Dual-loop Solvent-based CCS for Net Negative CO_2 Emissions with Lower Cost
DE-FE0032134

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http://uknow.uky.edu/research/unique-public-private-research-consortium-established-caer-co2-capture-pioneers

2023 Carbon Management Research Project Review Meeting
August 28-September 1, 2023

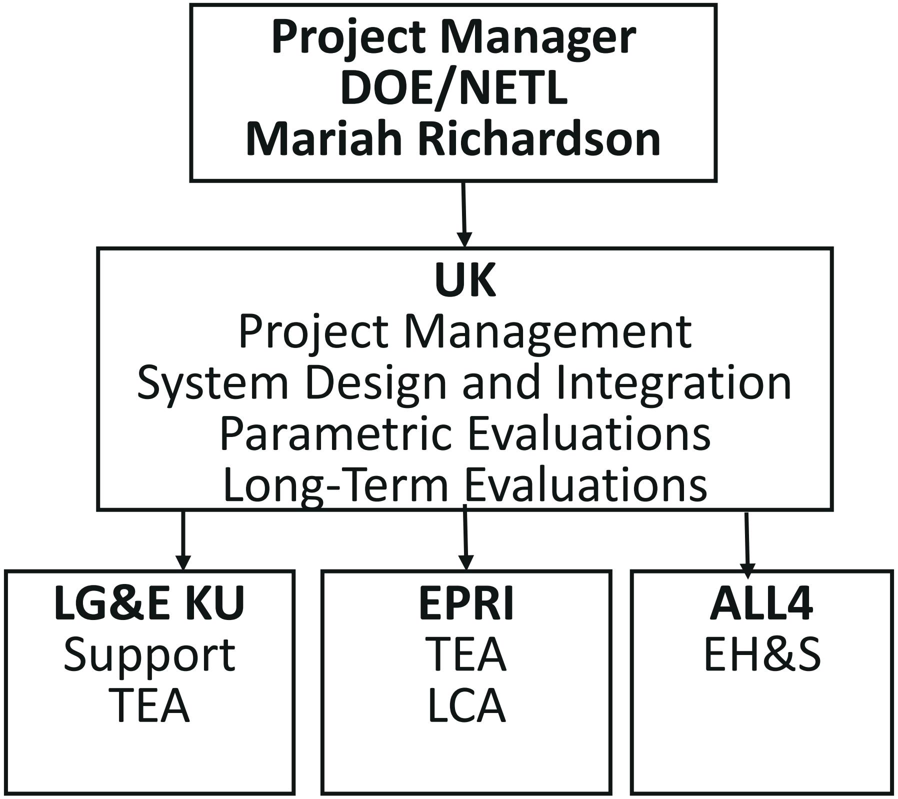
Project Objective

Demonstrate a negative CO_2 emissions technology for low CO_2 concentration flue gas with lower cost.

Performance Dates: 3/1/2022-2/28/2025

BP1	BP2	BP3
3/1/22-2/28/23	3/1/23-2/29/24	3/1/24-2/28/25
• Polishing Loop and Integrated System Design • Polishing Loop Fabrication and Installation, System Modification and Commissioning	• Parametric Evaluation • Polishing Loop Modeling	• Long-term Evaluation • TEA, LCA and EH&S

Project Team and Funding



Project Manager
DOE/NETL
Mariah Richardson

UK
Project Management
System Design and Integration
Parametric Evaluations
Long-Term Evaluations

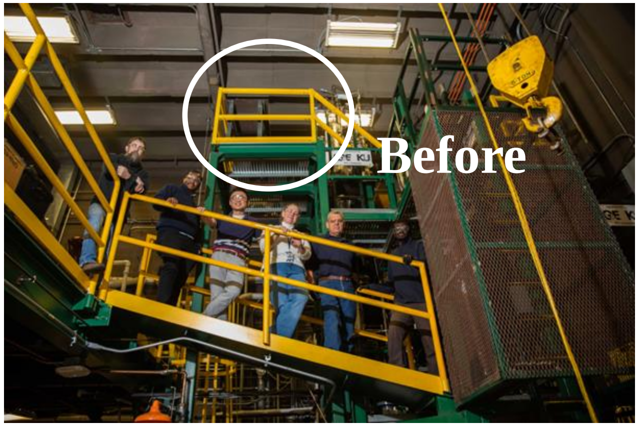
LG&E KU
Support
TEA

EPRI
TEA
LCA

ALL4
EH&S

	DOE-NETL	Cost Share	Total
	$2,452,268	$619,595	$3,071,863
Percent Share	80%	20%	100%

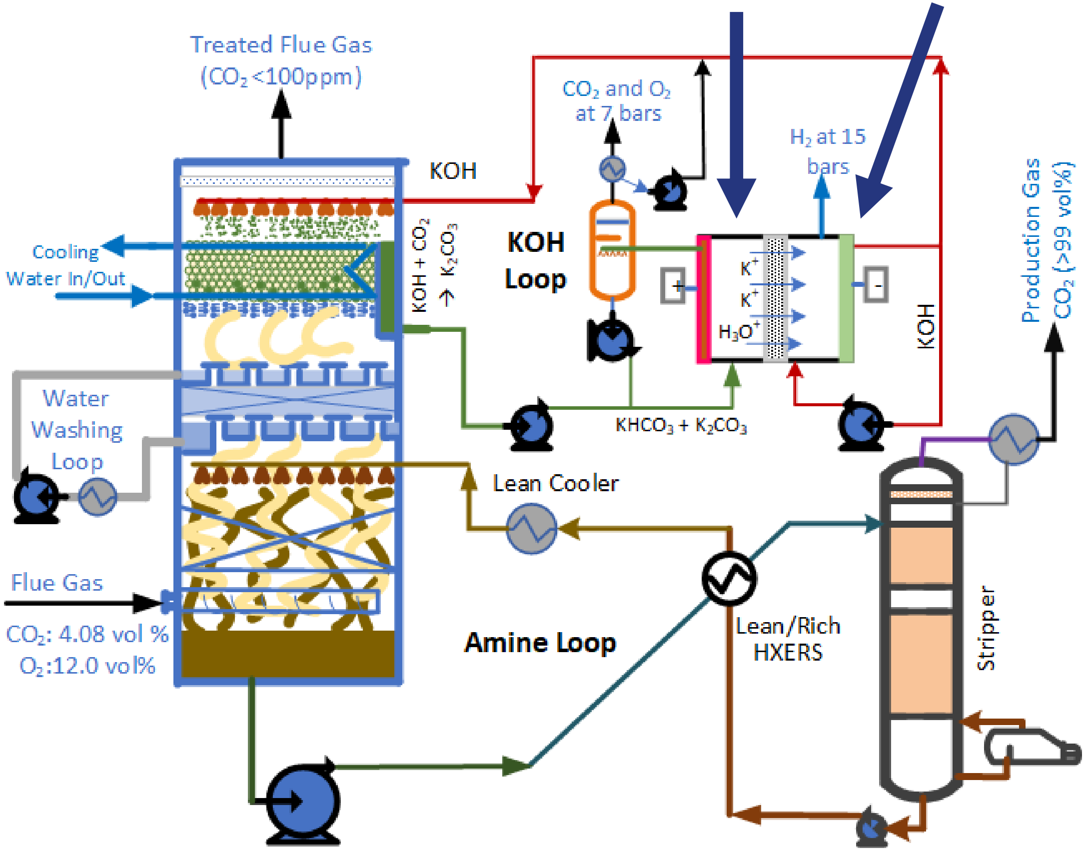
Executive Summary



- TMP and Test Plan complete
- Polishing loop design, installation and commissioning, complete
- Integration of polishing loop with existing 0.1 MWth bench scale CO_2 capture system, primary loop, complete
- Demonstrated negative emission via CO_2 capture targets achievable on both primary loop (85-95%) and polishing loop to ~100 ppm CO_2 emitted

Technology Background

1. UK Bench Post-combustion CO_2 Capture Facilities
2. Primary Loop – Water Lean Solvent
- ~85% CO_2 capture
- Conventional thermal regeneration
- Split rich feed to stripper
3. Polishing Loop – KOH
- ~15% CO_2 capture
- Spray and tray for absorption
- Electrochemical regeneration with H_2 as byproduct



Anode
$KHCO_3$ is flashed
CO_2 (~70%) and O_2 (~30%) are produced

Cathode
H_2 (99.9+%) is produced

Governing Fundamental Principle

CO_2 Capture Efficiency

90% → 95% → 99+%

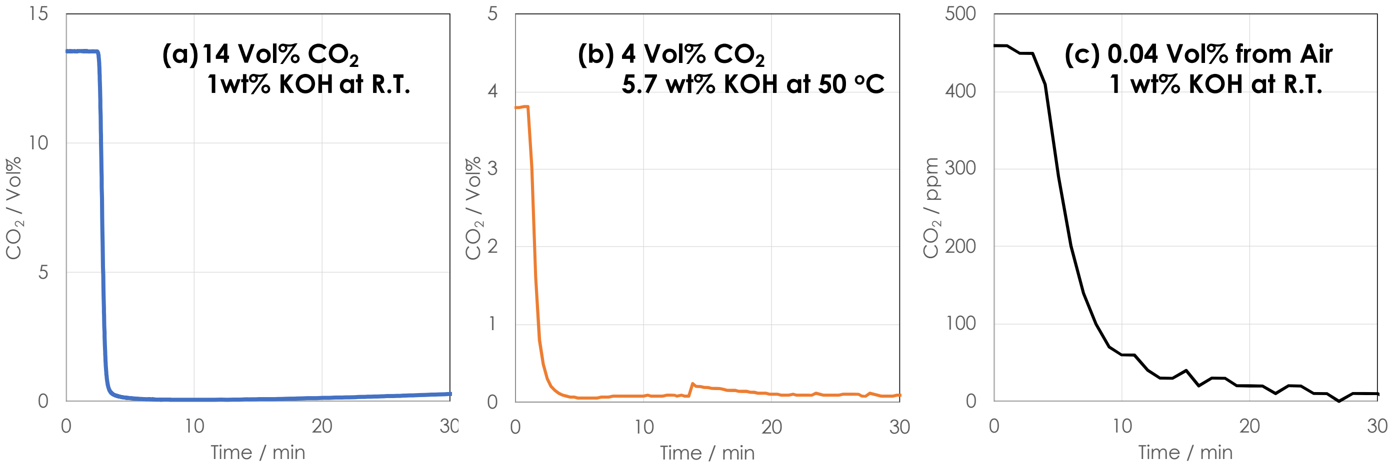
$$Mass\ Transfer = A \cdot k_G \left(P_{CO_2}^{g} - P_{CO_2}^{*}\right)$$

$$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O$$

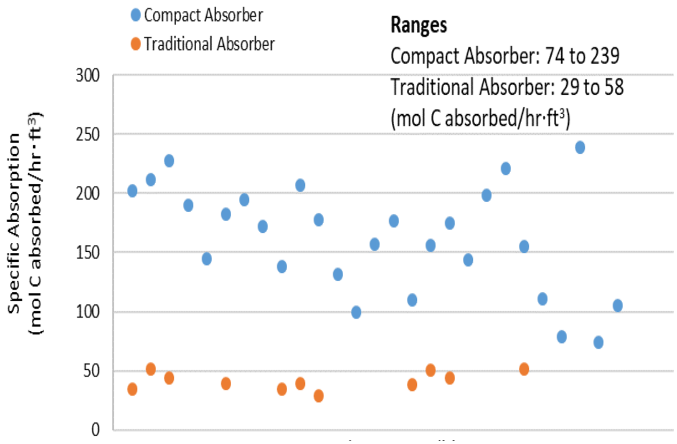
- Electrochemical regeneration is applied, drawing from experience, which also makes useful H_2 and O_2 products
- Spray and tray is applied to ensure good solvent-to-gas contact, drawing from experience

Previous Experimental Findings (I)

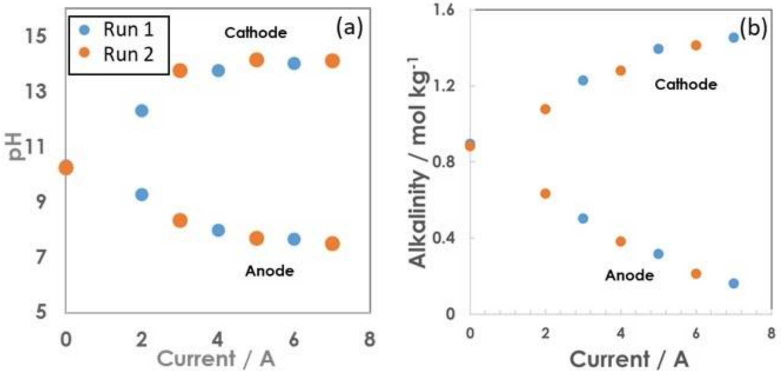
>95% CO_2 Capture Efficiency with KOH



Increased Mass Transfer with Solvent Spray



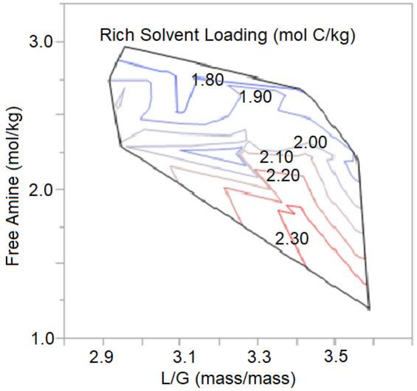
Electro-chemical Regeneration for pH and Alkalinity Control

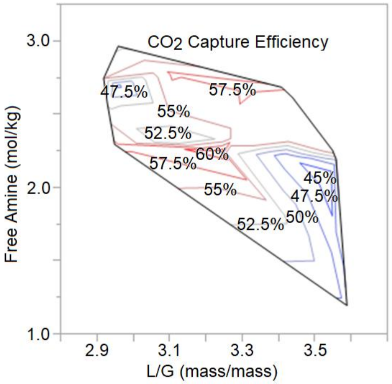


Prior Technology Development (II)

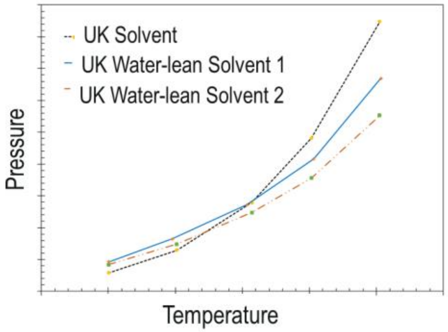
>10,000 hr Bench/Pilot Point Source CO_2 Capture Process Operation

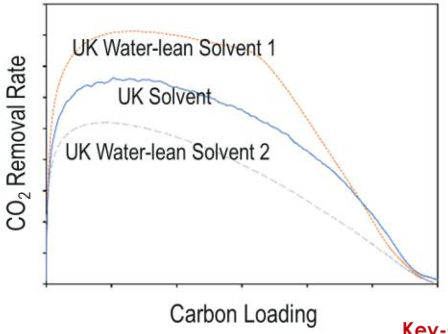
High Liquid:Gas Contact Surface Area Demonstrated (DE-FE0031733)



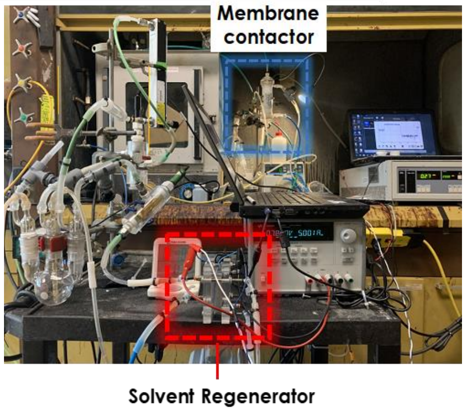


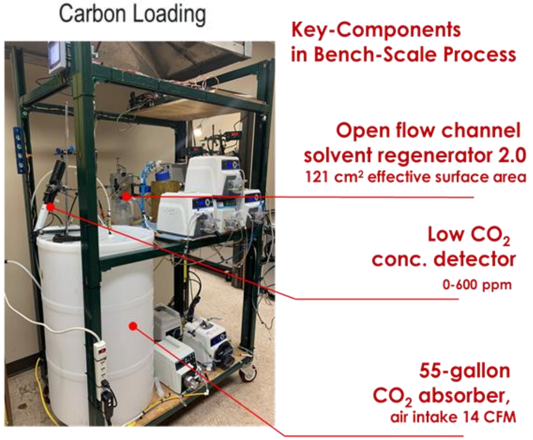
Good Water Lean Solvent Formulation Performance Predicted





DAC Process Demonstrated at 1-10 CFM Air with 0.4-3.0 M KOH Solvent (DE-FE0031962 and DE-FE0032123)





Advantages and Challenges

Technical Advantages

- Essentially 100% CO_2 capture
- Lower CO_2 capture cost
- H_2 and O_2 product streams might be sold to offset OPEX
- Flexibility to operate with primary loop only or both loops

Expected Technical Challenges

- Polishing loop longevity - electrochemical cell electrodes and membrane
- Polishing loop energy consumption - electrochemical cell potential and KOH regeneration energy
- Primary loop absorber performance - solvent distribution and temperature profile control

Experimental Plan

Parametric Primary Loop: Gas Flow Rate. L/G, Solvent Absorber Inlet T , Stripper Bottom T, Stripper P and Polishing Loop: Solvent Concentration, Solvent Circulation Rate, Solvent Absorber Inlet T, CO_3^{2-}/HCO_3^- Ratio

Long-Term Duration Continuous SS (1000 hr); Dynamic Operation (500 hr); Accelerated Life Cycle (500 hr)

Primary Capture Loop

Input	Output	Application
Flue Gas Composition Flue Gas Velocity and Residence Time Solvent Circulation Rate Lean Inlet Solvent Temperature Solvent Composition Lean Free Amine (Alkalinity and Loading)	Mass Transfer Temperature Profile Carbon Loading Profile Solvent Entrainment/Aerosols Pressure Drop	Absorber Design: Diameter, Packing Height, Packing Area/Efficiency, Pump Around, Intercooling, Turn Down Balance of Plant Design: Demisters/Water Wash Column, Rotational Equipment
Stripper Bottom Temperature Stripper Pressure	Lean Carbon Loading Energy Consumption Solvent Degradation	Stripper Design: Diameter, Packing Height, Packing Area/Efficiency, Steam Supply Balance of Plant Design: Additive System, Tanks, Rotational Equipment

Polishing Capture Loop

Input	Output	Application
Flue Gas Composition Flue Gas Velocity and Residence Time KOH Circulation Rate KOH Return Temperature	Mass Transfer Temperature Profile Carbon Loading Profile Pressure Drop	Absorber Design: Sizing, Solvent Spray/Tray, Internals Balance of Plant Design: Pumps, Tanks
CO_3^{2-}/HCO_3^- Ratio Loading Factor, Voltage, Current Pressure	Energy Requirement Charge Efficiency KOH Circulation Rate H_2 Production Rate	Electrochemical Regenerator Design: Sizing, Recycling Balance of Plant Design: Energy Storage/Co-Product Systems

Technical Approach

Demonstrate 99.9% CO_2 Capture

Approach

Add KOH polishing loop to the existing absorber with structured packing

Spray and tray applied for polishing loop

Use existing NG boiler to generate flue gas

Research Activity

Experimentally vary amine solvent circulation rate, lean inlet temperature, lean inlet loading, intercooling requirements for maximum rich loading

Experimentally changes KOH circulation rates, liquid droplet size, and temperature

Experimentally evaluate corrosion of electrode and degradation of membrane materials and qualify over 500 hours

Challenge Solved/Target

Establish the energy required for the possible CO_2 capture in each loop

Optimize the capture split between the primary and polishing loops for lowest overall energy requirement

Reduce Power Consumption

Approach

Reactor design: flow channel and its layout, membrane

Electrode design: material and geometric surface modification

Research Activity

Experimentally evaluate solvent KOH circulation rate and temperature

Study the concentration of electrolyte

Challenge Solved/Targeted

Polishing loop longevity - electrochemical cell electrodes and membrane

Polishing loop energy consumption - electrochemical cell potential and KOH regeneration energy

Pigman College of Engineering
University of Kentucky

Institute for Decarbonization and Energy Advancement at PPL R&D Center

Project Milestones

BP	Task	Description	Planned Completion Date	Actual Completion Date
1	1.0	Project Kickoff Meeting Held	3/25/2022	3/25/2022
1	1.2	TMP Complete	5/31/2022	5/31/2022
1	2.0	Test Plan Complete	6/30/2022	6/30/2022
1	3.0	PDP Complete	9/30/2022	9/30/2022
2	4.0	Integrated CO_2 Capture Process Complete Capable of 85% CO_2 Capture in Primary Loop and 15% Capture in Polishing Loop	2/28/2023	6/28/2023
2	5.0	Parametric Campaign Complete with 500 Operational Hours	2/29/2024	
2	6.0	Rate-based Polishing Loop Solvent Model Complete Predicting Rich Loading within 15% of Experimental Value	2/29/2024	
3	7.0	Long-term Campaign Complete with 1000 Continuous, Steady-State Operational Hours, 500 Dynamic Operational Hours and 500 Accelerated Degradation Hours	2/28/2025	
3	8.0	TEA Complete	10/31/2024	
3	9.0	LCA Complete	12/31/2024	
3	10.0	EH&S Complete	6/30/2024	

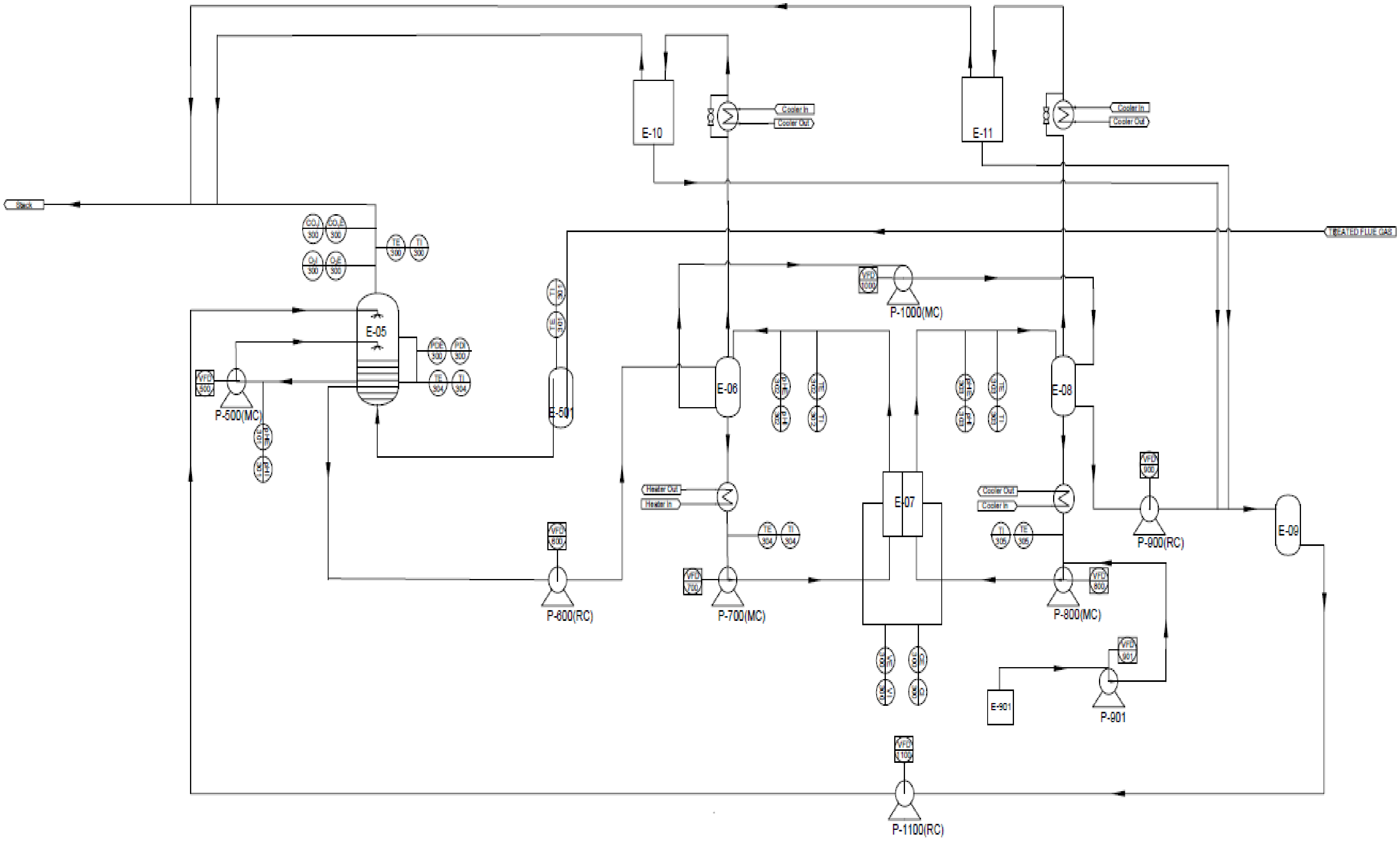
Project Success Criteria

Success Criterion		Accomplishments to Date
Completion of BP1 1) Integrated system commissioning complete with no operational issues	90%	- Integrated system commissioned with capture targets demonstrated on both primary and polishing loops. - Graphical User Interface (GUI) for polishing loop complete, controls in progress to be finally synced with the primary loop.
Completion of BP2 1) Demonstrated CO_2 capture of ≥99.8% and net negative CO_2 emissions when applied to a NGCC electrical generation plant 2) Demonstrated CO_2 product stream purity of ≥95%	100%	- >99.8% and negative CO_2 emissions demonstrated with <100 ppm CO_2 measured in the treated flue gas after the polishing loop with 8 cfm inlet flue gas flow, 4 vol% inlet CO_2 concentration and 95% capture in the primary loop.
Completion of BP3 1) At least one month of bench-scale integrated, continuous testing of the proposed net-negative CO_2 capture technology 2) Attainment of technology readiness level (TRL) 4 3) Electrochemical regenerator longevity demonstrated for 1000 hours with <30% cell resistivity increase 4) Process response time of <30 minutes with deliberate parameter step changes 5) No EH&S impediment to prevent further technology development and scale-up 6) Demonstrated progress toward 20% reduction in CO_2 capture cost for a NGCC plant with CO_2 capture that can justify technology scale-up in a subsequent program 7) 50% reduction in capital cost compared to the NETL B31B case		

Project Risks and Mitigation Strategies

Technical Risk	**Mitigation Strategy**
High Energy Consumption in Polishing Loop due to High Electrochemical Cell Potential	• Alternative nozzle/tray configuration may be used • Catalytical electrode will be explored
Electrochemical Cell Longevity including Membrane and Electrode	• Re-evaluate the relationship among current density, membrane and electrode stability • Consideration of the operating mode such as periodically alternating cathode and anode electrode
Poor Mass Transfer in Primary Loop due to Liquid Maldistribution	• Modify liquid distributor or install additional re-distributor • Alternative packing style may be used

Current Status



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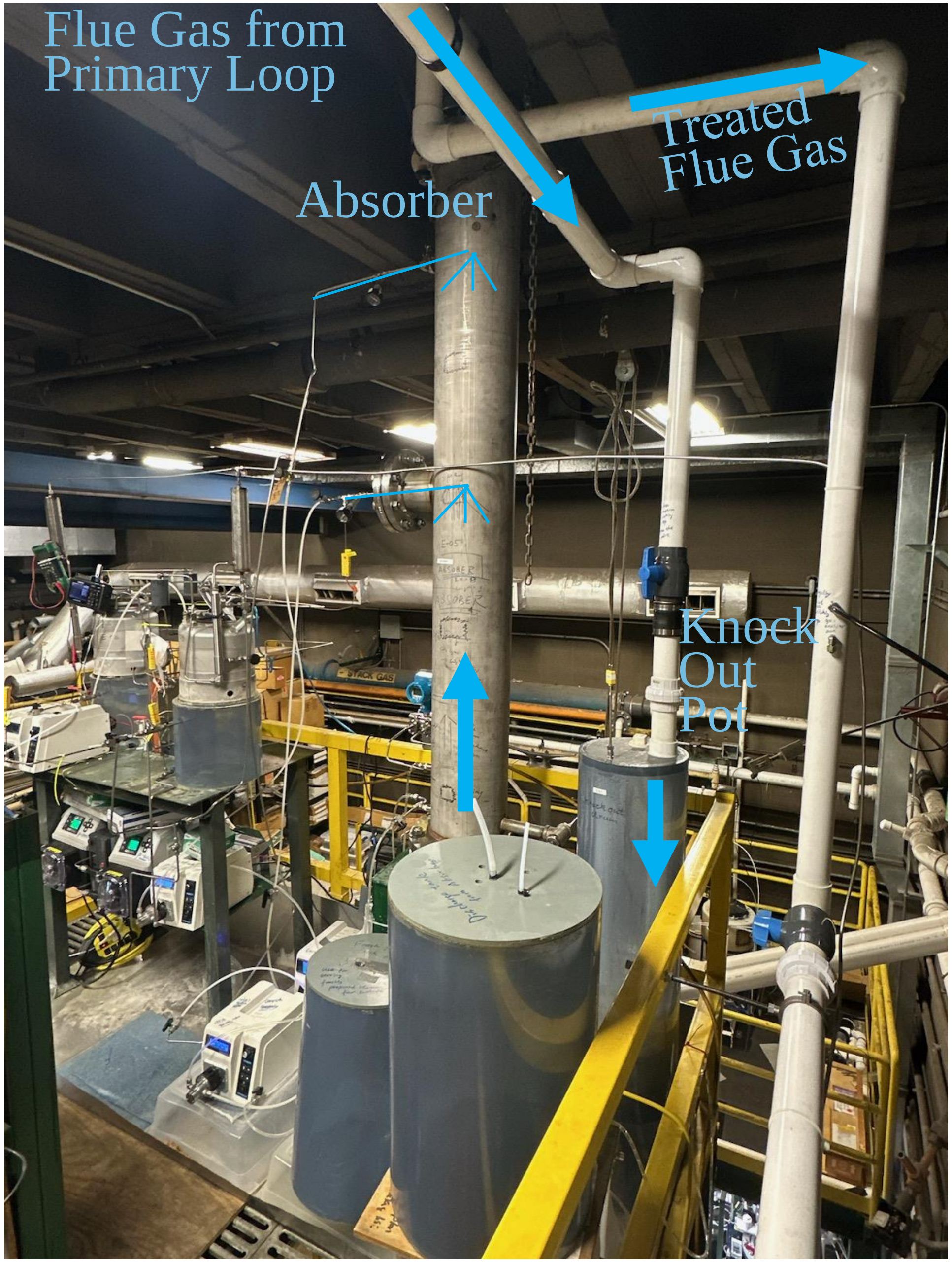

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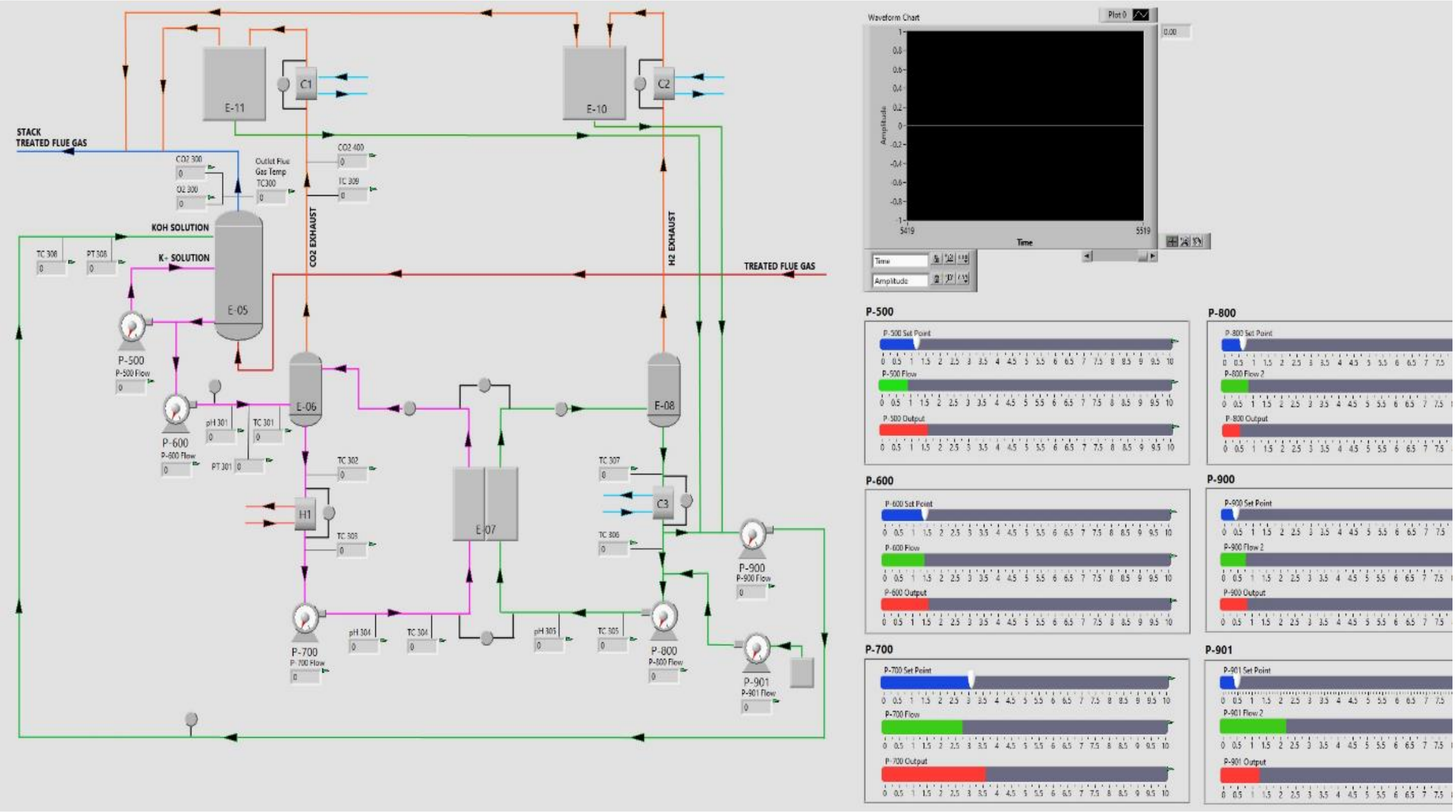
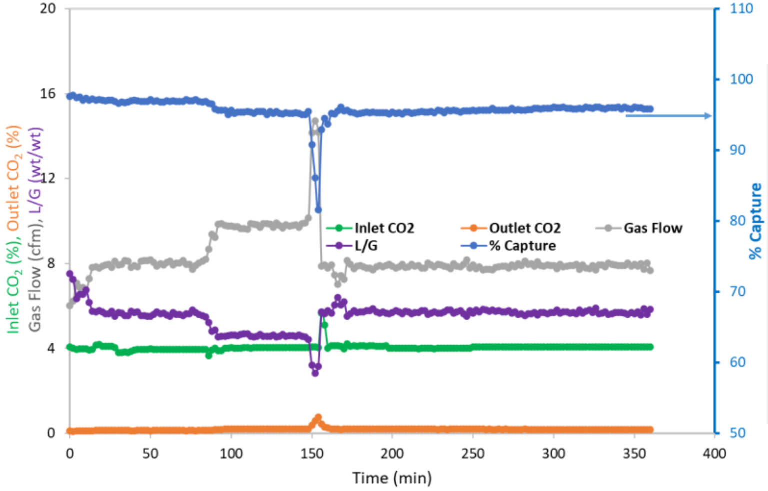
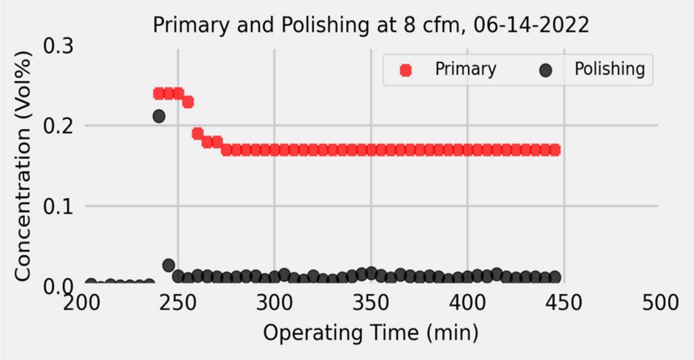


Current Status

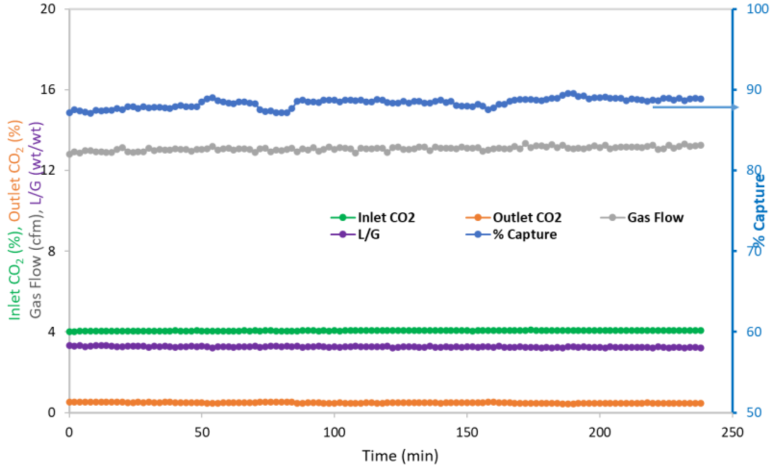
Demonstrated performance target of achieving 99.8% CO_2 capture

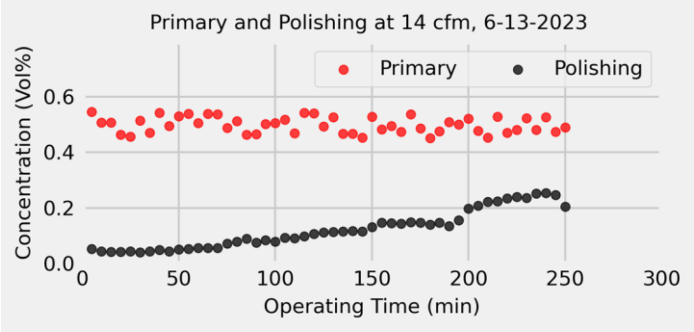
- 95+% CO_2 Capture in Primary Loop with high L/G
- <100 ppm CO_2 emitted after Polishing Loop
- >99.8% CO_2 Capture Overall



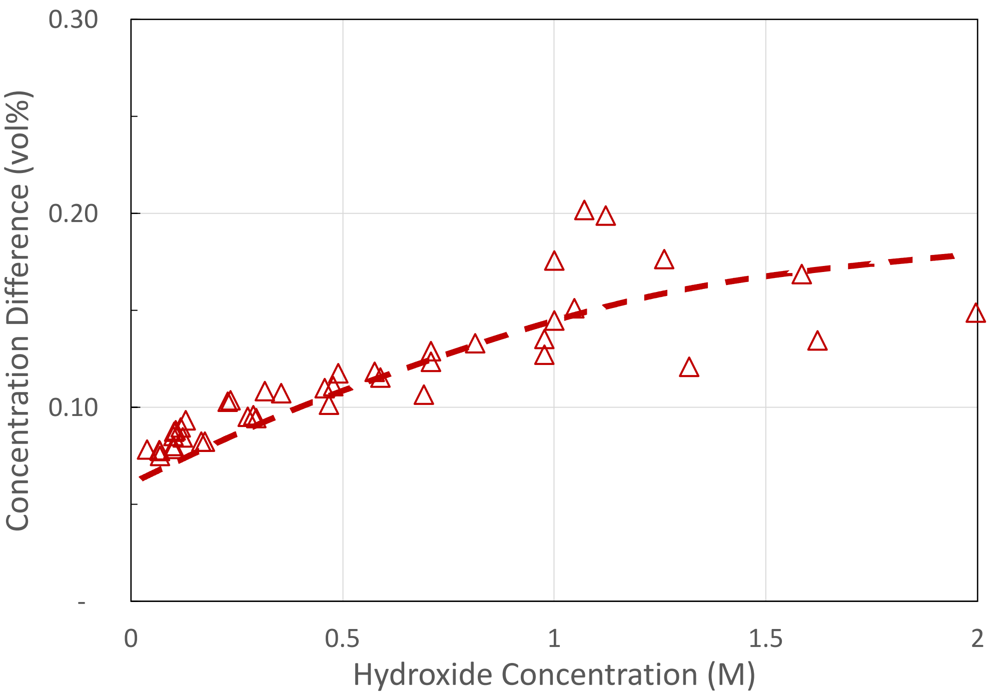


- 85-90% CO_2 Capture in Primary Loop with reduced L/G
- Polishing Loop Capture Drops Over Time

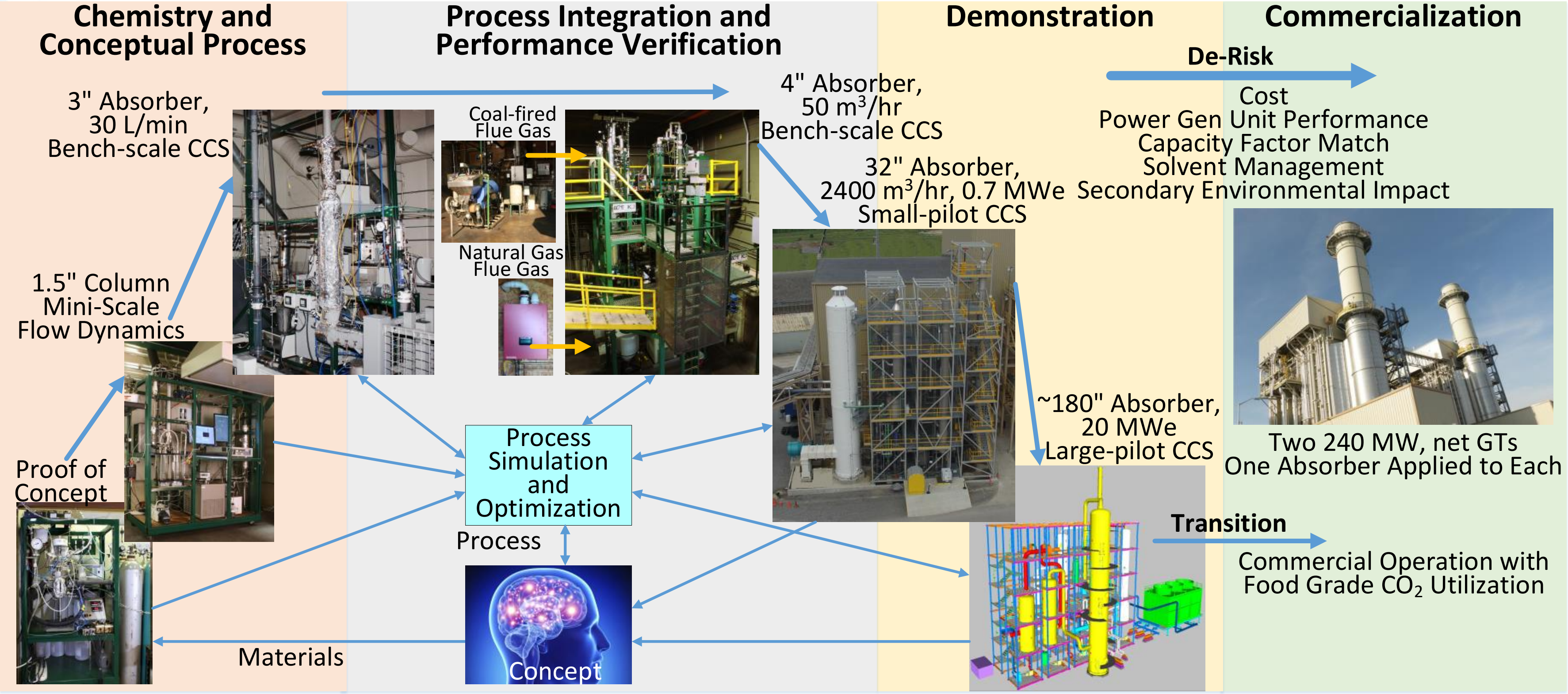




The Mass Transfer Inside Polishing Absorber



Development & Commercialization



Chemistry and Conceptual Process

Proof of Concept

1.5" Column Mini-Scale Flow Dynamics

3" Absorber, 30 L/min Bench-scale CCS

Materials

Process Integration and Performance Verification

Coal-fired Flue Gas

Natural Gas Flue Gas

Process Simulation and Optimization

Process

Concept

Demonstration

4" Absorber, 50 m^3/hr Bench-scale CCS

32" Absorber, 2400 m^3/hr, 0.7 MWe Small-pilot CCS

~180" Absorber, 20 MWe Large-pilot CCS

Commercialization

De-Risk

Cost
Power Gen Unit Performance
Capacity Factor Match
Solvent Management
Secondary Environmental Impact

Two 240 MW, net GTs
One Absorber Applied to Each

Transition

Commercial Operation with Food Grade CO_2 Utilization

Expected Output

- ≥99.8% CO_2 capture from NGCC
- 95+% overall CO_2 produce purity
- 15% CAPEX reduction compared to Reference Case B31B, Rev. 4
- 20% cost of electricity reduction below Reference Case B31B Rev. 4
- No EH&S impediment to prevent technology development and scale-up

Acknowledgements

U.S.DOE NETL: Mariah Young, Greg O’Neil, José Figueroa, Dan Hancu and Lynn Brickett

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EPRI: Adam Berger and Abhoyjit Bhown

ALL4: Karen Thompson

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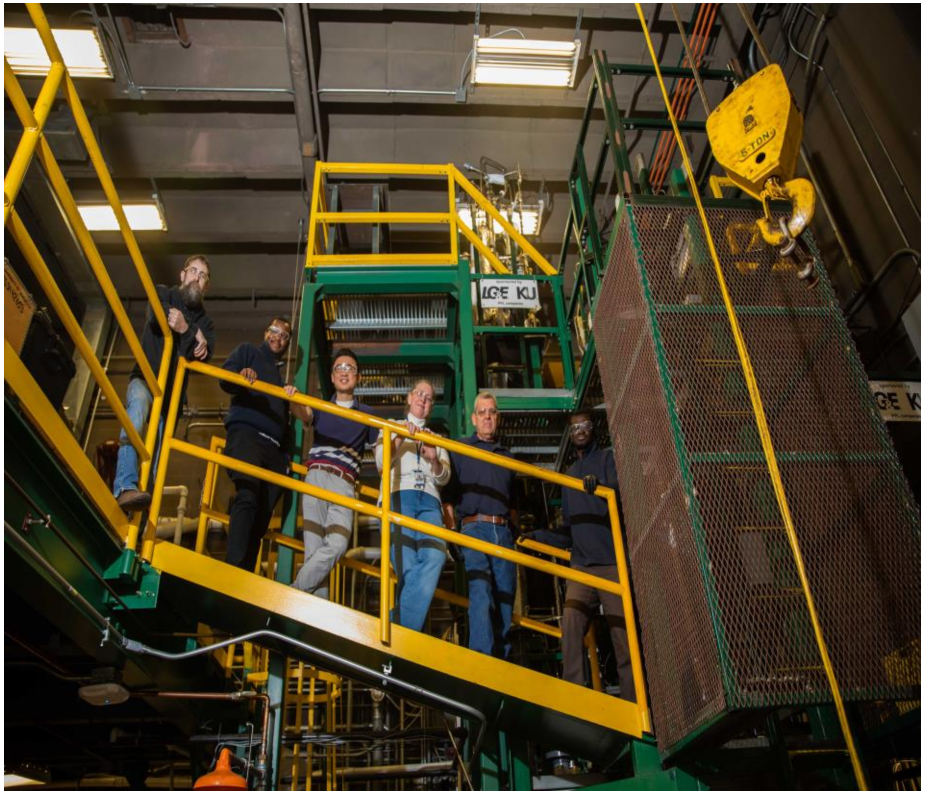
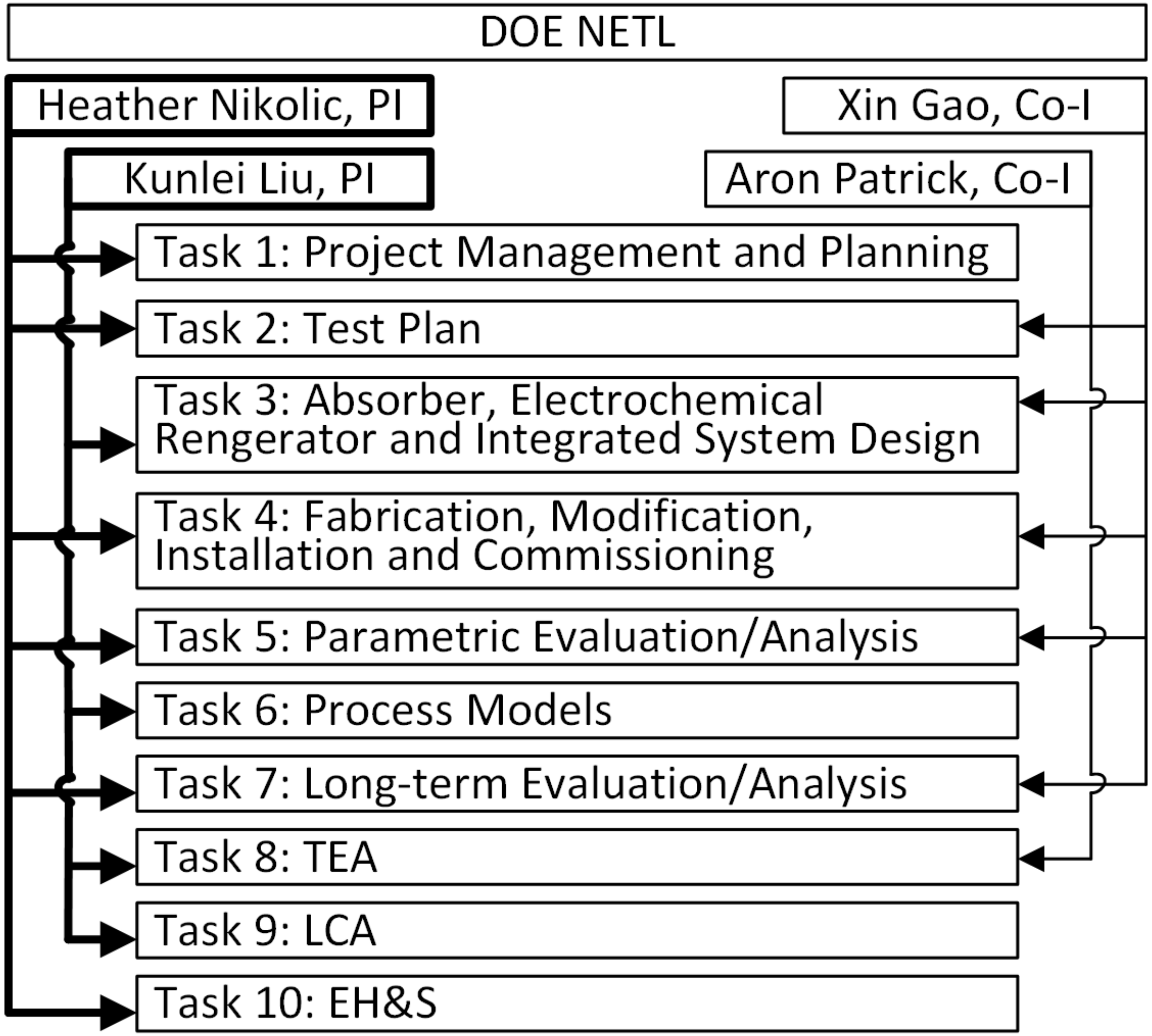


Appendix: Organizational Chart


DOE NETL
Heather Nikolic, PI
Xin Gao, Co-I
Kunlei Liu, PI
Aron Patrick, Co-I
Task 1: Project Management and Planning
Task 2: Test Plan
Task 3: Absorber, Electrochemical Rengerator and Integrated System Design
Task 4: Fabrication, Modification, Installation and Commissioning
Task 5: Parametric Evaluation/Analysis
Task 6: Process Models
Task 7: Long-term Evaluation/Analysis
Task 8: TEA
Task 9: LCA
Task 10: EH&S

Appendix: Gantt Chart

Task Name	Start	Finish
1.0 Project Management and Planning	Tue 3/1/22	Fri 2/28/25
1.1 PMP	Tue 3/1/22	Thu 3/31/22
1.2 TMP	Tue 3/1/22	Tue 5/31/22
Budget Period 1	**Tue 3/1/22**	**Tue 2/28/23**
2.0 Test Plan	Tue 3/1/22	Thu 6/30/22
3.0 Absorber, Electrochemical Regenerator and Integrated System Design	Sun 5/1/22	Fri 9/30/22
4.0 Fabrication, Modification, Installation and Commissioning	Mon 8/1/22	Tue 2/28/23
Budget Period 2	**Wed 3/1/23**	**Thu 2/29/24**
5.0 Parametric Evaluation/Analysis	Wed 3/1/23	Thu 2/29/24
5.1 Primary Loop Absorption Performance	Wed 3/1/23	Fri 6/30/23
5.2 Electrochemical Regenerator Performance	Sat 7/1/23	Thu 2/29/24
5.2.1 Flow Channel Design	Sat 7/1/23	Thu 8/31/23
5.2.2 Optimizing Circulation Rate	Fri 9/1/23	Tue 10/31/23
5.2.3 Electrode and Membrane Selection	Wed 11/1/23	Sun 12/31/23
5.3 Optimization of Capture Split	Mon 1/1/24	Tue 2/27/24
6.0 Polishing Loop Modeling	Wed 3/1/23	Thu 2/29/24
Budget Period 3	**Fri 3/1/24**	**Fri 2/28/25**
7.0 Long-term Evaluation/Analysis	Fri 3/1/24	Fri 2/28/25
7.1 Continuous, Steady-state Operation	Fri 3/1/24	Fri 5/31/24
7.2 Dynamic Operation	Sat 6/1/24	Mon 9/30/24
7.3 Accelerated Life Cycle Testing	Tue 10/1/24	Fri 2/28/25
8.0 TEA	Fri 3/1/24	Thu 10/31/24
8.1 Process Modeling/Validation	Fri 3/1/24	Sun 6/30/24
8.2 Equipment Sizing	Mon 7/1/24	Sat 8/31/24
8.3 Analysis	Sun 9/1/24	Thu 10/31/24
9.0 LCA	Fri 11/1/24	Tue 12/31/24
10.0 EH&S	Fri 3/1/24	Sun 6/30/24