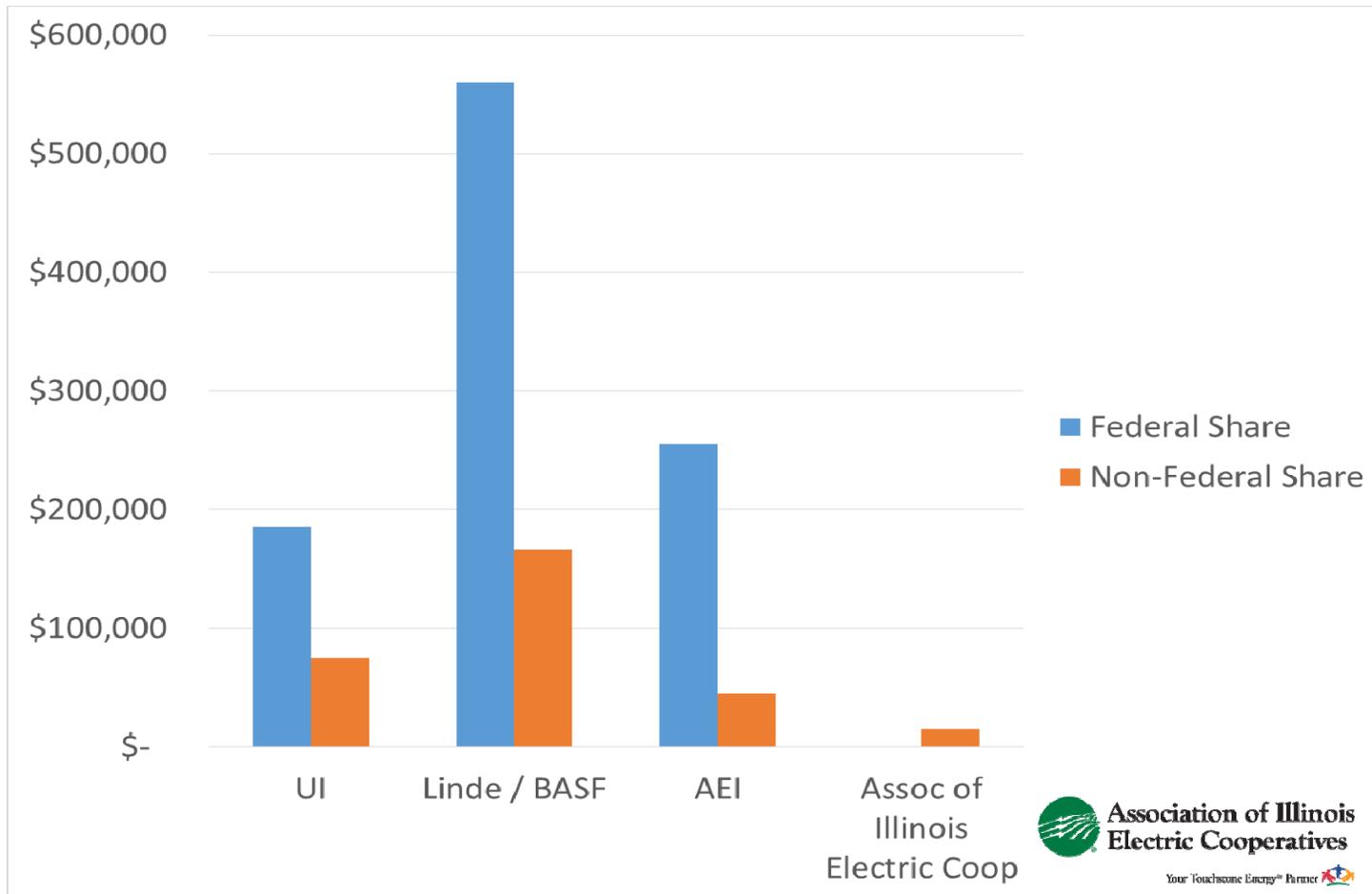
# PROJECT MANAGEMENT



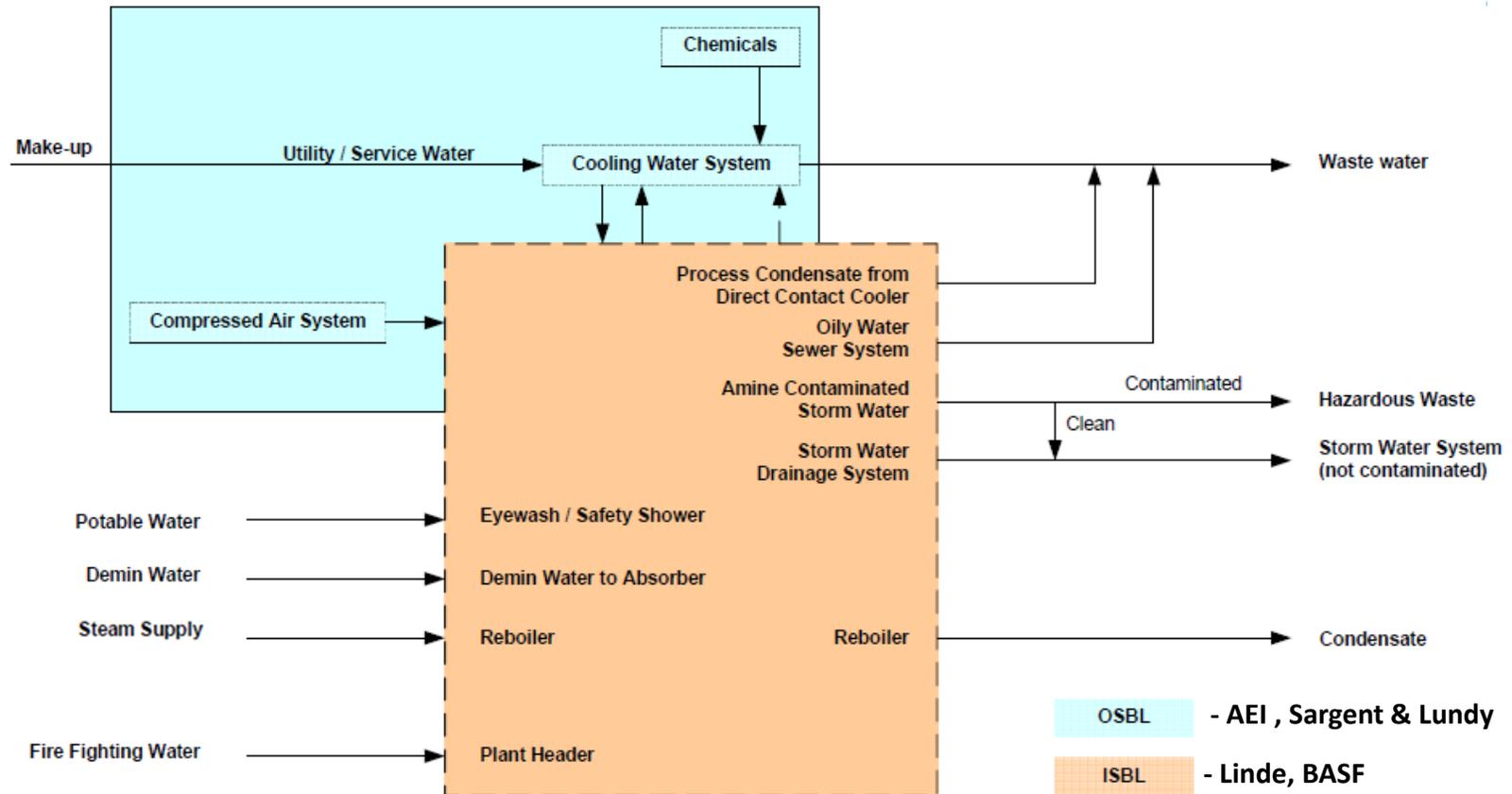
# Project Organization Chart



# Phase I Funds



# Team Roles & Responsibilities for Physical Infrastructure



# Key Personnel

Organization	Role	Key Personnel
University of Illinois	Host Site / Technology Evaluation	Dr. Kevin C OBrien Dr. Yongqi Lu
The Linde Group	Technology Developer, ISBL Engineering, Procurement, Construction	Dr. Krish Krishnamurthy Dr. Joseph Naumovitz
BASF	Technology Developer, basic design and solvent management	Dr. Sean Rigby
Affiliated Engineers	OSBL Engineering	David Guth, LEED AP
Sargent Lundy, LLC	OSBL Procurement, Construction	Kevin Lauzze, P.E.



# Roles & Responsibilities Mapped to WBS

WBS #	WBS Title	Scope Summary	UI	Linde	SL	AEI	BASF
1.0	<i>Project Management and Planning</i>						
1.1	Project Monitoring & Controls	Ensure project coordination and planning with DOE/NETL and participants.	X				
1.2	Briefings, Reports and Conferences		X	X	X	X	X



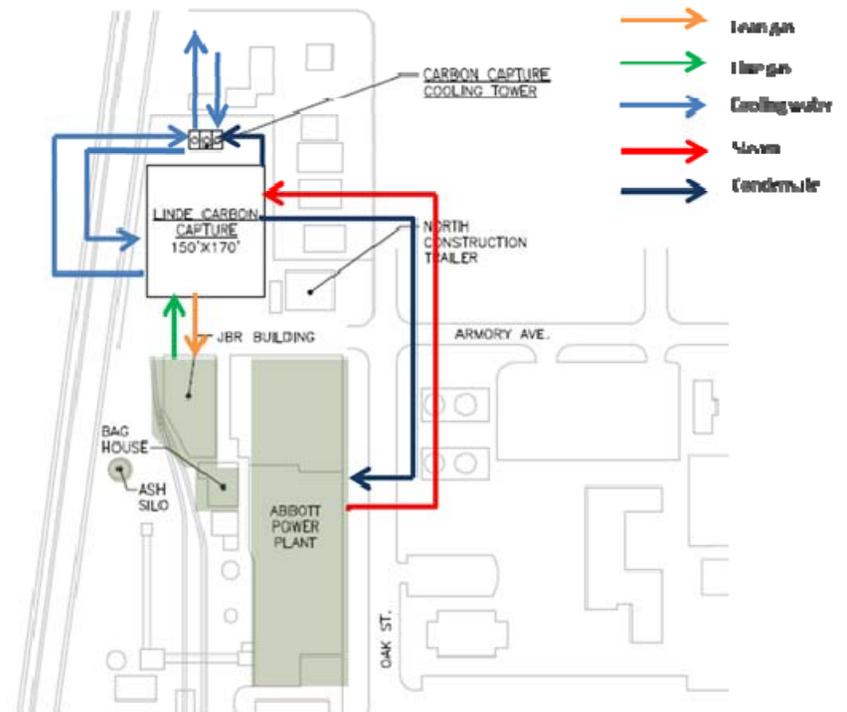
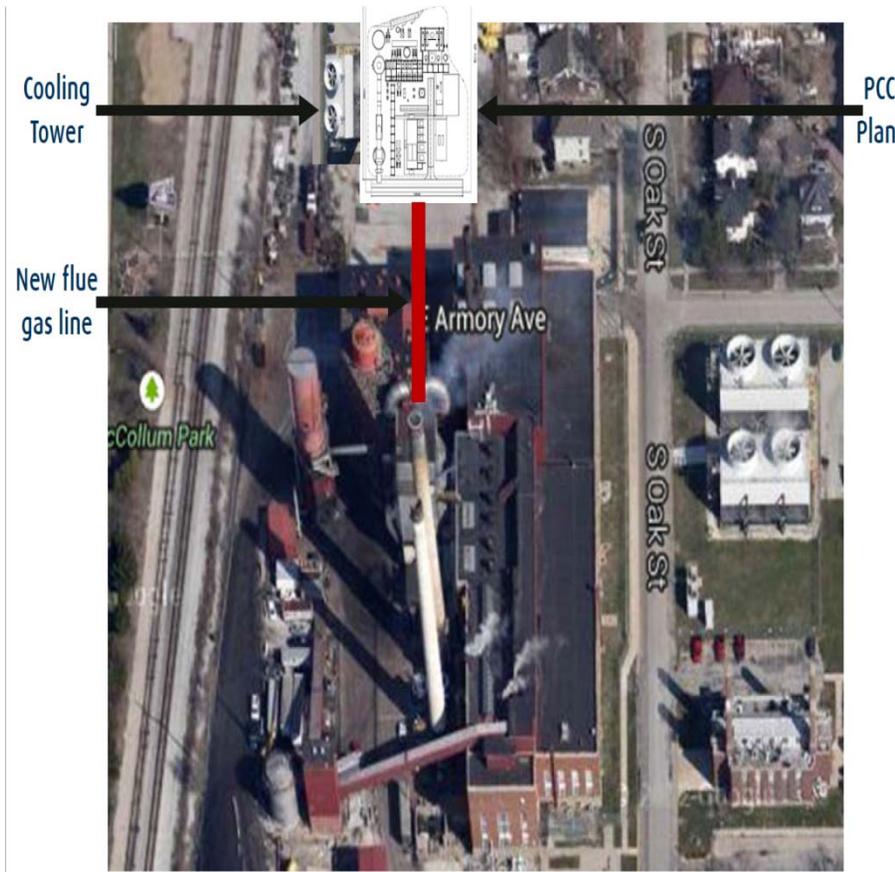
# Roles & Responsibilities Mapped to WBS

WBS #	WBS Title	Scope Summary	UI	Linde	SL	AEI	BASF
2.0	<b>Technology Engineering Design and Economic Analysis</b>						
2.1	Basis and Scope for the Power Plant with CO <sub>2</sub> Capture	Define the system boundaries and process design assumptions according to the specified DOE-NETL methodology		X			
2.2	Detailed Design of the Power Plant with Post-Combustion Capture	Update the detailed design of major equipment per specified NETL report		X			
2.3	Economic Analysis of the Power Plant with CO <sub>2</sub> Capture and Compression	Prepare cost estimates of all the major equipment per specified NETL report		X			



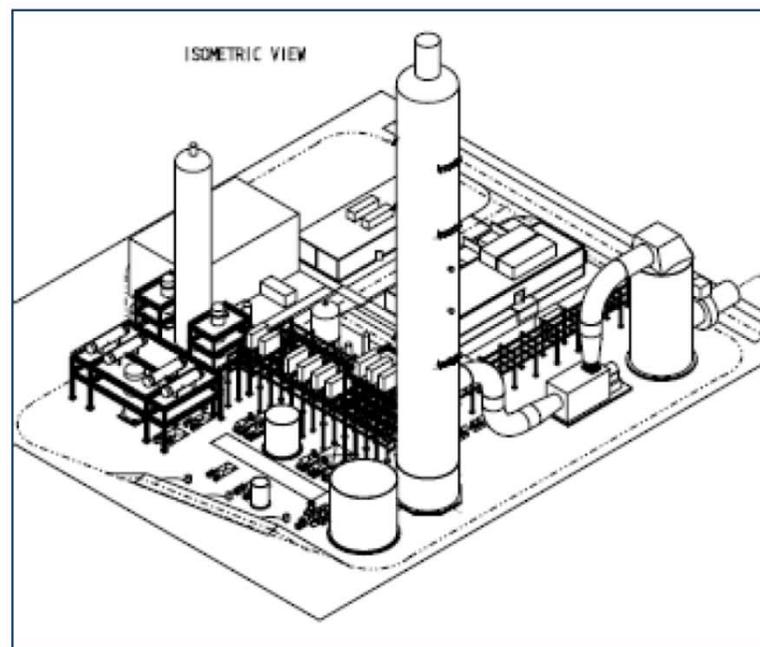
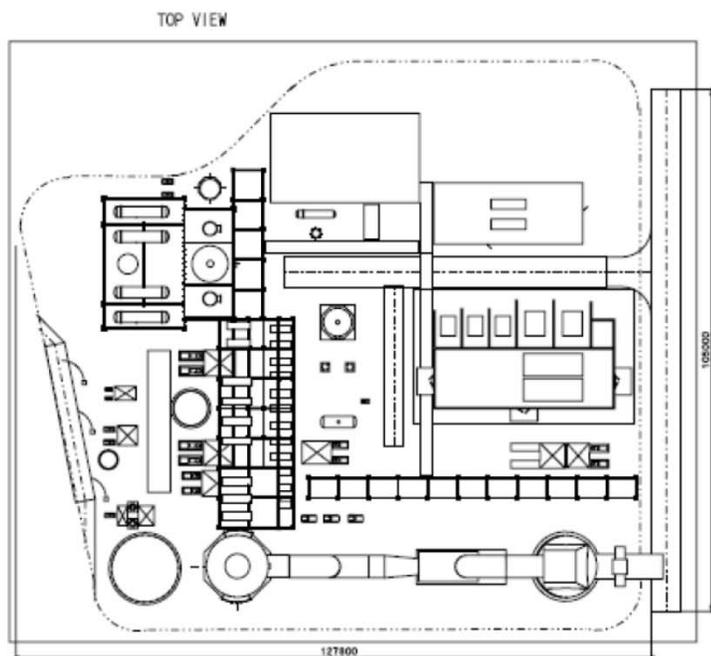
# Site for Carbon Capture Plant Established

*Located close to Abbott Power Plant*

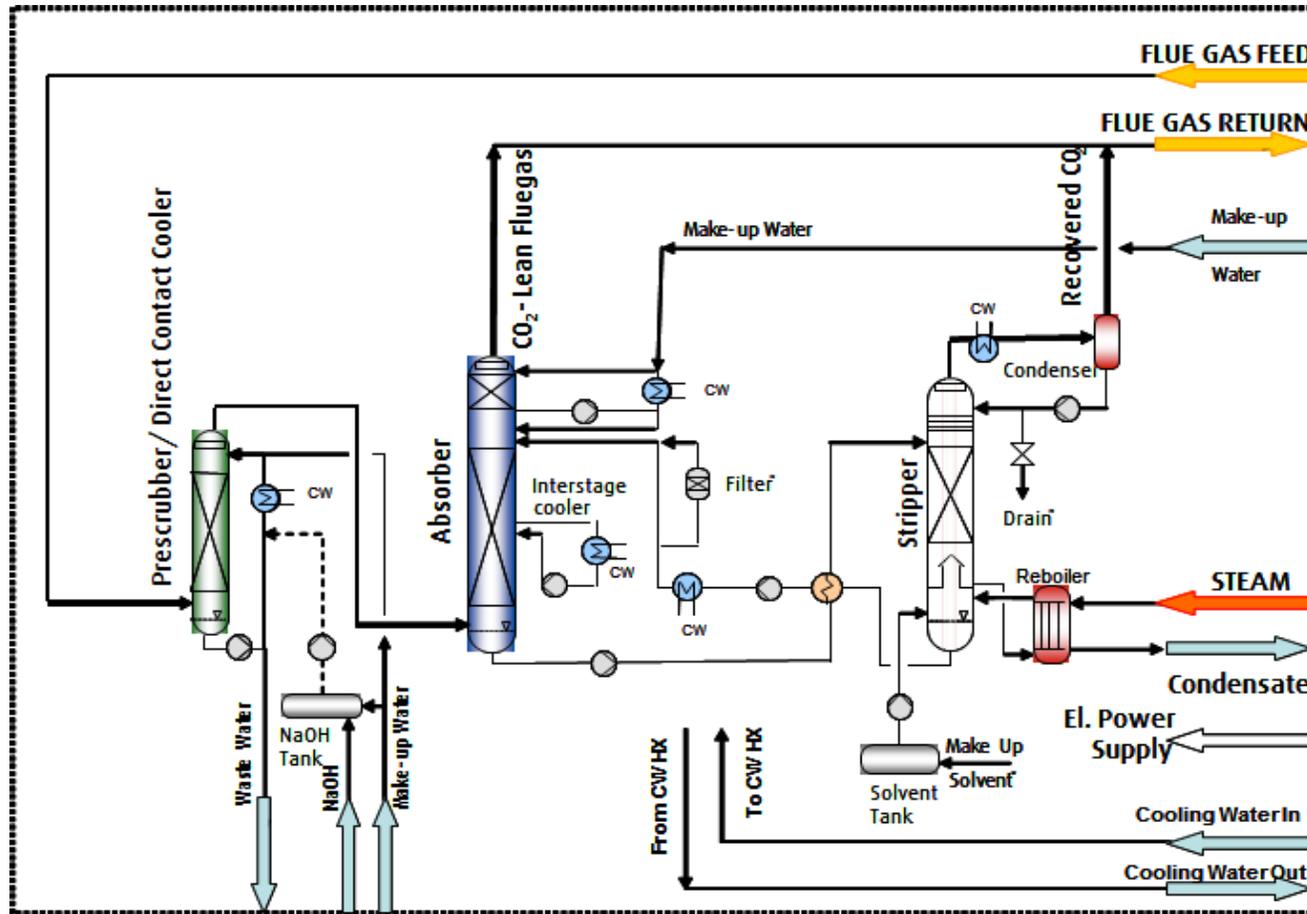


# Layout of Linde's Carbon Capture Plant

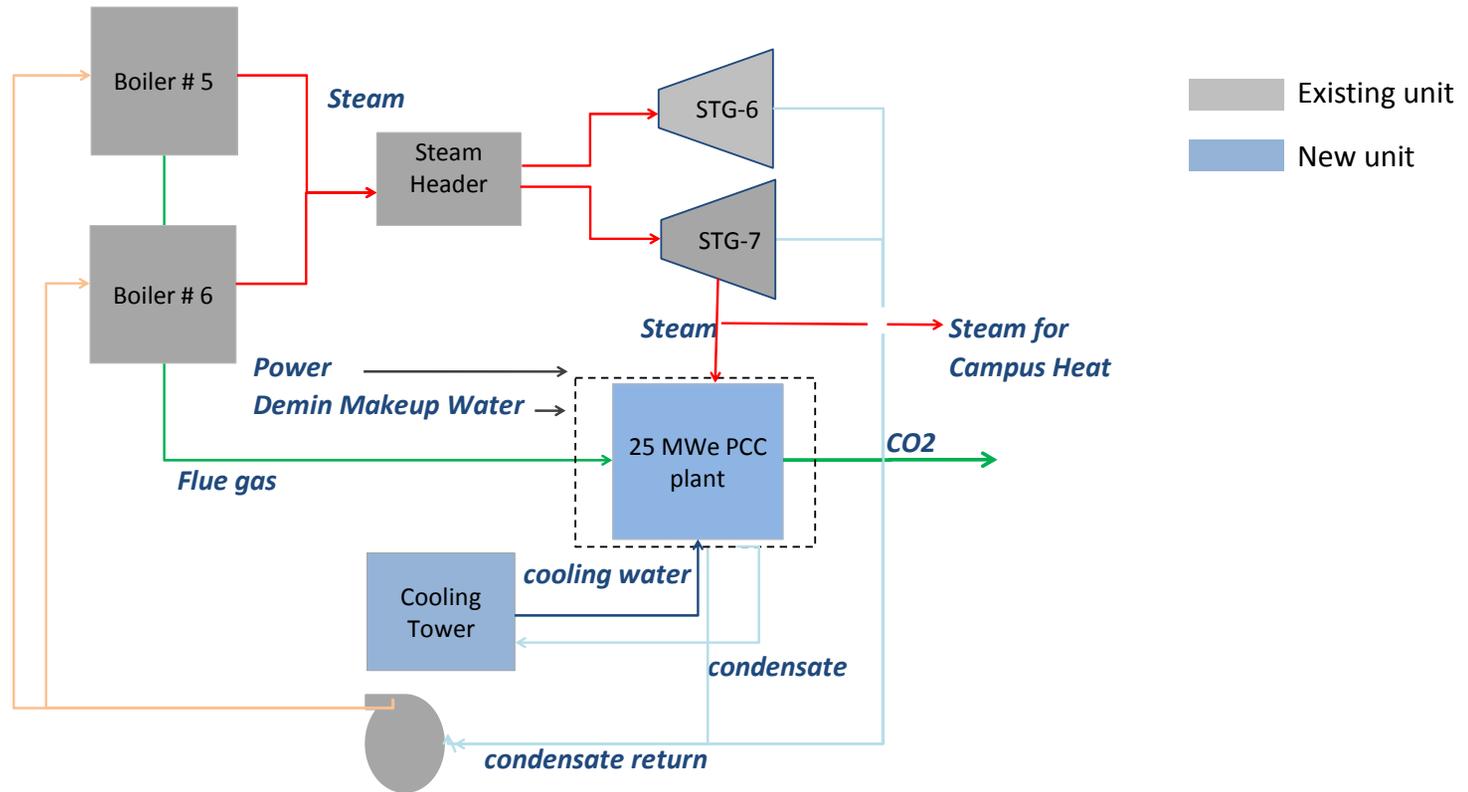
200 ft. x 200 ft. footprint



# Integration of PCC Plant with Power Plant Interface and Tie-In Points



# PCC Pilot Plant Integration with Power Plant with Utilities



# Roles & Responsibilities Mapped to WBS

WBS #	WBS Title	Scope Summary	UI	Linde	SL	AEI	BASF
3.0	<b><i>Environmental, health and safety (EH&amp;S) Risk Assessment</i></b>						
3.1	Preliminary EH&S Analysis		X	X			X
3.2	Phase II Environmental Questionnaire	Prepare Environmental Questionnaire for the Phase II project based on the results from the EH&S assessment	X				
3.3	Determine environmental permitting requirements and prepare documentation	Determine the permitting requirements for CO <sub>2</sub> capture at the existing power plant.	X				



# Roles & Responsibilities Mapped to WBS

WBS #	WBS Title	Scope Summary	UI	Linde	SL	AEI	BASF
4.0	<b><i>Technology Gap Analysis and Risk Management</i></b>						
4.1	Technology Gap Identification	Identify the impact of technology scaling gaps and assess their impact on performance.		X			X
4.2	Risk Mitigation Planning	Evaluate the impact of key design parameters and options to mitigate the risk		X			

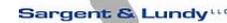
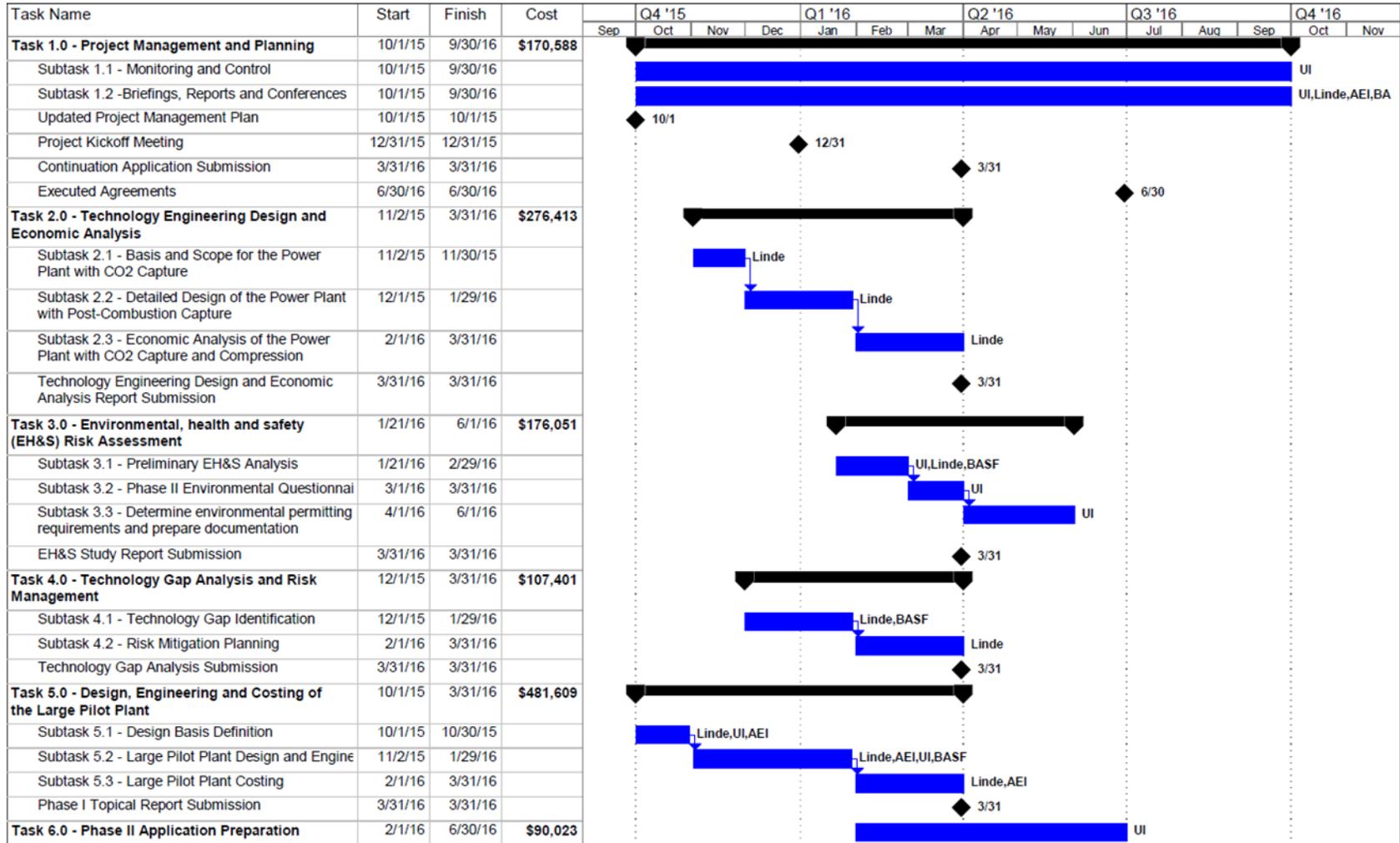


# Roles & Responsibilities Mapped to WBS

WBS #	WBS Title	Scope Summary	UI	Linde	SL	AEI	BASF
<b>5.0</b>	<b><i>Design, Engineering and Costing of the Large Pilot Plant</i></b>						
5.1	Design Basis Definition	Identify any modifications required at Abbott for CO <sub>2</sub> capture system.	X	X		X	
5.2	Large Pilot Plant Design and Engineering	An engineering package of the capture system integrated with the power plant will be developed.	X	X		X	X
5.3	Large Pilot Plant Costing	A detailed estimate of the overall capex of the large pilot as well as plant consumables and O&M labor will be compiled.		X		X	
<b>6.0</b>	<b><i>Phase II Application Preparation</i></b>	Prepare a Phase II proposal compliant with NETL / DOE guidelines listed in DE-FOA-0001190	X				



# Project Timeline and Milestones

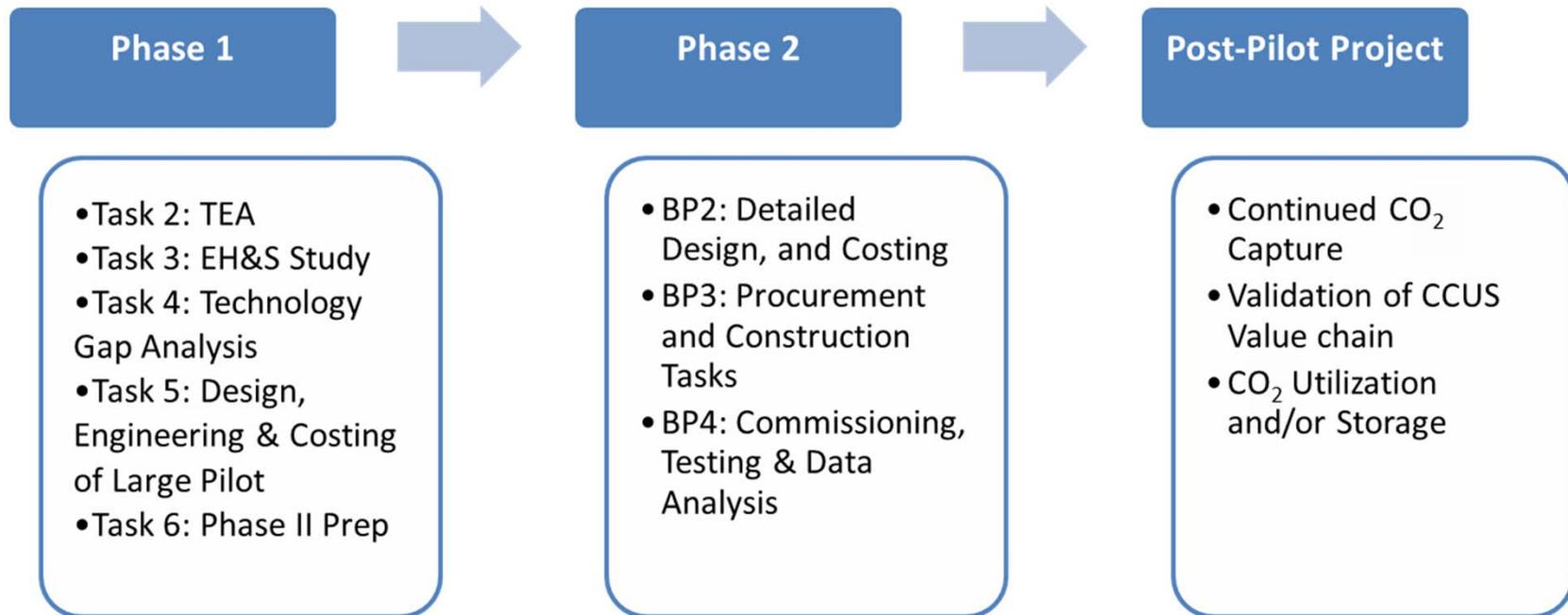


# Milestone Log

Budget Period	ID	Task Number	Description	Planned Completion Date	Actual Completion Date	Verification Method
1	a	1	Updated Project Management Plan	10/1/2015		Project Management Plan file
1	b	1	Kickoff Meeting	12/30/2015		Presentation file
1	c	2	TEA Completed	03/31/2016		Presentation file
1	d	3	EH&S Study Completed	03/31/2016		Presentation file
1	e	5	Phase 1 Topical Report Completed	3/31/2016		Presentation File
1	f	1	Host Site Agreement Completed	06/30/2016		Signed agreement



# Overview of Project Schedule



# Technical Risks & Mitigation

Description of Risk	Probability	Impact	Risk Management Mitigation and Response Strategies
Scale-up risk: Vapor and liquid mal-distribution in the absorber column	Low	Medium-High	<ul style="list-style-type: none"> <li>Leverage Linde experience in designing other large columns</li> <li>A model will be used to predict the distribution of fluids in the column</li> </ul>
Solvent-related issues (corrosion, adequate supply, handling)	Low	Medium-High	<ul style="list-style-type: none"> <li>BASF expertise and testing experience from 0.5 and 1.5 MWe pilot plants</li> <li>BASF confirmation of solvent supply</li> <li>Use data from corrosion coupon testing that was performed at 1.5 MWe scale</li> </ul>
Emissions and waste streams, including unknown contaminants	Low-Medium	Medium	<ul style="list-style-type: none"> <li>Leverage testing experience from 0.5 and 1.5 MWe pilot plants</li> <li>Confirm dry bed configuration for emissions control at large scale</li> <li>Detailed analysis (including heavy metals) of flue gas and liquid streams</li> </ul>
Integration with operations at the Abbott plant	Low	Medium	<ul style="list-style-type: none"> <li>Joint meetings to understand issues and incorporate into design, control logic, and operations plan</li> </ul>



# Resource Risks & Mitigation

Description of Risk	Probability	Impact	Risk Management Mitigation and Response Strategies
Flue gas and utilities non-availability from power plant	Low	High	<ul style="list-style-type: none"> <li>• Past experience is favorable. Work with Abbott to confirm no issues with flue gas and utility availability</li> <li>• Coordinate with Abbott plant to meet both Abbott production and pilot project requirements</li> <li>• Pilot plant design basis to be set based on specification of the flue gas and utility requirements, and confirmation from Abbott on availability</li> </ul>



# Management Risks & Mitigation

Description of Risk	Probability	Impact	Risk Management Mitigation and Response Strategies
Uncertainty of time required of obtaining environmental permits	Moderate	High	<ul style="list-style-type: none"> <li>• Detailed and thorough preparation work in Phase I;</li> <li>• Close communication with IEPA;</li> <li>• Include IEPA as a board member to follow project progress;</li> <li>• Involve professional compliance consulting company to accelerate preparation and application</li> </ul>
Uncertainty of time required for NEPA documentation especially if an Environmental Impact Statement (EIS) is determined to be required	Moderate	High	<ul style="list-style-type: none"> <li>• Involve professional environmental impact assessment personnel in the team;</li> <li>• Involve environmental consulting companies;</li> <li>• Experience and lessons from other projects with similar scale</li> </ul>



# HOST SITE DESCRIPTION



# Host Site: Abbott Power Plant

- Seven boilers total: three are coal based (Chain-grate stoker design) others natural gas
- Coal side has completely separate treatment system from natural gas side
- For testing will run two coal boilers
- Illinois high sulfur coal is burned
- Electrostatic precipitators and a wet Flue Gas Desulfurizer (FGD) in place
- Tradition of evaluating new emission technologies
- Tradition of showcasing technologies to other power plants and education groups



- Educational site for industry & students
- Facilitating future utilization approaches

## **ENABLING THE PROPAGATION OF CCUS: ADVANTAGES OF A UNIVERSITY TEST SITE**



# Advisory Board for Capture Project

*Key partnerships regionally and with China, India, and Brazil*



中石化石油工程设计有限公司  
Sinopec Petroleum Engineering Corporation



US Army Corps  
of Engineers®  
Engineer Research and  
Development Center



# Regional & Global Test Bed for CCUS

*Concentration of natural resources and intellectual capital*

