U.S. Department of Energy
Advanced Research Projects Agency – Energy

Announcement of Teaming Partner List for an upcoming Funding Opportunity Announcement:

SEA CO2: Sensing Exports of Anthropogenic Carbon through Ocean Observation

The Advanced Research Projects Agency – Energy (ARPA–E) intends to issue a new Funding Opportunity Announcement (FOA) that seeks to enable the accurate, spatially scaled and temporally persistent measurement and validation of marine Carbon Dioxide Removal (mCDR) techniques (which includes "direct ocean capture" or "DOC"), in which CO_2 is captured from the atmosphere and surface oceans before sequestration at depth. While direct air capture (or "DAC") approaches can be validated easily through direct measurement of CO_2 collected, the same cannot be said for mCDR techniques, which may involve complex reactions over a very large surface or volume of the ocean over comparatively long periods of time, during which a fraction of the carbon drawn down may be re-emitted to the atmosphere. The envisioned program aims to vastly expand our ability to measure carbon flux parameters in the ocean, enabling comprehensive Measurement, Reporting and Validation (MRV) of mCDR and the creation of a data-driven, model-based marine carbon accounting framework. This program effort would consist of a primary technical area focused on new sensor development and a supporting technical area focused on the development of targeted regional-scale marine CDR models and accompanying carbon accounting processes. Scalable, cost-effective technologies that perform MRV for various mCDR approaches are a critical need in this highly active space where claims of efficacy and permanence cannot yet be rigorously substantiated. Such technologies could also ensure that the quantity and quality of removals are correctly valued in carbon markets and support any economic incentive to accelerate the adoption of mCDR to remove historic emissions. Validation of sequestered carbon will promote the commercialization of mCDR techniques that are most effective and energy efficient in carbon removal rather than those that are merely easiest to implement but may not actually be as effective or may be so energy intensive themselves that they result in poor overall net lifetime carbon removal.

Sensor development will be geared towards enabling indirect, volumetric, or area-based (when applicable) sensing of ocean carbon flux-related parameters outlined in Table 1, beyond depths at which surface remote sensing becomes inviable, to improve large-scale quantification of marine carbon fluxes through either biological or inorganic carbon pumps. ARPA-E would look to fund the development of sensors that can characterize these parameters at rates on the order of 150 km^3/h when scaled to a one-gigaton industry, while matching the accuracy and precision of existing state-of-the-art sensors. Technologies developed under this category must be deployable at sea on commercially available platforms (e.g., off-the-shelf, Equipment-as-a-Service, etc.) down to 1000 m repeatedly or continuously for a minimum of 12 months without servicing, battery replacement, or maintenance. There will be an emphasis on wave-based inferential techniques that do not require co-location of the sensor with the sample of water being evaluated. As such, sensing approaches of interest include, but are not limited to, active or passive acoustic, multispectral optical (including luminescence spectroscopy, etc.), laser-based, distributed optical fiber, and active or passive electromagnetic systems.

Table 1. Ocean carbon flux related parameters of interest

pH	Carboxylic Acid	Fugacity of CO_2	Biologically sequestered mineralized carbon
Carbonate	Total Alkalinity	Dissolved Organic Carbon*	Vertically transported biological Carbon
Bicarbonate	Fugacity of O_2	Particulate Organic Carbon*	Sediment organic carbon*
*Emphasis on recalcitrant forms			

Model development would target regional-scale, hypothetical but realistic near-future mCDR vignettes within the United States' Exclusive Economic Zone (EEZ). Models will be developed to demonstrate viability using historical data, before being used as benchmark mCDR models that can be iterated, improved, and validated with future data collected via new sensor systems. The vignettes may include mCDR approaches described in the National Academy of Sciences report on Ocean CDR[1], or other mCDR approaches not described but that could be reasoned as techno-economically feasible given a drawdown cost of approximately $100/ton CO_2e at megaton to gigaton scale. ARPA-E would plan to fund one or more teams to develop these models. Models are expected to combine physical and biogeochemical ocean modeling, including comprehensive flux modeling of relevant parameters described in Table 1. Developed models would need to achieve a Root Mean Square Error (RMSE) value of no more than 0.1 over time and a temporal Anomaly Correlation Coefficient (ACC) of at least 0.7 when benchmarked against hold-out historical carbon parameter data, before estimates of mCDR effectiveness could be made. Model outputs will need to be developed in coordination with a carbon registry to create a data-based mCDR accounting framework that enables the assignment of credit quality and hence financial value to modeled mCDR events. Selected team(s) will be required to coordinate with a carbon registry to outline an MRV framework that can later be used as a foundation by mCDR project developers to author full protocols, which are peer-reviewed, market-ready methodologies that provide the basis for generating carbon credits. Such an assignment would require robust estimation of the quantity of CO_2 drawn down beyond a given temporal threshold (i.e., 10-year or 100-year sequestration) and an indication of the probability that a given quantity of CO_2 would remain out of the atmosphere or surface oceans for that duration.

Anticipated teams may consist of personnel with expertise and affiliations in the following areas:

Sensing technical area (primary):

- Sensor design and sensing methods for the ocean parameters listed in Table 1.
- Oceanographic instrumentation, marine biogeochemical and ecological sciences

Modeling technical area (secondary):

- Regional climate, biophysical process, and earth system modeling
- Carbon markets and registries

[1] https://nap.nationalacademies.org/catalog/26278/a-research-strategy-for-ocean-based-carbon-dioxide-removal-and-sequestration

In the first half of the program, sensor teams would develop core technologies that may enable new methods of sensing the ocean chemical parameters described in Table 1 in a volumetric or area-based manner. Initial work would culminate with a demonstration of their concept in a controlled underwater setting. The second half of the program would be focused on building the sensor into a prototype that could be fielded in increasingly realistic at-sea scenarios, culminating in an ocean test aboard an off-the-shelf instrumentation platform within a representative environment where an appropriate mCDR activity may take place.

The modeling team(s) would spend the first half of the program developing mCDR models in appropriate regional vignettes. Model performance would be evaluated using historical ambient data or pilot mCDR data, if available. The second half of the program would involve adapting these models for compatibility with data from the sensors under development and simulating the potential increase in MRV effectiveness that could be brought about using these sensors if they were matured and deployed at scale in a regional mCDR scenario. Models would also be used to develop an mCDR accounting framework using output data, evaluate potential improvements to statistical certainty, and assess preliminary implications for the techno-economic validity of the MRV approach. As such, the program would be designed such that modeling and sensor teams are required to coordinate and share data to enable this collaboration.

ARPA–E held a workshop on these topics on June 15-16, 2022. Information from this workshop can be found at the event webpage (https://arpa-e.energy.gov/events/marine-carbon-sensing-workshop). The component information remains consistent, but the scope and structure of the program have been updated from that presented in the workshop slides.

As a general matter, ARPA-E strongly encourages outstanding scientists and engineers from different organizations, scientific disciplines, and technology sectors to form project teams. Interdisciplinary and cross-sector collaboration spanning organizational boundaries enables and accelerates the achievement of scientific and technological outcomes that were previously viewed as extremely difficult, if not impossible.

The Teaming Partner List is being compiled to facilitate the formation of new project teams. The Teaming Partner List will be available on ARPA-E eXCHANGE (http://arpa-e-foa.energy.gov), ARPA-E's online application portal, starting November 18, 2022. The Teaming Partner List will be updated periodically, until the close of the Full Application period, to reflect new Teaming Partners who have provided their information.

Any organization that would like to be included on this list should complete all required fields in the following link: https://arpa-e-foa.energy.gov/Applicantprofile.aspx. Required information includes: Organization Name, Contact Name, Contact Address, Contact Email, Contact Phone, Organization Type, Area of Technical Expertise, and Brief Description of Capabilities.

By submitting a response to this Notice, you consent to the publication of the above-referenced information. **By facilitating this Teaming Partner List, ARPA-E does not endorse or otherwise evaluate the qualifications of the entities that self-identify themselves for placement on the Teaming Partner List.** ARPA-E will not pay for the provision of any information, nor will it compensate any respondents for the development of such information. Responses submitted to other email addresses or by other means

will not be considered.

This Notice does not constitute a FOA. No FOA exists at this time. Applicants must refer to the final FOA, expected to be issued in February 2023, for instructions on submitting an application and for the terms and conditions of funding.