CAS-Climate: Synthwave: Open-Source Testbench for Marine Electrochemical Carbon Dioxide Removal Through Community Science

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Personnel:
PI: Kristina Collins , Space Science Institute, kvcollins@spacescience.org (NSF ID 000794939)
Alexander Ose , OpenAir Collective, alexander.ose@gmail.com (NSF ID 0000A0H9X)

1 Concept Outline Narrative

The proposed work will **accelerate innovation in electrochemical marine carbon dioxide removal (mCDR)** by providing the research community with a **standard test apparatus** for **rapid, reproducible early-stage studies** of electrode chemistries. The project scope comprises the continued **development, validation and documentation** of ***Synthwave***[1] (Fig. 1), a **low-cost, open-source hardware platform** for research in mCDR. At present, Synthwave is a conceptual design and prototype; further resources are needed to make it a viable and replicable research tool. The deliverable will be a **detailed design** including component selection and manufacture, assembly, calibration/validation procedures, and instructions on use.

Motivation: Most carbon dioxide removal (CDR) technologies are at a relatively low level of readiness; therefore, fundamental research is warranted. Per IPCC, direct air capture and other forms of carbon dioxide removal will need to be implemented in the coming decades at far greater scale and efficiency than presently available in order to restrict warming. CDR research is accelerating rapidly, but early stage studies generally rely on custom hardware, discouraging replication and slowing progress.

As a cheap, modular, replicable and extensible system, Synthwave is designed with the aim of standardizing and simplifying tests of marine CDR techniques in order to accelerate mCDR research. This need has been identified by the research community: In their 2022 report on marine CDR strategies[2], the National Academies of Science and Engineering note that electrochemical mCDR "[d]emonstration projects could be commissioned relatively quickly (∼24 months) and [...] would be most effective if they were underpinned by smaller-scale laboratory-based instrumentation [...]" (emphasis added). The report rated electrochemical mCDR as highly likely to be effective, but the knowledge base underlying these technologies as "low-medium," noting that, while electrochemistry is a well-developed field, further research is needed to enable these technologies to mature and scale.

Deliverables: This proposal will support validation and documentation of this open-source hardware, as well as additional experiments with multiple electrode chemistries. As validation, the chemistry described by Kim et al[3] will be fully demonstrated and documented with Synthwave. Midterm progress reports will be given at AGU and Open Hardware Summit, or at comparable meetings. The final deliverable of this work will be the preparation of a peer-reviewed open-access paper in *HardwareX* or a similar journal, enabling other researchers to replicate and modify the design as needed.

Intellectual merit: This work will accelerate electrochemical mCDR research by providing a standardized platform for desktop-scale experiments. This standardization will have three benefits:
(1) *Rapidity:* it will free up researchers to focus on experimentation rather than building customized test apparatuses;
(2) *Replicability:* it will make electrochemical mCDR methods easier to replicate, thereby improving rigor and collaboration;
(3) *Reciprocity:* it will make electrochemical mCDR methods presented in the scientific literature easier to compare to one another.
Open source hardware development has been shown to stimulate technological progress and standardization in, *e.g.*, 3D printing and embedded computing, and the need for standardized benchtop systems such as Synthwave has already been noted in contemporary literature of the field, as discussed above.

[1] https://doi.org/10.5281/zenodo.10403598, https://github.com/alexose/synthwave
[2] https://doi.org/10.17226/26278
[3] 2023, https://doi.org/10.1039/d2ee03804h

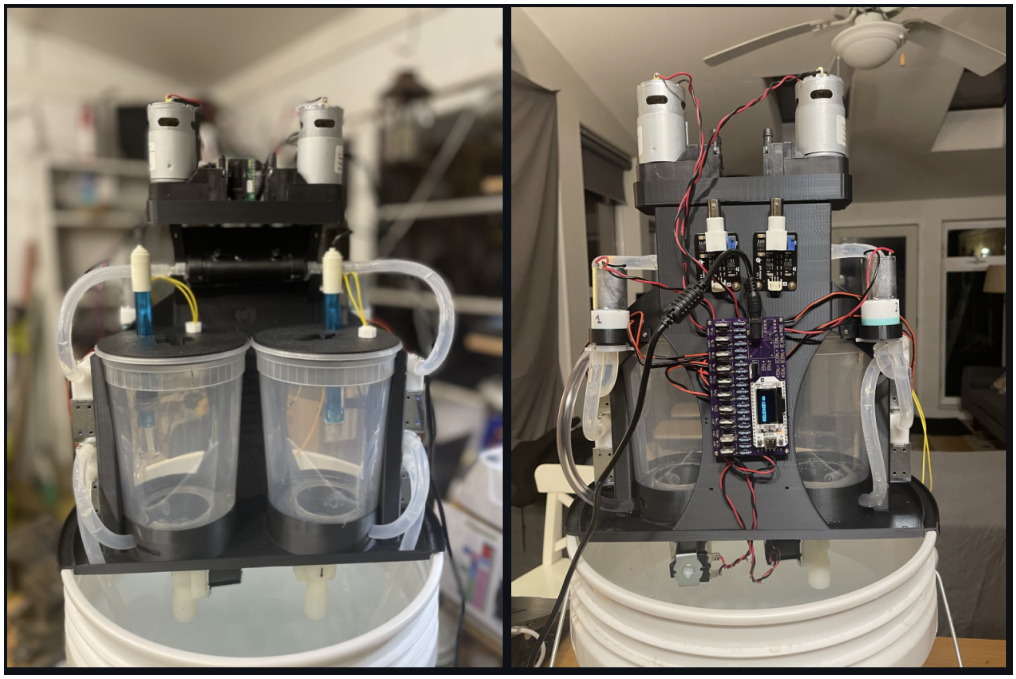

Figure 1: Current Synthwave prototype. Further validation, design, and documentation work are needed to make the system viable for research use.

Broader impacts: This proposal will help to seed a maturing open-source CDR sector, supporting informal STEM education as well as research. Upon completion, Synthwave will provide an exemplar for other open hardware projects by the volunteers of OpenAir[4], whose efforts represent community science (*i.e.*, citizen science motivated by community needs) at global scale. The proposal will support one early-career researcher, PI Collins. Dr. Collins has extensive experience in citizen science, including global crowdsourced radio science campaigns during solar eclipses from 2020-2024 and a central management role in the HamSCI Personal Space Weather Station network. She is involved in hackathons and makerspace programming, with four years' experience at think[box], the largest open-access innovation center and makerspace in the United States. As an active member of OpenAir and a postdoctoral researcher at the Space Science Institute, Dr. Collins will collaborate with Synthwave designer Alexander Ose and other citizen scientists to further develop Synthwave and bring it to the attention of the scientific community through a peer-reviewed publication.

2 Suitability

2.1 Suitability for CAS

This proposal is relevant to the CAS objectives of enhancing GHG sequestration (*viz.* improved approaches to carbon capture, including advanced materials; strategies to enhance sinks in aquatic systems) and research addressing synergistic topics (*viz.* education, capacity building, and broadening participation.)

2.2 Suitability for EAGER

1. **Early stage, exploratory work:** A prototype has been constructed and yields promising preliminary results (e.g., expected pH swings). To convert it from a standalone proof-of-concept to a fully featured design for laboratory equipment, it is necessary to (a) quantify the carbon dioxide captured by the system; (b) improve the flexibility of the system for multiple experiment types; and (c) build secondary prototypes to ensure that it can be effectively replicated based on the provided documentation.

2. **Potentially transformative research:** NSF's guide to transformative research notes that the category may encompass "key incremental or threshold advances [that] could put a discipline on a new scientific trajectory [...] or radically accelerate the rate of data collection." This proposal aims to shape the trajectory of electrochemical mCDR research by introducing a standardized tool to increase its efficacy and collaborative potential. Further, it incorporates novel disciplinary perspectives: Synthwave is an effort initiated and led by community scientists, and will strengthen ties between the research community and the open hardware movement.

[4] `https://openaircollective.com/`