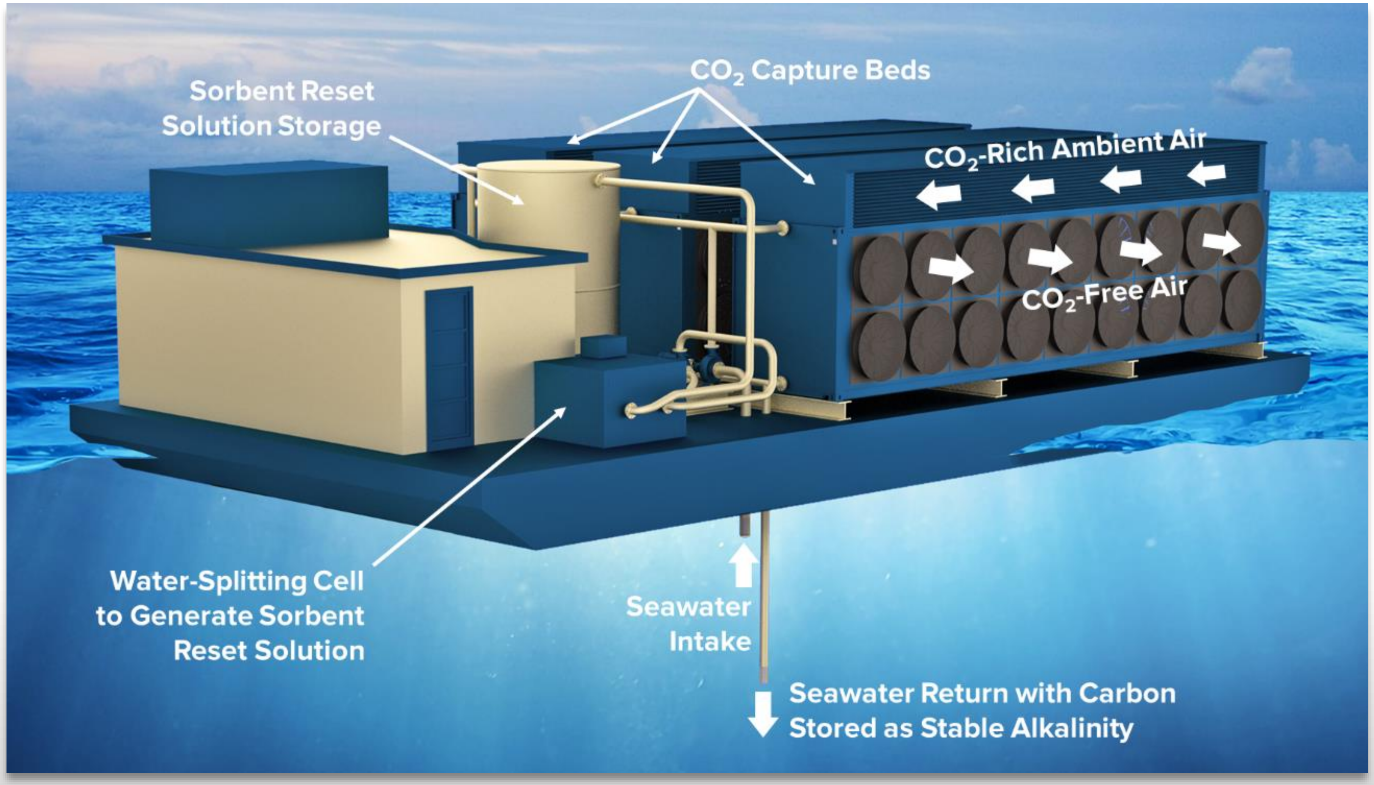
Ocean-Based Carbon Capture, Storage, and Alkalinity Improvement by a Seawater-Regenerated Metal-Polymer Hybrid Sorbent

Award Number: DE-FE0032406



Elizabeth Seber and Josh Charles

Advanced Cooling Technologies, Inc.

2024 FECM/NETL Carbon Management Research Project Review Meeting

August 9, 2024

Organization Chart

Advanced Cooling Technologies, Inc.
www.1-act.com (717) 205-6061

Joshua Charles (PI)
Elizabeth Seber
Robin Pham
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JEEVAN Technologies, Inc.
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Arup Sen Gupta
Hao Chen

Project Overview

Phase I Contract # DE-FE0032406

Overall Project Performance Dates

Budget Period 1	Start Date	End Date
Technical Performance	12/20/2023	12/19/2024
Administrative Performance	12/19/2024	09/19/2025

Funding

Project Participants	DOE Funds	Cost Share
ACT	$123,913	$25,000
Jeevan Technology, Inc.	$75,970	$25,116
Total	$199,883	$50,116

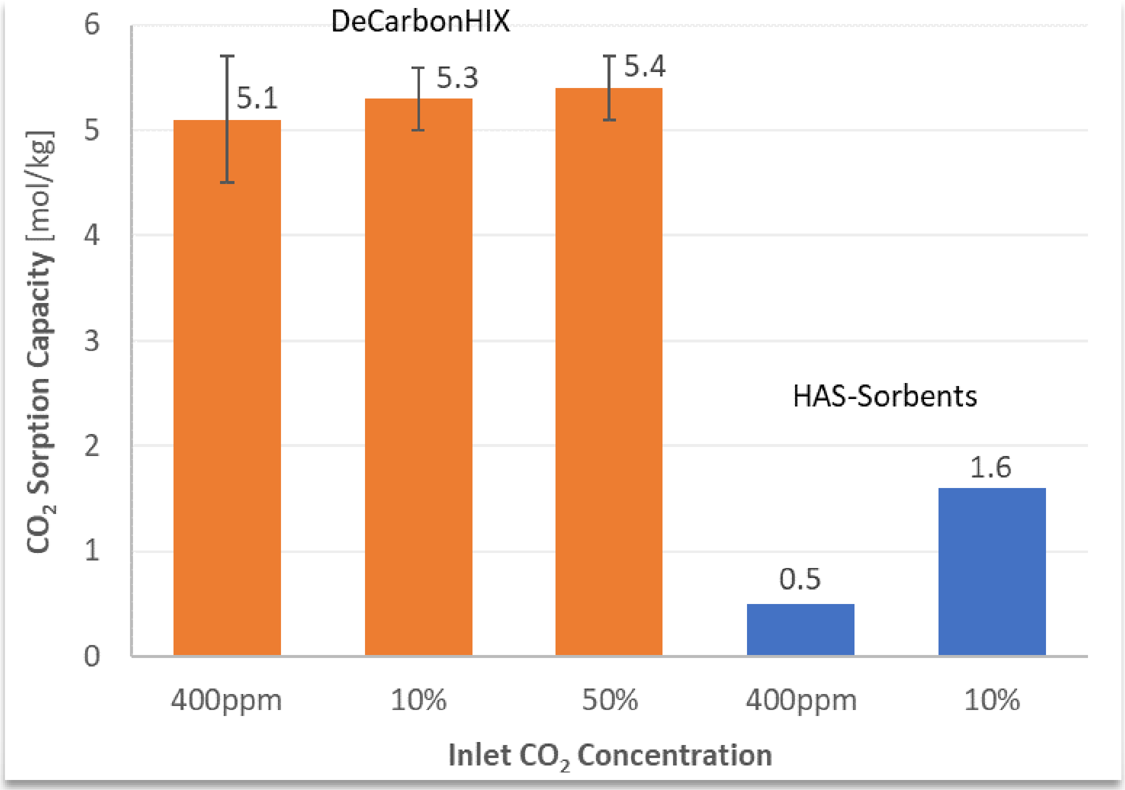
Project Overview

Overall Project Objectives:

1. Identify and gather a complete development and deployment team for a follow-on Phase II program.
2. Design and model a full-scale offshore DeCarbonHIX system and a conceptual pilot-scale system that will be benchmarked against SOTA carbon removal technologies and will be tested during a follow-on Phase II program
3. Design and fabricate DeCarbonHIX sub-systems for validation testing.
4. Benchmark the DeCarbonHIX system against SOTA OCR and on-shore CDR Technologies
5. Design and de-risk a conceptual pilot-scale, Phase II, DeCarbonHIX system.

Technology Background

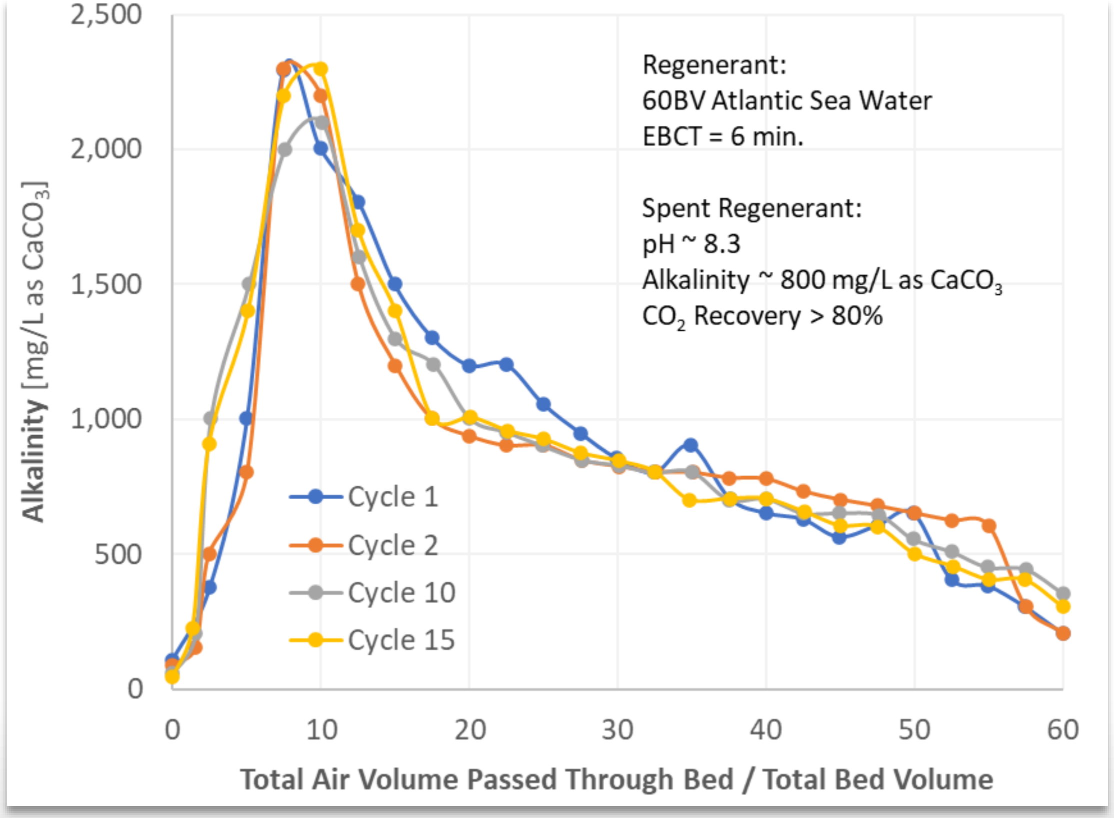
- DeCarbonHIX is an Ion-Exchange, Hydroxide Coated Amine Solid Sorbent
  - High CO_2 Capture Capacities at low concentrations



CO_2 sorption capacity of DeCarbonHIX at three different CO_2 concentrations compared to HAS-Sorbents.

Technology Background

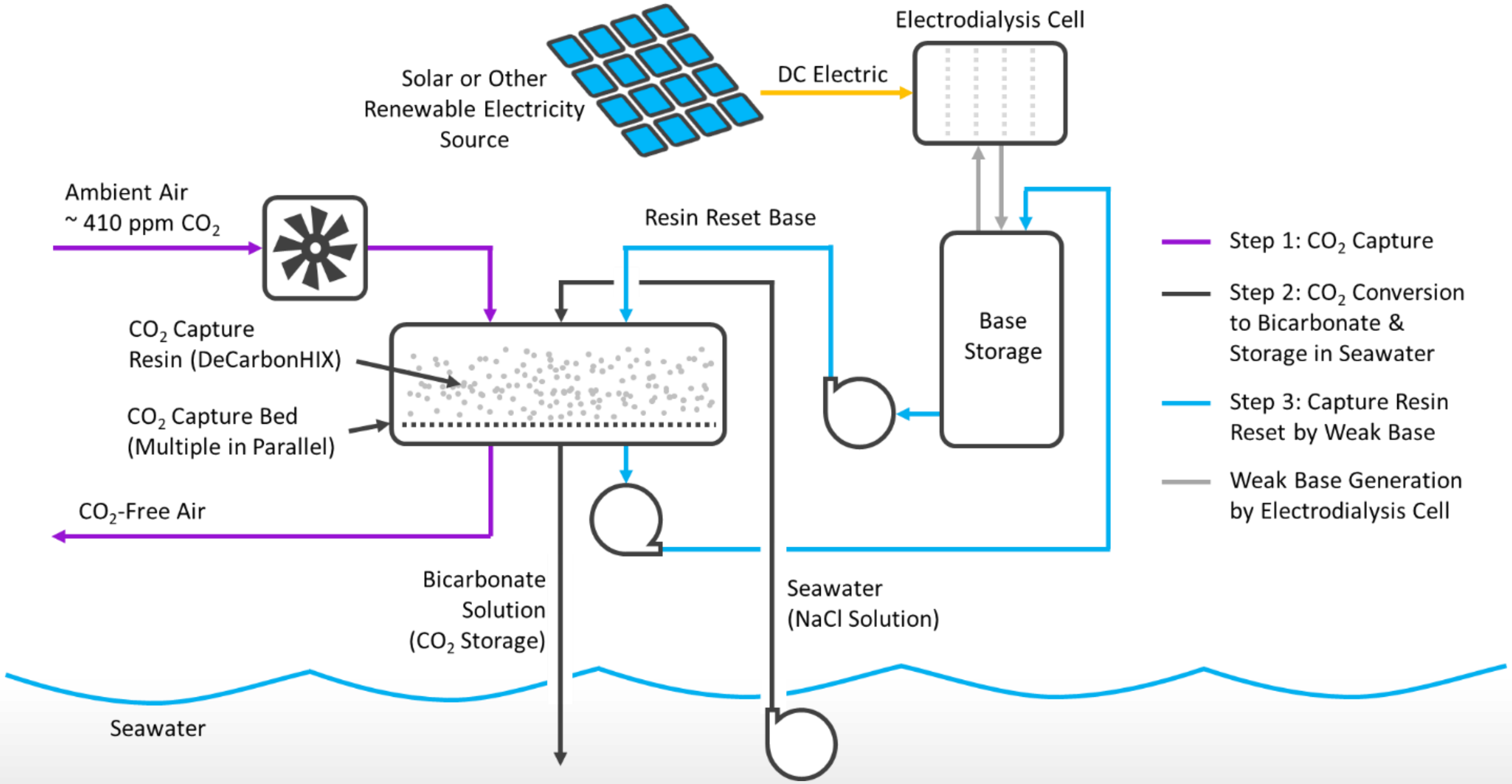
- DeCarbonHIX is an Ion-Exchange, Hydroxide Coated Amine Solid Sorbent
  - High CO_2 Capture Capacities at low concentrations
  - Seawater or brackish water with high salinity can be directly used to regenerate sorbent.



Elution Histories of Alkalinity from CO2-Saturated DeCarbonHIX Column with Seawater

Technology Background

- The entire process can be operated on or offshore at ambient temperatures.
- The DeCarbonHIX sorbent captures CO_2, and CO_2-free air is returned to the atmosphere.
- Seawater is flushed through the bed, where the CO_2 is released and stored in a stable bicarbonate form.
- A weak base solution is flushed through the resin to "reset" for the next capture cycle.



Schematic of DeCarbonHIX Ocean CO_2 Capture System

Technology Background

Advantages

- This system is unique in that the captured CO_2 is desorbed and sequestered in seawater in the form of alkalinity in a single step.
  - CO_2 does not need to be compressed for storage such as in underground injection.
  - Literature suggests that increasing the alkalinity in seawater is beneficial to reversing ocean acidification.
- The entire process can be operated on or offshore at ambient temperatures and is scalable.
  - Overall lower energy needs for operation.

Challenges

- Further subsystem development is needed:
  - Capture Bed Optimization
  - Base Generation
- Need to complete Techno-economic Analysis (TEA), and optimize the design to prevent higher-than-expected CO_2 capture cost
  - LCA has been completed for more than 150 cycles with base regeneration
- Marine safety needs to be explored

Technical Approach/Project Scope

1. Identify and gather a complete development and deployment team for a follow-on Phase II program.
   - Success represents commitment letters for industry and academic experts in marine science, offshore energy developers, NEPA compliance, LCA, and SCI.
2. Design and model a full-scale offshore DeCarbonHIX system and a conceptual pilot-scale system that will be benchmarked against SOTA carbon removal technologies and will be tested during a follow-on Phase II program.
   - Success will be based on completing the system models and designs. Models will be capable of fully characterizing the thermodynamic, chemical, and mass balance of a full-scale and pilot-scale DeCarbonHIX system. Preliminary CAD models will be completed to guide the project team in completing a full design during a follow-on Phase II program.
3. Design and fabricate DeCarbonHIX sub-systems for validation testing.
   - Success will be based on the completion of the fabrication and testing of the capture bed and base sorbent regeneration systems.
4. Benchmark the DeCarbonHIX system against SOTA OCR and on-shore CDR Technologies
   - Success will represent a preliminary techno-economic and life-cycle analysis comparison of the systems and a prediction of CO_2 capture cost at or below $100/ton or a near-term development pathway to that goal.
5. Design and de-risk a conceptual pilot-scale, Phase II, DeCarbonHIX system.
   - Success represents a complete pilot-scale DeCarbonHIX system mechanical design appropriate for deployment during a follow-on Phase II program. This work will result in a complete system-level (thermodynamic and chemical) design and preliminary mechanical design (CAD).

Technical Approach/Project Scope

Milestone Title & Description	Projected Completion Date	Verification Method
M1: Establish Relationships with Potential Phase II Team Members	6/19/24	Meet with potential Phase II team members in marine science, offshore energy, NEPA compliance, LCA, or SCI fields. Meetings with 3 to 10 potential members are expected, with a final down-selection of 3-5 team members for Phase II. The results of these meetings will be communicated to DOE during quarterly reports and briefings.
M2: Obtain Phase II Team Member Commitments	10/19/24	Commitment letters will be obtained from all Phase II team members, including, but not limited to, experts in marine science, offshore energy developers, NEPA compliance, LCA, and SCI. Commitment letters will be shared with DOE as an attachment to the quarterly report submitted at the end of the quarter in which they are obtained.
M3: Process Model of a Full-Scale OCR System	6/19/24	A complete process model demonstrating the operation of a proposed full-scale OCR system operating in an offshore environment. A complete thermodynamic, chemical, and mass balance of the system will be completed. The results of this modeling will be detailed in the quarterly report and briefing.
M4: Conceptual Design of a Phase II Pilot-Scale OCR System	8/19/24	The conceptual design of a Phase II pilot-scale DeCarbonHIX system will be presented to the DOE program manager for review. This design will include a preliminary CAD model design and process model prediction of system performance. Modeling results will be detailed in the quarterly report and briefing for the quarter in which they are completed.
M5: Design of a Sub-Scale Capture Bed	9/19/24	A sub-scale capture bed design will be presented to the DOE program manager for review during a quarterly briefing. This design will be fabricated and tested during Task 4 to demonstrate the bed's pressure drop and capture characteristics.

Technical Approach/Project Scope

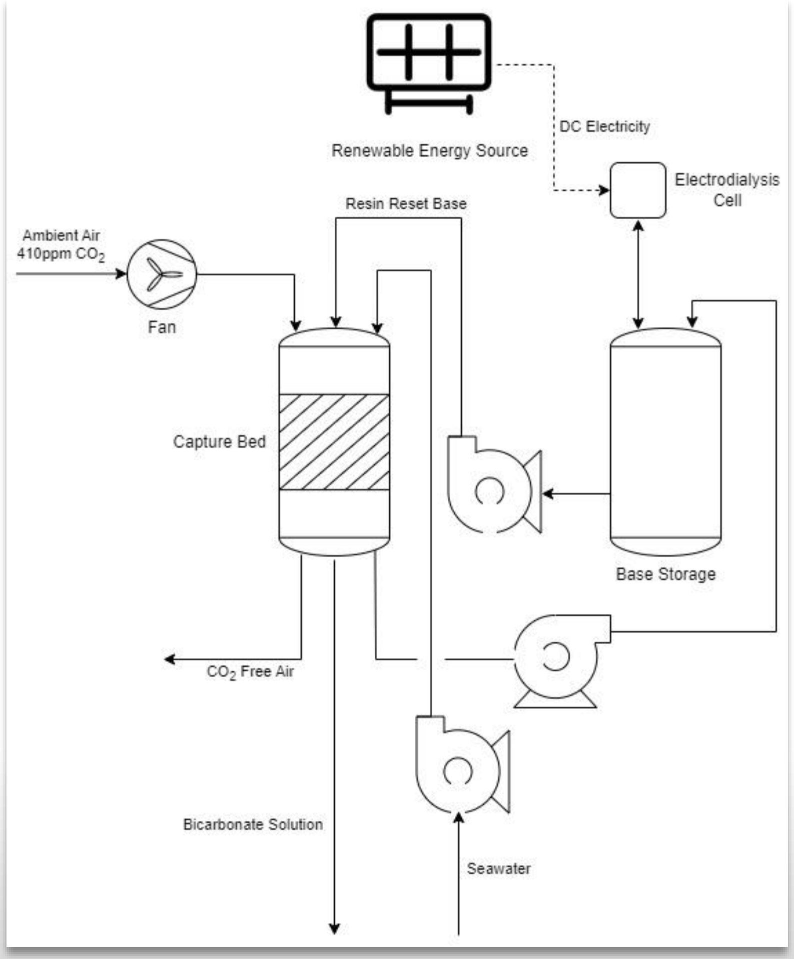
Milestone Title & Description	Projected Completion Date	Verification Method
M6: Demonstration of Capture Bed Performance	11/19/24	Demonstration of the sub-scale capture bed's pressure drop and CO2 capture characteristics. Pressure drop data will be compared against modeled results and suggestions for design improvements in Phase II. Demonstration results will be summarized in quarterly reports and corresponding briefings with the program manager.
M7: Demonstration of Base Regeneration System	11/19/24	The bipolar membrane electrodialysis cell and sorbent regeneration system will be fully tested with energy and chemical performance compared against model predictions. A demonstrated production of 0.5-1% NaOH solution is targeted for this Milestone, along with a 50% demonstrated improvement in electricity consumption compared to a traditional ion-exchange membrane cell. These findings will be presented in quarterly reports and their corresponding briefings with the DOE program manager.

Technical Approach/Project Scope

Perceived Risk	Risk Rating			Mitigation/Response Strategy
	Probability	Impact	Overall	
Technical/Scope Risks:				
Technoeconomic Analysis (TEA) and Life Cycle Assessment (LCA) Results Indicating a Higher-Than Expected CO_2 Capture Cost	Medium	High	High	Identify key cost drivers early in Phase I to provide time for an engineering-based assessment of these cost drivers. Early identification will allow the team to conduct research and development to demonstrate the lowest-cost methodologies that address this risk.
Assembling of a Phase II project team and establishment of working relationships.	Low	High	Medium	Identify and meet with potential Phase II project team members as early as possible in the Phase I program. Begin the team member commitment process by the middle of the Phase I program.
ES&H Risks:				
Unforeseen consequences to marine life or microbiomes	Low	High	Medium	Work with marine ecological experts early in the program to identify and address ecological risks of the DeCarbonHIX system.
External Factor Risks:				
Public perception	Medium	Low	Medium	Clearly communicate the ocean impact analysis by marine experts to the broader public. This involves significant community outreach.

Progress and Current Status of Project

- Full-Scale OCR System Model Completed
  - Uses Stoichiometry to balance reactions within the capture bed, alongside a mass and energy balance
  - When given a desired capture capacity, the system model determines the required volume of DeCarbonHIX, the required flowrates for input and output streams, and anticipated energy needs of the system.

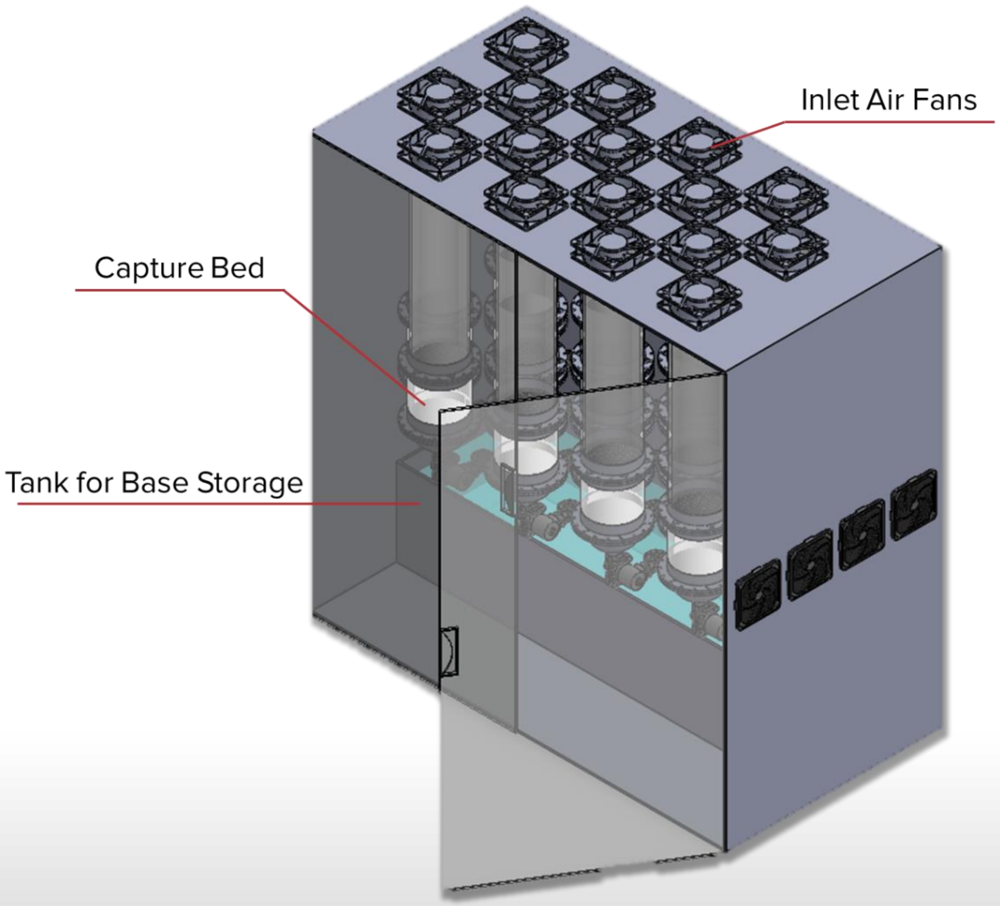


Schematic of OCR System Model and Relevant Components

Progress and Current Status of Project

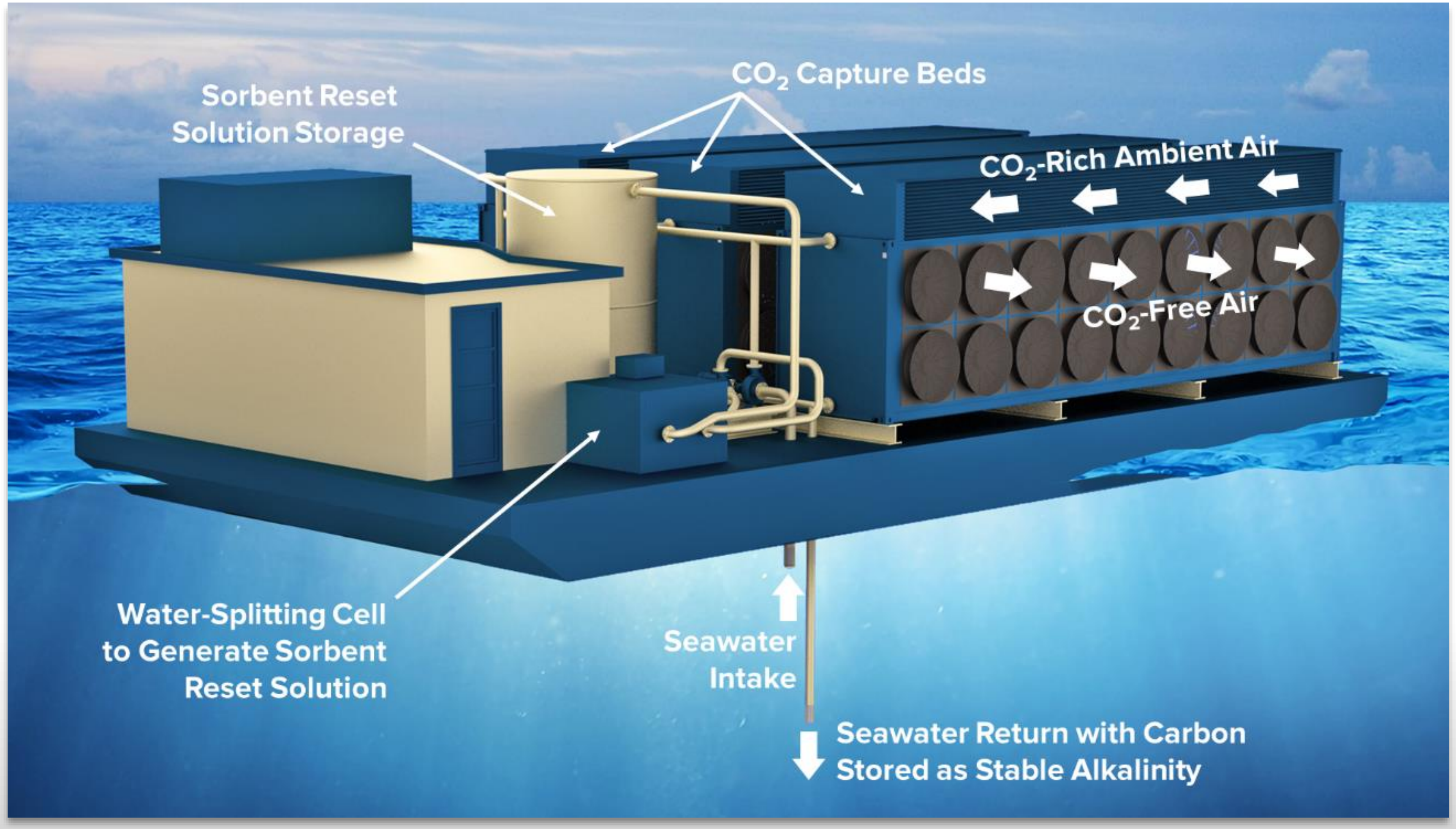
- Pilot-Scale System Conceptual Design Nearly Complete
  - Will Use Subscale System Test Data to Refine Design.

Parameter	Value
CO_2 Capture Capacity	50 tons/year
Total Sorbent Volume	43.12 L
Number of Beds	16
Bed Radius	4 inches
Bed Height	3.27 inches
Total Cycle Duration	3 hours
Capture Phase Duration	1 hour
Seawater/Carbonate Discharge Duration	1 hour
Base Regeneration Duration	1 hour



Preliminary Pilot-Scale CAD Design

Progress and Current Status of Project

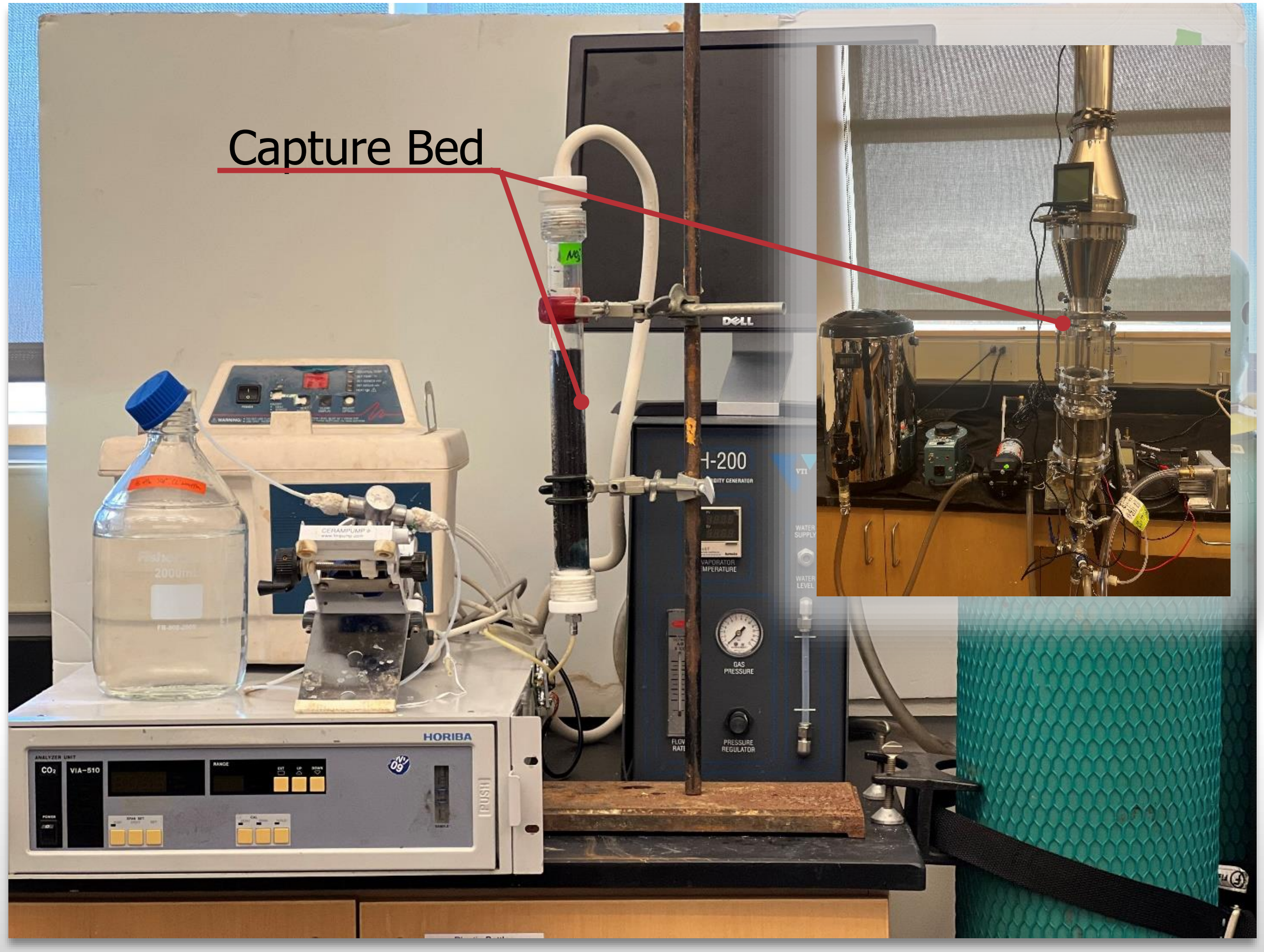


Conceptual Design of Full-Scale System

Progress and Current Status of Project

Sub-system Design and Testing:

- Subscale Capture Bed
  - Capture Rate Established in Previous Work
  - Currently Testing for Discharge Rate
  - Further Testing of Bicarbonate in Seawater under Agitation
  - Testing to Verify Marine Safety of System Effluent
- Subscale Base Generation
  - Benchmarking Electrodialysis Cell
  - Exploring the use of Steel Slag and other Alkaline Waste Products

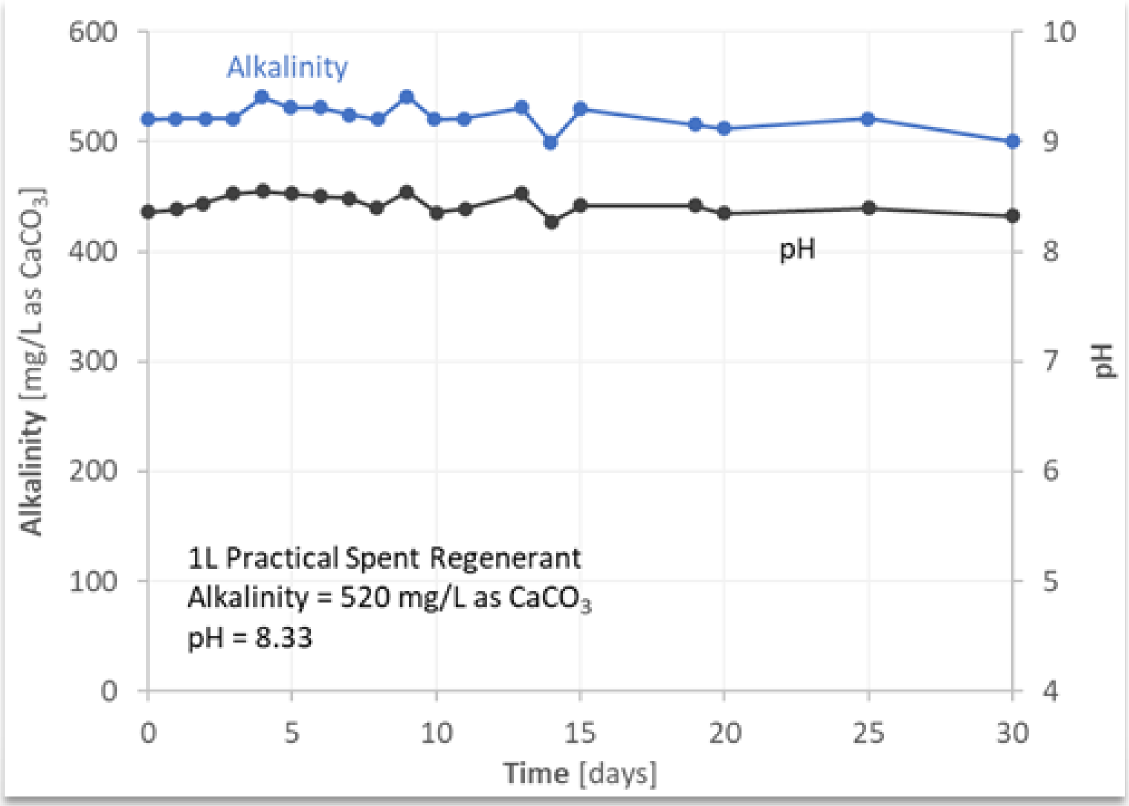


Subscale Capture Beds

Progress and Current Status of Project

Subscale Capture Bed:
Alkaline Stability

- Preliminary Test Indicate Good Stability
- Further Stability Validation:
  - Mechanical Agitation
  - Thermal Cycling
    - Ocean Temperatures range from -2 °C and 30 °C

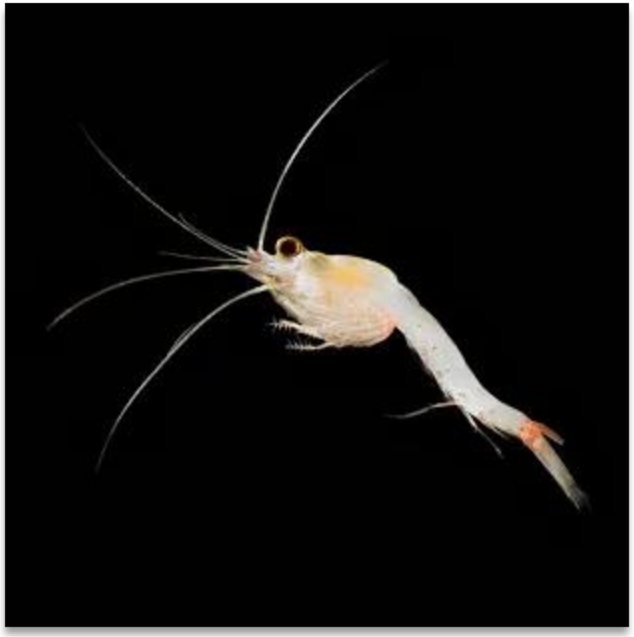


Changes in Alkalinity and pH in Effluent Seawater after Long-Term Exposure in the Open Air

Progress and Current Status of Project

Subscale Capture Bed: Marine Safety

- Testing of Effluent with EnviroScience
  - The mortality rate of two bioindicator species will be observed over 7 days
  - Results will provide the ecotoxicity data portion for an SDS
- Literature suggests alkalinity injection into the ocean could reverse ocean acidification
- Alkalinity in the form of bicarbonate could be used in algae farms to promote growth



Mysid Shrimp
https://encrypted-tbn0.gstatic.com/licensed-image?q=tbn:ANd9GcSwyFOL_gLuNtbixcWZayarDm7Ushf0Udt7Jh_Bzwue99-FuKQLTIoqDjAmSlDMLIC6my03cT78kRkbGx8

Sheepshead Minnows
https://www.floridamuseum.ufl.edu/discover-fish/florida-fishes-gallery/sheepshead-minnow/

Progress and Current Status of Project

Subscale Base Regeneration

- Electrodialysis Cell
  - Well-established technology
  - Generates the needed base, but also creates an acidic byproduct
  - Increases the energy needs of the system
- Steel Slag
  - Waste material that can be reused
  - Source of oxides that can produce the alkalinity we need

Steel Slag Sample from PA

Summary of Community Benefits

CBP Section	Effort Summary
Assistance and Validation	Ongoing efforts to connect with DOE, including submitting SCI plans, establishing a framework to evaluate and track progress over time; and aligning project goals with DOE's SCI expectations as defined in Funding Opportunity Announcement.
DEIA	Promotion and Adherence to ACT's DEIA Policy. Ongoing efforts for inclusive and equitable hiring practices. Outreach Groups within ACT work to increase diversity in the applicant pool. The majority of the project team consists of members identifying as minorities in STEM (6/8)
Justice 40	Through ongoing testing of CO_2 capture capacity, we can quantify the impact the system will have on the community in which it is deployed. From this, we can predict which areas will benefit the most from the proposed device. Currently Exploring a Phase II Testing Location, with an emphasis on Disadvantage Communities.
Community and Stakeholder Engagement	Identifying Relevant Community Partners based on Phase II testing site location. Currently engaging potential stakeholders, such as steel manufacturers,
Quality Jobs	Regular learning sessions and training for all employees. An Intern working on the Phase I effort was hired as a full-time engineer in June 2024.

Summary of Community Benefits

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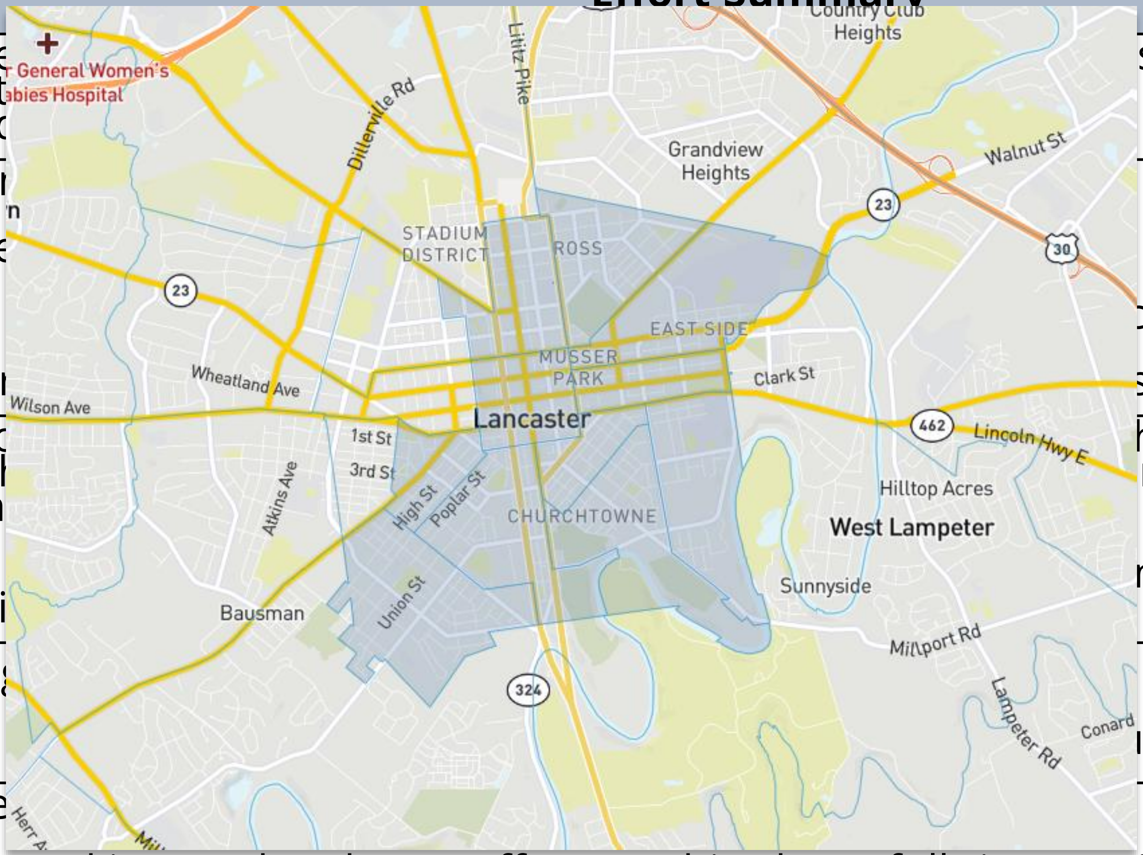

Lessons Learned

- Lessons Learned
  - Ongoing Testing; Lessons still being learned.
- Mitigation Strategies
  - Testing capture bed effluent to validate marine safety.
  - Exploring the use of steel slag for base regeneration to reduce energy needs, and therefore levelized cost, of captured CO_2.
  - Optimizing capture bed design to improve performance and reduce overall cost.

Plans for Future Testing/Development/Commercialization

In This Project:

- Complete Testing and Validation of Subsystems
- Complete Pilot-Scale System Design

Next Project (Phase II):

- Fabricate and Deploy Pilot-Scale System
- Design a Large-Scale System Capable of 1 Million Tons/Year of CO_2 Capture
- Partnering to Manufacture and Implement
- Community Engagement

Scale Up Potential:

- The technology itself is highly scalable
- Further TEA and LCA must be Completed to Justify Implementation

Summary Slide

Key Findings:

- DeCarbonHIX is an attractive CO_2 Capture and Storage solution due to the low energy requirements for operation, and the immediate storage of collected CO_2.

Future Plans:

- Complete Subsystem Testing and Update System Model and Pilot Scale Conceptual Design
- Fabricate and Deploy Pilot-Scale System
- Scale Up the System

Take-Away Message:

- CO_2 Storage as Alkalinity in Seawater shows promise for reversing Ocean Acidification and improving Marine Life.
- **Call to Action:** We are looking for partners for Phase II.

Further Questions:

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- Special thanks to our Program Managers: Kara Zabetakis & Erika Bittner