Phase III Review: Large Pilot Testing of Linde-BASF Advanced Post-Combustion CO_2 Capture Technology at a Coal-Fired Power Plant (FE-0031581)

Kevin C. OBrien, PhD
Director, Illinois Sustainable Technology Center
Director, Illinois State Water Survey
Prairie Research Institute
University of Illinois at Urbana-Champaign

Stephanie Brownstein
Assistant Research Engineer, Illinois
Sustainable Technology Center
University of Illinois at Urbana-Champaign

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PROJECT OVERVIEW

Phase II Funding: $3,736,684
DOE: $2,988,359
20% Cost Share: $748,325
Work Period: Sept. 1, 2019 – Jan. 15, 2021
Phase II Completed: May 31, 2021

Complete

Phase III Funding: $67,000,000
DOE: $47,000,000
Cost Share: $20,000,000 (supplied by the State of Illinois)
Work Period: June 1, 2021 – May 31, 2026

City Water, Light and Power (CWLP) in Springfield, IL

PROJECT OBJECTIVES:

Overall: Design, construct, and operate a 10 MW capture system based on the Linde / BASF advanced amine-based, post-combustion carbon dioxide (CO_2) capture technology at CWLP Dallman Unit 4, Springfield, IL.

Phase III: Build / Operate 10 MW capture system and compare performance with results from 1.5 MW testing at the NCCC. If successful, keep system for evaluating future capture and utilization testing technologies.

Part of Plan for Decarbonization of the Grid

WHY THE INVESTMENT BY THE STATE OF ILLINOIS?

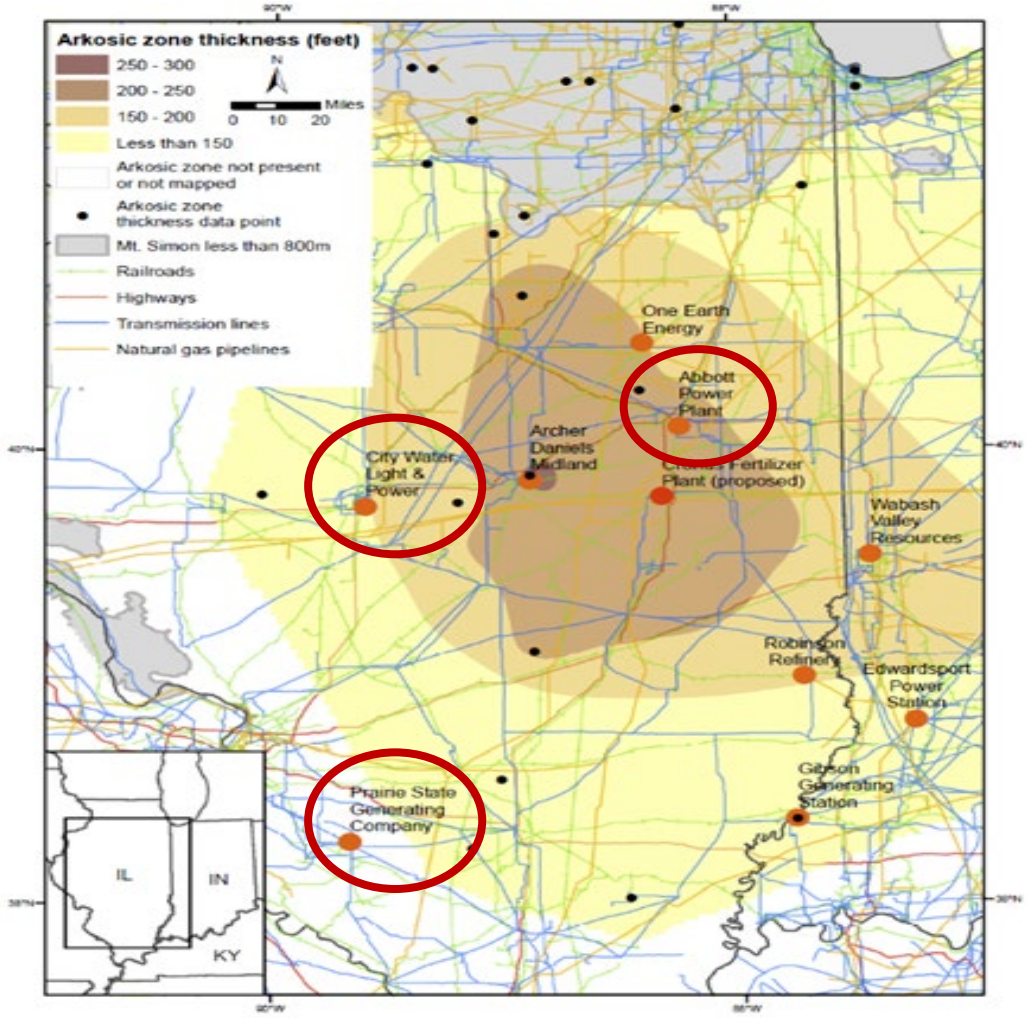
Illinois: A Confluence of Geology, Technology, Government Investment

Creates unique advantages for the state of Illinois

- Ability to store CO_2 has provided a major motivator for large capture pilots and large-scale capture demonstration projects at CO_2 emitters within the state
- Unique geology of Illinois a major asset for CO_2 storage
- 45Q has been a major incentive – a means to monetize CO_2
- US DOE funding has enabled the maturation of capture technologies that can be deployed at locations throughout the state
- State of Illinois' support with major cost share investment
- Elected officials at all levels interested in the job creation and regional economic benefits of these projects

Capture Studies Coordinated with Geological Storage Studies

CarbonSAFE Phase III: Geological Storage



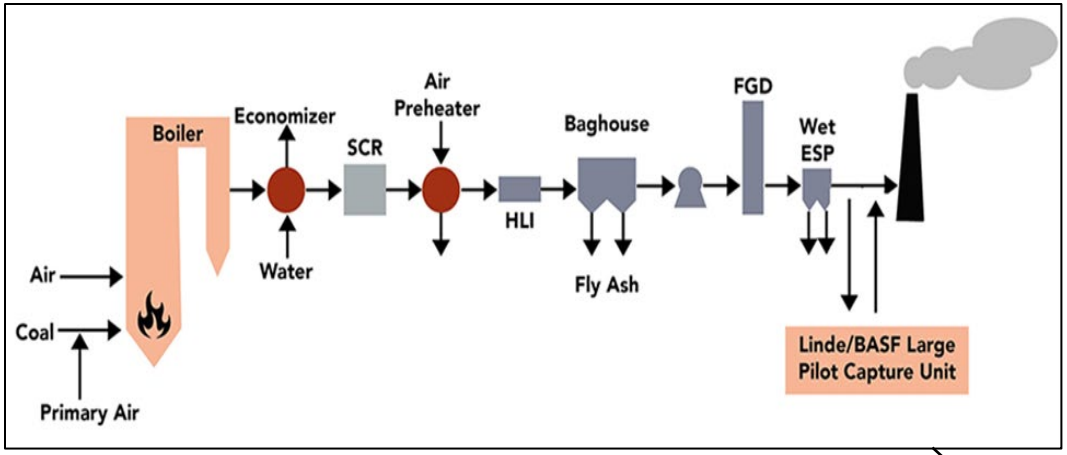
- ***Able to connect to CarbonSAFE's Phase III Illinois Geological Storage Corridor***
- ***Sufficient CO_2 geological storage capacity near the host sites***
- ***All sites within 100 miles of storage site***
- ***Immediate access to Interstate highway***

Build / Operate: Largest Capture R&D Pilot in the World (10 MW)

CITY WATER, LIGHT AND POWER

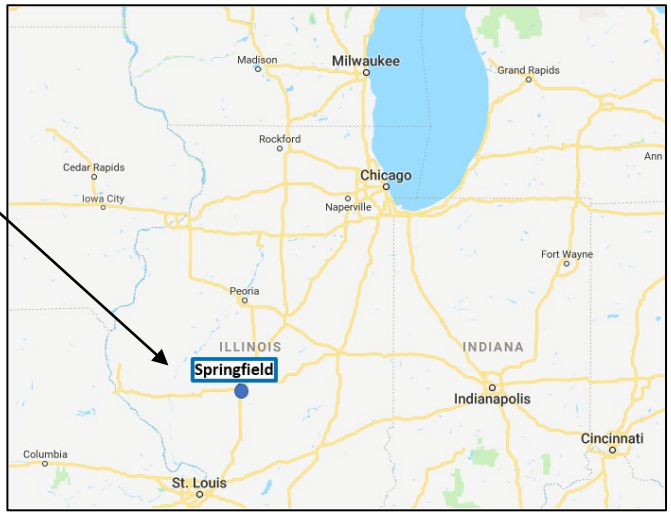
CWLP Location and Configuration

Traditional PC plant



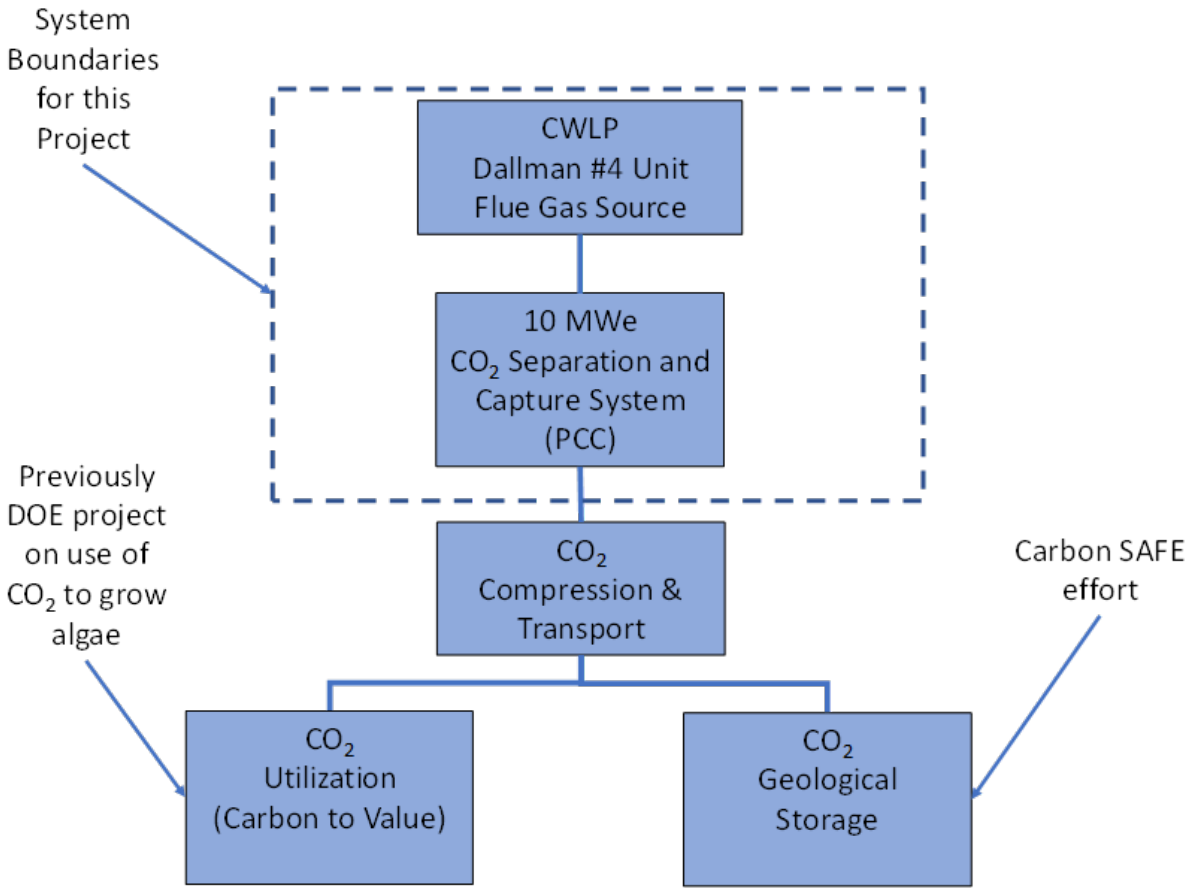
Dallman Unit 4 configuration

Location of city of Springfield within the state of Illinois



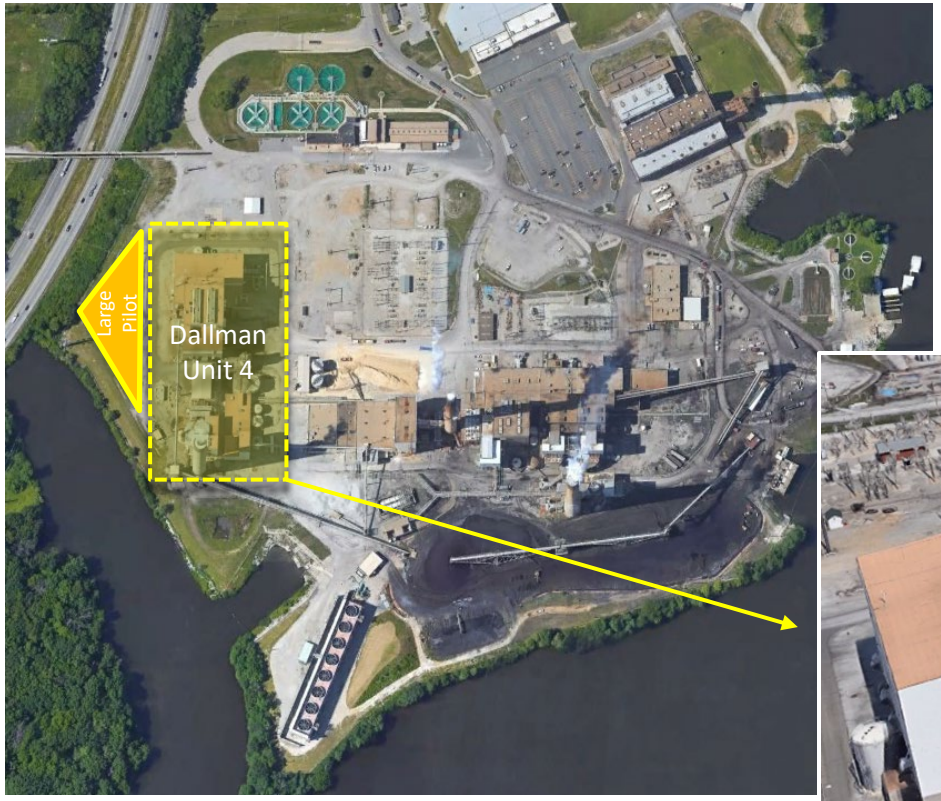
System Boundaries for Project

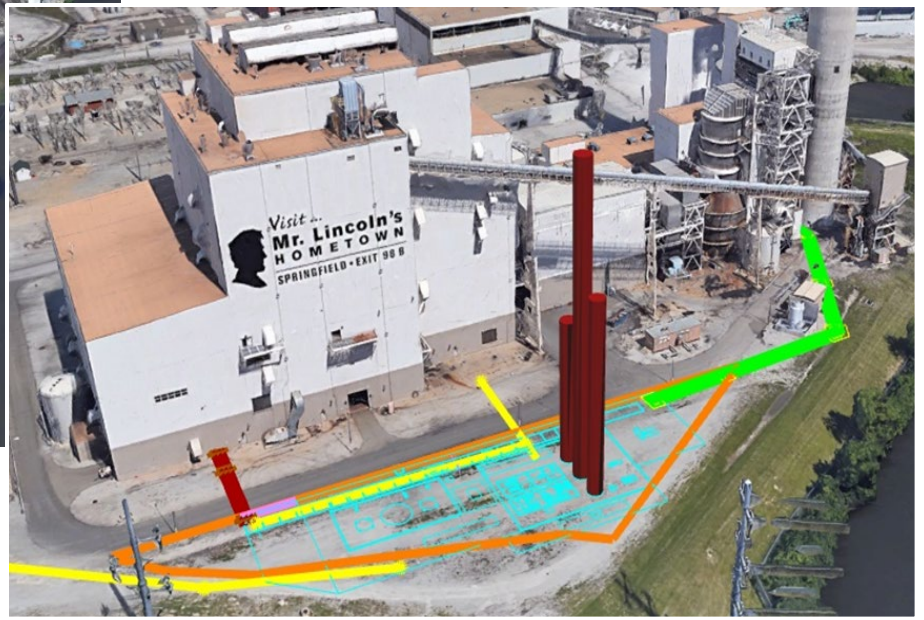
Follow-on projects can connect to existing DOE projects for storage and utilization



City Water, Light and Power (CWLP)

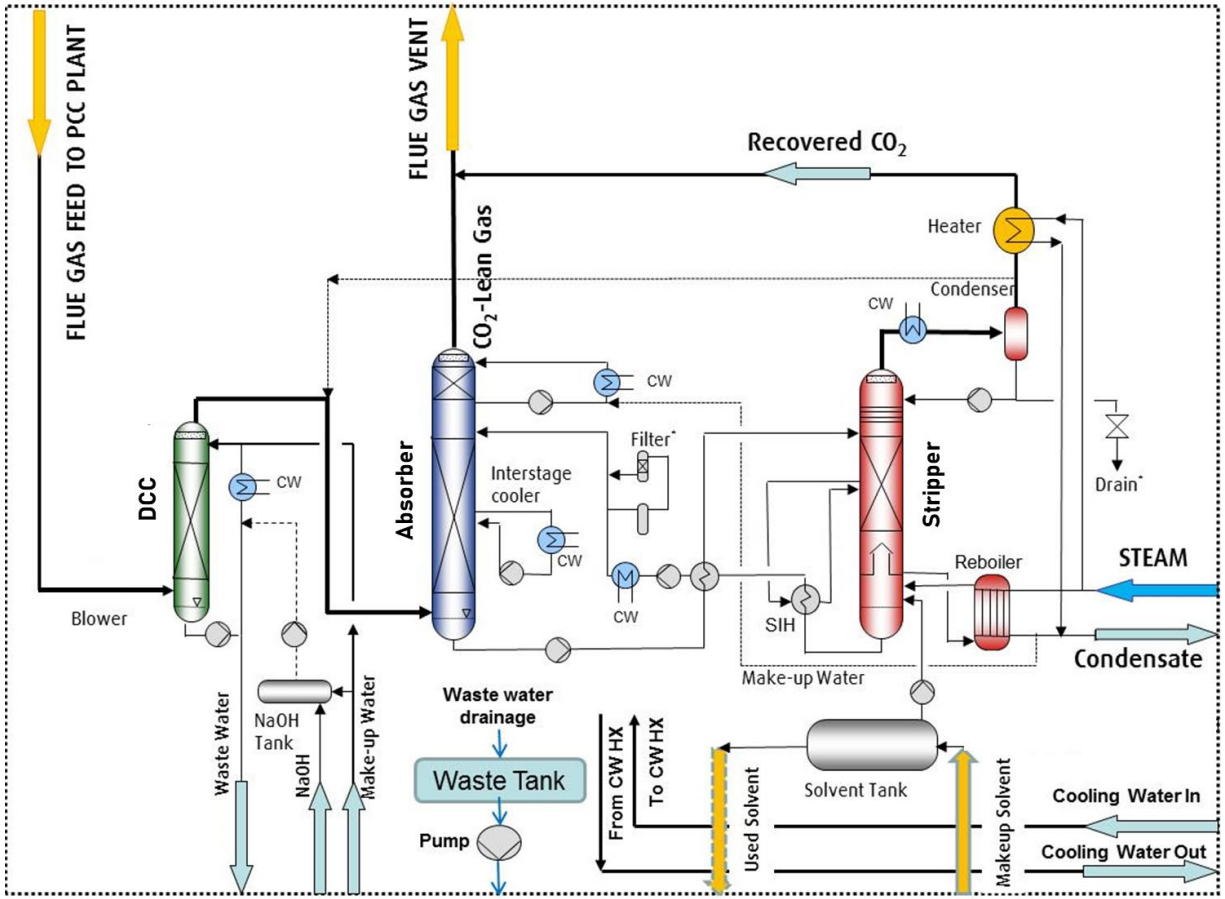
Water and power supplier for City of Springfield





TECHNICAL BACKGROUND

Linde / BASF Solvent Based Capture System



Reduced capital/energy costs

- Optimized BASF OASE® blue solvent
- Efficient CO_2 capture from low-pressure sources
- Longer solvent stability
- Lower solvent circulation rate

Notable Linde process improvements

- Dry bed water wash design to minimize solvent losses
- Stripper regeneration at 3.4 bars reducing CO_2 compressor cost and power consumption
- Advanced Stripper Interstage Heater to reduce regenerator steam consumption

Scale-up Factors at Each Stage for Development

DEVELOPMENT SCALE	YEAR	SIZE (MWe)	SCALE-UP FACTOR*	DEVELOPMENT STRAGETY
Lab scale; mini pilot	2004	0.015	n/a	Solvent selection and proof-of-concept under laboratory conditions
Bench scale: Niederaussem	2009	0.45	30	Solvent performance validation; emissions control testing under realistic conditions
Small pilot: NCCC	2016	1 to 1.5	3	Validation of unique process features aimed at reducing CAPEX – i.e., high-capacity structured packing, gravity-driven absorber inter-stage cooler, and unique reboiler design
Proposed large-scale pilot	2021-2026	10 to 12	7 to 8	Equipment performance validation at commercially relevant scale (i.e., uniform gas/liquid distribution in absorber and inter-stage heating in the stripper)
First commercial plant	2025-2030	200 to 600	20 to 50	At scale demonstration of complete CCS value chain (capture, compression, transport, and storage/ utilization)
nth commercial plant	2030+	600+	3 to 5	Safe, reliable, and economic operation in compliance with regulations

**Assumes PCC capacity of 20 tpd captured CO_2 for every 1 MWe (flue gas 13% CO_2 concentration)*

Attractive Techno-Economics for Linde / BASF Process

Baseline case: DOE-NETL supercritical PC power plants

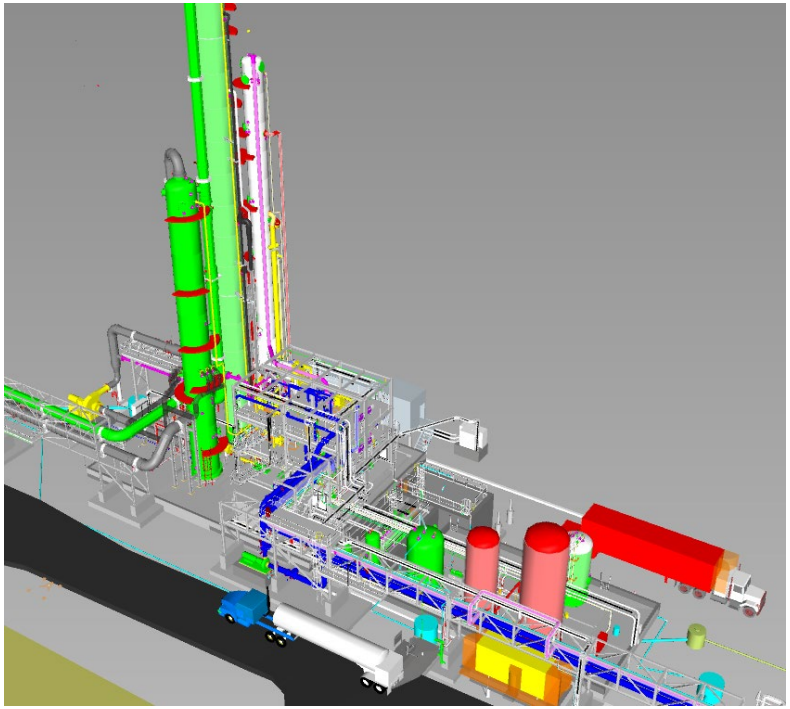
Parameter	DOE NETL Case B12A	DOE NETL Case B12B	Linde BASF LB1	Linde BASF SIH	Linde BASF WHR
Description	**No CO_2 Capture**	**90% Capture w/ Cansolv PCC process**	**90% Capture w/OASE® Blue**	**90% Capture w/ OASE® Blue and SIH**	**90% Capture w/ OASE Blue® SIH, and WHR**
Net Power Output (MWe)	650	650	650	650	650
Gross Power Output (MWe)	685	770	748	746	743
Coal Flow Rate (tonne/hr)	214.1	273.6	268.1	263.9	253.7
Net HHV plant efficiency (%)	40.3%	31.5%	32.2%	32.7%	34.0%
CAPEX without T&S ($/MWh)	N/A	$50.98	$40.59	$40.18	$39.11
OPEX without T&S ($/MWh)	N/A	$54.24	$51.35	$50.70	$49.04
Cost of CO_2 captured with T&S ($/MT)*	N/A	$55.60	$41.60	$41.01	$39.40
Cost of CO_2 captured without T&S ($/MT)*	N/A	$45.65	$31.44	$30.69	$28.66
COE ($/MWh) with T&S*	N/A	$114.12	$100.84	$99.78	$97.05
PCC specific reboiler duty (GJ/MT CO_2)	N/A	2.48	2.61	2.30	1.50

Case implemented in Phase III

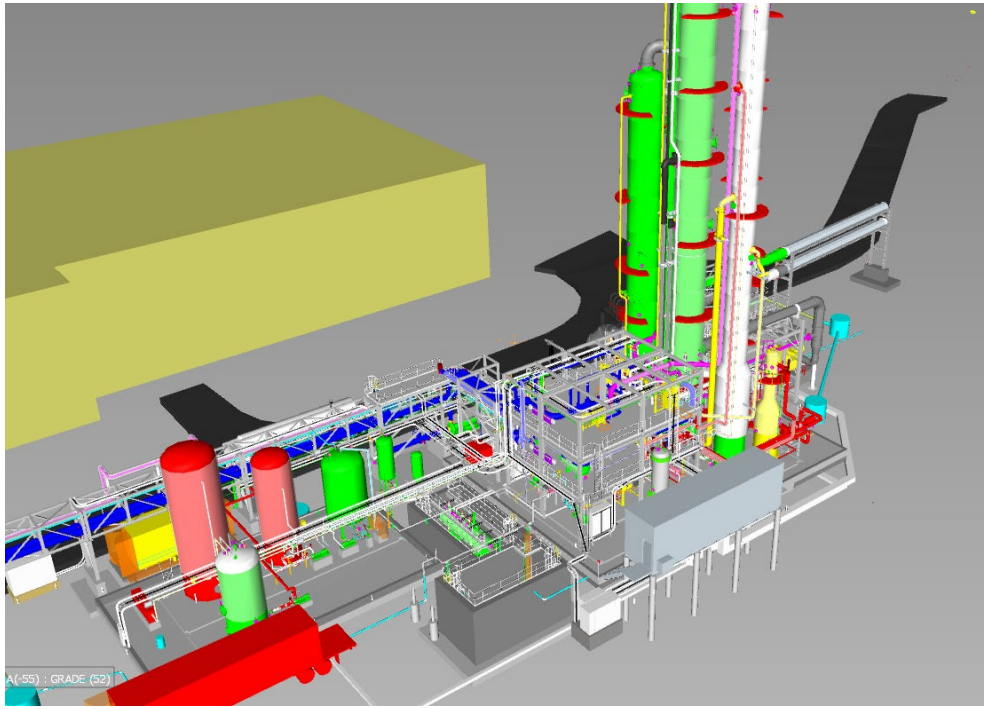
Linde/BASF Capture Unit

3D Rendering

Facing West
(towards Lake Springfield / I-55)



Facing East
(towards Dallman #4)

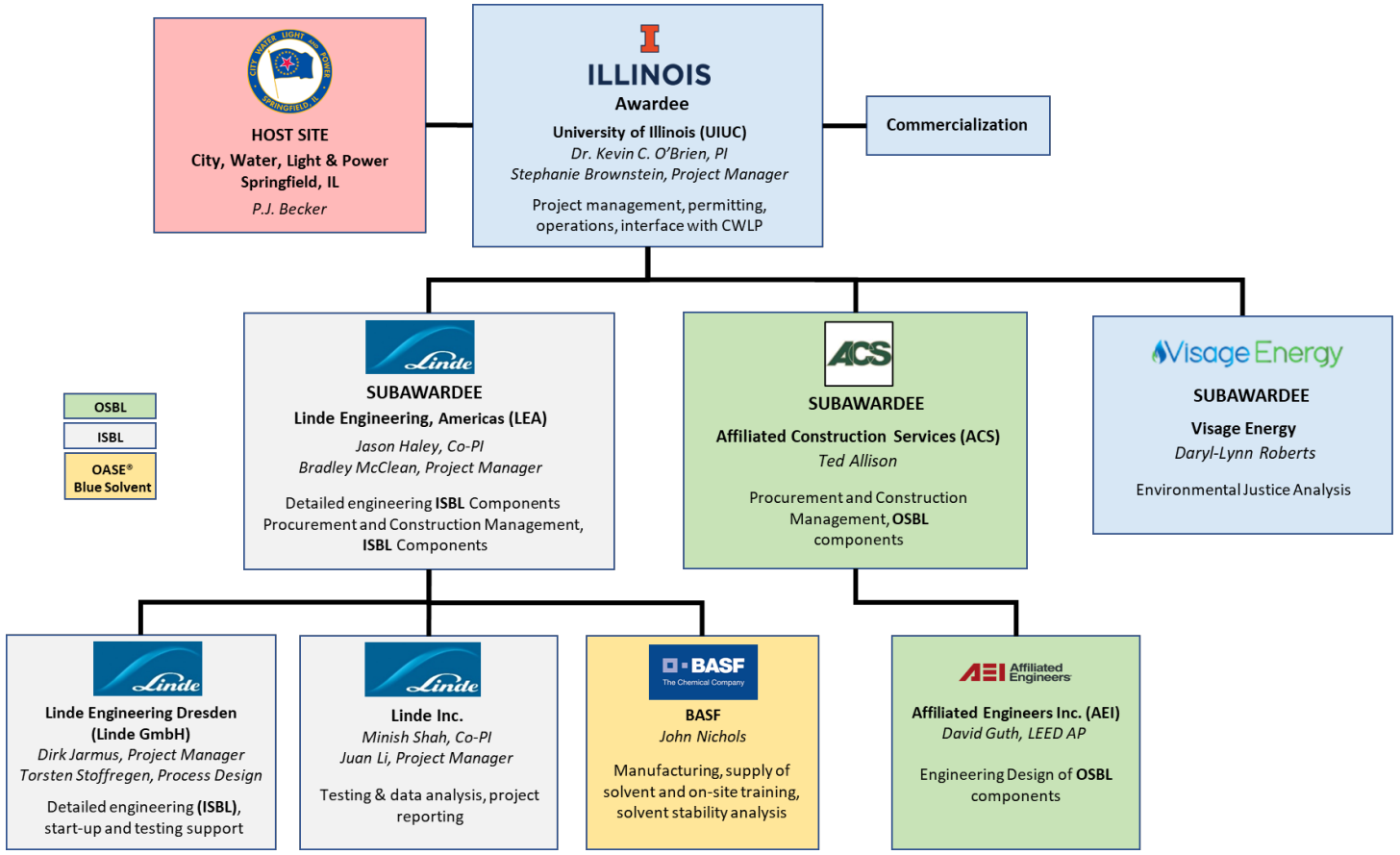


Phase III Kickoff / Transition from BP3 to BP4

PROJECT MANAGEMENT & RISK MANAGEMENT

Phase III: Project Management Structure

Consistent team throughout all phases



Blue = "Complete"

Project Tasks

BP1 for Phase III = BP3 overall for project

All BP3 tasks completed

Started Task 7

Task #	Task	BP
1.0	Project Management and Planning	All BP
2.0	Baseline Techno-Economic Analysis (TEA)	BP3
3.0	Detailed Engineering and Specifications	
4.0	Permit Application	
5.0	Construction and Execution Plan	
6.0	Long Lead Item Equipment Procurement	
7.0	Equipment Procurement and Fabrication	BP4
8.0	Site Preparation and Foundations Installation	
9.0	Plant Construction and Installation	
10.0	Commissioning and Test Plan	
11.0	Start-up and Operations	BP5
12.0	Operations and Testing	
13.0	Analysis of Test Campaign Results	
14.0	Updated Techno-Economic Analysis (TEA)	
15.0	Update of EH&S Assessment, TMP, and TCP	
16.0	Economic Revitalization and Job Creation Outcomes Analysis	
17.0	Dismantling and Removal	

Task vs. Responsible Organization

Blue = "Complete"

WBS #	WBS Title	UIUC	Linde	ACS	BASF	Visage
1	Project Management and Planning	X	X	X	X	
1.4	Workforce Readiness for Technology Development	X				
1.5	Environmental Justice Analysis					X
2	Baseline TEA		X			
3	Detailed Engineering and Specifications		X	X	X	
4	Permit Application	X				
5	Construction and Execution Plan		X	X		
6	Long Lead Item Equipment Procurement		X	X		
7	Equipment Procurement and Fabrication		X	X		
8	Site Preparation and Foundations Installation	X	X	X		
9	Plant Construction and Installation		X	X		
10	Commissioning and Test Plan	X	X			
11	Start-up and Operations	X	X		X	
12	Operations and Testing	X	X		X	
13	Analysis of Test Campaign Results	X	X			
14	Updated TEA		X			
15	Update of EH&S Assessment, TMP, and TCP	X	X			
16	Economic Revitalization and Job Creation Outcomes Analysis	X				
17	Dismantling and Removal	X	X			

Completed in BP3

Blue = "Complete"

Milestones for Phase III

BP1 for Phase III = BP3 overall for project

Budget Period	Task Number	Description	Planned Completion Date	Actual Completion Date
3	1	Updated Project Management Plan	9/15/21	9/15/21
3	1	Updated Host Site Agreement	10/15/21	9/15/21
3	1	Phase III Kickoff Meeting	11/15/21	10/13/21
3	4	Permitting Issuances Complete	5/15/22	5/18/22
3	1	Resource Loading Schedule in Place	5/31/22	5/27/22
3	1	EVMS & Risk Management System in Place	5/31/22	5/27/22
3	3	Detailed Engineering Complete	5/31/22	5/31/22
4	7	Equipment Fabrication Complete	1/31/23	
4	9	Construction & Installation Complete	9/30/23	
5	11	Commissioning and Pre-Start-up Checks Complete	12/31/23	
5	11	Steady-State Operations Established	2/29/24	
5	12	Parametric Testing Complete	11/30/24	
5	12	Steady-State Testing Complete	8/31/25	
5	14	Updated TEA	5/31/26	
5	15	Updated EH&S / TMP / TCP	5/31/26	
All	1	Quarterly RPPR report	Each quarter	Quarterly

Blue = "Complete"

Deliverables for Phase III

Task/ Subtask	Deliverable	Due Date
1	Project Management Plan	Update due 30 days after award. Revisions to the PMP shall be submitted as requested by the Project Manager.
1	Resource Loaded Schedule	Update due 30 days after award. Revisions to the PMP shall be submitted as requested by the Project Manager.
1	Earned Value & Risk Management Systems	Update due 30 days after award. Revisions to the PMP shall be submitted as requested by the Project Manager.
1	Workforce Readiness Plan	End of Budget Period 5
1	Environmental Justice Analysis	End of Budget Period 5
2	Baseline TEA	End of Budget Period 3
3.1	PFDs, P&IDs, and Utility Balances	End of Budget Period 3
3.1	Equipment Lists and Process Data Sheets	End of Budget Period 3
3.2	Plant Layout and General Arrangement Drawings	End of Budget Period 3
3	Final Detail Design Report	End of Budget Period 3
5	Construction Plan	End of Budget Period 3
10	Pre-Startup Safety Review (PSSR) Report	End of Budget Period 4
10	Pilot Commissioning and Test Plan	End of Budget Period 4
14	Updated TEA	End of Budget Period 5
15	Update of EH&S Assessment, TMP, and TCP	End of Budget Period 5
16	Updated Economic Revitalization and Job Creation Outcomes Analysis	End of Budget Period 5

Project Status Update

Highlights

- BP3 successfully completed on time and on budget
  - Detailed engineering, permit applications, and construction planning complete
  - Procurement of high priority equipment and materials complete
- Approval granted by DOE to proceed into BP4 in mid-June
  - Breaking ground September 2022
  - Procurement of remaining equipment and material items

Budget/Schedule

- To keep the project on schedule, it was decided to proceed into BP4 with available funding while efforts to quantify and plan around cost increases continue.
- Despite cost increases, the system can still be built and operated at the host site with existing funds.

Risk Management Review

Updated April 2022 / Ongoing (Living Document)

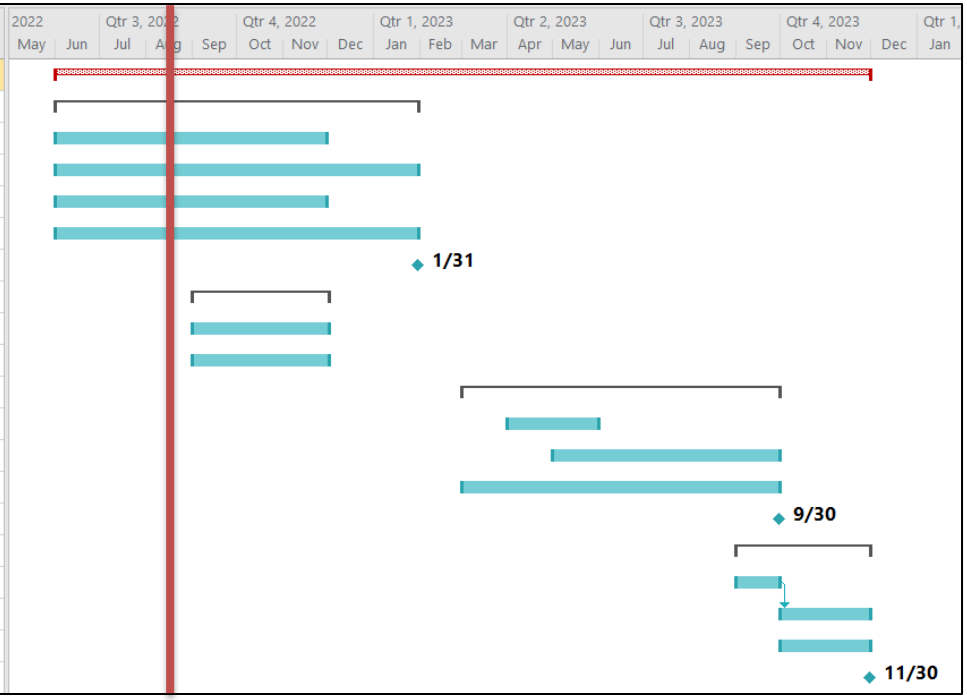
OVERALL RISK	Description	Probability	Impact	Risk Management Mitigation and Response Strategies
	Technical Risks			
Low	Scale-up risk: Vapor and liquid mal-distribution in the absorber column	Very Low	Medium	• Linde designs take into account vapor and liquic maldistribution issues. • Structured packing that was validated as part of the 1.5 MW pilot has been incorporated into the absorber design for the 10 MW demo. • Packing supplier is performing a double check o specifications. • During installation of columns the levels will be checked to meet specifications.
Low	Solvent-related issues (corrosion, adequate supply, handling)	Very Low	Low	• BASF expertise and testing experience from 0.5 and 1.5 MWe pilot plants. • BASF developed a plan for solvent supply. • Data from corrosion coupon testing from pilot plants has been incorporated into material selection. • Early coordination discussions complete around storage and unloading requirements. • Containment design has progressed.
Medium	Unknown contaminants in the flue gas and amine carry-over	Low	Medium	• Addressed in Phase I by aerosol measurements and detailed flue gas analysis. • Managed through analytical capability and established procedures.
Medium	Integration with operations at the selected host site	Low	Medium	• Implemented biweekly coordination meetings between ISBL, OSBL and the host site.
Medium	Wastewater stream management	Medium	Medium	• A strategy for wastewater handling was finalize The project will create three wastewater streams DCC condensate, amine contaminated, and rainwater. Uncontaminated rainwater will be discharged separately to CWLP's outfall point. Amine contaminated will first be minimized through process conditions. A reclaiming unit ha been included in the design to reuse the amines contained in the wastewater. Any remaining amine contaminated water will be contained and shipped off-site. DCC condensate will be treated for sulfites and then discharged to SCWRD.
Medium	Testing of new process units for energy optimization	Low	Medium	• Overall team expertise and external partners' know-how will be leveraged for the process optimization • A test program will be developed in BP4 with objectives and metrics for validation of the stripper inter-stage heater (SIH).
	Cost/schedule Risks			
High	ISBL equipment and module cost overruns	High	High	• BP3 updated quotes showing cost escalation caused by unforeseen changes in the market. • 60% of equipment has been quoted, the remaining 40% has escalation added. • Total cost forecast has been quantified.
Medium	OSBL equipment and materials	Low	High	• Quotes for FRP and steel came in at budget. • PO's not yet issued.
High	ISBL construction and installation cost overruns	Very High	High	• Cost escalation 30% estimate based on Linde's current commercial project portfolio pricing (no yet quoted). • Shifting to more shop fabrication versus field fabrication to control cost.
High	OSBL construction and installation cost overruns	High	High	• Budget estimates for construction were based or bids from local contractors familiar with local conditions. Multiple bidders were invited for eac scope of work. • Anticipate cost escalations during final quotes.
Medium	Operations and maintenance cost overruns	Medium	High	• A detailed operations and maintenance (O&M) cost estimate (including staff, consumables, and utilities) was prepared as part of the costs for Phase III. • Potential sources of operation personnel have been identified for the 24-month period. Operators will be coordinated through a 3rd party Engineers and site managers will be provided by Linde. Daily water/solvent analysis support will be coordinated by the University. • The operations phase can be adjusted to control costs.
Medium	Cost over-runs due to unknowns	Medium	Medium	• Continued lack of clarity on supply chain impac to overall costs. • Equipment, construction, and operating cost assessment are shown separately above.
Medium	Equipment / Module fabrication delay	Medium	Medium	• Communications with the fabricator will be maintained during the fabrication period to resolve issues as they occur. • Where possible, the engineering team will visit the fabrication shop during the fabrication perio to assess progress and compliance. • Major schedule impacts are reflected in cost increase.
	Financial Risks			
Low	Inability to meet cost share requirements	Very Low	High	• The team has secured a commitment from the State of IL for $20 MM cost share. This money has been set aside and allocated for this project.
High	Inability to meet Phase III original budget	High	High	• The project team is requesting additional funds from DOE based on the identified escalations.

Ongoing Risk Mitigation

- Project Team will have weekly discussions on PO status, etc.
  - Include DOE on discussions to provide “just in time” awareness of variations in PO status and construction costs
- If costs begin to vary from the plan (either decrease or increase), PI will provide updates on operating time implications.

BP4 Schedule – In Progress

Task Name	Start	Finish
BP4 (18 months)	**6/1/22**	**11/30/23**
7.0 Equipment Procurement and Fabrication	**6/1/22**	**1/31/23**
7.1 Remaning ISBL Procurement	6/1/22	11/30/22
7.2 ISBL Module Fabrication and Construction Packages	6/1/22	1/31/23
7.3 Remaining OSBL Procurement	6/1/22	11/30/22
7.4 OSBL Shop Fabrication	6/1/22	1/31/23
Equipment Fabrication Complete	1/31/23	1/31/23
8.0 Site Preparation and Foundations Installation	**9/1/22**	**12/1/22**
8.1 Archaeological Monitoring	9/1/22	12/1/22
8.2 Site Preparation and Foundations	9/1/22	12/1/22
9.0 Plant Construction and Installation	**3/1/23**	**9/30/23**
9.1 Module and Equipment Installation	4/1/23	5/31/23
9.2 Onsite Construction and System Integration	5/1/23	9/30/23
9.3 OSBL Onsite Construction and Tie-ins	3/1/23	9/30/23
Constrution and Installation Complete	9/30/23	9/30/23
10.0 Commissioning and Test Plan	**9/1/23**	**11/30/23**
10.1 Pre-Commissioning	9/1/23	9/30/23
10.2 Commissioning	10/1/23	11/30/23
10.3 Test Plan	10/1/23	11/30/23
BP4 Review - Go/No Go Decision	11/30/23	11/30/23



Current progress

DOE Site Tour

June 26, 2022

Civil Contractor Bid Walkthrough

July 19 & 20, 2022

Soil Sampling

July 19, 2022

Environmental Justice Analysis

EJ of major interest since Qualified Opportunity Zones present in Springfield, IL

Objective

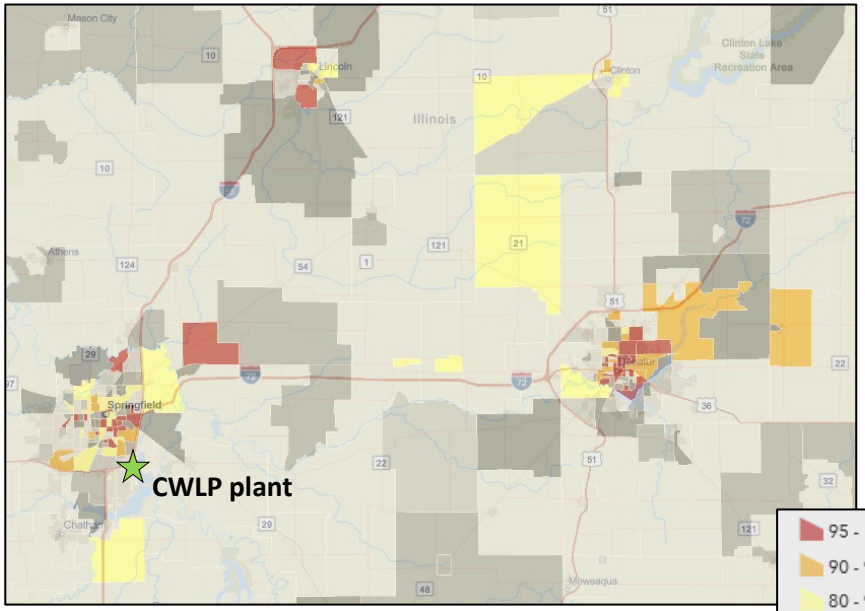
- Assess project impact on surrounding communities and potential distribution of anticipated benefits with key focus on traditionally marginalized and disproportionately impacted areas.
- Facilitate involvement of affected stakeholders by encouraging information exchanges and a mixture of engagement techniques, such as focus groups, small discussions, and educational workshops.

Progress

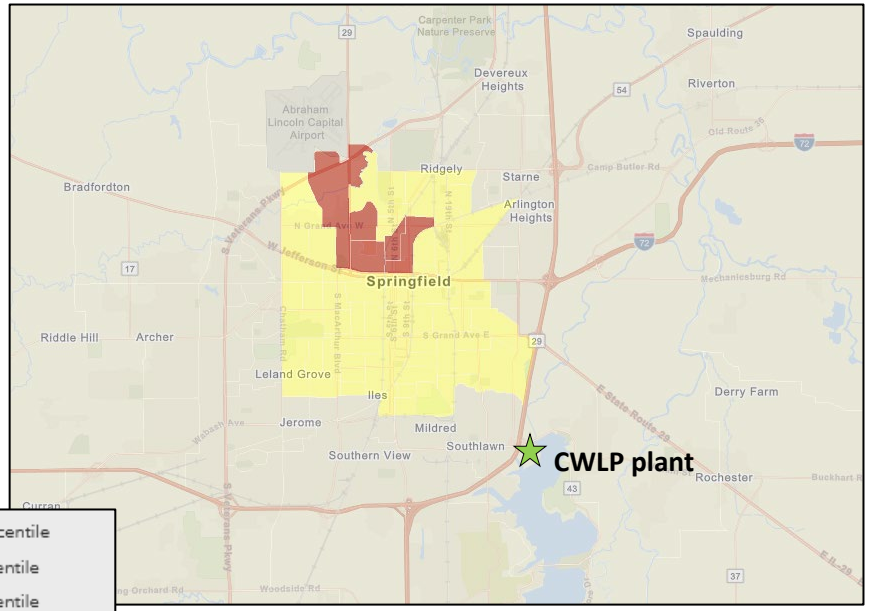
- Initiated social characterization/stakeholder mapping process of the surrounding areas to assess key EJ issues impacting regions.
    - Springfield is not characterized as DAC but existence of high levels of air toxics cancer risk and sections of unemployment/low income.
    - Surrounding DACs to be considered are: East St. Louis, Pike, Will, Gallatin, and Chicago.
- Intend to leverage coalition building and community engagement accomplished through recently passed Illinois Climate and Equitable Jobs Act which is aligned with DOE's Justice40 Initiative objectives.

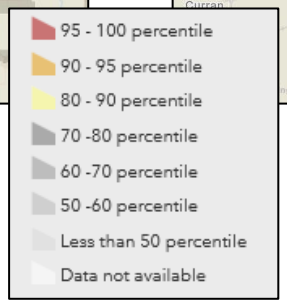
Environmental Justice Maps (National Percentiles)

Unemployment Rate



2017 Air Toxics Cancer Risk





Summary and Conclusions

- BP3 competed on time and within budget
- Transitioned to BP4
- Long lead time procurement initiated
- Market induced cost increases have occurred for materials, equipment, and construction
- With current budget can still build and operate Large Pilot system
- Implemented risk mitigation plan to address cost increases
- EJ assessment in progress

Acknowledgements

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