Ocean Climate Restoration Using Offshore Carbon Capture and Storage

Project E045 - Summary Report

June 4, 2022

Table of Contents

List of Figures

List of Tables

Acknowledgements

This project was supported with funding from Natural Resources Canada's Emissions Reduction Fund, Offshore RD&D program, which is managed and administered by Energy Research & Innovation Newfoundland & Labrador.

The team at Planetary is grateful for support from the Canadian Government, the team at Energy Research & Innovation Newfoundland & Labrador (ERINL), our project coordinator Kim Coady and partners at DST, SGS, Stantec and B&M Consulting. Together, we have moved the needle on a high-potential climate solution, bringing us closer to commercialization and impact.

1. Project Description

1.1 Background

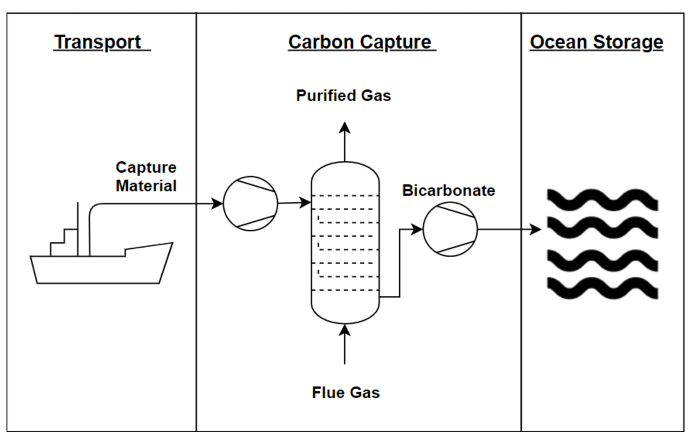
The oceans are the world's largest surface store of carbon, with almost 40,000 Gt of carbon naturally locked within seawater chemistry. The potential to accelerate the oceans' ability to safely consume carbon dioxide emissions has been studied in various forms for the last 30 years. The implementation of this concept, called Ocean Alkalinity Enhancement (OAE), can potentially store billions of tonnes of atmospheric carbon permanently within ocean chemistry, while countering the effects of climate change-driven ocean acidification and restoring the marine environment[1].

This approach is gaining interest around the world but has not yet been deployed outside of a research setting. While CCS and Carbon Capture Utilization and Storage (CCUS) technologies have seen significant investment and several promising deployments around the world, the primary mechanisms for CO_2 storage are subsurface storage, direct use or use as feedstock for the production of fuels. OAE offers a new "sink" for captured carbon, adding it to the already extensive carbon store in the ocean and locking it away for more than 100,000 years.

Planetary's process uses renewable energy to produce a low carbon form of alkalinity from abundantly available mine tailings. This form of alkalinity can be used to directly capture carbon or to enhance the ocean's natural uptake of carbon dioxide from the atmosphere.

This project aimed to develop a methodology to capture carbon dioxide from gas turbines on offshore oil and gas facilities using our low carbon alkalinity and than store it safely and effectively in the ocean as bicarbonates.

Figure 1: Carbon capture using low-carbon alkalinity and ocean storage.



1 https://www.nationalacademies.org/our-work/a-research-strategy-for-ocean-carbon-dioxide-removal-and-sequestration

1.2 Project Objectives

The objective of this project was to advance research to enable offshore platforms to economically perform carbon capture and storage (CCS) in-situ by providing a method of permanently sequestering captured carbon from gas turbines used for power generation within ocean chemistry.

This was divided into three work streams:

1. **Low-carbon production of alkalinity:** produce solid magnesium hydroxide from abundant local silicate rocks (mine tailings) through acid-leaching, using reactants produced from our electrochemical cells.
2. **Process simulation study for offshore implementation and integration:** use a contacting device to capture the CO_2 emissions produced by the electrical generation systems aboard offshore oil and gas production platforms.
3. **Environmental and Regulatory Requirements Assessment:** Determine regulatory requirements to process this captured carbon into purified bicarbonate that can be permanently sequestered in the ocean.

1.3 Partners, Collaborators and Stakeholders

Several collaborators, partners and stakeholders were involved in the conduct of the project:

SGS Canada: Performed amenability testing on select mine tailings, supported the development of a metallurgical process to produce magnesium sulphate using the tailings, and conducted a series of tests on a bench-scale electrochemical cell prototype used to precipitate pure magnesium hydroxide, $Mg(OH)_2$.

Stantec: Conducted a feasibility study for the integration of an effective and compact design of a CO_2 - $Mg(OH)_2$ absorption system such that it can be accommodated on the space constrained offshore platform and does not require substantial power demand to offset the monetary benefit of this novel approach.

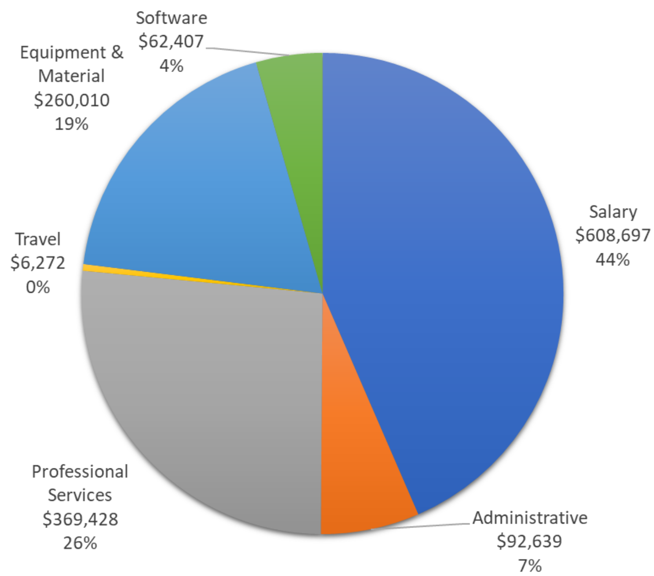
Dundee Sustainable Technologies: Provided expert advice and logistical support for leaching trials, including provisioning of tailings and initial metallurgical process consultations.

Donna Morykot, P.Eng., PMP: Conducted a review of the offshore Newfoundland & Labrador (NL) regulatory framework as it relates to Planetary's carbon capture and sequestration process on offshore oil and gas facilities, primarily focusing on the requirements of the Canada-Newfoundland and Labrador Atlantic Accord Implementation Act and the Canada-Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act.

1.4 Total Project Costs

Costs for the project totalled $1,399,452.40. A breakdown by expenditure category is shown in Figure 2.

Figure 2: Total Project Cost breakdown by expenditure category



2. Project Results

2.1 Summary of Key Results and Findings

Overall the project successfully developed and tested a method of producing low-carbon alkalinity from mine tailings. This formed the basis for a successful XPRIZE Carbon Removal $1M USD milestone submission completed in Q1 of 2022 and awarded on Earth Day. Planetary was one of 15 companies to receive the award from over 1100 teams competing internationally.

The feasibility study for the integration of an effective and compact design of a CO2 - $Mg(OH)_2$ absorption system for offshore oil and gas facilities determined that it is not an economic solution to mitigate greenhouse gas (GHG) emissions directly from gas turbines due to space constraints, but shows significant potential for land-based deployments.

A method of direct ocean CO_2 capture by alkalizing produced water discharged from an offshore platform was considered under the regulatory review but was outside the scope of this project. Further investigation of this promising carbon removal pathway is recommended.

2.1.1 Progress Towards Key Milestones and Performance Measures

Several key milestones were achieved as a result of the project:

- A low-carbon method to leach magnesium and other pay metals, including nickel and cobalt from magnesium-rich mineral feedstocks using the acid generated as a by-product of our proprietary salt-splitting electrochemical process was advanced from TRL 4 to TRL 6;

- A prototype $MgSO_4$ splitting cell was built and tested over a series of operational parameters advancing it from TRL 2 to TRL 4, proving it's viability and potential to greatly simplify the Planetary Accelerated Carbon Transition (ACT) platform overall;

- Process simulations conducted in collaboration with Stantec concluded that space constraints on offshore oil and gas platforms challenge the economics of gas turbine flue gas capture using Planetary's mild alkalinity; and

- Further investigation into the use of alkalinity enhancement via produced water from offshore oil & gas platforms is warranted given the potential for direct ocean air capture through this pathway.

Figure 3: Column testing for leaching (left) and $Mg(OH)_2$ precipitation testing with prototype electrochemical cell (right).

Performance Measures:

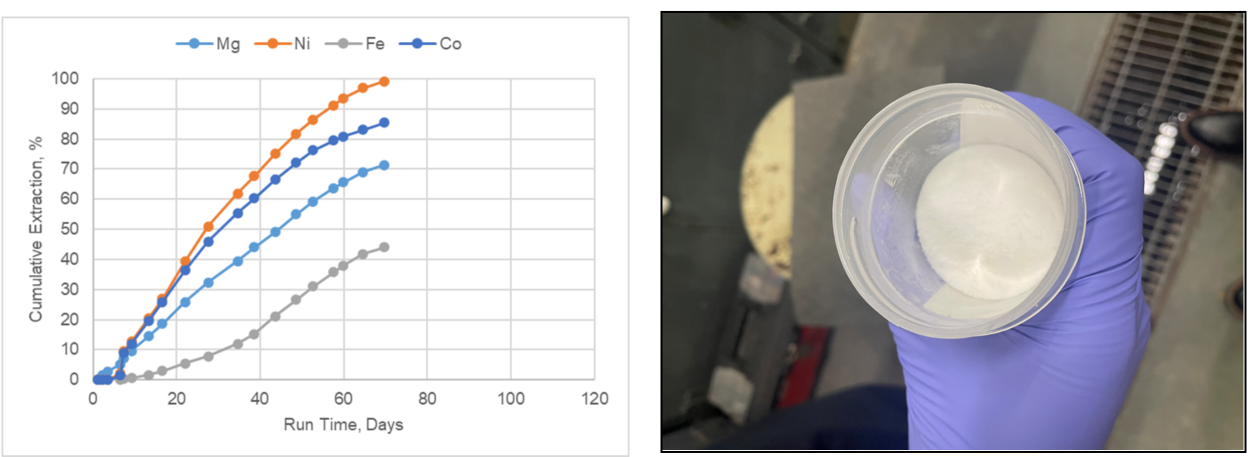
- Using raw tailings ore in an unoptimized heap leach simulation test, 78% extraction of total magnesium, 83% of Nickel, and 69% of cobalt contained in the original ore was achieved. These results not only outperform heap leaching industry standards of 60-70% recovery, they indicate we can achieve outstanding metallurgical performance, without any traditional energy-intensive metal extraction techniques or comminution (crushing or grinding).

- High extraction efficiency demonstrates a major strength of Planetary's solution by reducing the tonnage of tailings needed to be processed in order to produce desired quantities of $Mg(OH)_2$ and coproducts and therefore minimizing CAPEX, OPEX, power consumption, and the carbon footprint of the overall process.

- Preliminary $Mg(OH)_2$ precipitation tests using Planetary proprietary electrochemical cell produced 89% pure product which was independently verified by SGS.

- Preliminary experimentation has demonstrated that adding $Mg(OH)_2$ to natural seawater raises alkalinity and pH, and subsequently induces atmospheric CO_2 invasion in an approximate ratio of 0.9:1 moles $Mg(OH)_2$ added/ mole air CO_2 transferred to and stored in seawater. This provides direct experimental evidence that CDR into seawater is possible via the addition of $Mg(OH)_2$.

Figure 4 - Plot of metal extraction (left) from tailings and photo of final pure $Mg(OH)_2$ (right).



2.2 Main Outputs and Outcomes

The project ran from March 10th, 2021 to February 28th, 2022 with one major amendment to Task 3. The amendment de-scoped the Preliminary Front-end Engineering and Design (Pre-FEED) offshore integration study originally proposed based on process simulation results. This resulted in a $551,081.27 reduction in project spend.

Table 1: Project Deliverables & Outcomes

Task	Deliverables	Outcome
Acid Leaching Trials	1. Bench-scale prototype of acid leaching process 2. Report documenting mineral analysis results, experimental iterations, and final process flow.	Completed
Mineral Hydroxide Precipitation Trials	1. Bench-scale prototype of mineral hydroxide precipitation process. 2. Report documenting the analysis results, experimental iterations, and final process flow.	Completed
Preliminary Front-end Engineering and Design (Pre-FEED) Study for Offshore Implementation and process integration study including simulations	1. Report outlining process simulations results and operational limitations to implementing an offshore CCS system using hydroxide generated onshore and transported to an offshore oil and gas platform. 2. Preliminary Front End Engineering and Design (Pre-FEED) outlining costs (+/- 30-50%) and operational limitations to implementing an offshore CCS system using hydroxide generated onshore and transported to an offshore oil and gas platform.	Deliverable 1 completed, deliverable 2 de-scoped based on process simulation results.
Environmental and Regulatory Requirements Assessment	1. A report assessing regulatory requirements for conducting offshore CCS using ocean alkalinity enhancement	Completed
Final Project Report	1. Final Project Report and presentation	Completed

2.3 Benefits of the Project

This project met and exceeded many of the benefits described by the Offshore RD&D program, including:

- GHG Reduction Potential: Supporting Canada's commitment to lower GHG emissions under the Paris agreement by developing a highly efficient low-carbon method of alkalinity production for carbon dioxide removal (CDR), a pathway which has the potential to remove and store millions of tonnes of CO_2/year directly from the air in Canada and billions of tonnes globally;

- Advancing Technological Readiness Levels from TRL 2 to 6: Advanced the readiness of Planetary's Accelerated Carbon Transition platform components including the metallurgical process and electrochemical production of pure $Mg(OH)_2$.

- OAE Regulatory Review: Demonstrating the feasibility of direct carbon capture and sequestration through ocean alkalinity enhancement (OAE) as well as outlining the regulatory requirements for pursuing this offshore using produced water from oil and gas platforms;

- Direct & indirect employment: Contributed to the development of a strong and resilient workforce through the direct employment and growth of Planetary's team from 7 to 15 full-time employees. A further 5 full-time equivalent positions are estimated as an indirect benefit of this project.

- Intellectual Property: Four additional provisional patents were submitted as a result of the project growing Planetary's IP portfolio from 4 to 8 patents.

- Knowledge Products: Two technical papers describing the metallurgical and electrochemical processes developed during the project were accepted by Metallurgy & Materials Society for presentation at the 61st Annual Conference of Metallurgists.

- Highly Qualified Personnel (HQP) development: Indirectly supported ongoing collaborations with Dalhousie University contributing to the development of over a dozen HQPs in the ocean sector.

These results laid the groundwork for larger-scale ocean alkalinity enhancement trials and the production of a second-generation prototype electrochemical cell which is currently being tested.

2.4 Key Lessons

Several key lessons resulted from the completion of this project:

1. There are sufficient readily available mine tailings to scale Planetary's low-carbon alkalinity production to millions of tonnes per year in Quebec and Newfoundland alone,

displacing the entire global market for $Mg(OH)_2$ (~1.3 MT/yr[2]), with the potential for 10-20 MT CO_2 removal/yr from existing permitted outfalls.

2. The properties of $Mg(OH)_2$ that make it safe for OAE and increasingly popular in wastewater treatment plants, also make it challenging for offshore oil and gas platforms as it requires longer residence times and therefore more space to directly capture flue gas. Exploring the use of alkalinity to treat produced water from these platforms and capture CO_2 in the surface ocean around the platform requires further study.

3. Regulatory frameworks for the treatment of produced water provide a pathway to further explore alkalinity enhancement.

4. Carbon Dioxide Removal (CDR) via OAE onshore may be cheaper (<$150/tonne of CO_2 removed and stored) than CCS of flue gas from offshore oil and gas platforms.

5. Ocean-based CDR has tremendous potential for climate impact and reaching Canada's 2030 and 2050 emissions targets. As the country with the longest coastline, abundant clean electricity resources and readily available mineral feedstocks, OAE as a CDR pathway requires further attention and resources to close knowledge gaps and accelerate commercialization[3].

3. Next Steps

Since completion of this project in Q1 of 2022 the Planetary team has scaled up OAE testing to pool-sized experiments at the Dalhousie University Aquatron; won the XPRIZE Carbon Removal Milestone award; kicked-off studies with the University of Miami looking at the benefits of OAE for coral reefs, and continued metallurgical and electrochemical testing with SGS and DST.

The remainder of this year will see ocean trials of OAE with a wastewater treatment plant in Hayle, the UK as well as continued ocean studies with Dalhousie University and the University of Miami. Plans for a 100-tonne leaching circuit at a mine site in Quebec are being finalized to pilot the metallurgical process developed during this project. Next year will see the integration of the electrochemical cell with this full-scale leach for a fully integrated pilot facility for the production of low carbon alkalinity.

These activities will inform the engineering and design of a 1 kilotonne CO_2 removal plant with a target commissioning date of Q1 2024. This demonstration project will encompass the entire Accelerated Carbon Transition platform including mine site and coastal outfall locations as well as the logistics link between the two sites.

---

[2] https://www.globenewswire.com/en/news-release/2022/04/26/2429381/0/en/Magnesium-Hydroxide-Market-Projected-to-witness-a-growth-rate-of-5-8-over-the-forecast-period-of-2022-and-2030.html

[3] https://www2.oceanvisions.org/roadmaps/ocean-alkalinity-enhancement/

Prepared by: ___________________________ Reviewed by: ______________________

Jason Vallis, P.Eng, VP External — Mike Kelland, CEO