Depolarized Electrochemical Reactor for Ocean Alkalinity Enhancement and Facile Recovery of High Purity Carbon

DE-FE0032402

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Program Overview

Project Title	Depolarized Electrochemical Reactor for Ocean Alkalinity Enhancement and Facile Recovery of High Purity Carbon
Award #	DE-FE0032402
Funding	DOE: $200,000 Cost-Share: $50,000
Project Goals	Design and develop a chemical-additive free and implementable electrochemically-driven direct ocean capture system.
Duration	12/20/2023 – 12/20/2024, 1 Budget Period
Project Participants	UKy, URI, EPRI, All4 Inc, Kiewit, and PPL Corporation

Project Objectives

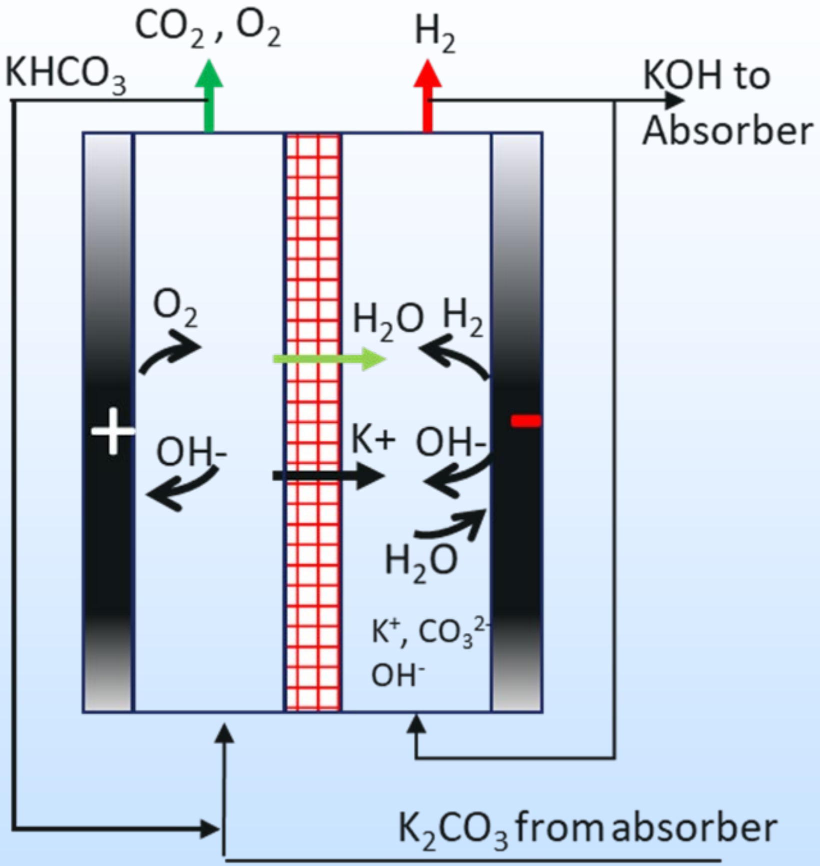
Provide a thorough analysis on an electrochemically-enabled aqueous-based ocean CO_2 capture located near PPL Corporation's off-shore wind farm near the Rhode Island coast by:

- Performing a feasibility and conceptual study with detailed guidelines on site selection, major equipment and their specification, preliminary facility design and general arrangement, cost estimates and pilot-project schedule

- Demonstrating a performance-confirmed UKy process for producing a ≥95% CO_2 purity stream at <1.8 V to target <200 kJ/mol

- Provide analysis on TEA, EH&S, LCA and Community Benefits.

UKy Electrochemical Technology



<u>Key Electrochemical Reactions</u>

$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ (0 V)

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ (-1.2 V)

or

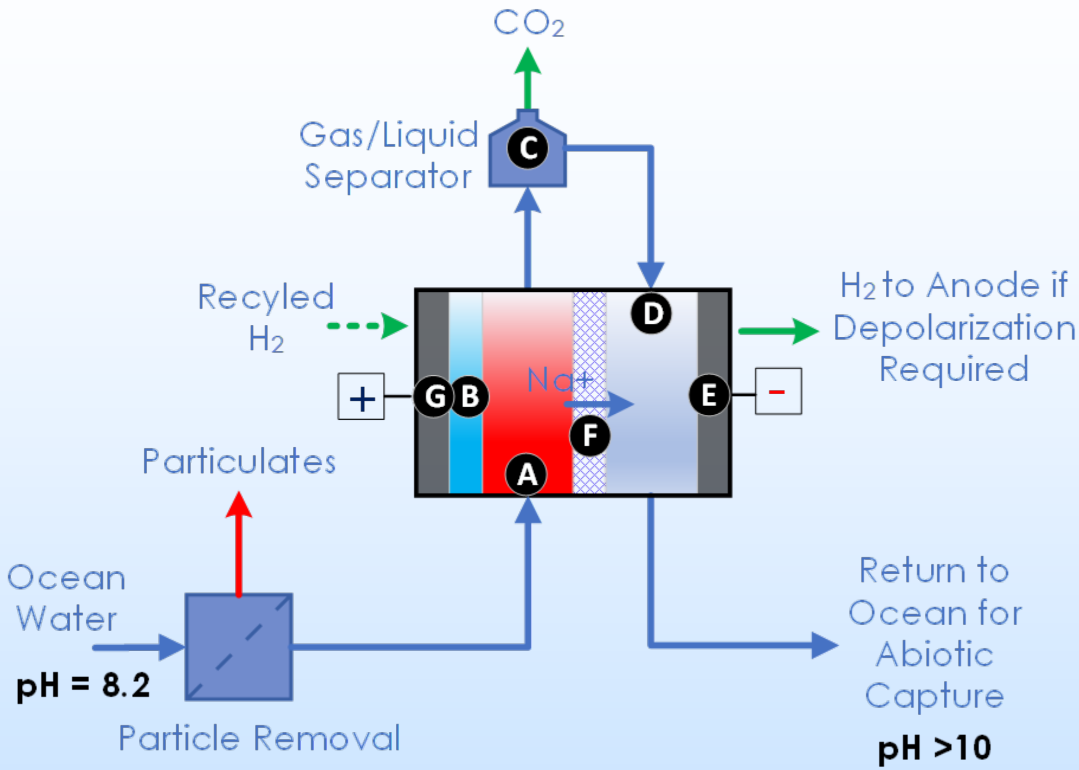
$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$ (-1.2 V)

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

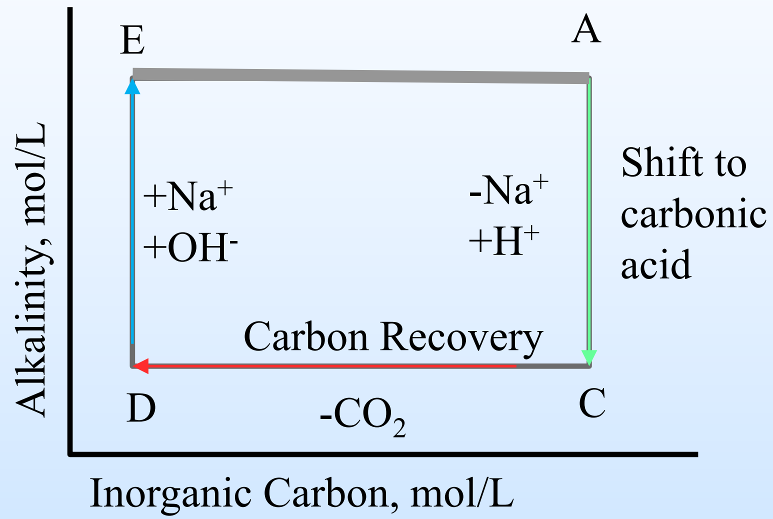
Water Rectification: $H_2O = H^+ + OH^-$

- Protons generated by electrochemical oxidation of water or hydroxide
- Requires only one electron process for CO_2 removal
- Hydrogen is available to reduce the energy cost of the process or as a product for sale

UKy DER for Ocean CO_2 Removal

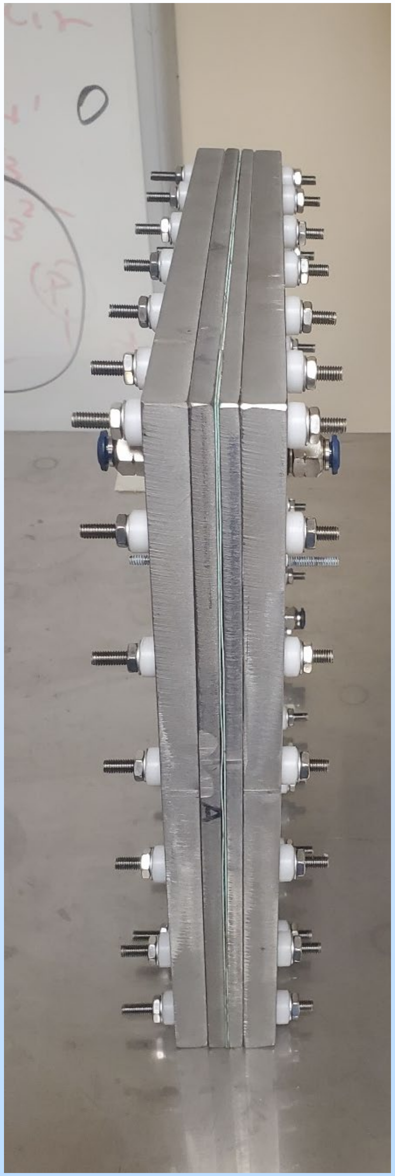


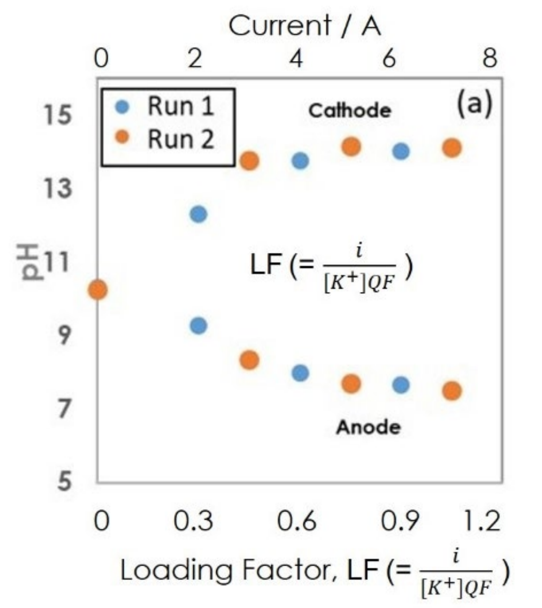
*Note: A, C, D, E – same as left plot

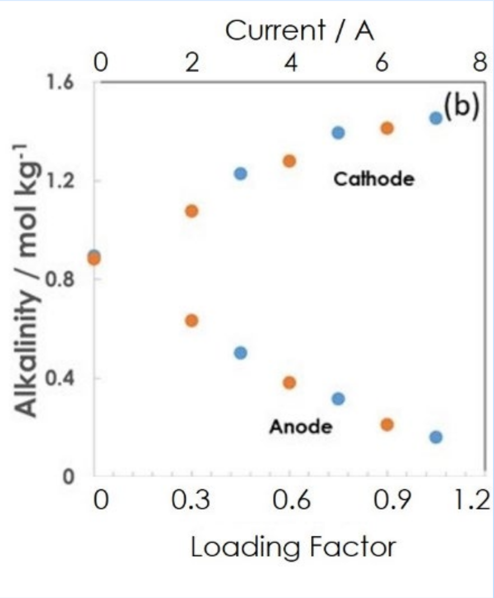


- Three chamber Configuration
- No Cl_2 evolution, alkalinity enhancement in cathodic chamber
- Reduced operational energy

UKy Previous Results : Performance of Electrochemical solvent Regenerator Scale-up

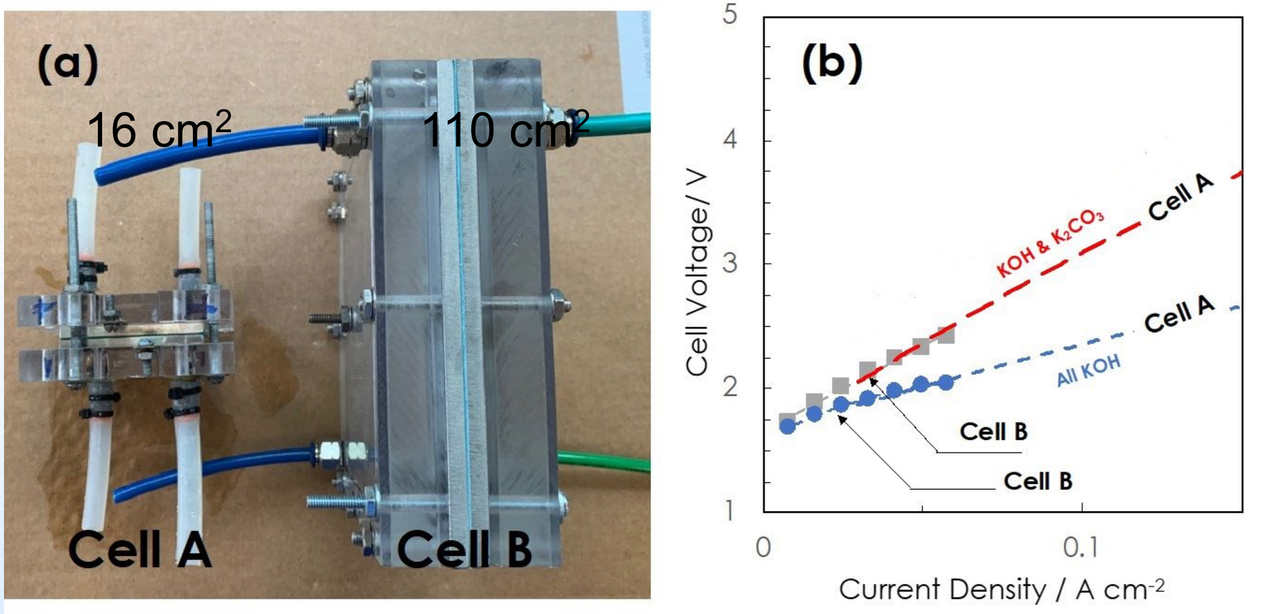


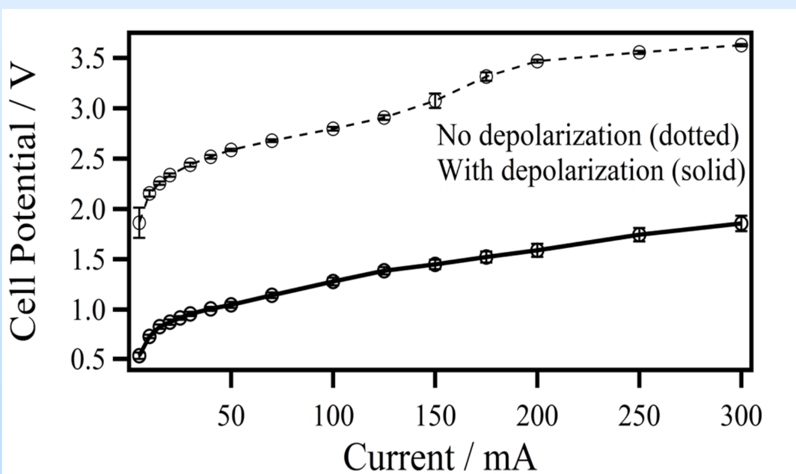




- Load Factor = i_{Total}/FQC_{K+} F, Q, and C_{K+} are Faraday's number, volumetric flow rate and potassium concentration
- Electrochemical regenerator reconditions the capture solvent to high pH at the cathode and low pH at anode for carbon recovery; pH swing increases with Load Factor
- Alkalinity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

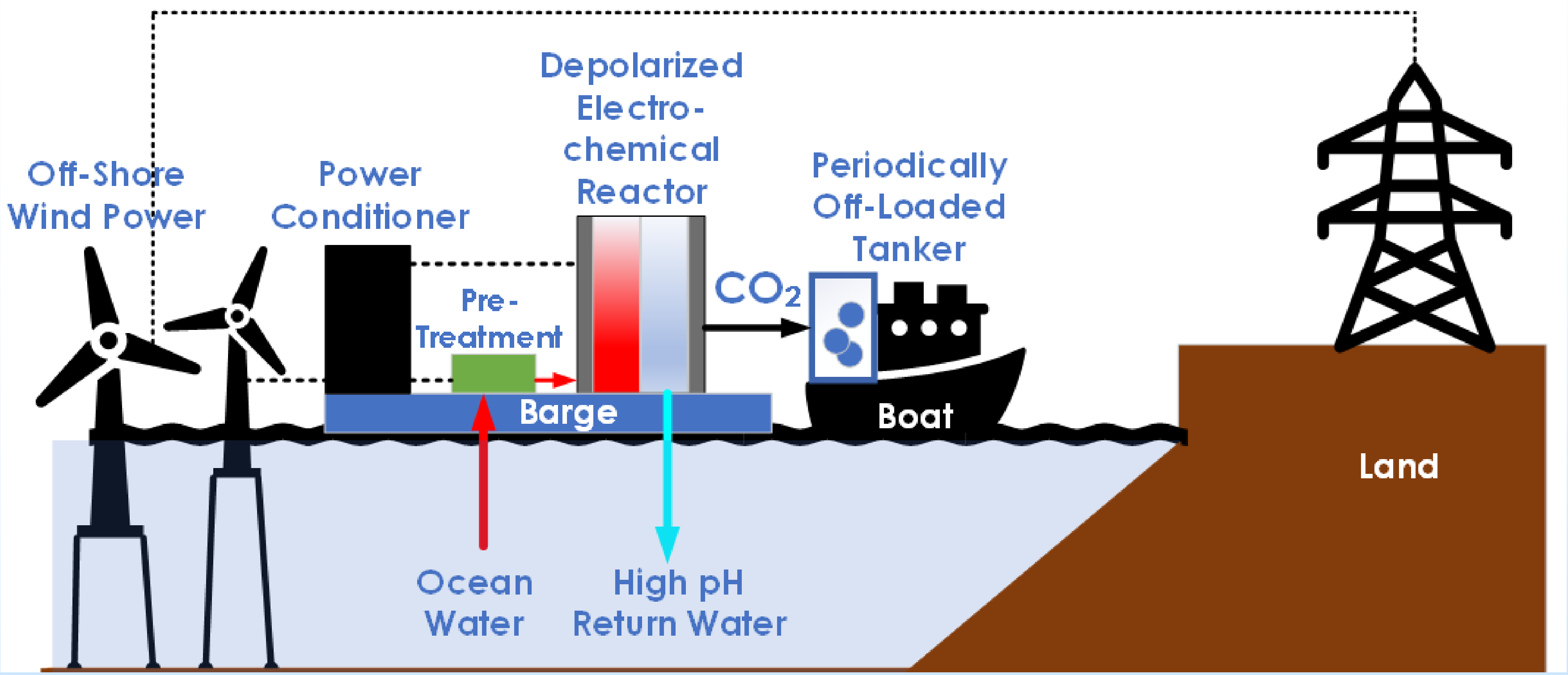
UKy Previous Results : Electrochemical Regenerator





- ≥95% pure CO_2 calculated as the pH values of the solution in acidifying chamber
- No Cl_2 detected.

Proposed Technology



UKy DOC Process

1. Use oceanic water as the absorber
2. Use low carbon footprint energy to recover high-purity carbon for storage
3. Minimize impact on the oceanic environment

Project Schedule

				2023					2024											
	TASK DESCRIPTION	PLAN START	PLAN END	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
1	**Project Management and Planning**	12/20/2023	12/20/2024																	
1.1	1A. Update Project Management Plan	12/20/2023	1/20/2024																	
1.1	1B. Kickoff Meeting	12/20/2023	3/20/2024																	
1.2	2A. Initial Technology Maturation Plan	12/20/2023	3/20/2024																	
1.2	2B. Final Technology Maturation Plan	10/21/2024	12/20/2024																	
1.3	State Point Data Table	10/21/2024	12/20/2024																	
1.4	Preliminary Technoeconomic Analysis	9/21/2024	12/20/2024																	
1.5	Preliminary Life Cycle Analysis	9/21/2024	12/20/2024																	
1.6	Technology Gap Analysis	9/21/2024	12/20/2024																	
1.7	Technology EH&S Assessment	9/21/2024	12/20/2024																	
2	R&D Community Benefits Plan	12/20/2023	12/20/2024																	
2	Update J40 PDP	12/20/2023	3/20/2024																	
2	Update Engagement PDP	12/20/2023	3/20/2024																	
2	R&D Community Benefits Plan Package	9/21/2024	12/20/2024																	
3	Experimental Work on DER Assessment	12/20/2023	7/20/2024																	
4	Process Deployment Analysis, Design, and Costing	12/20/2023	12/20/2024																	
4.1	Analysis of off-shore integration capability	12/20/2023	4/20/2024																	
4.2	Analysis of Ocean eco-sustainability	12/20/2023	4/20/2024																	
4.3	Site selection	4/20/2024	6/20/2024																	
4.4	Dispersion modelling for effluent discharge	4/20/2024	8/19/2024																	
4.5	Process Design Package	4/20/2024	8/19/2024																	
4.6	Floating AOC Cost Estimate	4/20/2024	8/19/2024																	

Deployment Consideration and Analysis

- Four potential locations identified by conducting initial discussions with local state agencies. All locations are near Rhode Island coasts, including at the URI Bay campus pier.

- Both floating and fixed platforms can be used near the coastline. A fixed platform is preferred due to cost and simplicity. However, a floating barge offers more flexibility in terms of deployment location and permit.

- If battery storage is used, the full energy demand of the pilot DER can be provided based on renewable energy. However, additional analysis is underway depending on the site.

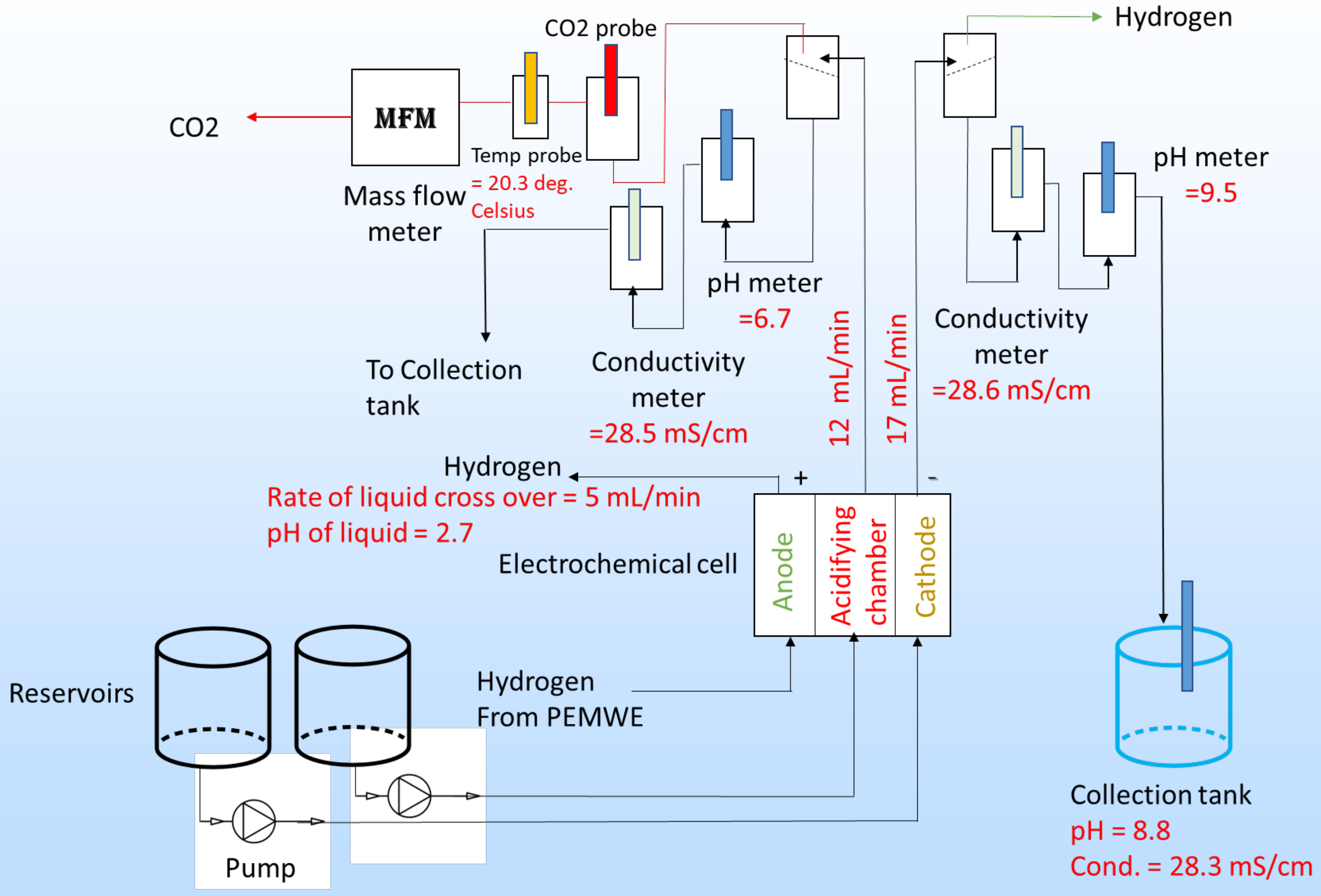
- INFLOW: How should the inflowing seawater be collected to minimize energy use and reduce the ecosystem impacts?

- EFFLUENT: How should the effluent of the DER be introduced back to the ocean?
    - ➢ We want to guarantee that effluent stays at ocean surface.

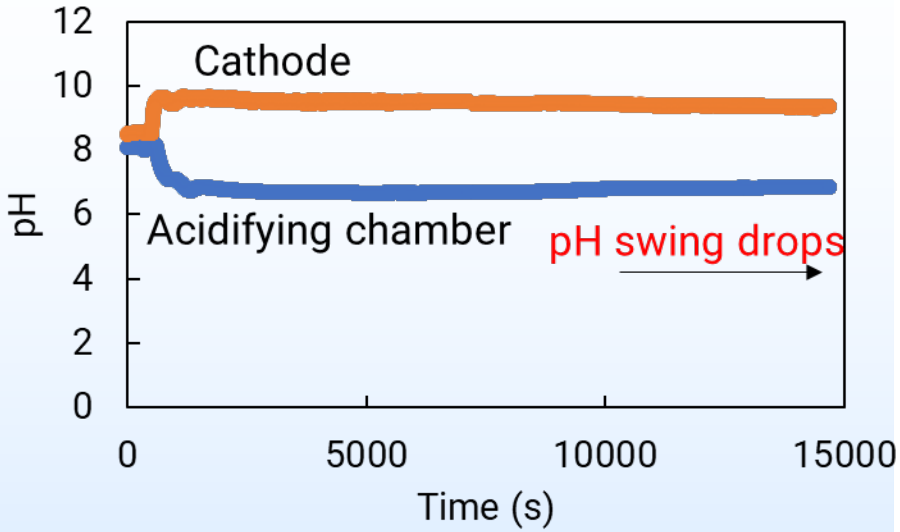
Real Ocean Water Evaluation

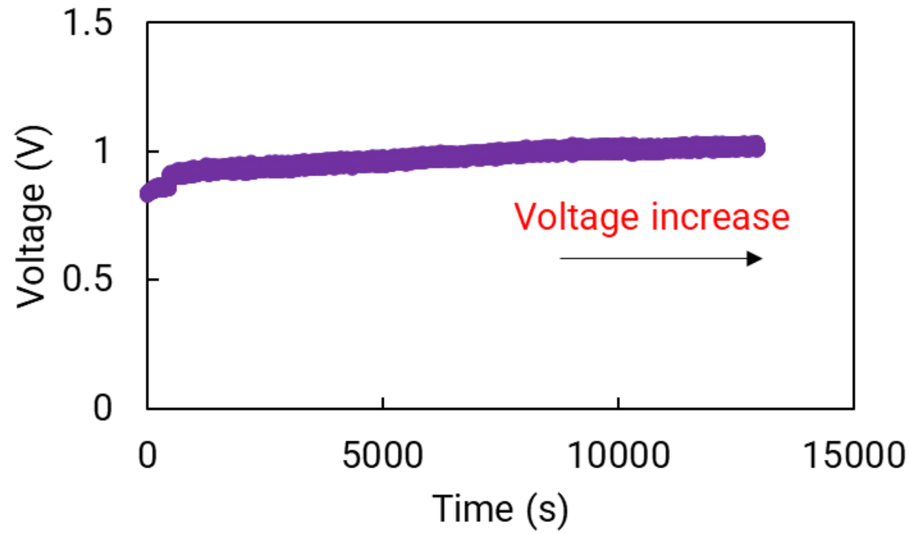
- Investigate the impact of alkali metal by comparing data to synthetic ocean water, as well the potential of solid precipitation.
- Investigate change in concentration of alkali metal post process.
- **Response variables:** Voltage, electrical conductivity and pH of individual and combined (acidifying chamber + cathode) effluents.
- **Controlled parameters**: Current, Flow rate

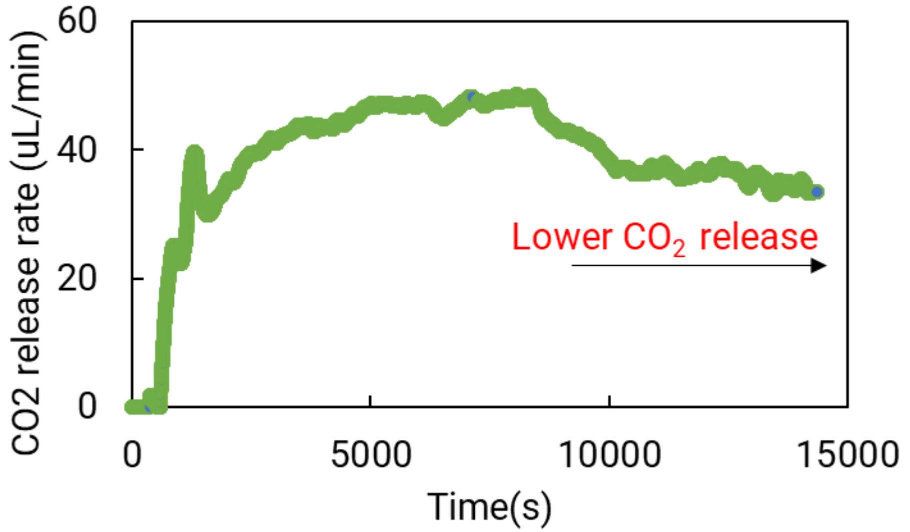
Scheme of Alkalinity Enhancement and Facile Recovery of Carbon



Performance with Ocean Water





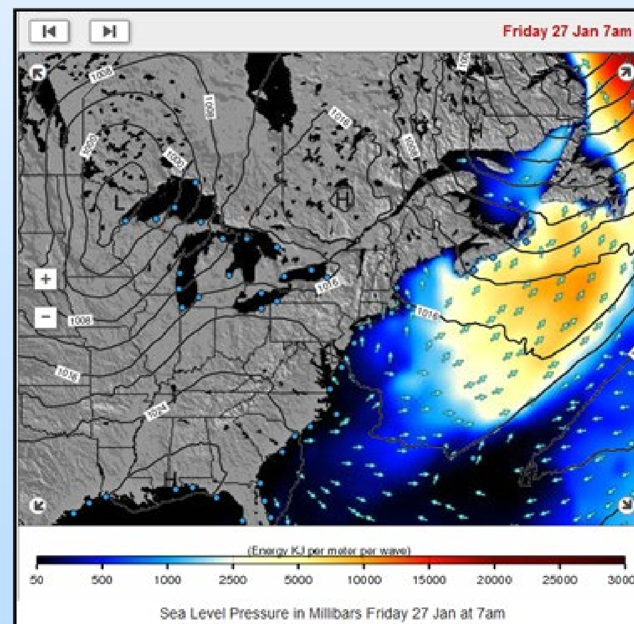


- CO_2 release with targeted purity
- pH drop in acidifying chamber and increase in cathode chamber as expected
- Liquid cross over from acidifying chamber to hydrogen side was observed
- Water with pH ~10 returned to ocean.

Technical Approach-Optimize Power Minimize Risks

Impactful Site Selection

- Community benefits
- Permitting requirement
- Ocean Eco System
- Off-shore power characterization and Integration
- Minimize conflict with current ocean users
- Available resource for AOC



1. Analyze off-shore integration capability and ocean eco-sustainability
2. Analyze effluent dispersion
3. Select site
4. Process design and DOC cost estimate

Community Benefits Plan

DEIA

- Maya Rao to start work in July
- Seven Mays has begun volunteering

CSE

Using Survey Monkey to draft and distribute survey. 50% complete with drafting.

> - Two new community benefits: Higher pH ocean water can help restore marine life affected by ocean acidification. Process prefilter will remove micro plastics.

J40

DAC may change based on the site chosen.

Summary

- Simplified and cost-effective DOC process for producing H_2 for internal consumption to reduce energy cost requirement or as a saleable byproduct

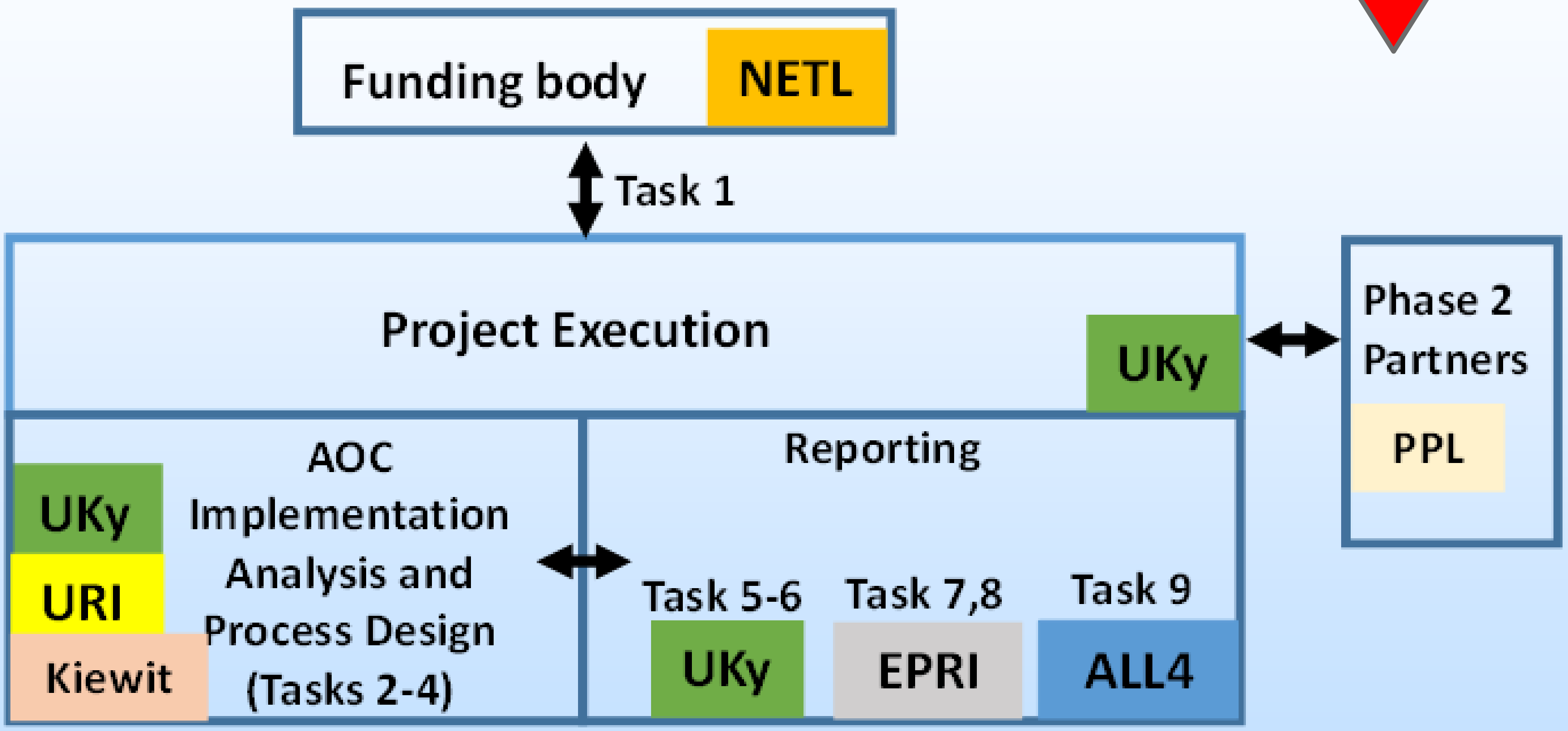
- Negative carbon emissions

- No foreign chemical addition to the process, the avoidance of chlorine generation and multiple intake points and discharge water will mitigate environmental risks to the local aquatic environment

Acknowledgements

- **DOE-NETL**: Mike Bergen and Andy Jones
- **EPRI**: Adam Berger
- **ALL4**: Karen Thompson
- **URI**: Reza Hashemi, Brice
- **Kiewit**: Bob Slettehaugh
- **PPL Corporation**: Aron Patrick

Organization Chart



Project Team and Task Leads

Activity Leaders	Tasks and Roles
Kunlei Liu (UK)	• Project management; DER Engineering and Optimization, Reporting
Xin Gao (UK)	• Technical development of DER, CBP
Kunlei Liu/Brad Irvin (UK)	• Conceptual design, partner coordination and communication
Adam Berger (EPRI)	• TEA & LCA
Karen Thompson (ALL4)	• EH&S
Reza Hashemi (URI)	• Lead offshore wind integration analysis
Brice Loose (URI)	• Lead ocean sustainability assessment
Bob Slettehaugh (Kiewit)	• Lead off-shore DER facility costing
Aron Patrick (PPL)	• Advisory

Milestones Log

Task /Subtask	Milestone Description	Planned Completion Date	Actual Completion Date	Verification method
1.1	Updated Project Management Plan	1/20/2024	1/10/2024	PMP File
1.1	Kickoff Meeting	3/20/2024	02/12/2024	Presentation File
1.2	Initial Technology Maturation Plan (TMP)	3/20/2024		TMP Report
3	Completed Functional DER at >100 kg/yr	7/20/2024		Quarterly Report
10	Phase 2 Application	12/20/2024		Application Document
5	Engagement PDP Update	3/20/2024		Topical Report
2	J40 PDP Update	3/20/2024		Topical Report
1.2	Final Technology Maturation Plan	12/20/2024		TMP Report
1.3	Update State Point Data Table	12/20/2024		Quarterly Report
2	Community Benefits Plan Package	12/20/2024		CBP Package Report
1.4	Preliminary Techno-Economic Analysis	12/20/2024		Topical Report
1.5	Preliminary Life-Cycle Analysis	12/20/2024		Topical Report
1.6	Technology Gap Analysis	12/20/2024		Topical Report
1.7	Initial EH&S Analysis	12/20/2024		Topical Report

Deliverables Log

Task/ Subtask	Deliverable Title	Due Date	Actual Submission Date
1.1	Project Management Plan	1/20/2024	1/10/2024
1.2	Technology Maturation Plan (TMP) Initial	3/20/2024	
1.2	Technology Maturation Plan (TMP) Final	12/20/2024	
2.0	J40 PDP	3/20/2024	
2.0	Engagement PDP	3/20/2024	
1.3	State Point Data Table	12/20/2024	
1.4	Preliminary Techno-Economic Analysis (TEA)	12/20/2024	
1.5	Preliminary Life Cycle Analysis (LCA)	12/20/2024	
1.6	Technology Gap Analysis (TGA)	12/20/2024	
1.7	Technology EH&S Risk Assessment	12/20/2024	
2.0	R&D Community Benefits Plan (CBP)	12/20/2024	