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Negative-Emissions Enabled Direct Air Capture with Coupled Electro-Production of Hydrogen at a 5 kg-per-hour Scale

DE-FE0032255

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

Program Overview

- Funding: DOE $2,999,681 and non-federal Cost Share $749,943
- Project Performance Dates: 08/1/2023 – 7/31/2026
- No. of Budget Periods: 3
- Project Participants: University of Kentucky, EPRI, PPL Corporation, Total Energy

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Project Objectives

- Developing a negative emissions capture technology to extract CO_2 from the atmosphere that reduces system-boundary carbon emissions and the cost of capture through:

- Leveraging low carbon foot-print power source and H_2 credit;

- Developing a 2-unit process operation with facile CO_2 capture at mild to high pH conditions and low gaseous pressure drop in the CO_2 absorber while regenerating CO_2 at less than 3 V in the ER by using catalytic electrodes;

- Demonstrating a continuous and reliable electrochemical regenerated solvent DAC process at the air flow rate of ≥ 4000 CFM with capture efficiency >70% for ≥1 month, thereby establishing the data for the next-scale development.

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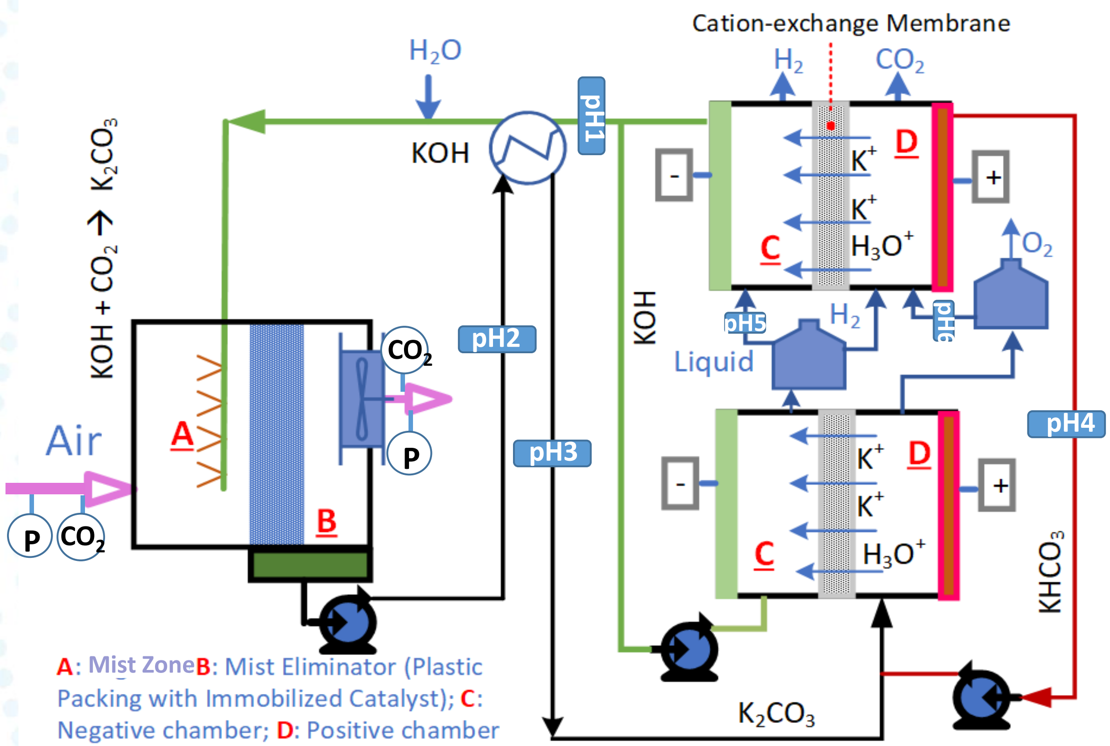
Technology Background



Key Electrochemical Reactions

(0V, $2H_2O$ + electrons = $H_2 + 2OH^-$)

(-1.2V, $2H_2O = O_2 + 4H^+$ + electrons)

CO_2 Capture

(Fast) $CO_2 + 2OH^- = CO_3^{2-} + H_2O$

$CO_2 + H_2O \xrightarrow{\text{catalyst}} H^+ + HCO_3^-$

CO_2 Release

$H^+ + CO_3^{2-} \rightarrow HCO_3^-$

$H^+ + HCO_3^- \rightarrow CO_2 + H_2O$

or

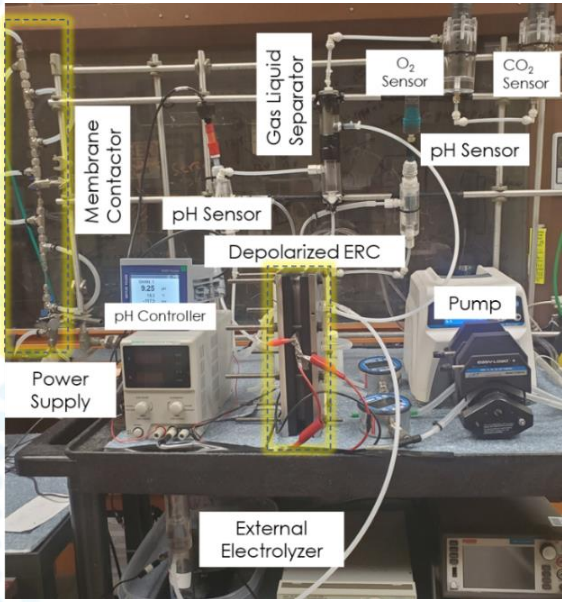
$2HCO_3^- \rightarrow CO_2 + CO_3^{2-} + H_2O$

via flashing

A: Permeate chamber for CO_2 absorption
B: Feed chamber for mixture of KOH and K_2CO_3
C: Positive chamber **D**: Negative chamber
E: Open-tower for CO_2 absorption
F: Air entrance and liquid sump

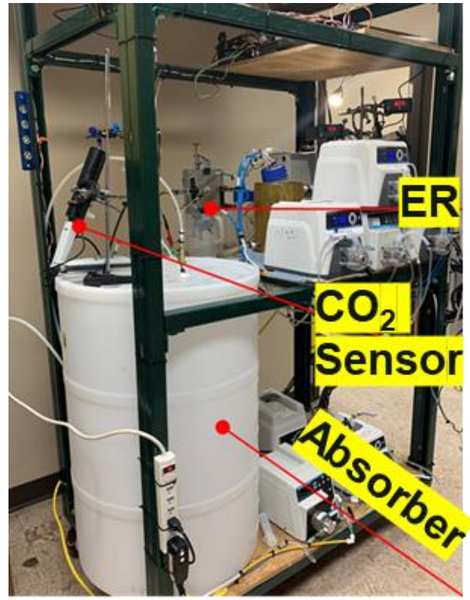
- Fast Kinetics Solvent
- Catalyzed capture at mild pH for DAC energy cost minimization
- Simplified Process and Operation
- Byproducts of H_2 and O_2 for sale

Development of Electrochemically-Regenerated Solvent Carbon Capture Systems at UKy



2020-2021

- ~30 W Regenerator
- 0.03-2L/min Air Absorber
- Standard operation and explored depolarized operation
- DAC 1.0, < 1 kg/year process
- H_2 < 1 kg/year



2021-2023

- ~210 W Regenerator
- 280L/min Air Absorber
- Explored in-situ water recovery and bicarbonate flashing, zero-gap cell design
- DAC 2.0, < 200 kg/year process
- H_2 production @ 10 kg/year

2021-2023

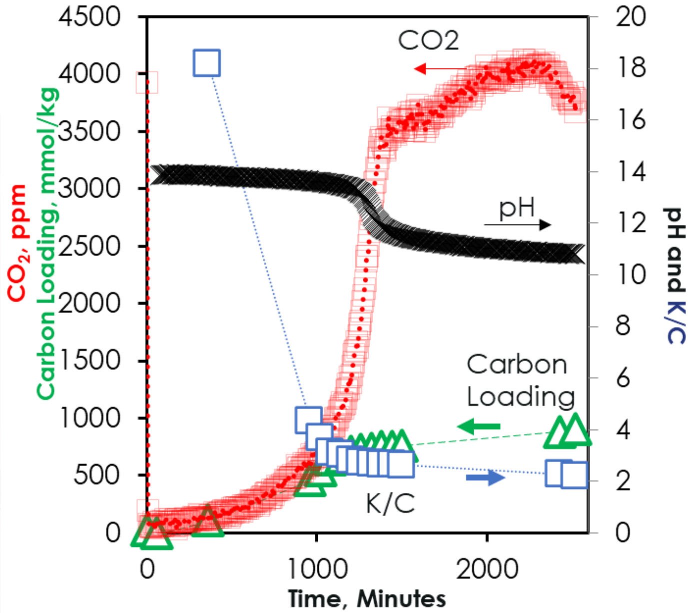
- 600 W Regenerator
- 15 CFM gas with ~4000 ppm CO_2 Absorber
- Negative Emissions; Integrated with point source capture (3-5% CO_2) as polisher
- Carbon polisher, 1700 kg/year process
- H_2 production @ 77 kg/yr

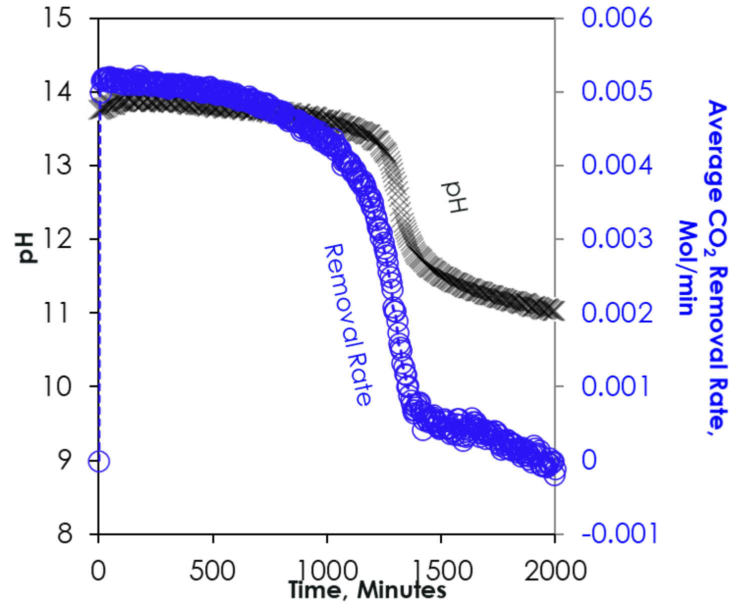
UKy Previous Results : Performance of the Alkaline Solvent Absorber

Kinetic controlled CO_2 capture rate e.g. depends on OH concentration

(~90% capture from primary loop as basis)

30 L/min gas feed, 1.1 L/min, 10 L 2M KOH, 4000 ppm CO_2





Facile capture achieved at high pH

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UKy Previous Results : Performance of the Electrochemical Solvent Regenerator

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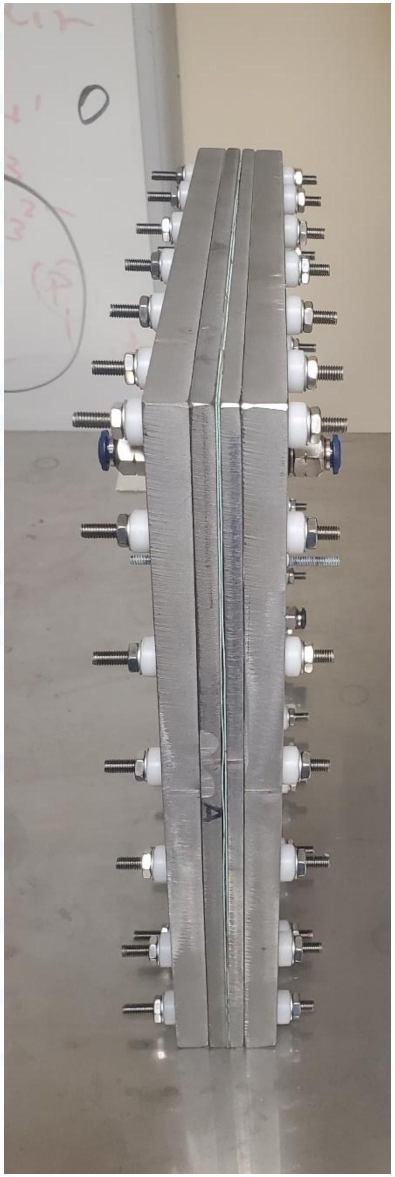
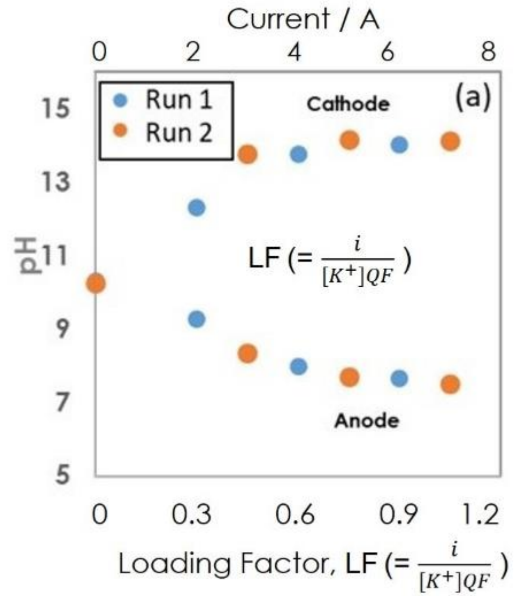
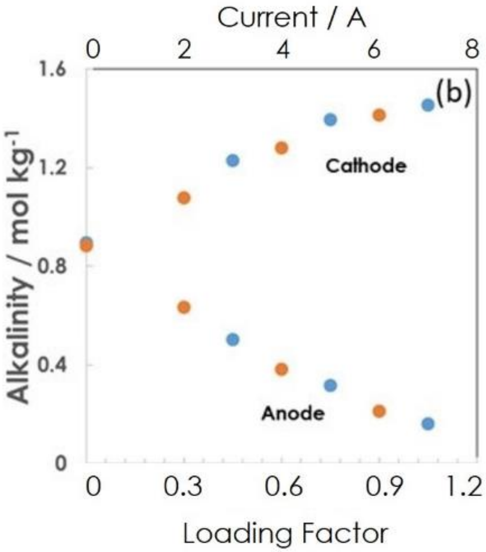


Electrochemical Regenerator





- Load Factor = i_{Total}/FQC_{K+} F, Q, and C_{K+} are Faradays number, flow rate and potassium concentration
- Electrochemical regenerator reconditions the capture solvent to high pH at the cathode and low pH at anode for carbon recovery; pH swing increases with Load Factor
- Alkalinity swing confirms potassium transport via the cation selective membrane; swing increases with Load Factor

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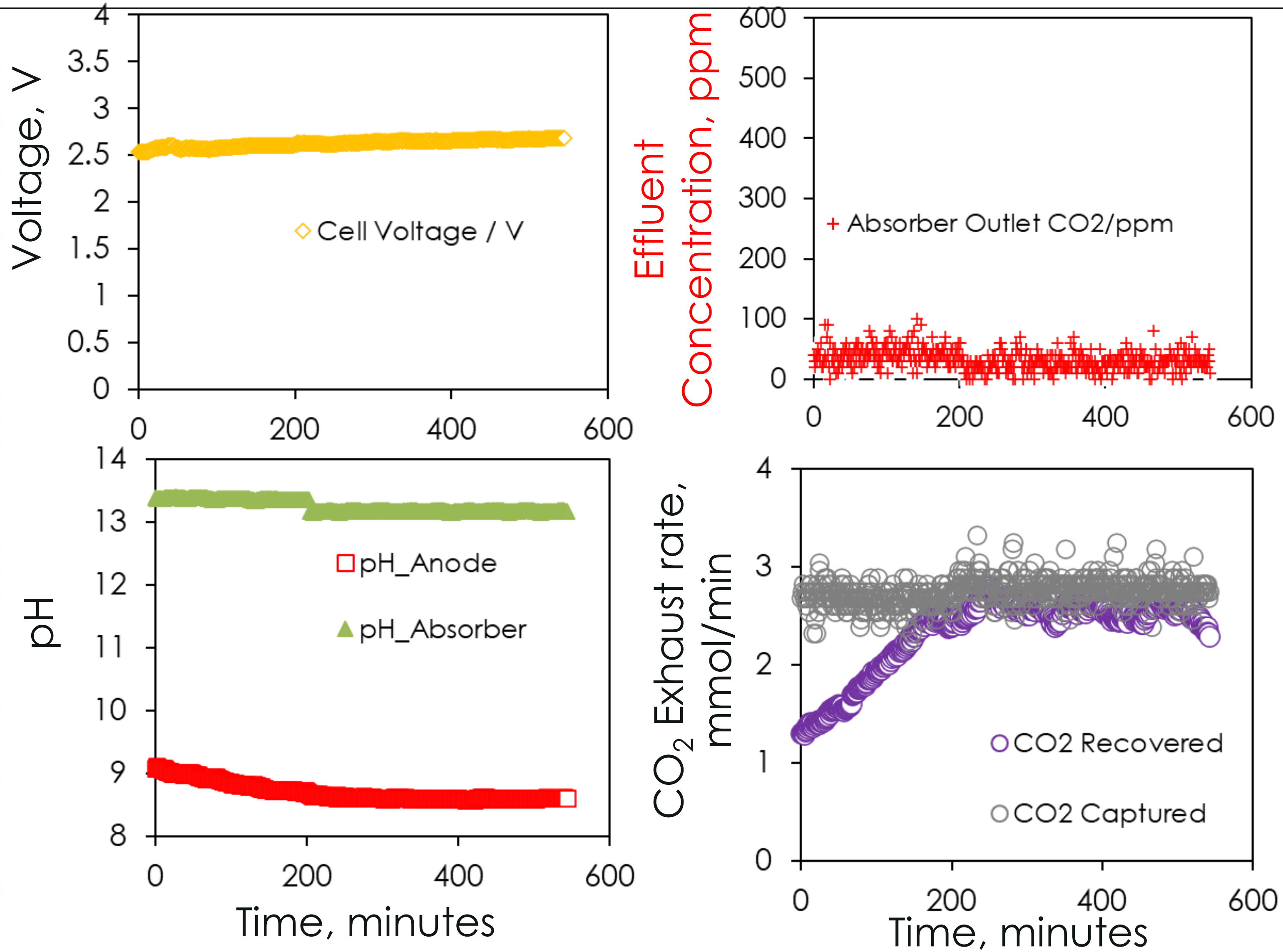
UKy Previous Results : Integrated Operation

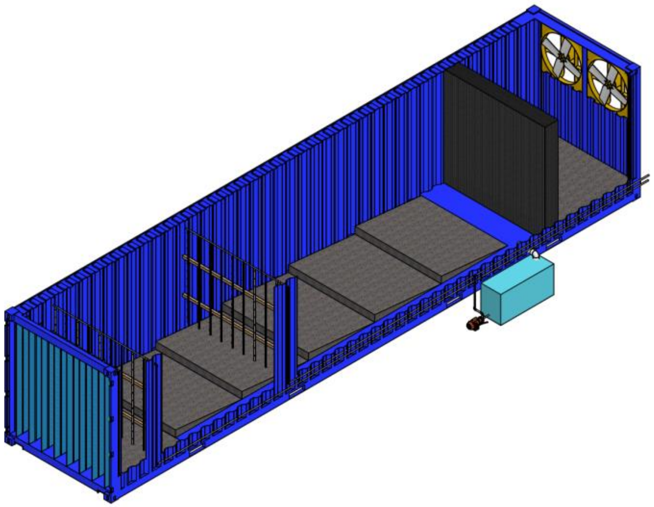


<u>Anode pH swing for CO_2 release; Lower anode pH required for more facile carbon release and pH maintained at cathode for CO_2 capture</u>

Host Site for Negative Emissions Demonstration

Renewable Power including hydro (30 MWe), solar (>10 MWe), and wind, courtesy of PPL corporation ready to deliver low carbon foot-print power to DAC skid

Anticipated UKy DAC Capture Unit



Stacked standard shipping containers, with 350 ton/year each operated under cross-flow configuration

Project Scope

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Work plan

- Design, fabrication, and research on hybrid absorber (HA), electrochemical regenerator (ER) with catalytic electrodes including initial TEA and LCA (Task 2-4, BP1)
- Scale up and commissioning of integrated DAC process (HA + ER) (Task 5, BP2)
- Parametric and long-term testing of DAC system and reporting on TEA, LCA, EH&S, TGA, TMP (Task 6-10, BP3)

Project Success Criteria

Decision Point	Date	Success Criteria
Completion of BP1	07/31/24	• Demonstrate a 10% increase in CO_2 solvent loading • Demonstrate 100 hours of ER operation with <15% performance degradation
Completion of BP2	07/31/25	• Demonstrate operation-ready integrated DAC process • Demonstrate continuous testing of the net-negative 0.5 kg/hrCO_2 capture technology with > 90% capture efficiency
Project Completion	07/31/26	• Attain TRL 5 and no EH&S impediment to prevent further technology development • At least one month of bench-scale testing • Net-negative 5 kg/hrCO_2 capture technology achieves > 70% capture efficiency • Operating voltage of < 3V per cell

Plans for Future Development

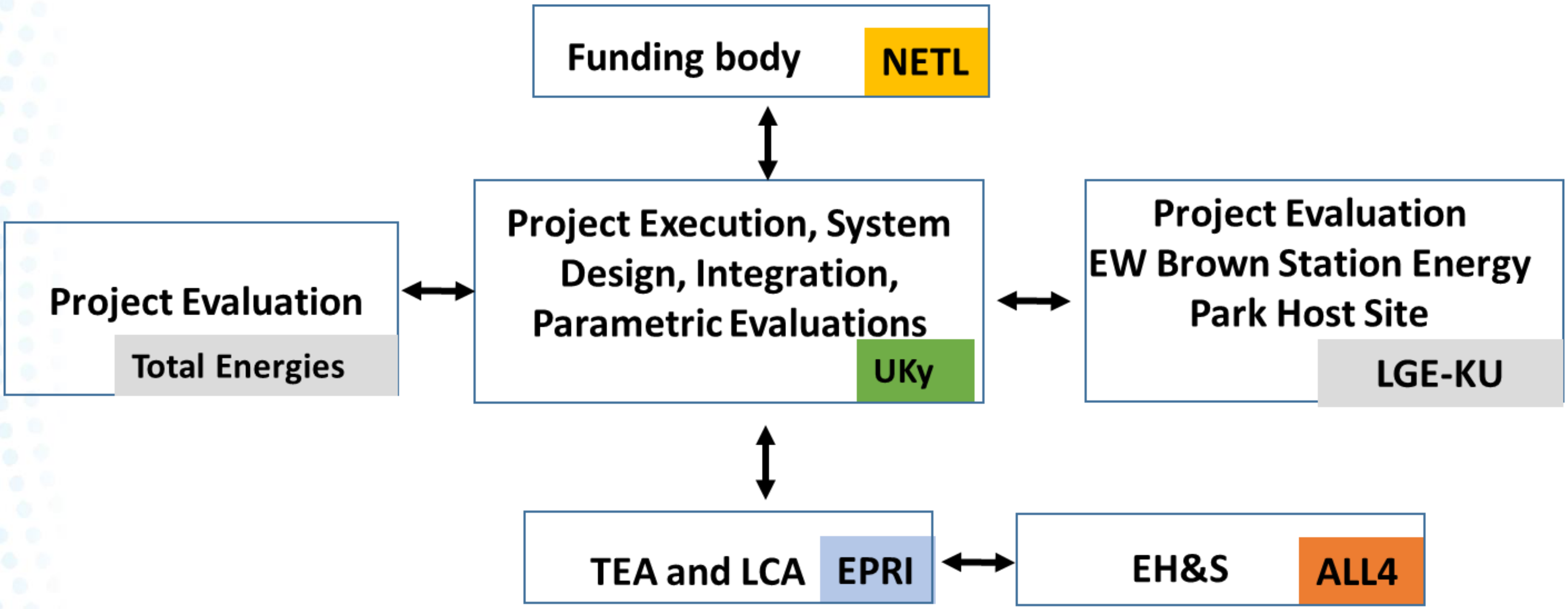
- Scale-up of electrochemical DAC system with hydrogen co-generation to ~3500 tonne CO_2/year, ~160 tonne H_2/year process

- Explore electrochemical solvent regenerator for cost-effective direct ocean capture

Acknowledgements

- **DOE-NETL**: Elliot Roth, Jose Figueroa, Andrew P. Jones
- **UK**: Jinwen Wang, Emmanuel Ohiomoba, Steve Summers and Lisa Richburg
- **EPRI**: Adam Berger and Abhoyjit Bhown
- **PPL Corporation**: Aron Patrick
- **Total Energies**: Phuc-Tien Thierry

Organization Chart



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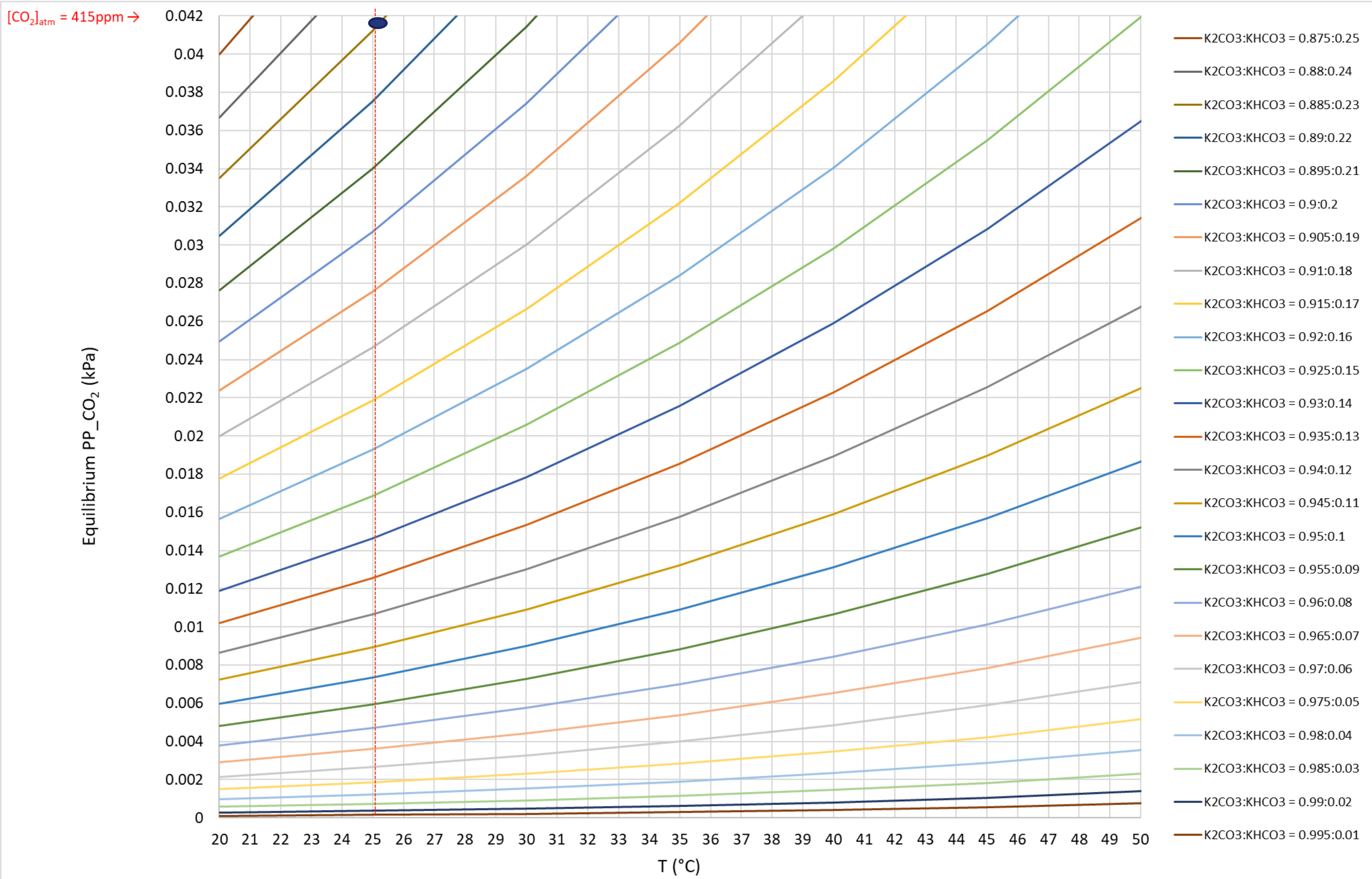
Gantt Chart

	TASK DESCRIPTION	PLAN START	PLAN END
1	**Project Management and Planning**	8/1/2023	7/31/2026
1.1	1A. Update Project Management Plan	8/1/2023	8/31/2023
1.1	1B. Kickoff Meeting	8/1/2023	10/31/2023
1.2	2A. Initial Technology Maturation Plan	8/1/2023	10/31/2023
1.2	2B. Final Technology Maturation Plan	1/1/2026	4/2/2026
BP1	**BP1: Design and Development**	8/1/2023	7/31/2024
2	**DAC Hybrid Absorber Development**	8/1/2023	3/31/2024
2.1	CA Mimics Development	8/1/2023	10/31/2023
2.2	Catalyst Immobilization	11/1/2023	3/31/2024
2.3	Hybrid Absorber Design	1/1/2024	3/31/2024
2.4	Fabrication and Testing of Absorber Components	3/1/2024	7/30/2024
3	**Electrochemical Regenerator R&D**	8/1/2023	5/1/2024
3.1	Commercial Electrode Selection	8/1/2023	12/31/2023
3.2	Stability of ERC	12/1/2023	5/1/2024
4	**Recruitment, Initial Analysis and Design Package**	8/1/2023	7/31/2024
4.1	Student Recruiment and Mentoring	8/1/2023	7/31/2024
4.2	Process Design Package	10/1/2023	3/29/2024
4.2	Initial Technoeconomic Analysis	8/1/2023	11/29/2023
4.3	Initial Life Cycle Analysis	8/1/2023	11/29/2023
BP2	**BP2 Scale up, System Integration and Modulation**	8/1/2024	7/31/2025
5.1	Procurement and Balance of Plant	8/1/2024	11/1/2024
5.2	Process Control and Monitoring and P&ID	10/2/2024	2/2/2025
5.3	Integration with Solar Energy Park	2/2/2025	5/2/2025
5.4	Startup and Comissioning	3/3/2025	7/28/2025
BP3	**BP3: Parametric, Long-Term, and Technology Analyses**	8/1/2025	7/31/2026
6.1	Parametric Testing	8/1/2025	2/1/2026
6.2	Long Term Testing and Analysis	12/1/2025	7/31/2026
7.1	Final Technoeconomic Analysis	11/3/2025	5/2/2026
8.1	Life Cycle Analysis	11/3/2025	5/2/2026
9.1	EH&S Assessment	11/3/2025	5/2/2026
10.1	Technology Gap Analysis	11/3/2025	5/2/2026

Energy Analysis with VLE and Carbon Speciation in K+ Solution



~0.23M/Liter of $KHCO_3$ can be under equilibrium of 415ppm of gas CO_2 at room temperature