FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

ADVANCED RESEARCH PROJECTS AGENCY – ENERGY (ARPA-E)
U.S. DEPARTMENT OF ENERGY

SENSING EXPORTS OF ANTHROPOGENIC CARBON THROUGH OCEAN OBSERVATION (SEA CO2)

Announcement Type: Initial Announcement
Funding Opportunity No. DE-FOA-0002989
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Funding Opportunity Announcement (FOA) Issue Date:	February 16, 2023
First Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, March 24, 2023
Submission Deadline for Concept Papers:	9:30 AM ET, April 4, 2023
Second Deadline for Questions to ARPA-E-CO@hq.doe.gov:	5 PM ET, TBD
Submission Deadline for Full Applications:	9:30 AM ET, TBD
Submission Deadline for Replies to Reviewer Comments:	5 PM ET, TBD
Expected Date for Selection Notifications:	September 2023
Total Amount to Be Awarded	Approximately $45 million, subject to the availability of appropriated funds.
Anticipated Awards	ARPA-E may issue one, multiple, or no awards under this FOA. Awards may vary between $500,000 and $10 million.

- For eligibility criteria, see Section III.A of the FOA.
- For cost share requirements under this FOA, see Section III.B of the FOA.
- To apply to this FOA, Applicants must register with and submit application materials through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). For detailed guidance on using ARPA-E eXCHANGE, see Section IV.H.1 of the FOA.
- Applicants are responsible for meeting each submission deadline. Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.
- For detailed guidance on compliance and responsiveness criteria, see Sections III.C.1 through III.C.4 of the FOA.

Questions about this FOA? Check the Frequently Asked Questions available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, email ARPA-E-CO@hq.doe.gov (with FOA name and number in subject line); see FOA Sec. VII.A. Problems with ARPA-E eXCHANGE? Email ExchangeHelp@hq.doe.gov (with FOA name and number in subject line).

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REQUIRED DOCUMENTS CHECKLIST

For an overview of the application process, see Section IV.A of the FOA.

For guidance regarding requisite application forms, see Section IV.B of the FOA.

For guidance regarding the content and form of Concept Papers, Full Applications, and Replies to Reviewer Comments, see Sections IV.C, IV.D, and IV.E of the FOA.

SUBMISSION	COMPONENTS	OPTIONAL/ MANDATORY	FOA SECTION	DEADLINE
Concept Paper	• Each Applicant must submit a Concept Paper in Adobe PDF format by the stated deadline. The following sections of the Concept Paper must not exceed 4 pages in length including graphics, figures, and/or tables, and must include the following: ○ Concept Summary ○ Innovation and Impact ○ Proposed Work ○ Team Organization and Capabilities • The Concept Paper shall also include two Appendices, each not to exceed 1 page, for a total maximum of 6 pages: ○ mCDR Approaches ○ Technical Area-Specific Content	Mandatory	IV.C	9:30 AM ET, April 4, 2023
Full Application	[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]	Mandatory	IV.D	9:30 AM ET, TBD
Reply to Reviewer Comments	[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]	Optional	IV.E	5 PM ET, TBD

I. FUNDING OPPORTUNITY DESCRIPTION

A. AGENCY OVERVIEW

The Advanced Research Projects Agency – Energy (ARPA-E), an organization within the Department of Energy (DOE), is chartered by Congress in the America COMPETES Act of 2007 (P.L. 110-69), as amended by the America COMPETES Reauthorization Act of 2010 (P.L. 111-358), as further amended by the Energy Act of 2020 (P.L. 116-260):

"(A) to enhance the economic and energy security of the United States through the development of energy technologies that—
(i) reduce imports of energy from foreign sources;
(ii) reduce energy-related emissions, including greenhouse gases;
(iii) improve the energy efficiency of all economic sectors;
(iv) provide transformative solutions to improve the management, clean-up, and disposal of radioactive waste and spent nuclear fuel; and
(v) improve the resilience, reliability, and security of infrastructure to produce, deliver, and store energy; and
(B) to ensure that the United States maintains a technological lead in developing and deploying advanced energy technologies."

ARPA-E issues this Funding Opportunity Announcement (FOA) under its authorizing statute codified at 42 U.S.C. § 16538. The FOA and any cooperative agreements or grants made under this FOA are subject to 2 C.F.R. Part 200 as supplemented by 2 C.F.R. Part 910.

ARPA-E funds research on, and the development of, transformative science and technology solutions to address the energy and environmental missions of the Department. The agency focuses on technologies that can be meaningfully advanced with a modest investment over a defined period of time in order to catalyze the translation from scientific discovery to early-stage technology. For the latest news and information about ARPA-E, its programs and the research projects currently supported, see: http://arpa-e.energy.gov/.

ARPA-E funds transformational research. Existing energy technologies generally progress on established "learning curves" where refinements to a technology and the economies of scale that accrue as manufacturing and distribution develop drive improvements to the cost/performance metric in a gradual fashion. This continual improvement of a technology is important to its increased commercial deployment and is appropriately the focus of the private sector or the applied technology offices within DOE. By contrast, ARPA-E supports transformative research that has the potential to create fundamentally new learning curves. ARPA-E technology projects typically start with cost/performance estimates well above the level of an incumbent technology. Given the high risk inherent in these projects, many will fail to progress, but some may succeed in generating a new learning curve with a projected cost/performance metric that is significantly better than that of the incumbent technology.

ARPA-E funds technology with the potential to be disruptive in the marketplace. The mere creation of a new learning curve does not ensure market penetration. Rather, the ultimate value of a technology is determined by the marketplace, and impactful technologies ultimately become disruptive – that is, they are widely adopted and displace existing technologies from the marketplace or create entirely new markets. ARPA-E understands that definitive proof of market disruption takes time, particularly for energy technologies. Therefore, ARPA-E funds the development of technologies that, if technically successful, have clear disruptive potential, e.g., by demonstrating capability for manufacturing at competitive cost and deployment at scale.

ARPA-E funds applied research and development. The Office of Management and Budget defines "applied research" as an "original investigation undertaken in order to acquire new knowledge…directed primarily towards a specific practical aim or objective" and defines "experimental development" as "creative and systematic work, drawing on knowledge gained from research and practical experience, which is directed at producing new products or processes or improving existing products or processes."[1] Applicants interested in receiving financial assistance for basic research (defined by the Office of Management and Budget as "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts")[2] should contact the DOE's Office of Science (http://science.energy.gov/). Office of Science national scientific user facilities (http://science.energy.gov/user-facilities/) are open to all researchers, including ARPA-E Applicants and awardees. These facilities provide advanced tools of modern science including accelerators, colliders, supercomputers, light sources and neutron sources, as well as facilities for studying the nanoworld, the environment, and the atmosphere. Projects focused on early-stage R&D for the improvement of technology along defined roadmaps may be more appropriate for support through the DOE applied energy offices including: the Office of Energy Efficiency and Renewable Energy (http://www.eere.energy.gov/), the Office of Fossil Energy and Carbon Management (https://www.energy.gov/fecm/office-fossil-energy-and-carbon-management), the Office of Nuclear Energy (http://www.energy.gov/ne/office-nuclear-energy), and the Office of Electricity (https://www.energy.gov/oe/office-electricity).

B. PROGRAM OVERVIEW

Marine carbon dioxide removal (mCDR) will be an essential component of a future negative emissions industry, which alongside emissions reduction is necessary to restrict climate warming to less than 2°C and avoid global, irreversible, and catastrophic changes caused by this temperature rise. This program seeks to accelerate the development of the mCDR industry through the development of scalable Measurement, Reporting and Validation (MRV) technologies. MRV must be of sufficient quality to quantify carbon drawdown magnitudes, the degree of permanence, and bound the uncertainties associated with these parameters so that

[1] OMB Circular A-11 (https://www.whitehouse.gov/wp-content/uploads/2018/06/a11_web_toc.pdf), Section 84, pg. 3.

[2] OMB Circular A-11 (https://www.whitehouse.gov/wp-content/uploads/2018/06/a11_web_toc.pdf), Section 84, pg. 3.

carbon markets can ascertain credit quality and financial institutions can make informed decisions regarding investment risk. To achieve these goals, a paradigm shift in chemical oceanographic data collection is required, moving from a single-point collection paradigm towards a goal of persistent sensing of parameters across large areas and/or volumes.

ARPA-E considers the advancements outlined in **Table 1** below to be those that would most rapidly enable effective MRV and the robust establishment of financial value for the mCDR industry.

	Technology Development Objectives
1	Sensing approaches able to quantify relevant oceanographic properties, including (but not limited to) volumetrically or area-wise, for seafloor or other relevant applications.
2	Large spatial scale, volumetric, or area-survey sensors capable of precision and accuracy (equivalent to bias and variance), comparable to today's single-point state-of-the-art sensing approaches.
3	Sensors whose size, weight, and power requirements enable utilization on existing ocean data collection platforms.
4	Sensors capable of deployment periods exceeding one year without a reliance on physical human interaction.
5	Regionally focused models suitable for Observation System Simulation Experiments (OSSEs) that demonstrate root-mean-square errors (RMSE) and anomaly correlation coefficients (ACC) at least comparable to general state-of-the-art ocean physical and biogeochemical models available today.

Table 1. ARPA-E objectives for technological advancement in MRV for mCDR.

ARPA-E anticipates two Technical Areas (TAs) under this FOA: marine carbon sensors and ocean carbon flux models. Teams may apply to one or both TAs.

Technical Area 1 (TA1) will address the development of new sensors, emphasizing high-endurance spatial coverage through approaches such as (but not limited to) radiated energy-based (i.e., optical, acoustic, electromagnetic) oceanographic **sensor technologies** that enable large-scale volumetric or swath quantification of mCDR-relevant ocean chemical parameters. Sensors must operate beyond depths sensed by satellite systems, at spatial and temporal scales sufficient to transform the fundamental understanding of the ocean carbon cycle, quantify mCDR efficacy, and to reduce or eliminate under-sampling concerns that limit carbon credit quality.

mCDR-relevant ocean chemical parameters of interest to ARPA-E are listed in **Table 2**. Submissions for sensor technology may focus on one or more of these parameters, but integration with other mCDR-relevant chemical sensors or essential ancillary data collection systems must be feasible within the constraints imposed by the program metrics. The major milestone for TA1 teams will be a sensor proof-of-concept demonstration in a laboratory setting, and a validation of sensor performance against SOA instrumentation at sea at the end of the project.

Technical Area 2 (TA2) will focus on the development of regional-scale, ocean **carbon flux models** that integrate and estimate the combined major carbon cycles (i.e., physical, inorganic chemical, micro and macro-biological) likely to be impacted by one or more selected mCDR approaches for the selected region. Regional models and accompanying hypothetical or planned mCDR approaches should be sized in the 100's of megatons to one gigaton range and constitute techno-economically realistic mCDR scenarios that may become reality within a twenty-year timeframe.

Models will be developed under this program to achieve state-of-the-art performance levels for bias and variance for carbon parameters and will form the basis for a carbon accounting framework. The final program steps for TA2 teams will be the creation of a model-based, data-driven approach to carbon accounting and a framework for generating protocols that will be utilized by mCDR carbon registries in certifying credits and assigning quality ratings. Limited sensor development that seeks to mitigate specific sources of uncertainty in models is also of interest, and may require close collaboration between TA1 and TA2 teams.

Table 2. Ocean carbon flux parameters of interest to this program, along with representative state-of-the-art uncertainties for each parameter.

Parameter		SOA Uncertainty[3]
pH	Ion Sensitive Field Effect Transistor (ISFET)	± 0.001[4]
	Acoustic Decay	Not yet established[5]
Total DIC	Acidification and extraction	± 1 µmol/kg[6]
Total Alkalinity	Titration	±2–4 µmol/kg[4]
	Active ISFET	Not yet established[7]
Fugacity	CO_2	±1 µatm[4]
	O_2	± 0.3 mg/L[4]
Dissolved Organic Carbon		±4 µg/L[8]
Particulate Organic Carbon	Mass loss	±0.1 nmol/m^3 [9]
	Optical counting	Not yet established[10]
Particulate Inorganic Carbon[11]		±0.1 mmol/m^3
Sediment carbon %		±0.1 mg/m^2 [12]
Biologically Ingested (i.e., macro-organism vertical transport)		Not yet established[13]

[3] For the purposes of this table "SOA uncertainty" is defined as the reproducibility around a measured value by a state-of-the-art, calibrated lab-based sensor.

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[6](a) Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.) 2007. *Guide to best practices for ocean CO_2 measurements*. PICES Special Publication 3, 191 pp. (b) Wang, Zhaohui & Sonnichsen, Frederick & Bradley, Albert & Guay, Katherine & Lanagan, Thomas & Chu, Sophie & Hammar, Terence & Camilli, Richard. (2015). In Situ Sensor Technology for Simultaneous Spectrophotometric Measurements of Seawater Total Dissolved Inorganic Carbon and pH. Environmental science & technology. 10.1021/es504893n. (c) Johnson, K M. (1992). "Single-operator multiparameter metabolic analyzer (SOMMA) for total carbon dioxide (C{sub T}) with coulometric detection. Operator`s manual". United States. https://doi.org/10.2172/10194787. https://www.osti.gov/servlets/purl/10194787.

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[9] (a) Baker, C. A., Henson, S. A., Cavan, E. L., Giering, S. L. C., Yool, A., Gehlen, M., Belcher, A., Riley, J. S., Smith, H. E. K., and Sanders, R. (2017), Slow-sinking particulate organic carbon in the Atlantic Ocean: Magnitude, flux, and potential controls, Global Biogeochem. Cycles, 31, 1051–1065, doi:10.1002/2017GB005638; (b) Riley, J. S., Sanders, R., Marsay, C., Le Moigne, F. A. C., Achterberg, E. P., and Poulton, A. J. (2012), The relative contribution of fast and slow sinking particles to ocean carbon export, Global Biogeochem. Cycles, 26, GB1026, doi:10.1029/2011GB004085; (c) Alldredge, A. (1998). The carbon, nitrogen and mass content of marine snow as a function of aggregate size, Deep Sea Res., Part I, 45(4–5), 529–541.

[10] Giering SLC, Cavan EL, Basedow SL, Briggs N, Burd AB, Darroch LJ, Guidi L, Irisson J-O, Iversen MH, Kiko R, Lindsay D, Marcolin CR, McDonnell AMP, Möller KO, Passow U, Thomalla S, Trull TW and Waite AM (2020) Sinking Organic Particles in the Ocean—Flux Estimates From in situ Optical Devices. Front. Mar. Sci. 6:834. doi: 10.3389/fmars.2019.00834https://doi.org/10.3389/fmars.2019.00834

[11] Mitchell, C., Hu, C., Bowler, B., Drapeau, D., & Balch, W. M. (2017). Estimating particulate inorganic carbon concentrations of the global ocean from ocean color measurements using a reflectance difference approach. Journal of Geophysical Research: Oceans, 122, 8707–8720. https://doi.org/10.1002/2017JC013146

[12] (a) House, K.Z.; Schrag, D.P.; Harvey, C.F.; Lackner, K.S. (2006). Permanent carbon dioxide storage in deep-sea sediments. PNAS 103 (33) 12291-12295; (b) Wai Ting Tung, J.; Tanner, P.A. (2003). Instrumental determination of organic carbon in marine sediments. Marine Chemistry 80(2-3) 161-170; (c) Atwood. T.B.; Witt, A.; Mayorga, J.; Hammill, E.; Sala, E. (2020). Global Patterns in Marine Sediment Carbon Stocks. Front. Mar. Sci. 7:165

[13] (a) Archibald, K. M., Siegel, D. A., & Doney, S. C. (2019). Modeling the impact of zooplankton diel vertical migration on the carbon export flux of the biological pump. Global Biogeochemical Cycles, 33(2), 181-199; (b) Pinti, J., DeVries, T., Norin, T., Serra-Pompei, C., Proud, R., Siegel, D. A., Kiorboe, T., Petrik, C. M., Brierley, A. S. & Visser, A. W. (2022). The global importance of metazoans to the biological carbon pump. BioRxiv, 2021-03; (c) Herndandez-Leon, S., Franchy, G., Moyano, M., Menéndez, I., Schmoker, C., & Putzeys, S. (2010). Carbon sequestration and zooplankton lunar cycles: Could we be missing a major component of the biological pump?. Limnology and Oceanography, 55(6), 2503-2512.

The program is designed so that sensor and model development proceed independently during the first Phase. Closer collaboration between the two TAs is anticipated to begin in Phase 2, after sensor capability and feasibility demonstrations take place and model performance has been established. TA1 and TA2 teams may propose together or enter collaborative partnerships at the beginning of Phase 2. A high-level diagram of the program progression is shown below.

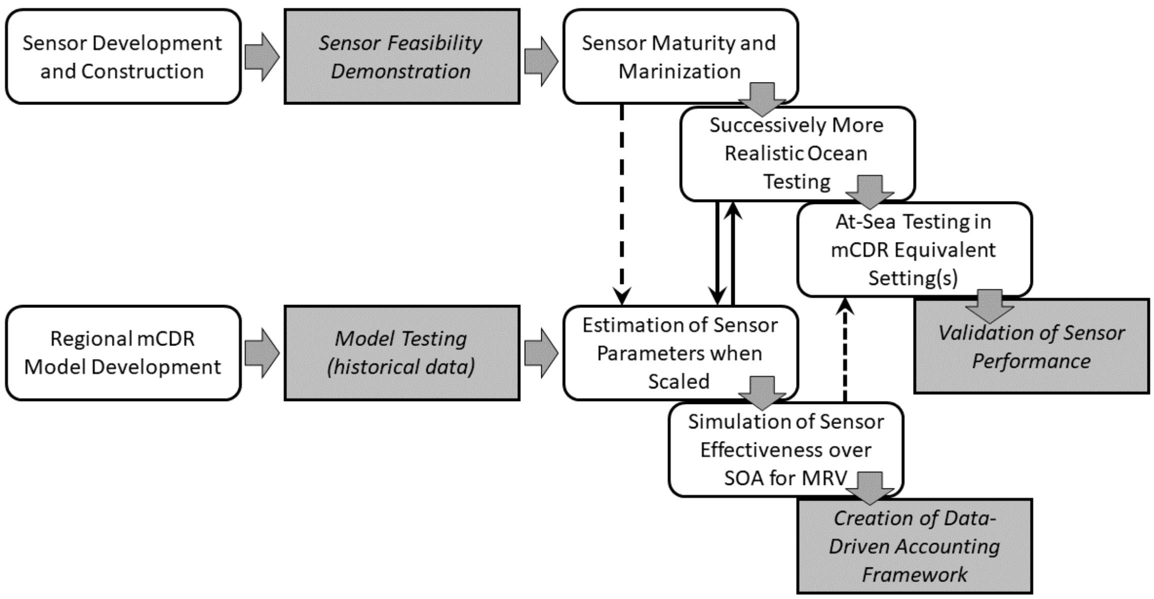

Figure 1. SEA CO2 program design. Dashed arrows represent anticipated collaborative information transfer between TAs (coarse – sensor capability projections, fine – optimized sampling approaches). Solid arrows represent possible sensor-based mitigation of specific model uncertainties. Grey boxes represent milestones, occurring at ~18 months and project end. Acronyms: SOA – State of the Art; TEA – Techno-Economic Analysis.

The feasibility of a team's sensor technology will first be demonstrated in controlled seawater conditions within a laboratory setting. Given that mature MRV processes are likely to rely largely on validated model outputs, teams with successful sensor demonstrations will be encouraged to coordinate with a TA2 team in the second half of the program. This integration will adapt the TA2 team model to estimate sensor capabilities when scaled and to conduct a simulation of sensor effectiveness over State of the Art (SOA) technology. These Observing System Simulation Experiments (OSSEs) will demonstrate the value of new MRV technology and will provide a platform for the quantification of uncertainties. Moving forward, these model outputs will inform at-sea experimental design and evaluation protocols to maximize the sampling effectiveness of future MRV approaches.

More detail on the program structure is provided in Section I.C. Program Objectives.

1. PROGRAM CONTEXT

The Intergovernmental Panel on Climate Change (IPCC) has indicated that we must limit global warming to below 2°C by 2100 to avoid significant, irreversible, and negative climate change impacts to our society[14]. Achieving this goal can only occur through a combination of net-zero, and emissions abatement and removal technologies[15]. The more aspirational goal of limiting global warming to 1.5°C by 2070 requires even more decarbonization, both abatement and negative emissions technologies, at a much-accelerated rate. The United Nations Environment Program Emissions Gap Report 2017[16] estimated the impact of hard-to-decarbonize industries (steel, cement, air travel, shipping, etc.), and indicated that negative emissions technologies are required to offset the contribution of these, as illustrated in Figure 2. According to the National Academies report on "Negative Emission Technologies and Reliable Sequestration[17]", at least 20 Gt/yr. of CO_2 must be removed from the atmosphere by 2100 to achieve global climate goals.

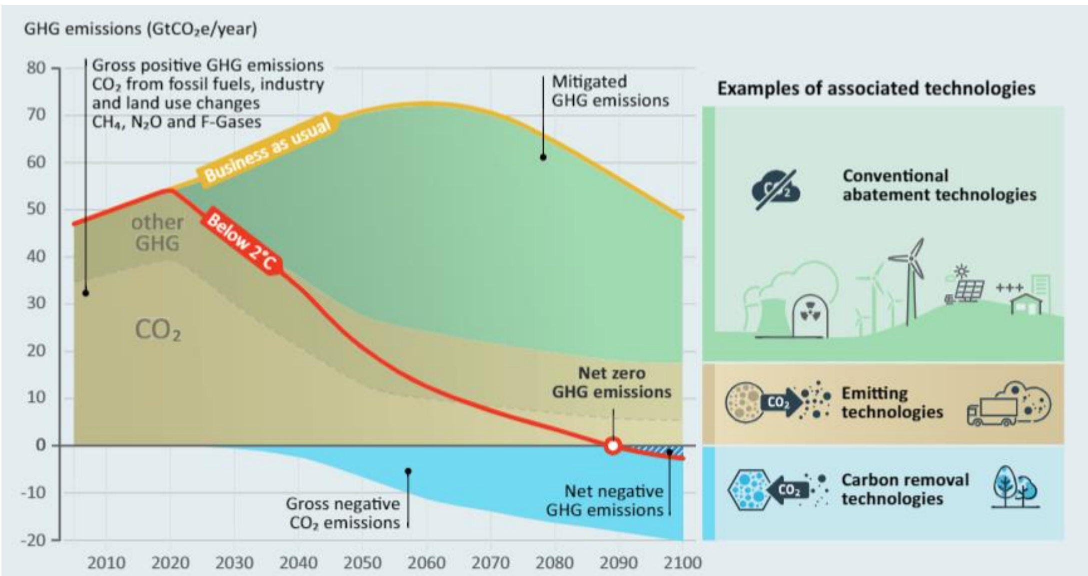

Figure 2. Conventional emissions reductions paired to negative emissions technologies modeled with at least a 66% chance of keeping warming below 2 degrees Celsius relative to pre-industrial levels[4].

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[14] IPCC, 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.

[15] Rogelj, J., D. Shindell, K. Jiang, S. Fifita, P. Forster, V. Ginzburg, C. Handa, H. Kheshgi, S. Kobayashi, E. Kriegler, L. Mundaca, R. Séférian, and M.V.Vilariño, 2018: Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. 2019

[16] UNEP (2017). The Emissions Gap Report 2017. United Nations Environment Programme (UNEP), Nairobi 2017

[17] Board, O. S., & National Academies of Sciences, Engineering, and Medicine. (2019). Negative emissions technologies and reliable sequestration: A research agenda.

2. THE ROLE OF THE GLOBAL CARBON CYCLE IN CDR

While most existing and nascent CDR strategies are land-based, terrestrial sequestration has the potential to conflict with human needs such as housing and agriculture, leading to adverse ecological and social impacts. Additionally, land-based strategies may require more investment due to comparatively limited land resources[18], while potentially becoming less effective as temperatures rise[19]. Given that land comprises 29% of the Earth's surface area while the ocean occupies 71%, adoption of mCDR is inevitable for scalable and affordable negative emission solutions.

The natural marine carbon cycle already uptakes 2.5 gigatons of CO_2 annually and contains 38,000 gigatons of carbon on a near permanent basis[20]. Considering the scale of this natural process, mCDR technologies can bring about long-term sequestration, are scalable to gigaton levels, and could reduce energy and land use requirements of CDR. The IPCC and National Academies forecast that mCDR technology is essential to address the negative emissions requirements of the 1.5-2 °C warming goals.

mCDR includes a range of methods that broadly focus on enhancing natural carbon cycling through electrochemical, geochemical, or biological processes. These technologies are still in early stages of development but the community, understanding, and investment are growing rapidly. More detail on mCDR technologies is available in the National Academies report on *A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration*[21].

Most mCDR methods currently under development offer a potentially viable mechanism by which at-sea, gigaton-scale CO_2 sequestration may be enabled. However, the process to assign economic value to this drawdown is not well defined as the verifiable quantity (tons of CO_2) and quality (permanence and uncertainty) of credits cannot be ascertained using current sensing and modelling tools. Large-scale carbon flux sensing and modeling is currently based on satellite and/or aerial remote sensing, which makes it impossible to obtain measurements once carbon is transported below optical depths. These remote measurements can be augmented through point measurements on surface vehicles, underwater vehicles, drifters, or buoys, but these point measurements cannot scale to the spatial or temporal scope needed for comprehensive evaluation. As mCDR scales, persistent detailed sensing at a regional scale will be required until validated mCDR models can be developed to predict the success of mCDR approaches.

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[18] Dooley, K., & Kartha, S. (2018). Land-based negative emissions: risks for climate mitigation and impacts on sustainable development. International Environmental Agreements: Politics, Law and Economics, 18(1), 79-98.

[19] Wang, S., Zhang, Y., Ju, W., Chen, J. M., Ciais, P., Cescatti, A., ... & Peñuelas, J. (2020). Recent global decline of CO2 fertilization effects on vegetation photosynthesis. Science, 370(6522), 1295-1300.

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[21] NASEM (2022). National Academies of Sciences, Engineering, and Medicine. 2022. *A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26278.

Consequently, while the technical feasibility and scalability of some mCDR approaches is known, their economic feasibility cannot yet be compared when including MRV costs. Developing scalable sensing technology that enables viable MRV for mCDR will allow the carbon market to quantitatively evaluate the feasibility and efficacy of different approaches enabling competition and performance-based regulation. This quantitative evaluation will support the alignment of market forces with the most efficient negative carbon systems to accelerate the adoption of the most economical, highest quality mCDR methods.

With the economic feasibility of mCDR techniques at regional scales currently unknown, ARPA-E remains agnostic to the mCDR techniques for which MRV sensing and modeling technologies will be developed. As such, this program seeks to develop sensors and models that could be applied to one or more mCDR approaches. **Table 1** lists the parameters ARPA-E considers most important for enabling the sensing of ocean carbon fluxes, and thus defines the scope of sensing parameters associated with this program.

3. The Interdependency of MRV Sensors and Models

MRV of mCDR approaches is critical to the growth of the maritime negative carbon industry. Estimation of the following three parameters is essential to understand the effectiveness of mCDR approaches and for the monetization of CO_2 drawn down from the atmosphere and surface oceans:

- The additional quantity of CO_2 that has been drawn down through a particular mCDR approach, over and above ambient natural processes and variability. While potentially distributed over a large volume, this additional quantity may be miniscule per unit area (i.e., < 1% of natural levels) and standard error may overlap significantly with those of natural processes, presenting a significant signal-to-noise challenge that may only be mitigated through a data-assimilated, probabilistic model.
- The duration over which CO_2 is removed from the atmosphere and surface oceans via mCDR. Such a measurement may require persistent sensing approaches that can operate to depths of at least 1000 m for open ocean mCDR methods.
- The probability or uncertainty associated with the above two parameters, as required to assign financial value.

Quantifying these variables allows the assignment of insurable value to mCDR technologies, quantifies potential and real return on investments in a carbon market, and addresses many of the current "mobilization challenges" for rapid growth of the mCDR industry[22].

ARPA-E contends that any economically feasible and scaled MRV approach would consist of credit values and quantities being assigned through the utilization of parameter estimates (i.e., those listed in **Table 2**) and estimates of their uncertainties, made through a largely model-

[22] TSVCM (2021). Task Force on Scaling Voluntary Carbon Markets, Final Report 2021 accessed at: TSVCM_Report.pdf (iif.com)

based approach. The effectiveness of the model will be constrained by the quantity and quality of observational data used to both train and validate it, explicitly linking model performance with sensor types and capabilities. The way value is assigned, and investments are made in the weather derivatives market is an example of this paradigm: the modeling of a partly stochastic system, for which the uncertainties are well characterized, is factored into financial models. In addition to sensor development, ARPA-E thus considers model development and design for utility in a carbon market to be a critical component of maturing MRV capabilities. Once an MRV industry has scaled, relatively few observational datasets would be used to continuously validate models and refine them to reflect how external environmental factors may change mCDR efficacy over time.

The bias and variance of model outputs will be dependent on the data used for their construction and continued validation. Consequently, the inclusion of unprecedentedly large quantities of data that come from wide-area or volumetric undersea sensing approaches will enable the application of modern data-based model training techniques to the development of mCDR models that cannot rely on satellite-derived data sets alone. It is hoped that the development of such sensors will enable step changes in model performance- estimating both the carbon drawdown quantity and permanence, and the uncertainties that drive the assignment of quality to carbon credits.

4. STATE-OF-THE-ART: MARINE CARBON SENSORS

The National Academies framework for ocean-based CDR states "(t)he present state of knowledge on many ocean CDR approaches is inadequate, based in many cases only on laboratory-scale experiments, conceptual theory, and/or numerical models"[9]. Real-world data at both the spatial and temporal resolutions necessary for a total accounting of the ocean carbon cycle is a requirement for the attribution of CO_2 capture and sequestration to an individual mCDR project and thus to the enabling of a mCDR industry. Compounding this lack of real-world data is the annual-to-decadal cyclic variability of many of the natural processes involved in the marine carbon cycle, making a holistic assessment of baseline carbon cycle variables difficult[23]. In general, there is a need for high quality and low-cost sensors to "close the loop" on the primary carbon flux processes related to an individual mCDR operation. These sensors are also needed to monitor secondary processes to establish a well-defined baseline against which the additionality – defined as artificial addition or subtraction of material from naturally occurring quantities that would not have occurred without the artificial process – of the operation may be quantified. Such MRV capability will represent a paradigm shift in oceanographic sensing.

[23] Gonsior, M., Powers, L., Lahm, M., and Mcallister, S. L., New Perspectives on the Marine Carbon Cycle–The Marine Dissolved Organic Matter Reactivity Continuum, E*nviron. Sci. Technol.* 2022, 56, 9, 5371–5380.

Present-day MRV sensing capabilities for mCDR are inadequate for three main reasons:

- Insufficient quantification of carbon drawdown magnitudes and the associated degree of permanence.
- Unacceptably high MRV capital and operational costs at the required temporal and spatial scales for megaton- and gigaton-scale mCDR.
- Very low mCDR Signal to Noise Ratio: Discerning and quantifying carbon flux signals produced by an mCDR system in an environment where the amplitude of natural variation exhibited by the relevant oceanographic parameters may be orders of magnitude greater than levels facilitated by mCDR. The variation referred to in this case occurs in both time and space.

Consequently, mCDR approaches cannot at present be rigorously evaluated for their effectiveness and associated credit value. Hence, mCDR credits are only traded on the voluntary market, mCDR infrastructure cannot be insured for a certified value, and investors cannot accurately evaluate investment risk in the industry. These factors impede the development of mCDR into the gigaton scale industry that is required to limit global warming to less than 2°C.

a) MONITORING MARINE CARBON PROCESSES

Conventional marine carbon cycle monitoring relies on sensors capable of probing four general processes, a simplified model for which is represented in **Table 3**[24].

Table 3. Parameters of interest in monitoring the carbon cycle: partial pressure/fugacity of CO_2 (fCO_2); dissolved inorganic carbon (DIC); total alkalinity (TA); dissolved organic carbon (DOC); pH3. Note "Transport" in this case refers to storage and transport in ocean waters, while "Export" refers to removal of carbon to depth. (Reproduced from Schuster 2009)

PROCESS	**PARAMETER OF INTEREST**				
	fCO_2	DIC	TA	DOC	pH
AIR-SEA FLUX	✓				
OCEAN ACIDIFICATION		✓	✓		✓
CARBON TRANSPORT		✓	✓		
CARBON EXPORT				✓	

The sensors underpinning many of these measurements can be broadly generalized as either (1) inorganic carbon sensors; (2) organic carbon sensors; or (3) physical/enabling sensors

[24] Schuster, U., Hannides, A., Mintrop, L., and Körtzinger, A., Sensors and instruments for oceanic dissolved carbon measurements, *Ocean Sci.*, 5, 547–558, 2009.

addressing the solubility cycle, the carbonate cycle, and the biological cycle; as well as initiatives to include the fourth (microbial) carbon cycle[25].

Regardless of the process being monitored, the challenges facing sensors for marine processes are equivalent to those for many other marine environmental monitoring applications, namely the achievement of the following performance factors:

- High accuracy (i.e., low bias) and ability to quantify signal over noise through high precision (i.e., low variance)
- Rapid response times
- Sufficiently high reporting frequency
- Insensitivity to other environmental parameters such as temperature and pressure
- Tolerance to biofouling or sedimentation
- Low power consumption
- Low drift/long-term stability
- Internal quality control/quality assurance or self-calibration capabilities

Generally, the accuracy of modern-day instruments – defined as closeness of a measured or simulated value to the true value - is sufficient, but that accuracy requires untenable interventions (e.g., recalibration, recharging of reagents) or complex instrumentation that necessitates shipboard operation. There exists a significant body of work related to the development and implementation of sensors capable of discrete sampling at depth, autonomous mesocosm studies, and continuous near shore/shallow measurement for academic investigations[26]. Less attention has been paid to the cost requirements necessary to enable the scale of observational data collection at the monitoring intervals a mCDR industry requires[9]. Individual size, weight, power, and cost (SWaP-C) requirements vary based upon platform and measurement depth, but general cost and interdiction/service interval requirements need to be minimized for practical operability and to maximize the scaling potential of an applicable mCDR approach. Beyond initial sensor capability, there implicitly exists a tradeoff between volumetric or areal coverage, range capability, sensor endurance, and cost. If point-sensors are to be developed, further tradeoffs between unit cost and economies of scale, unit spatial density, and parameter correlation length scale exist. These requirements and tradeoffs are addressed in Section I.E.

b) INORGANIC CARBON SENSOR LIMITATIONS

State-of-the-art sensors that quantify the inorganic carbon pump focus on fugacity (thermodynamic property of a real gas, which if substituted for the pressure or partial pressure

[25] Legendre, L., Rivkin, R.B., Weinbauer, M.G., Guidi, L. and Uitz, J., The microbial carbon pump concept: Potential biogeochemical significance in the globally changing ocean, *Prog. Oceanog.*, 2015, 134.

[26] Byrne, R.H., DeGrandpre M.D., Short, R.T., Martz, T.R., Merlivat, L., McNeil, C., Sayles, F.L., Bell, R., and Fietzek, P., Sensors and Systems for In Situ Observations of Marine Carbon Dioxide System Variables in *Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2),* Venice, Italy, 21-25 September 2009, Hall, J., Harrison, D.E. & Stammer, D., Eds., ESA Publication WPP-306, *and references herein.*

in the equations for an ideal gas, gives equations applicable to the real gas), DIC, pH, and TA. If at least two of these four variables are measured, the others can be calculated using equilibrium constants and coupled physical measurements (salinity, temperature, etc.)[27]. Sensors for DIC and TA are the closest in readiness level for long term, autonomous or remote deployments with minimal intervention.

In general, sensors for inorganic carbon (DIC, pH, TA, fCO_2) are limited by the need for:

- Sample titration (coulometric and potentiometric methods),
- Indicators or reagents,
- Complex instrumentation (sensitive to biofouling; requiring consistent recalibration),
- Sample integration times exceeding 1 second, and
- Volumetric limitations, i.e., the requirement that sensors are co-located with the water sample.

c) ORGANIC CARBON SENSOR LIMITATIONS

State-of-the-art sensors used to quantify the organic carbon cycle are categorized as systems that sense dissolved organic carbon (DOC), particulate organic carbon (POC) and the quantification of carbon in marine sediment. Particulate Inorganic Carbon (PIC) may arise from the decomposition of POC and may be sensed simultaneously or resolved separately. A consensus on how to quantify carbon transport (the movement of carbon in ocean systems before it reaches desired reservoirs for storage) in the ocean through mechanisms that involve biological ingestion currently does not exist, due to associated ecosystem-specific and mCDR-approach-specific aspects. The DOC pool is the second largest known carbon pool in the ocean and the least instrumented fraction of the carbon cycle, and thus represents the largest gap in sensor capabilities[28]. Measurement of dissolved oxygen; micronutrients; and the individual species involved in primary production (photosynthesis or chemosynthesis) are necessary to improve monitoring of the carbon transition between organic and inorganic pools. This would also allow for a more accurate accounting of sequestration by deep ocean export processes. In addition, quantification of the relative ratios or absolute magnitudes of labile (a compound that is readily and likely to be re-mineralized) and recalcitrant (does not re-mineralize or does so at very slow rates) DOC are necessary to valorize the component of CO_2 drawn down to the DOC pool by mCDR processes.

Sensing of Particulate Organic Matter (POM) and Particulate Inorganic Matter (PIM) are typically performed via collection of vertical fluxes through a sediment trap that is then analyzed in a laboratory setting, or through quantification in an optical trap. Optical systems for quantifying POM/PIM are capable of discerning particle size, distribution, and density; and in

[27] Dickson, A. G., Sabine, C. L., & Christian, J. R. (2007). *Guide to best practices for ocean CO2 measurements*. North Pacific Marine Science Organization.

[28] Moore T.S., Mullaugh K.M., Holyoke R.R., Madison A.S., Yücel M., and Luther G.W. 3rd. Marine chemical technology and sensors for marine waters: potentials and limits. *Ann. Rev. Mar. Sci*. 2009.

some circumstances particle type (i.e., fecal matter, species composition, etc.) but presently do not offer mechanisms by which the bulk carbon content of particulates may be evaluated *in situ*.

The sequestration of carbon in stable, deep ocean sediments represents the goal for several mCDR approaches. Once entrained within these sediments, the residence time of carbon drawn down from the atmosphere and surface oceans may be measured in millennia or more. Some mCDR approaches involve the enhancement of carbon storage in shallow-water sediments through the restoration of biological processes such as accretionary carbon storage, including recalcitrant carbon, through seagrass restoration or the deposition of mineralized carbon through the restoration of calcifying reefs and their associated ecosystems. In general, quantification of the sediment carbon fraction and identification of stable carbon compounds requires direct sampling of sediments through coring and subsequent analysis in a laboratory setting. Methods potentially enabling noninvasive quantification of carbon compounds in near-surface sediments exist, but the accuracy and scaling potential of these technologies is yet to be demonstrated.

In general, sensors for organic and organically-stored carbon are limited by the requirements for:

- Selectivity for specific species/analytes.
- Signal-to-noise ratios.
- The ability to discriminate between non-carbon and carbon constituents.
- The ability to discriminate between recalcitrant and labile compounds.
- Laboratory-based analysis, requiring sample extraction and transportation.
- Volumetric or area limitations, i.e., the requirement that sensors are co-located with the water sample.

d) PHYSICAL AND ENABLING SENSORS

State-of-the-art physical oceanographic sensors are designed to measure ancillary properties required for a complete picture of the mCDR process being monitored. These include, but are not limited to, temperature, salinity, eddy covariance/turbulence, and pressure. These foundational sensors form the basis for oceanographic surveys and are generally well developed, available commercially at a reasonable cost, and robust to degradation. However, development of the envisioned MRV capabilities for mCDR evaluation may be aided by new approaches for sensing of these fundamental parameters capable of estimating the dynamic ocean environment across large volumes efficiently, explicitly alongside the sensing of carbon parameters relevant to mCDR. Consequently, approaches for transformative physical oceanographic sensing approaches are in scope for this program, but only in a supporting role that is explicitly tied to the simultaneous implementation of a carbon flux sensor that requires the resultant oceanographic data.

5. State-of-the-Art and Limitations: Modeling

The long-term quantification and estimation of additional CO_2 drawdown in the vast, temporally dynamic, 3-D, heterogeneous ocean volume is not possible at gigaton scales with improved sensor capabilities alone. A simultaneous understanding of what would have occurred if a given mCDR approach did not exist (i.e., a baseline) is necessary to estimate the additional CO_2 drawdown created by the approach. Therefore, regularly validated mCDR models are necessary to comprehensively assess the dynamic ocean carbon cycles for MRV. Some existing global models, such as the Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC) Earth System Model and Circulation and Climate of the Ocean (ECCO)-Darwin model, integrate underlying physical and biogeochemical mechanisms and observations to estimate the global carbon cycle[29,30]. However, there are several barriers to overcome before estimation or even prediction of the efficacy of mCDR methods with such models, particularly at the required spatial and temporal scales[31].

Most advanced global carbon models today are not designed to evaluate mCDR approaches, produce estimates of carbon drawdown, or provide the necessary parameters and uncertainties from which calculations of financial value can be made. Earth system carbon models are typically coarse in spatial resolution (on the order of tens to hundreds of km). Anticipated mCDR approaches will be regional events and sufficient modeling of such scenarios requires sub-mesoscale (1-10km) chemical oceanographic and biological information, which is rarely available in sufficient quantities for high-resolution model development.

Another significant challenge involves accommodating the differences in time scales between the various ocean processes influenced by mCDR, which in turn depend on each specific mCDR scenario and the oceanographic region in which the approach is situated. Therefore, the following timescale issues, the consequent model run expense, and potential mitigation of this expense, must be considered in any proposed modeling approach:

- The timescale of physical and chemical changes associated with mCDR may generally be shorter than for biological processes.
- Carbon dynamics in the deep ocean occur over longer timescales than in coastal or shelf regions.
- Some mCDR approaches are typified by periodic or localized injections of carbon to the ocean carbon cycle, which may occur over shorter timescales than climate and earth carbon systems.

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[29] Carroll, D., Menemenlis, D., Adkins, J. F., Bowman, K. W., Brix, H., Dutkiewicz, S., *et al*. (2020). The ECCO-Darwin data-assimilative global ocean biogeochemistry model: Estimates of seasonal to multidecadal surface ocean pCO2 and air-sea CO2 flux. Journal of Advances in Modeling Earth Systems, 12, e2019MS001888. https://doi.org/10.1029/2019MS001888

[30] Lovato, T., Peano, D., Butensch.n, M., Materia, S., Iovino, D., Scoccimarro, E., *et al*. (2022). CMIP6 simulations with the CMCC Earth System Model (CMCCESM2). Journal of Advances in Modeling Earth Systems, 14, e2021MS002814. https://doi.org/10.1029/2021MS002814

[31] Siegel, D. A., DeVries, T., Doney, S. C., & Bell, T. (2021). Assessing the sequestration time scales of some ocean-based carbon dioxide reduction strategies. Environmental Research Letters, 16(10), 104003.

It is expected that MRV modeling for each mCDR scenario will be tailored to the specific environmental circumstances of the region, the mCDR approach, and the anticipated major carbon pathways that are most likely to be modified through mCDR. Consequently, in order to perform effective parameterization, MRV models may thus initially require higher spatial and temporal resolutions than what is typically modeled today.

The biological ocean carbon cycle is typified by nonlinear reactions and feedbacks, rendering the estimation of biological processes associated with mCDR efficacy a formidable challenge. ARPA-E considers the quantification of ocean biological carbon fluxes to be the least understood, but potentially the most critical element of effective MRV, especially for mCDR approaches that leverage biological productivity. The development of regional scale (i.e., spatial scales sufficient for the order of hundreds of megatons to one gigaton mCDR) biological carbon flux sensing approaches and modeling capabilities is therefore an important goal for this program.

Today, most biogeochemical models are based on the Nutrient-Phytoplankton-Zooplankton-Detritus (NPZD) formalism[32], and many of the model-development efforts have focused on describing the nutrient-phytoplankton relationships. In contrast, the representation of zooplankton is often limited to only two or three size classes (e.g., in the National Oceanographic Atmospheric Administration's s Ocean Biogeochemical Model COBALTv2) and a few have extended toward modeling higher trophic levels in a limited context. State-of-the-art biological models that could be adapted to predict carbon fluxes remain comparatively simple, in contrast with the known complexities of the natural ecosystem, due to our limited understanding of contributors to the biological carbon cycle such as the roles of gelatinous zooplankton, the microbial loop, the dissolved organic matter (DOM) – POM continuum, and the vertical migration of pelagic organisms in the deep ocean[33]. While significant challenges remain in accurately estimating ocean carbon fluxes through these pathways, or quantifying the unknowns associated with them, volumetric sensors and associated models developed through this program would offer new and fundamental insights toward understanding the roles of these carbon pathways in determining the fate of CO_2 drawn down in the surface oceans through biological processes.

C. <u>PROGRAM OBJECTIVES</u>

The anticipated timing and milestones described here are subject to change. If an applicant is selected for award negotiations, timing and milestones will be mutually agreed upon during the negotiation period.

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[32] Fasham, M. J., Ducklow, H. W., & McKelvie, S. M. (1990). A nitrogen-based model of plankton dynamics in the oceanic mixed layer. *Journal of Marine Research*, *48*(3), 591-639.

[33] Burd, Adrian B., Buchan, Alison, Church, Matthew J., Landry, Michael R., McDonnell, Andrew M. P., Passow, Uta, Steinberg, Deborah K., Benway, Heather M., "Towards a transformative understanding of the ocean's biological pump: Priorities for future research - Report on the NSF Biology of the Biological Pump Workshop", 2016-08-24, DOI:10.1575/1912/8263, https://hdl.handle.net/1912/8263

1. Technical Area 1: Sensors

The primary focus of this program is the development of sensors able to measure the ocean chemical and carbon-flux relevant parameters listed in **Table 2** in a manner that achieves the first four technical developments listed in **Table 1**. As such, more than half of program funding will be allocated to this TA. ARPA-E will consider submissions to develop appropriate sensor technology applicable to one or more of the parameters listed in **Table 2**. Submissions proposing the development of sensing capabilities for other parameters without exceptionally strong justification are discouraged. Preference will be given to sensors that quantify multiple relevant parameters that are known to be necessary for MRV across a wider range of mCDR approaches. **Applicants should justify, in a one page Appendix to the Concept Paper, a, the potential for applicability of a proposed sensor technology to one or more mCDR approaches** described in the National Academies report, and associated ideal regional areas where representative testing could occur. Other feasible mCDR methods for which MRV technology could be developed may be of interest to ARPA-E **if justification can be provided that defines a feasible roadmap** to a 100s of megaton- to gigaton-scale mCDR industry through the approach.

ARPA-E emphasizes the significant knowledge gaps associated with quantification of the ocean biological carbon cycle. While the challenge of quantifying nonlinear biological carbon cycles in the ocean is significant, ARPA-E encourages submissions of any sensing technology that could quantify, at scale, the role biological processes play in carbon drawdown, transport, and sequestration in coastal, shelf, pelagic, and deep ocean environments.

The anticipated TA1 program approach will consist of two Phases, each lasting 18 months. In Phase 1, teams will develop the core technologies that enable their sensing concept. Phase 1 will culminate in a controlled test and in-water experiment to show sensor functionality using ocean-sourced seawater in a laboratory setting. This milestone is designed to demonstrate that the fundamental sensor concept functions as intended, and that the technology has the potential to mature toward a sensor system of sufficient relevance to MRV needs that could be deployed at scale in the ocean.

If selected for continuation in Phase 2, sensor teams will mature their systems and test operability in increasingly realistic in-water scenarios. Integration of the sensor system onto a commercially available off-the-shelf (COTS) platform will occur during Phase 2. This system will be appropriate as an MRV platform for one or more indicated mCDR approaches and may include, but is not limited to, surface or subsurface autonomous systems, drifters, gliders, buoys, seafloor cables, or moorings. This Phase will culminate in an ocean-going test where the sensor and COTS platform will be deployed in an ocean region appropriate for an associated mCDR event. At a minimum, the TA1 team will deploy their sensor system to quantify carbon fluxes associated with natural baselines. If possible, teams may leverage pilot-scale mCDR operations that may be taking place at that time. ARPA-E encourages applicants to leverage other federal and privately funded programs that aim to further mCDR development and implementation.

Coordination between Technical Areas
TA1 teams are required to work with TA2 teams during Phase 2 to develop estimates of scaled sensor capability and adopt at-sea sampling strategies informed by models to minimize parameter uncertainty. In specific cases, sensors may also be developed to aid in model verification if quantification of a key parameter would significantly decrease model uncertainty, although the primary focus of sensor development is to enhance spatial and temporal capabilities. TA1 and TA2 applicants may prepare inter-related submissions in response to the FOA or enter collaborative partnerships at the beginning of Phase 2. Note that while sensor teams may focus on one or more parameters, modelers are required to simulate the dynamics of all relevant ocean carbon parameters for a given mCDR scenario simultaneously. Consequently, a TA2 team may work with multiple TA1 teams in Phase 2.

Since TA2 teams will need to utilize sensitive, potentially proprietary and "protected" data from TA1 awarded teams, TA2 awardees must commit to and the TA2 award will require maintaining strict confidentiality regarding such data and the results that are generated using such data that are identifiable with a specific TA1 awardee unless the collaborating TA1 awardee agrees otherwise. Data to be generated by a TA2 team about individual TA1 awardee data will only be provided to the specific TA1 awardee whose data has been utilized unless agreed to otherwise by the TA1 awardee and to ARPA-E. A TA2 awardee cannot refuse to collaborate with a TA1 team who requires that the above restrictions apply to the collaboration with a TA1 team.

2. TECHNICAL AREA 2: MODELS

While sensor technologies will be developed independently of applications to specific mCDR types, modeling teams are required to focus on one or more mCDR scenarios at regional scales where the size of the hypothetical operation has the potential to draw down hundreds of megatons to one gigaton or more of CO_2 per year. Submissions for modeled scenarios should include the following:

Applicants must justify, in a one page Appendix to the Concept Paper:

- **Specific mCDR approach(es)** (i.e., iron fertilization, seagrass restoration, alkalinity enhancement, etc.), and hypothetical logistical approach(es) (e.g., injection site, proximity to material resources, etc.) that will be modeled. Approaches must be realistic in that a hypothetical yet feasible techno-economic scenario (at 100's of megatons to 1 gigaton scale) can be developed based on a nominal CO_2 credit value of US$100/ton at that scale.
- **Regionally constrained area(s),** geographically and oceanographically appropriate for each chosen mCDR approach scenario. Regional areas must be limited in size so that high resolution regional ocean models may be run within a reasonable timeframe. The purpose of TA2 is to develop new or enhance existing models that are more accurate and precise through improved modeling of fundamental processes, vs. a brute-force approach to improving model performance.

Models should simulate carbon fluxes from atmospheric or recently dissolved CO_2 in the mixed layer through what applicants consider to be the major inorganic and organic pathways that are economically relevant for the mCDR scenario(s) of interest. Teams should include a **table** with their submission that identifies which of the parameters listed in **Table 2** are relevant to their submission, as well as a rationale on why the chosen ocean carbon parameters should each be considered major pathways within the vignette, and why the parameters that were not chosen should be excluded.

Model parameters should be chosen in coordination with carbon market consultants and/or carbon registries in a best effort to minimize computational burden and maximize output utility for valuing a mCDR exercise and developing a carbon accounting framework for the chosen mCDR approach(es). Given the significant number of unknowns, initial estimates of parameters such as resolution, time step, and spatial and temporal ranges may be updated as sensitivity analyses and potential data assimilation from existing or prototype sensors provide scope for optimization. Model and registry requirements are expected to evolve as collaborators determine an optimal framework to translate model outputs to accountability metrics developed as projects progress.

Model outputs will initially be tailored to demonstrate model performance against hold-out historical oceanographic data. Therefore, preference will be given to geographic regions ideal for mCDR but also for which existing, curated and high-quality historical oceanographic data sets are available, enabling expedited model development and verification on previously collected data.

As models are developed to achieve performance benchmarks demonstrating state-of-the-art levels of bias and variance, an additional MRV-specific suite of model outputs will be developed to inform a data-driven accreditation process. TA2 teams will develop these processes jointly with carbon market consultants and/or a carbon registry.

Coordination between Technical Areas

During Phase 1 (1-18 mo.), TA2 teams will build mCDR models of their proposed regional mCDR approaches, incorporating the simulation of selected major organic and inorganic carbon pathways and coordinating with a carbon registry to determine model parameters most conducive to informing a data-driven carbon accounting framework. At the culmination of Phase 1, teams will demonstrate the performance of mCDR models through the estimation of baseline ocean parameters using hold-out historical data (or actual mCDR event data, if available). Note that metrics for model bias and variance only apply to performance against this historical hold-out data. Further metrics for Phase 2 performance may be determined on a case-by-case basis that is dependent on performance in Phase 1.

During Phase 2 (19-36 mo.), TA2 teams will collaborate with one or more TA1 teams to perform an OSSE that estimates the scaled sensing capability of prototype TA1 systems and inform at-sea sampling strategies to minimize parameter uncertainty. The goal of this effort is to estimate how these sensor capabilities would impact carbon accounting and the quantification of uncertainty within the accounting framework designed in Phase 1 through more accurate CO_2 drawdown magnitudes, permanence, uncertainties, and carbon credit quality. Model outputs should consist not only of carbon flux parameter values, uncertainties, and temporal permanence estimates and uncertainties; but should also include the potential increase in financial value associated with the enhanced credit quality derived from more definitive projections of uncertainty. As such, **at the end of Phase 2,** a forward-looking techno-economic analysis of the mCDR vignette, including estimates of potential scaled MRV cost and enhancement of credit value, will be required.

Note that while sensor teams may focus on one or more parameters, modelers are required to simulate the dynamics of all relevant ocean carbon parameters for a given mCDR scenario simultaneously. Consequently, a TA2 team may work with multiple TA1 teams in Phase 2. If measurement of a specific parameter is critical for the satisfactory performance of a model, limited sensor development for the purposes of quantifying this parameter and thus strengthening models is within scope. In the case that significant model performance improvements are likely, TA2 teams may engage in limited data collection and assimilation activities.

Verified, regularly refined mCDR models will enable cost-effective MRV and quantitative estimates of carbon additionality for a scaled mCDR industry. Data from sensor technology developed in TA1 will likely be instrumental in the development and continued verification of such models. Because sensor development and maturation timelines are likely to exceed the duration of this program, models that predict the potential enhancement to MRV in terms of accuracy in quantifying CO_2 drawdown, its permanence, and quantification of uncertainties will be important in demonstrating the utility of new sensor technologies to the mCDR community.

3. Independent Verification & Validation (IV&V)

One or more IV&V teams may evaluate sensor maturity against ARPA-E performance metrics including compatibility with COTS platforms, and seaworthiness of sensing systems (see the ‘Program Metrics’ in Section I.E) at agreed-upon intervals beginning at the end of Phase 1. The budget for this IV&V service and identification of IV&V team(s) may be determined under a separate agreement at a later date. As such, teams are only required to budget for their proposed work.

4. Program Structure and Deliverables

SEA CO2 is a program offered in two separate programmatic phases. At the full application stage, applicants must provide detailed budgets and task descriptions that cover both SEA CO2 Phase 1 and SEA CO2 Phase 2. Additional details are provided below.

Phase 1:
TA1: SEA CO2 Phase 1 focuses on the conceptual design of the proposed marine carbon sensor, along with proof-of-concept development and testing within a laboratory environment to address the associated risks with the proposed solution/technology. SEA CO2 TA1 Phase 1 will end with a sensor proof of concept in a laboratory setting to demonstrate that the fundamental sensor concept functions as intended, and that the technology has the potential to mature toward a sensor system of sufficient relevance to MRV needs that could be deployed at scale in the ocean and achieve the program objectives and the specific performance metrics tabulated in **Table 4.**

TA2: SEA CO2 Phase 1 focuses on mCDR model buildout of the proposed regional mCDR approaches, incorporating the simulation of selected major organic and inorganic carbon pathways and coordinating with a carbon registry to determine model parameters most conducive to informing a data-driven carbon accounting framework. At the culmination of Phase 1, TA2 teams will demonstrate the performance of mCDR models through the estimation of baseline ocean parameters using hold-out historical data (or actual mCDR data, if available) with successful teams meeting the performance requirements listed in **Table 4.**

SEA CO2 Phase 1 can be proposed for a maximum of 18 months, based on the Applicant's individual assessment and the proposed project's schedule. All projects will initially be provided the funding for Phase 1 only. Based on each individual project's technical success, including meeting technical targets of SEA CO2 Phase 1, ARPA-E may select one or more projects to continue to SEA CO2 Phase 2, subject to the availability of appropriated funds.

Phase 2:
TA1: During SEA CO2 Phase 2, successful projects will mature their sensor systems and test operability in increasingly realistic in-water scenarios. This Phase will culminate in an ocean-going test where the sensor and COTS platform will be deployed in an ocean region appropriate for an associated mCDR activity. At a minimum, the TA1 team will deploy their sensor system to quantify carbon fluxes associated with natural baselines. The final deliverable should be designed to meet the relevant metrics outlined in **Table 4.**

TA2: During Phase 2, TA2 teams will collaborate with one or more TA1 teams to perform an OSSE that estimates the scaled sensing capability of prototype TA1 systems and inform at-sea sampling strategies to minimize parameter uncertainty. Model outputs should consist not only of carbon flux parameter values, uncertainties, and temporal permanence estimates and uncertainties; but should also include the potential increase in credit quality derived from more definitive projections of uncertainty. This information should be incorporated into a refined carbon accounting framework. As such, at the end of Phase 2, a forward-looking techno-economic analysis of the regional mCDR activity, including TA1-related costs and estimates of potential scaled MRV cost, will be required.

SEA CO2 Phase 2 can be proposed for a maximum of 18 months.

D. TECHNICAL AREAS OF INTEREST

1. TECHNICAL AREA 1: SENSORS

Sensor technology of interest to this program must be a demonstrable step away from present-day capabilities. The primary goal of TA1 is to develop sensors that can quantify the carbon-related oceanographic properties in **Table 2** at a large spatial scale, ideally (but not limited to) volumetrically or area-wise, expanding both spatial and temporal sensing capabilities for these parameters and providing significantly larger quantities of higher-resolution data to model development efforts. No specific volume or area metric per sensor is provided, only a survey rate associated with a scaled MRV system appropriate for a gigaton-scale mCDR operation. As such, this metric (and the qualitative metric addressing cost at scale) creates an implicit tradeoff between the range of a sensor and the cost. A single, expensive sensor must be capable of surveying significant ocean volumes at a high rate. Conversely, a larger number of less expensive sensor systems with limited or even no range may be equally permissible. Systems incorporating large numbers of networked sensor nodes must still satisfy the endurance and accuracy metrics on a per-sensor basis. In the case of point sensors, evidence must be provided showing that the **correlation length scales of the parameter remain consistent** over ranges such that a techno-economically realistic sparse network of point sensors could sufficiently resolve fluxes from a CDR event. Note that for sensor development purposes only, installation on "ARGO" platforms is permissible despite the disposable nature of these profilers. In general, ARPA-E discourages the use of disposable sensor and platform approaches for this FOA.

The depths to which sensors must operate depends upon the location and mCDR approach. A nominal depth rating is a minimum of 1000 m. However, more accurate estimations of maximum operating depth can be deduced from studies indicating depths beyond which transported carbon is effectively removed from the atmosphere and surface ocean for 100 years or more[19]. Thus the 1000 m requirement may be relaxed if it is sufficiently reasoned that a proposed sensing technology could perform effective MRV for an mCDR approach with a lesser depth rating.

To adhere to the requirements for scalable MRV, ARPA-E encourages a non-exclusive emphasis on radiated energy-based sensing approaches in which a system could potentially quantify ocean carbon parameters in a location not co-incident with the sensor. While these types of 'remote' sensing have facilitated a revolution in our understanding of atmospheric and surface ocean-related processes, most remote sensing approaches that resolve oceanographic properties today cannot be extended beyond the first optical depth (also known as the penetration depth[34]) in the ocean. In addition, the drift and recalibration requirements for radiated energy-based sensors are expected to be significantly reduced in comparison to reagent-based sensing approaches.

[34] Gordon, H. R., & McCluney, W. R. (1975). Estimation of the depth of sunlight penetration in the sea for remote sensing. *Applied optics*, *14*(2), 413-416.

Potential sensor approaches of interest are listed below. Approaches could serve to quantify any parameter listed in **Table 2**. This list is not exhaustive and is only meant to serve as a guide to the types of sensing approaches of interest to ARPA-E.

- Optical fiber-based chemical oceanographic sensors, with simultaneous sensing of environmental parameter data necessary to disentangle the effects of temperature, vibration, etc.
- Acoustic methods, both passive and active. ARPA-E encourages the submission of concepts that leverage chemically dependent in-water acoustic properties such as that between the borate-boric acid equilibrium reaction, acoustic attenuation, and pH. ARPA-E additionally encourages the submission of high frequency, spatially integrative or directional 'acoustic color' concepts for characterization of particulate matter and seabed material properties.
- Optical methods including, but not limited to, reflectance and/or absorption based, hyperspectral/multispectral, optical Micro-Electrical Mechanical Systems (MEMS) systems, dual frequency comb laser-based spectroscopy, remote Raman, florescence/luminance-based, and laser induced breakdown spectroscopy (LIBS) as pertinent to quantification of relevant seawater and sediment parameters. Methods may be active (coherent or incoherent sources) or passive (i.e., bioluminescence-based, sunlight-based). Solid-state, as opposed to spinning aperture, systems are of particular interest due to their suitability to underwater applications. ARPA-E encourages the submission of concepts that enable range-dependent optical sensing that may be facilitated by, for example, nanosecond time-gated backscatter spectroscopy. Given that transmission of light in the ocean is limited by strong attenuation in comparison to atmospheric scenarios, sensor cost and the potential to leverage economies of scale may be important considerations uniquely associated with optical sensing techniques.
- Electromagnetic techniques, both passive and active. Little is known regarding the ability to quantify seawater and seafloor chemical parameters listed in **Table 2** using variations in resistivity and other electromagnetic properties. In addition, little is known regarding the characterization of biological activity and potentially the transport of ingested carbon sensed through electromagnetic methods. However, if demonstrated in a manner that is scalable, electromagnetic sensing of seawater parameters could fundamentally change the understanding of chemical and biological oceanographic processes.
- Large-N, networked point receivers that sample parameters relevant to a range of mCDR approaches, the design of which could uniquely leverage economies of scale. Submissions involving point receivers must include evidence of parameter correlation length scales, estimates of minimum spatial resolution to adequately resolve mCDR driven events given this length scale, and a techno-economic analysis based on the resultant instrument density.
- Other sensor approaches that are not included in the above list, but which could serve to create spatially scaled, volumetric or area-based carbon flux parameter sensing capability.

ARPA-E has not set a definitive metric regarding the spatial resolution of new sensor technology, as the minimum spatial resolution at which collected data would characterize the smallest relevant parameter structures is undefined and likely dependent on the mCDR approach. However, preference will be given to approaches that either integrate parameters of interest over a given sampling path or are capable of sampling multiple discrete points stepping out from the sensor itself to the limits of sensor range.

2. TECHNICAL AREA 2: MODELS

The goals of TA2 are to develop regional marine carbon cycle models specifically for simulating mCDR capable of first simulating natural fluxes with accuracy and bias comparable with state-of-the-art Regional Ocean Modeling Systems (ROMS). These models will then be used in mCDR simulations and Observation System Simulation Experiments (OSSEs) to estimate the impact of new sensor technology on evaluating the quantity and quality of credits earned through mCDR, and to design model operations and outputs to support the development of a data-driven carbon accounting framework for mCDR. In addition, model runs will be used to inform TA1 groups during at-sea experimental design to maximize the effectiveness of new sensor systems in performing MRV. The variety of mCDR approaches and the heterogeneity of suitable regional environments mean that only general metrics concerning bias (Root Mean Square Error) and variance (Anomaly Correlation Coefficient) are applied to evaluate models. These model bias and variance metrics apply only to parameters listed in **Table 2** for which concentrations/distributions may be significantly modified by mCDR. Note that TA2 applicants must identify and rationalize which parameters in **Table 2** are considered significantly modified for their modeled mCDR approach.

Models must incorporate the simulation and tracking of multiple chemical oceanographic parameters, the dynamics of which are likely to be influenced by physical and biological processes at multiple scales. Given that fundamental uncertainties exist regarding representation of the biological system, ARPA-E encourages the submission of efforts that also seek to resolve basic research questions regarding combined physical-biological models that incorporate multiple, interacting biological carbon pathways that may be of consequence to one or more mCDR approaches. However, the same project outcomes regarding the support of OSSEs and the development of carbon registry frameworks apply.

Potential modeling approaches of interest are listed below. This list is not exhaustive and is only meant to serve as a guide to the types of TA2 submissions of interest to ARPA-E:

- Physical oceanographic models at sub-mesoscale resolutions to discern important small-scale variability in processes relevant to some mCDR approaches (e.g., alkalinity enhancement, iron fertilization). An ideal physical model should be able to accurately estimate ocean processes at fine temporal and spatial scales, including the dynamics of key physical pumps such as the mixed layer pump, the eddy subduction pump, and large-scale subduction pumps.

- High-resolution physical models should also be used to advance the development of biogeochemical models, particle tracking modeling, ecosystem models, and other models related to mCDR. Parameterizing these processes for future computational efficiency will be an important deliverable in this case.
- Biogeochemical models simulating the dynamics of the carbonate system affected by mCDR activities. ARPA-E encourages submissions for models that further consider the effects of mCDR on related phytoplankton community shifts between calcifiers and silicifiers.
- Biogeochemical models that could evaluate the effects of mCDR on one or more processes, including a) primary production and consequent sinking/export of particulate and dissolved carbon to depths at which storage would exceed 100 years, b) multi-trophic-level carbon fluxes from microbial to macro-organism communities, and c) the vertical gradient and flux of dissolved carbon. ARPA-E encourages interdisciplinary, multispecies and ecosystem modeling with a focus on the detailed dynamics of carbon fluxes throughout these complex systems.
- Unprecedented biological models that track the transport and storage of organic carbon through vertical migration. An ideal model should consider ingestion, excretion, and respiration in the water column, as well as the potential effects of mCDR on the composition, population, and vertical migration behaviors of these organisms. It is also desirable for the model to consider multiple species at various trophic levels, including crustacean, gelatinous zooplankton, fish, and other animals that conduct vertical migration, and their life stages.
- Data assimilation capabilities to improve model parameters, facilitate the design and selection of model structures, quantify uncertainties, and estimate true aggregated carbon fluxes in the ocean. An effective data assimilation approach is critical for enhancing model performance in the event sensor data from TA1 is available before the culmination of the program. Assimilation will eventually allow for the real (rather than simulated) assessment of new sensing technologies on carbon flux quantification accuracy, error, and consequently credit quality. This program only seeks to simulate assessments through an OSSE approach as the length of time required to develop new sensor technology is uncertain.

If the bounding of a specific parameter is critical for the satisfactory performance of a CDR model, limited sensor development for the purposes of quantifying this parameter for model validation and thus strengthening model outputs is within the scope of this program.

ARPA-E intends to support interdisciplinary collaboration between sensor developers, oceanographic scientists, modelers, and the carbon market industry to develop viable and scalable MRV technologies for mCDR. As such, ARPA-E encourages TA2 applicants to consider utilizing a collaborative forum for information and idea exchange between modelers, oceanographers, sensor developers, and carbon registries. Such a platform would require interoperability between members of these diverse disciplines and offer information storage and/or computational capabilities to enable the translation and processing of relevant data sets. The forum would expedite community acceptance of standardized protocol and encourage the correct use of modeling tools, leading to credible results that are accepted by the market. In addition, a modular approach in which the same physics or biological process kernel, assimilation process, user interface and cluster access protocol are applied to several different mCDR approaches over a variety of regional scenarios may be proposed as standardization and integration between different modeling efforts is also encouraged.

E. TECHNICAL PERFORMANCE TARGETS

Given that the mCDR market does not yet exist, this program sets goals designed to inspire transformative ocean carbon sensing technologies to accelerate the formation of this market. Five key performance metrics drive the technical innovation thrusts in this program, listed below in **Table 4.**

Table 4. Summary of SEA CO2 key performance metrics.

Metric #	Description	Quantitative Value	Details
M1	Volumetric Capability	150 km^3/h (volume or 3D sensing) 150 km^2/h (sediment or 2D sensing)	Volumetric or area-sensing requirement when the MRV approach is scaled to 1 gt CO_2/yr size. Note that this metric implies the requirement of a competitive techno-economic analysis for a future scaled market, where MRV costs should not exceed 5% of the value of CO_2 drawn down.
M2	Accuracy	See **Table 2**	Accuracy of new sensor designs must be within 10% of the state-of-the-art for individual carbon parameters.
M3	Size, Weight and Power	COTS platform	Requirement to match what is offered by an appropriate COTS platform available today or within 18 months of project start.
M4	Sensor Endurance	1 year	Sensors must function continuously or at appropriate cycle rates without physical human intervention for one year or more.
M5	Model Accuracy (historical data)	RMSE ≤ 0.25 ACC ≥ 0.7	Performance of MRV models based on hold-out historical data must meet state-of-the-art values, unless model types are unprecedented.

In addition to the quantitative metrics defined in **Table 4,** ARPA-E will evaluate submissions and projects under the following context:

- The volumetric or area-based survey rate metric implies a tradeoff between cost and spatial sensing capability per sensor. A survey rate of 150 $km^{2\text{-}3}$/h for a 1 gigaton per year mCDR system could be achieved by a small number of sensor systems capable of long-range quantification, a larger number of sensor systems capable of sensing over a shorter distance, or a solution in between these extremes. Consequently, TA1 teams will need to estimate **through a forward-looking techno-economic analysis included with their submission** that their sensor technology, if scaled, will satisfy a future cost-performance market. Given that such a market does not yet exist, the following speculative estimates should be used as assumptions:

- An MRV cost of no more than 5% of the value of CO_2 drawn down via an example scaled mCDR system.
- A nominal price of $100 per ton of CO_2 drawn down, for a minimum 100-year period at 95% probability.

Consequently, sensors could feature higher priced technologies if they enable large-volume sensing capability from a small number of systems. Or, if sensing approaches are volumetrically limited then sensor cost will be more important for success while maintaining accuracy and precision, reliability, endurance, and leveraging economies of scale. In the latter case, teams are encouraged to consider technologies that could lead to maximal leveraging of economies of scale and resilience against supply chain vulnerabilities.

The sensor technology developed under this program must be able to effectively survey the ocean for one or more parameters listed in **Table 2** below the first optical depth of the selected region at rates of at least 150 km^3/h, persistently for periods of at least one year, when deployment is scaled to a size commensurate with a gigaton-level negative carbon mCDR approach. In cases where MRV requires the quantification of seafloor parameters, this metric reduces to 150 km^2/h. In a scaled scenario, new volumes and areas would need to be surveyed per hour rather than, for example, the same 150 km^3 water mass. This rate of volumetric survey is expected to enable sufficient quantification of carbon fluxes through observation alone at regional scale. It would also provide enough data at suitable resolution for effective mCDR models to be developed and validated.

The oceanographic chemical sensing community has been pursuing sensor accuracy and dependability goals for some time (e.g.,[35]) ARPA-E feels that advancements in accuracy over state-of-the-art would confer incremental improvements to MRV, rather than the transformative improvements that enhancements of survey scale would bring. Consequently, teams are required to demonstrate sensor accuracy to within 10% of the state-of-the-art values listed in **Table 2**.

The size, weight, and power consumption of sensor systems must be compatible with autonomous ocean sensor platforms and the mission profiles for which they are designed. Virtually all COTS platforms are limited in their payload capacity by a variation of these three metrics. Timely deployment and maturation of sensor technology requires efficient integration with appropriate ocean-going platforms, best brought about through the consideration of these

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[35] Martz, T. R., Connery, J. G., & Johnson, K. S. (2010). Testing the Honeywell Durafet® for seawater pH applications. *Limnology and Oceanography: Methods*, *8*(5), 172-184.

limitations at the initial design phase. Sensor systems must thus be sized suitably so they may physically fit within an appropriate COTS platform, remain within manufacturer-recommended payload weight/density limits, and within manufacturer-recommended power consumption rates so that typical mission profiles are not significantly limited by energy consumption. Choices regarding the type of sensor platform are left open to teams, although selections should be made considering anticipated mission profiles associated with one or more mCDR approaches. ARPA-E encourages the adoption of persistent platforms that can harvest energy in-situ and offer a surplus sufficient to operate the sensor payload. Such a platform is consistent with the spirit of the sensor endurance metric and combined with a sensor system that meets that metric, could result in a sensor-platform system capable of extended deployments without physical human interaction for purposes such as swapping batteries. This approach would offer greater value to a commercial mCDR operation as the cost of MRV hardware could be amortized over a greater quantity of carbon credits surveyed.

Sensors must demonstrably be shown to operate in a manner that would be suitable for autonomous, error-free operation over a period of at least one year without physical human intervention. This metric is intended to address sensor drift issues (i.e., systems will require automatic re-calibration if drift is large enough to fail metric #2 in **Table 4**), reliability, avoid a reliance on consumables, energy consumption and practical considerations such as biofouling and corrosion. ARPA-E considers one year a nominal minimum due to the seasonal characteristics of some mCDR approaches such as ocean iron fertilization in regions such as the Southern Ocean, and seaweed sinking in temperate waters.

Models developed under TA2 must meet state-of-the-art performance metrics for bias and variance. When tested on historical hold-out data, predictions of baseline parameters listed in **Table 2**, to the maximum reasonable extent permissible by available historical datasets, should demonstrate a root-mean-squared error (RMSE) of ≤ 0.25 (averaged over time, when predicted at equivalent spatial scales to historical data), and a time-series anomaly correlation coefficient (ACC) of greater than or equal to 0.7. Models should meet these performance metrics by the culmination of Phase 1, before estimations of MRV enhancement through new sensing technologies are made. An exception may be made for attempts to model mCDR processes that cannot be reasonably compared to existing SOA models. In these cases, if a submission is selected, metrics for the purpose of verifying accuracy and precision will be determined during award negotiation.

F. TECHNOLOGY-TO-MARKET (T2M) EXPECTATIONS

All selected teams will be required to develop technology-to-market strategies to bring their MRV products to market, which will need to account for uncertainties regarding a forthcoming mCDR industry. The paths to market are anticipated to vary by team and will largely depend on the modularity of the MRV solutions developed, the technical area of focus, and the mCDR approaches considered. The eventual primary customer of these MRV technologies is ultimately expected to be mCDR project developers, who will be responsible for data acquisition and reporting to carbon registries before the final issuance of carbon credits for mCDR activities.

Potential commercialization frameworks may include, but are not limited to, the following: a) licensing novel marine carbon sensor designs to established oceanographic sensor manufacturers; b) direct sales of MRV models or devices, perhaps through manufacturing partnerships with established marine platform developers; c) offering end-to-end MRV solutions as a Data-as-a-Service (DaaS) or Equipment-as-a-Service (EaaS) provider.

Strong submissions are likely to include:

- Team members with commercialization expertise.
- A high-level technology-to-market strategy, including a preliminary IP whitespace analysis.
- Partnerships with carbon market entities and ocean observing organizations.
- Considerations for the technical area of focus, as described below.

1. T2M Considerations for Technical Area 1: Sensors

The primary use-case of the marine carbon sensing capabilities developed through this program will be to support and potentially accelerate the adoption of mCDR technologies by validating the scientific and technical efficacy of engineered mCDR processes. This validation will likely require teams to partner with NGOs and/or other research groups that need robust carbon accounting technologies to track carbon fluxes and sequestration in their pilot or demonstration scale mCDR projects.

mCDR MRV will require sensing technologies that are economically suitable for collecting continuous data across large areas, substantial depths, and over long durations. Therefore, the sensing capabilities developed under this program will also be valuable to existing ocean observing programs, which may be a first market for these technologies until the mCDR industry reaches commercial and regulatory maturity. Ocean observing is primarily driven by government, academic, and philanthropic funding, where autonomous, low-cost, persistent, and scalable sensing solutions are desirable. Robust marine carbon sensing capabilities applied to ocean observing will contribute to broader scientific efforts to baseline natural carbon fluxes and model climate change-influenced processes in the ocean. Collecting data about natural marine carbon pathways will serve the future mCDR industry by defining the baselines from which engineered processes can be measured or estimated (i.e., “additionality”). Therefore, teams will be encouraged to consult with national/regional/local ocean observing programs to potentially address additional technical requirements that do not conflict with the primary use-case (i.e., mCDR MRV).

2. T2M Considerations for Technical Area 2: Models

The high-growth commercialization potential for MRV technologies is based in measuring/verifying the quantity, additionality, and durability of carbon dioxide removals for valuation in carbon markets. Ascribing value in carbon markets will require direct measurements, modeling capabilities, as well as vetted protocols that define the methods/metrics by which carbon dioxide removals are translated into validated carbon credits with tangible financial value in the marketplace. Modeling teams will be encouraged to coordinate with an existing carbon market entity of their choosing as a project team member to co-develop a high-level MRV framework for the mCDR approach of focus. These vetted frameworks can then serve as foundations for future full-fledged carbon registry protocols, which will support market adoption of the mCDR industry. Collaboration with carbon market entities should inform model development and refinement by defining the input/output parameters most important for valorization.

G. LEVERAGING COLLABORATION WITH MCDR PROGRAM EFFORTS

While this program does not seek to fund mCDR development itself, ARPA-E is aware of several other government and non-government funding efforts that seek to understand, develop, and implement mCDR technology. ARPA-E has coordinated with the agencies participating in the recent National Oceanographic Partnership Program (NOPP) call for mCDR implementation[36] and development. ARPA-E encourages collaborations between teams working in these areas in order to coordinate technology leveraging, sea tests, and information sharing.

H. TEAM EXPECTATIONS

TA1 teams are encouraged to include the following roles on their project teams. These are not intended to be mandates and are only suggestions for team composition.

- Sensor development experts who would perform the core technical development work
- Oceanographic instrumentation experts who would marinize the sensor technology, adapt it to the constraints associated with COTS ocean data collection platforms, and conduct tests in ocean conditions
- Marine biology and biogeochemical experts who could advise on sensor specifications, and perform analysis and interpretation of acquired data
- Project management and administrative staff

It is recommended that TA1 teams incorporate partners with ready access to both sensor fabrication and maritime testing facilities in environments generally representative of mCDR-appropriate regions for the anticipated rapid testing and iteration of sensor development and maturation in Phase 2.

TA2 teams are encouraged to include the following roles on their project teams. These are not intended to be mandates and are only suggestions for team composition.

- Regional Ocean Modeling Systems (ROMS) experts
- Ocean biogeochemical modeling experts
- Marine biology and biogeochemical experts

[36] https://nopp.org/2022/marine-carbon-dioxide-removal-mcdr-research-and-development-for-assessing-large-scale-carbon-removal-and-local-scale-ocean-acidification-mitigationdepartment-of-commerce/

- Carbon registry and/or carbon marketplace experts
- Project management, administrative, data handling and IT support staff

I. Collaboration Requirements

Addressing the disposition of IP as between team members of a specific award is required (see Section VI.B.7, IP and Data Management Plan). A legal agreement between TA1 and TA2 project teams that collaborate will also be required to address the disposition of IP as between the collaborating teams subject to the restrictions set forth above in Section I.C.1. A single agreement among all these collaborating parties is also satisfactory.

J. Data Storage and Access Plan

At the Full Application stage, applicants must provide a detailed data storage and access plan that describes how curated data and metadata collected through the project funding will be archived and made publicly available without restriction on further use for the purposes of transparency and peer review. Data storage and access plans must be based on standards, best practices, and follow the FAIR Guiding Principles (findable, accessible, interoperable, and reusable). Teams should plan to store their data in a long-term archive and the costs for data management, archiving, and access should be clearly articulated in the budget and reflected in the total project cost. If applicable, applicants at the Full Application stage will be encouraged to address how historical or legacy data will be integrated into the project. Applicants that propose to collaborate with data centers or networks are advised to obtain letters of commitment that affirm the collaboration. Where possible, all applicants are strongly encouraged to use existing data centers and data portals to archive and disseminate their data. Applicants will provide the widest practical access to data collected under this program and the data storage and access plan must describe how these requirements will be satisfied.

With a full application, the data storage and access plan should be submitted as a separate section of up to two pages describing the types of data and information expected to be generated during the course of the project; the target date by which data will be shared and archived; policies addressing data stewardship and preservation; procedures for providing data access and security; prior experience in publishing such data; and an indication of the project member/level of funding dedicated for the data management components of the project. Submissions should identify one or more members of the team to document and archive data in accordance with the plan and to ensure that the data products are made available via open access portals and data platform.

Once an award has been finalized this data storage and access and storage plan may be included in the IP and Data Management Plan described at Section VI.B.7 that is required during award performance.

II. Award Information

A. Award Overview

ARPA-E expects to make approximately $45 million available for new awards, subject to the availability of appropriated funds. ARPA-E anticipates making approximately 6-12 awards under this FOA. ARPA-E may, at its discretion, issue one, multiple, or no awards.

Individual awards may vary between $500,000 and $10 million in Federal share.

The period of performance for funding agreements may not exceed 36 months. ARPA-E expects to issue funding agreements in January 2024, or as negotiated.

ARPA-E encourages submissions stemming from ideas that still require proof-of-concept R&D efforts as well as those for which some proof-of-concept demonstration already exists.

Submissions requiring proof-of-concept R&D can propose a project with the goal of delivering on the program metric at the conclusion of the period of performance. These submissions must contain an appropriate cost and project duration plan that is described in sufficient technical detail to allow reviewers to meaningfully evaluate the proposed project. If awarded, such projects should expect a rigorous go/no-go milestone early in the project associated with the proof-of-concept demonstration. Alternatively, submissions requiring proof-of-concept R&D can propose a project with the project end deliverable being an extremely creative, but partial solution. However, the Applicants are required to provide a convincing vision how these partial solutions can enable the realization of the program metrics with further development.

Applicants proposing projects for which some initial proof-of-concept demonstration already exists should submit concrete data that supports the probability of success of the proposed project.

ARPA-E will provide support at the highest funding level only for submissions with significant technology risk, aggressive timetables, and careful management and mitigation of the associated risks.

ARPA-E will accept only new submissions under this FOA. Applicants may not seek renewal or supplementation of their existing awards through this FOA.

ARPA-E plans to fully fund the negotiated budget at the time of award.

B. Renewal Awards

At ARPA-E's sole discretion, awards resulting from this FOA may be renewed by adding one or more budget periods, extending the period of performance of the initial award, or issuing a new award. Renewal funding is contingent on: (1) availability of funds appropriated by Congress for the purpose of this program; (2) substantial progress towards meeting the objectives of the approved application; (3) submittal of required reports; (4) compliance with the terms and conditions of the award; (5) ARPA-E approval of a renewal application; and (6) other factors identified by the Agency at the time it solicits a renewal application.

C. ARPA-E FUNDING AGREEMENTS

Through cooperative agreements, other transactions, and similar agreements, ARPA-E provides financial and other support to projects that have the potential to realize ARPA-E's statutory mission. ARPA-E does not use such agreements to acquire property or services for the direct benefit or use of the U.S. Government.

Congress directed ARPA-E to "establish and monitor project milestones, initiate research projects quickly, and just as quickly terminate or restructure projects if such milestones are not achieved."[37] Accordingly, ARPA-E has substantial involvement in the direction of every Cooperative Agreement, as described in Section II.D below.

1. COOPERATIVE AGREEMENTS

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients.[38]

Cooperative Agreements involve the provision of financial or other support to accomplish a public purpose of support or stimulation authorized by Federal statute. Under Cooperative Agreements, the Government and Prime Recipients share responsibility for the direction of projects.

ARPA-E encourages Prime Recipients to review the Model Cooperative Agreement, which is available at https://arpa-e.energy.gov/technologies/project-guidance.

2. FUNDING AGREEMENTS WITH FFRDCS/DOE LABS, GOGOS, AND FEDERAL INSTRUMENTALITIES

Any Federally Funded Research and Development Centers (FFRDC) involved as a member of a Project Team must provide the information requested in the "FFRDC Lab Authorization" and "Field Work Proposal" section of the Business Assurances & Disclosures Form, which is submitted with the Applicant's Full Application.

When a FFRDC/DOE Lab (including the National Energy Technology Laboratory or NETL) is the

[37] U.S. Congress, Conference Report to accompany the 21st Century Competitiveness Act of 2007, H. Rpt. 110-289 at 171-172 (Aug. 1, 2007).
[38] The Prime Recipient is the signatory to the funding agreement with ARPA-E.

lead organization for a Project Team, ARPA-E executes a funding agreement directly with the FFRDC/DOE Lab and a single, separate Cooperative Agreement with another entity on the Project Team. Notwithstanding the use of multiple agreements, the FFRDC/DOE Lab is the lead organization for the entire project, including all work performed by the FFRDC/DOE Lab and the rest of the Project Team.

When a FFRDC/DOE Lab is a *member* of a Project Team, ARPA-E executes a funding agreement directly with the FFRDC/DOE Lab and a single, separate Cooperative Agreement with the Prime Recipient, as the lead organization for the Project Team. Notwithstanding the use of multiple agreements, the Prime Recipient under the Cooperative Agreement is the lead organization for the entire project, including all work performed by the FFRDC/DOE Lab and the rest of the Project Team.

Funding agreements with DOE/NNSA FFRDCs take the form of Work Authorizations issued to DOE/NNSA FFRDCs through the DOE/NNSA Field Work Proposal system for work performed under Department of Energy Management & Operation Contracts. Funding agreements with non-DOE/NNSA FFRDCs, GOGOs (including NETL), and Federal instrumentalities (e.g., Tennessee Valley Authority) will be consistent with the sponsoring agreement between the U.S. Government and the Laboratory. Any funding agreement with an FFRDC or GOGO will have similar terms and conditions as ARPA-E's Model Cooperative Agreement (https://arpa-e.energy.gov/technologies/project-guidance/pre-award-guidance/funding-agreements).

Non-DOE GOGOs and Federal agencies may be proposed to provide support to the Project Team members on an applicant's project, through a Cooperative Research and Development Agreement (CRADA) or similar agreement.

3. OTHER TRANSACTIONS AUTHORITY

ARPA-E may use its "other transactions" authority under the America COMPETES Reauthorization Act of 2010 and DOE's other transactions authority as codified at 42 USC §7256 to enter into an other transaction agreement with Prime Recipients, on a case-by-case basis.

ARPA-E may negotiate an other transaction agreement when it determines that the use of a standard cooperative agreement, grant, or contract is not feasible or appropriate for a project.

In general, an other transaction agreement normally requires a minimum cost share of 50%. See Section III.B.2 of the FOA.

D. STATEMENT OF SUBSTANTIAL INVOLVEMENT

ARPA-E is substantially involved in the direction of projects from inception to completion. For the purposes of an ARPA-E project, substantial involvement means:

- Project Teams must adhere to ARPA-E's agency-specific and programmatic requirements.
- ARPA-E may intervene at any time in the conduct or performance of work under an award.
- ARPA-E does not limit its involvement to the administrative requirements of an award. Instead, ARPA-E has substantial involvement in the direction and redirection of the technical aspects of the project as a whole.
- ARPA-E may, at its sole discretion, modify or terminate projects that fail to achieve predetermined Go/No Go decision points or technical milestones and deliverables.
- During award negotiations, ARPA-E Program Directors and Prime Recipients mutually establish an aggressive schedule of quantitative milestones and deliverables that must be met every quarter. In addition, ARPA-E will negotiate and establish "Go/No-Go" milestones for each project. If the Prime Recipient fails to achieve any of the "Go/No-Go" milestones or technical milestones and deliverables as determined by the ARPA-E Contracting Officer, ARPA-E may – at its discretion - renegotiate the statement of project objectives or schedule of technical milestones and deliverables for the project. In the alternative, ARPA-E may suspend or terminate the award in accordance with 2 C.F.R. §§ 200.339 – 200.343.
- ARPA-E may provide guidance and/or assistance to the Prime Recipient to accelerate the commercial deployment of ARPA-E-funded technologies. Guidance and assistance provided by ARPA-E may include coordination with other Government agencies and nonprofits[39] to provide mentoring and networking opportunities for Prime Recipients. ARPA-E may also organize and sponsor events to educate Prime Recipients about key barriers to the deployment of their ARPA-E-funded technologies. In addition, ARPA-E may establish collaborations with private and public entities to provide continued support for the development and deployment of ARPA-E-funded technologies.

[39] The term "nonprofit organization" or "nonprofit" is defined in Section IX.

III. Eligibility Information

A. Eligible Applicants

This FOA is open to U.S. universities, national laboratories, industry and individuals.

1. Individuals

U.S. citizens or permanent residents may apply for funding in their individual capacity as a Standalone Applicant,[40] as the lead for a Project Team,[41] or as a member of a Project Team. However, ARPA-E will only award funding to an entity formed by the Applicant.

2. Domestic Entities

For-profit entities[42], educational institutions[43], and nonprofits[44] that are incorporated in the United States, including U.S. territories, are eligible to apply for funding as a Standalone Applicant, as the lead organization for a Project Team, or as a member of a Project Team.

FFRDCs/DOE Labs are eligible to apply for funding as the lead organization for a Project Team or as a member of a Project Team that includes institutions of higher education, companies, research foundations, or trade and industry research collaborations, but not as a Standalone Applicant.

State, local, and tribal government entities are eligible to apply for funding as a member of a Project Team, but not as a Standalone Applicant or as the lead organization for a Project Team.

Federal agencies and instrumentalities (other than DOE) are eligible to apply for funding as a member of a Project Team, but not as a Standalone Applicant or as the lead organization for a Project Team.

3. Foreign Entities

Foreign entities, whether for-profit or otherwise, are eligible to apply for funding as Standalone Applicants, as the lead organization for a Project Team, or as a member of a Project Team.

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[40] A Standalone Applicant is an Applicant that applies for funding on its own, not as part of a Project Team.
[41] A Project Team consists of the Prime Recipient, Subrecipients, and others performing or otherwise supporting work under an ARPA-E funding agreement.
[42] For-Profit Organizations (Other than Small Businesses) (or *large businesses*): Means entities organized for-profit other than small businesses as defined elsewhere in this Glossary.
[43] Institutions of Higher Education (or educational institutions): Has the meaning set forth at 20 U.S.C. 1001.
[44]Nonprofit organizations described in section 501(c)(4) of the Internal Revenue Code of 1986 that engaged in lobbying activities after December 31, 1995 are not eligible to apply for funding as a Prime Recipient or Subrecipient.

Foreign entities must designate in the Full Application a subsidiary or affiliate incorporated (or otherwise formed or to be formed) under the laws of a State or territory of the United States to receive funding. The Full Application must state the nature of the corporate relationship between the foreign entity and domestic subsidiary or affiliate. All work under the ARPA-E award must be performed in the United States. The Applicant may request a waiver of this requirement in the Business Assurances & Disclosures Form, which is submitted with the Full Application and can be found at https://arpa-e-foa.energy.gov/ (see "View Template Application Documents"). Refer to the Business Assurances & Disclosures Form for guidance on the content and form of the request.

4. Consortium Entities

Consortia, which may include domestic and foreign entities, must designate one member of the consortium as the consortium representative to the Project Team. The consortium representative must be incorporated in the United States. The eligibility of the consortium will be determined by reference to the eligibility of the consortium representative under Section III.A of the FOA. Each consortium must have an internal governance structure and a written set of internal rules. Upon request, the consortium entity must provide a written description of its internal governance structure and its internal rules to the Contracting Officer (ARPA-E-CO@hq.doe.gov).

Unincorporated consortia must provide the Contracting Officer with a collaboration agreement, commonly referred to as the articles of collaboration, which sets out the rights and responsibilities of each consortium member. This collaboration agreement binds the individual consortium members together and shall include the consortium's:

- Management structure;
- Method of making payments to consortium members;
- Means of ensuring and overseeing members' efforts on the project;
- Provisions for members' cost sharing contributions; and
- Provisions for ownership and rights in intellectual property developed previously or under the agreement.

B. Cost Sharing[45]

Applicants are bound by the cost share proposed in their Full Applications.

1. Base Cost Share Requirement

ARPA-E generally uses Cooperative Agreements to provide financial and other support to Prime Recipients (see Section II.C.1 of the FOA). Under a Cooperative Agreement or Grant, the Prime

[45] Please refer to Section VI.B.3-4 of the FOA for guidance on cost share payments and reporting.

Recipient must provide at least 20% of the Total Project Cost[46] as cost share, except as provided in Sections III.B2 or III.B.3 below.[47]

2. Increased Cost Share Requirement

Large businesses[48] are strongly encouraged to provide more than 20% of the Total Project Cost as cost share. ARPA-E may consider the amount of cost share proposed when selecting applications for award negotiations (see Section V.B.1 of the FOA).

Under an "other transaction" agreement, the Prime Recipient is normally expected to provide at least 50% of the Total Project Cost as cost share. ARPA-E may reduce this cost share requirement, as appropriate.

3. Reduced Cost Share Requirement

ARPA-E has reduced the base cost share requirement for the following types of projects:

- A domestic educational institution or domestic nonprofit applying as a Standalone Applicant is required to provide at least 5% of the Total Project Cost as cost share.

- Project Teams composed exclusively of domestic educational institutions, domestic nonprofits, and/or FFRDCs/DOE Labs/Federal agencies and instrumentalities (other than DOE) are required to provide at least 5% of the Total Project Cost as cost share. Small businesses – or consortia of small businesses – may provide 0% cost share from the outset of the project through the first 12 months of the project (hereinafter the "Cost Share Grace Period").[49] If the project is continued beyond the Cost Share Grace Period, then at least 10% of the Total Project Cost (including the costs incurred during the Cost Share Grace Period) will be required as cost share over the remaining period of performance.

- Project Teams where a small business is the lead organization and small businesses perform greater than or equal to 80% of the total work under the funding agreement (as measured by the Total Project Cost) are entitled to the same cost share reduction and Cost Share Grace Period as provided above to Standalone small businesses or consortia of small businesses.

[46] The Total Project Cost is the sum of the Prime Recipient share and the Federal Government share of total allowable costs. The Federal Government share generally includes costs incurred by GOGOs and FFRDCs.
[47] Energy Policy Act of 2005, Pub.L. 109-58, sec. 988(c)
[48] The term "For-Profit Organizations (Other than Small Businesses)" or "large business" is defined in Section IX.
[49] The term "small business" is defined in Section IX.

- Project Teams where domestic educational institutions, domestic nonprofits, small businesses, and/or FFRDCs perform greater than or equal to 80% of the total work under the funding agreement (as measured by the Total Project Cost) are required to provide at least 10% of the Total Project Cost as cost share. However, any entity (such as a large business) receiving patent rights under a class waiver, or other patent waiver, that is part of a Project Team receiving this reduction must continue to meet the statutory minimum cost share requirement (20%) for its portion of the Total Project Cost.

- Projects that do not meet any of the above criteria are subject to the base cost share requirements described in Sections III.B.1 and III.B.2 of the FOA.

4. Legal Responsibility

Although the cost share requirement applies to the Project Team as a whole, the funding agreement makes the Prime Recipient legally responsible for paying, or ensuring payment of the entire cost share. The Prime Recipient's cost share obligation is expressed in the funding agreement as a static amount in U.S. dollars (cost share amount) and as a percentage of the Total Project Cost (cost share percentage). If the funding agreement is terminated prior to the end of the period of performance, the Prime Recipient is required to contribute at least the cost share percentage of total expenditures incurred through the date of termination.

The Prime Recipient is solely responsible for managing cost share contributions by the Project Team and enforcing cost share obligations assumed by Project Team members in subawards or related agreements.

5. Cost Share Allocation

Each Project Team is free to determine how much each Project Team member will contribute towards the cost share requirement. The amount contributed by individual Project Team members may vary, as long as the cost share requirement for the project as a whole is met.

6. Cost Share Types and Allowability

Every cost share contribution must be allowable under the applicable Federal cost principles, as described in Section IV.G of the FOA.

Project Teams may provide cost share in the form of cash or in-kind contributions. Cash contributions may be provided by the Prime Recipient or Subrecipients. Allowable in-kind contributions include but are not limited to personnel costs, indirect costs, facilities and administrative costs, rental value of buildings or equipment, and the value of a service, other resource, or third party in-kind contribution. Project Teams may use funding or property received from state or local governments to meet the cost share requirement, so long as the funding or property was not provided to the state or local government by the Federal Government.

The Prime Recipient may not use the following sources to meet its cost share obligations:

- Revenues or royalties from the prospective operation of an activity beyond the period of performance;
- Proceeds from the prospective sale of an asset of an activity;
- Appropriated Federal funding or property (e.g., Federal grants, equipment owned by the Federal Government); or
- Expenditures that were reimbursed under a separate Federal program.

In addition, Project Teams may not use independent research and development (IR&D) funds[50] to meet their cost share obligations under Cooperative Agreements. However, Project Teams may use IR&D funds to meet their cost share obligations under "other transaction" agreements.

Project Teams may not use the same cash or in-kind contributions to meet cost share requirements for more than one project or program.

Cost share contributions must be specified in the project budget, verifiable from the Prime Recipient's records, and necessary and reasonable for proper and efficient accomplishment of the project. Every cost share contribution must be reviewed and approved in advance by the Contracting Officer and incorporated into the project budget before the expenditures are incurred.

Applicants may wish to refer to 2 C.F.R. Parts 200 and 910, and 10 C.F.R Part 603 for additional guidance on cost sharing, specifically 2 C.F.R. §§ 200.306 and 910.130, and 10 C.F.R. §§ 603.525-555.

7. COST SHARE CONTRIBUTIONS BY FFRDCS AND GOGOS

Because FFRDCs are funded by the Federal Government, costs incurred by FFRDCs generally may not be used to meet the cost share requirement. FFRDCs may contribute cost share only if the contributions are paid directly from the contractor's Management Fee or a non-Federal source.

Because GOGOs/Federal Agencies are funded by the Federal Government, GOGOs/Federal Agencies may not provide cost share for the proposed project. However, the GOGO/Agency costs would be included in Total Project Costs for purposes of calculating the cost-sharing requirements of the applicant.

[50] As defined in Federal Acquisition Regulation SubSection 31.205-18.

8. Cost Share Verification

Upon selection for award negotiations, Applicants are required to provide information and documentation regarding their cost share contributions. Please refer to Section VI.B.3 of the FOA for guidance on the requisite cost share information and documentation.

C. Other

1. Compliant Criteria

Concept Papers are deemed compliant if:

- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Concept Paper complies with the content and form requirements in Section IV.C of the FOA; and
- The Applicant entered all required information, successfully uploaded all required documents, and clicked the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA.

Concept Papers found to be noncompliant may not be merit reviewed or considered for award. ARPA-E may not review or consider noncompliant Concept Papers, including Concept Papers submitted through other means, Concept Papers submitted after the applicable deadline, and incomplete Concept Papers. A Concept Paper is incomplete if it does not include required information. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.

Full Applications are deemed compliant if:

- The Applicant submitted a compliant and responsive Concept Paper;
- The Applicant meets the eligibility requirements in Section III.A of the FOA;
- The Full Application complies with the content and form requirements in Section IV.D of the FOA; and
- The Applicant entered all required information, successfully uploaded all required documents, and clicked the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA.

Full Applications found to be noncompliant may not be merit reviewed or considered for award. ARPA-E may not review or consider noncompliant Full Applications, including Full Applications submitted through other means, Full Applications submitted after the applicable deadline, and incomplete Full Applications. A Full Application is incomplete if it does not include required information and documents, such as Forms SF-424 and SF-424A. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.

Replies to Reviewer Comments are deemed compliant if:

- The Applicant successfully uploads its response to ARPA-E eXCHANGE by the deadline stated in the FOA; and
- The Replies to Reviewer Comments comply with the content and form requirements of Section IV.E of the FOA.

ARPA-E will not review or consider noncompliant Replies to Reviewer Comments, including Replies submitted through other means and Replies submitted after the applicable deadline. ARPA-E will not extend the submission deadline for Applicants that fail to submit required information due to server/connection congestion. ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be noncompliant.

2. RESPONSIVENESS CRITERIA

ARPA-E performs a preliminary technical review of Concept Papers and Full Applications. The following types of submissions may be deemed nonresponsive and may not be reviewed or considered:

- Submissions that fall outside the technical parameters specified in this FOA.
- Submissions that have been submitted in response to currently issued ARPA-E FOAs.
- Submissions that are not scientifically distinct from applications submitted in response to currently issued ARPA-E FOAs.
- Submissions for basic research aimed solely at discovery and/or fundamental knowledge generation.
- Submissions for large-scale demonstration projects of existing technologies.
- Submissions for proposed technologies that represent incremental improvements to existing technologies.
- Submissions for proposed technologies that are not based on sound scientific principles (e.g., violates a law of thermodynamics).
- Submissions for proposed technologies that are not transformational, as described in Section I.A of the FOA.
- Submissions for proposed technologies that do not have the potential to become disruptive in nature, as described in Section I.A of the FOA. Technologies must be scalable such that they could be disruptive with sufficient technical progress.
- Submissions that are not distinct in scientific approach or objective from activities currently supported by or actively under consideration for funding by any other office within Department of Energy.
- Submissions that are not distinct in scientific approach or objective from activities currently supported by or actively under consideration for funding by other government agencies or the private sector.
- Submissions that do not propose a R&D plan that allows ARPA-E to evaluate the submission under the applicable merit review criteria provided in Section V.A of the FOA.

3. Submissions Specifically not of Interest

Submissions that propose the following will be deemed nonresponsive and will not be merit reviewed or considered:

ARPA-E programs fund high-risk, potentially disruptive new technology development efforts that may presently be unattractive to follow-on funding groups due to the number of unknowns, risk of failure, or uncertainty regarding performance. As such, ARPA-E is not interested in submissions that propose work that could be described as the following:

- Exclusively existing ocean sensor technologies for parameters listed in **Table 2** used in a new application.
- Submissions describing incremental improvements to existing sensing or modeling systems.
- Efforts to coordinate the scientific community that do not emphasize specific proposed technological development as the primary directive.
- Sensor technologies not conducive to spatially scaled, volumetric or area-sensing strategies.
- Sensors designed to mount on disposable platforms, or disposable sensors themselves (apart from ARGO).
- Sensor platform technology development.
- Submissions consisting of significant policy and regulatory framework in the absence of new sensor technology.
- Investigations that prioritize non-monetary environmental impacts (i.e., measurements that do not serve to directly quantify the number of, quality of, and duration of potential carbon credits earned).
- Regional or Global CDR models or vignettes outside of the U.S. Exclusive Economic Zone (EEZ), unless submissions are led by a U.S. institution and a clear mechanism exists for the valorization of potential carbon credits earned outside the U.S. EEZ in a U.S. carbon market by a U.S. entity. Note that ARPA-E is open to submissions from international teams, but the lead organization must be a U.S. based group eligible to receive federal funding.
- MRV approaches for mCDR techniques that cannot reasonably scale to 100s of megatons to 1 gigaton per year carbon drawdown, or for mCDR techniques that cannot be shown to remove CO_2 from the atmosphere and surface ocean for periods of time exceeding 100 years at minimum.
- MRV for CDR methods that are not ocean-based.

4. Limitation on Number of Submissions

ARPA-E is not limiting the number of submissions from Applicants. Applicants may submit more than one application to this FOA, provided that each application is scientifically distinct.

IV. Application and Submission Information

A. Application Process Overview

1. Registration in ARPA-E eXCHANGE

The first step in applying to this FOA is registration in ARPA-E eXCHANGE, ARPA-E's online application portal. For detailed guidance on using ARPA-E eXCHANGE, please refer to Section IV.H.1 of the FOA and the "ARPA-E eXCHANGE User Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

2. Concept Papers

Applicants must submit a Concept Paper by the deadline stated in the FOA. Section IV.C of the FOA provides instructions on submitting a Concept Paper.

ARPA-E performs a preliminary review of Concept Papers to determine whether they are compliant and responsive, as described in Section III.C of the FOA. Concept Papers found to be noncompliant or nonresponsive may not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Concept Paper based on the criteria and program policy factors in Sections V.A.1 and V.B.1 of the FOA.

ARPA-E will encourage a subset of Applicants to submit Full Applications. Other Applicants will be discouraged from submitting a Full Application in order to save them the time and expense of preparing an application submission that is unlikely to be selected for award negotiations. By discouraging the submission of a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. Unsuccessful Applicants should continue to submit innovative ideas and concepts to future FOAs.

3. Full Applications

Applicants must submit a Full Application by the deadline stated in the FOA. Applicants will have approximately 45 days from receipt of the Encourage/Discourage notification to prepare and submit a Full Application. Section IV.D of the FOA provides instructions on submitting a Full Application.

ARPA-E performs a preliminary review of Full Applications to determine whether they are compliant and responsive, as described in Section III.C of the FOA. Full Applications found to be noncompliant or nonresponsive may not be merit reviewed or considered for award. ARPA-E makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.2 and V.B.1 of the FOA.

4. REPLY TO REVIEWER COMMENTS

Once ARPA-E has completed its review of Full Applications, reviewer comments on compliant and responsive Full Applications are made available to Applicants via ARPA-E eXCHANGE. Applicants may submit an optional Reply to Reviewer Comments, which must be submitted by the deadline stated in the FOA. Section IV.E of the FOA provides instructions on submitting a Reply to Reviewer Comments.

ARPA-E performs a preliminary review of Replies to determine whether they are compliant, as described in Section III.C.1 of the FOA. ARPA-E will review and consider compliant Replies only. ARPA-E will review and consider each compliant and responsive Full Application, even if no Reply is submitted or if the Reply is found to be non-compliant.

5. PRE-SELECTION CLARIFICATIONS AND "DOWN-SELECT" PROCESS

Once ARPA-E completes its review of Full Applications and Replies to Reviewer Comments, it may, at the Contracting Officer's discretion, conduct a pre-selection clarification process and/or perform a "down-select" of Full Applications. Through the pre-selection clarification process or down-select process, ARPA-E may obtain additional information from select Applicants through pre-selection meetings, webinars, videoconferences, conference calls, written correspondence, or site visits that can be used to make a final selection determination. ARPA-E will not reimburse Applicants for travel and other expenses relating to pre-selection meetings or site visits, nor will these costs be eligible for reimbursement as pre-award costs.

ARPA-E may select applications for award negotiations and make awards without pre-selection meetings and site visits. Participation in a pre-selection meeting or site visit with ARPA-E does not signify that Applicants have been selected for award negotiations.

6. SELECTION FOR AWARD NEGOTIATIONS

ARPA-E carefully considers all of the information obtained through the application process and makes an independent assessment of each compliant and responsive Full Application based on the criteria and program policy factors in Sections V.A.2 and V.B.1 of the FOA. The Selection Official may select all or part of a Full Application for award negotiations. The Selection Official may also postpone a final selection determination on one or more Full Applications until a later date, subject to availability of funds and other factors. ARPA-E will enter into award negotiations only with selected Applicants.

Applicants are promptly notified of ARPA-E's selection determination. ARPA-E may stagger its selection determinations. As a result, some Applicants may receive their notification letter in advance of other Applicants. Please refer to Section VI.A of the FOA for guidance on award notifications.

B. Application Forms

Required forms for Full Applications are available on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov), including the SF-424 and Budget Justification Workbook/SF-424A. A sample Summary Slide is available on ARPA-E eXCHANGE. Applicants may use the templates available on ARPA-E eXCHANGE, including the template for the Concept Paper, the template for the Technical Volume of the Full Application, the template for the Summary Slide, the template for the Summary for Public Release, the template for the Reply to Reviewer Comments, and the template for the Business Assurances & Disclosures Form. A sample response to the Business Assurances & Disclosures Form is available on ARPA-E eXCHANGE.

C. Content and Form of Concept Papers

The Concept Paper is mandatory (i.e. in order to submit a Full Application, a compliant and responsive Concept Paper must have been submitted) and must conform to the following formatting requirements:

- The Concept Paper (Sections 1a – 1d below) must not exceed 4 pages in length including graphics, figures, and/or tables.
- Concept Paper Appendices (Sections 1e and 1f below) must each not exceed 1 page, including graphics, figures, and/or tables, for a total maximum of two (2) pages in length for appendices.
- The Concept Paper must be submitted in Adobe PDF format.
- The Concept Paper must be written in English.
- All pages must be formatted to fit on 8-1/2 by 11 inch paper with margins not less than one inch on every side. Single space all text and use Times New Roman typeface, a black font color, and a font size of 12 point or larger (except in figures and tables).
- The ARPA-E assigned Control Number, the Lead Organization Name, and the Principal Investigator's Last Name must be prominently displayed on the upper right corner of the header of every page. Page numbers must be included in the footer of every page.
- The first paragraph must include the Lead Organization's Name and Location, Principal Investigator's Name, Technical Category, Proposed Funding Requested (Federal and Cost Share), and Project Duration.

Concept Papers found to be noncompliant or nonresponsive may not be merit reviewed or considered for award (see Section III.C of the FOA).

Each Concept Paper must be limited to a single concept or technology. Unrelated concepts and technologies must not be consolidated into a single Concept Paper.

A fillable Concept Paper template is available on ARPA-E eXCHANGE at https://arpa-e-foa.energy.gov.

Concept Papers must conform to the content requirements described below. If Applicants exceed the maximum page length indicated above, ARPA-E will review only the authorized number of pages and disregard any additional pages.

1. Concept Paper

a. Concept Summary

- Describe the proposed concept with minimal jargon, and explain how it addresses the Program Objectives of the FOA.

b. Innovation and Impact

- Clearly identify the problem to be solved with the proposed technology concept.
- Describe how the proposed effort represents an innovative and potentially transformational solution to the technical challenges posed by the FOA.
- Explain the concept's potential to be disruptive compared to existing or emerging technologies.
- To the extent possible, provide quantitative metrics in a table that compares the proposed technology concept to current and emerging technologies and to the Technical Performance Targets in Section I.E of the FOA for the appropriate Technology Category in Section I.D of the FOA.

c. Proposed Work

- Describe the final deliverable(s) for the project and the overall technical approach used to achieve project objectives.
- Discuss alternative approaches considered, if any, and why the proposed approach is most appropriate for the project objectives.
- Describe the background, theory, simulation, modeling, experimental data, or other sound engineering and scientific practices or principles that support the proposed approach. Provide specific examples of supporting data and/or appropriate citations to the scientific and technical literature.
- Describe why the proposed effort is a significant technical challenge and the key technical risks to the project. Does the approach require one or more entirely new technical developments to succeed? How will technical risk be mitigated?
- Identify techno-economic challenges to be overcome for the proposed technology to be commercially relevant.
- Estimated federal funds requested; total project cost including cost sharing.

d. Team Organization and Capabilities

- Indicate the roles and responsibilities of the organizations and key personnel that comprise the Project Team.
- Provide the name, position, and institution of each key team member and describe in 1-2 sentences the skills and experience that he/she brings to the team.
- Identify key capabilities provided by the organizations comprising the Project Team and how those key capabilities will be used in the proposed effort.
- Identify (if applicable) previous collaborative efforts among team members relevant to the proposed effort.

e. Appendix 1: mCDR Approaches

- Please provide an additional 1-page description of the mCDR approach(es) to which sensor concepts and/or model outputs may apply, including identification of regionally-constrained areas.

f. Appendix 2: Technical Area-Specific Content

- Technical Area 1 Only, include:
  - A hypothetical, forward-looking techno-economic analysis.
  - A description of proposed marine operations during Phase 2 of the project.
  - The commercial-off-the-shelf sensor platform of choice, with rationale.
- Technical Area 2 Only, include:
  - The significant and non-significant parameters for the team's chosen mCDR approach(es) from Table 2 in Section I.B of the FOA, with justification for each decision.

D. Content and Form of Full Applications

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

E. Content and Form of Replies to Reviewer Comments

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

F. Intergovernmental Review

This program is not subject to Executive Order 12372 (Intergovernmental Review of Federal Programs).

G. FUNDING RESTRICTIONS

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

H. OTHER SUBMISSION REQUIREMENTS

1. USE OF ARPA-E eXCHANGE

To apply to this FOA, Applicants must register with ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/Registration.aspx). Concept Papers, Full Applications, and Replies to Reviewer Comments must be submitted through ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx). ARPA-E will not review or consider applications submitted through other means (e.g., fax, hand delivery, email, postal mail). For detailed guidance on using ARPA-E eXCHANGE, please refer to the "ARPA-E eXCHANGE Applicant Guide" (https://arpa-e-foa.energy.gov/Manuals.aspx).

Upon creating an application submission in ARPA-E eXCHANGE, Applicants will be assigned a Control Number. If the Applicant creates more than one application submission, a different Control Number will be assigned for each application.

Once logged in to ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/login.aspx), Applicants may access their submissions by clicking the "My Submissions" link in the navigation on the left side of the page. Every application that the Applicant has submitted to ARPA-E and the corresponding Control Number is displayed on that page. If the Applicant submits more than one application to a particular FOA, a different Control Number is shown for each application.

Applicants are responsible for meeting each submission deadline in ARPA-E eXCHANGE. **Applicants are strongly encouraged to submit their applications at least 48 hours in advance of the submission deadline.** Under normal conditions (i.e., at least 48 hours in advance of the submission deadline), Applicants should allow at least 1 hour to submit a Concept Paper, or Full Application. In addition, Applicants should allow at least 15 minutes to submit a Reply to Reviewer Comments. Once the application is submitted in ARPA-E eXCHANGE, Applicants may revise or update their application until the expiration of the applicable deadline.

Applicants should not wait until the last minute to begin the submission process. During the final hours before the submission deadline, Applicants may experience server/connection congestion that prevents them from completing the necessary steps in ARPA-E eXCHANGE to submit their applications. **ARPA-E will not extend the submission deadline for Applicants that fail to submit required information and documents due to server/connection congestion.**

ARPA-E may not review or consider incomplete applications and applications received after the deadline stated in the FOA. Such applications may be deemed noncompliant (see Section

III.C.1 of the FOA). The following errors could cause an application to be deemed "incomplete" and thus noncompliant:

- Failing to comply with the form and content requirements in Section IV of the FOA;
- Failing to enter required information in ARPA-E eXCHANGE;
- Failing to upload required document(s) to ARPA-E eXCHANGE;
- Failing to click the "Submit" button in ARPA-E eXCHANGE by the deadline stated in the FOA;
- Uploading the wrong document(s) or application(s) to ARPA-E eXCHANGE; and
- Uploading the same document twice, but labeling it as different documents. (In the latter scenario, the Applicant failed to submit a required document.)

ARPA-E urges Applicants to carefully review their applications and to allow sufficient time for the submission of required information and documents.

V. APPLICATION REVIEW INFORMATION

A. CRITERIA

ARPA-E performs a preliminary review of Concept Papers and Full Applications to determine whether they are compliant and responsive (see Section III.C of the FOA). ARPA-E also performs a preliminary review of Replies to Reviewer Comments to determine whether they are compliant.

ARPA-E considers a mix of quantitative and qualitative criteria in determining whether to encourage the submission of a Full Application and whether to select a Full Application for award negotiations.

1. CRITERIA FOR CONCEPT PAPERS

(1) *Impact of the Proposed Technology Relative to FOA Targets* (50%) - This criterion involves consideration of the following:

- The potential for a transformational and disruptive (not incremental) advancement compared to existing or emerging technologies;
- Achievement of the technical performance targets defined in Section I.E of the FOA for the appropriate technology Category in Section I.D of the FOA;
- Identification of techno-economic challenges that must be overcome for the proposed technology to be commercially relevant; and
- Demonstration of awareness of competing commercial and emerging technologies and identifies how the proposed concept/technology provides significant improvement over existing solutions.

(2) *Overall Scientific and Technical Merit* (50%) - This criterion involves consideration of the following:

- The feasibility of the proposed work, as justified by appropriate background, theory, simulation, modeling, experimental data, or other sound scientific and engineering practices;
- Sufficiency of technical approach to accomplish the proposed R&D objectives, including why the proposed concept is more appropriate than alternative approaches and how technical risk will be mitigated;
- Clearly defined project outcomes and final deliverables; and
- The demonstrated capabilities of the individuals performing the project, the key capabilities of the organizations comprising the Project Team, the roles and responsibilities of each organization and (if applicable) previous collaborations among team members supporting the proposed project.

Submissions will not be evaluated against each other since they are not submitted in accordance with a common work statement.

2. Criteria for Full Applications

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

3. Criteria for Replies to Reviewer Comments

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

B. Review and Selection Process

1. Program Policy Factors

In addition to the above criteria, ARPA-E may consider the following program policy factors in determining which Concept Papers to encourage to submit a Full Application and which Full Applications to select for award negotiations:

I. **ARPA-E Portfolio Balance**. Project balances ARPA-E portfolio in one or more of the following areas:
   a. Diversity of technical personnel in the proposed Project Team;
   b. Technological diversity;
   c. Organizational diversity;
   d. Geographic diversity;
   e. Technical or commercialization risk; or
   f. Stage of technology development.

II. **Relevance to ARPA-E Mission Advancement.** Project contributes to one or more of ARPA-E's key statutory goals:
   a. Reduction of U.S. dependence on foreign energy sources;
   b. Stimulation of U.S. manufacturing and/or software development
   c. Reduction of energy-related emissions;
   d. Increase in U.S. energy efficiency;
   e. Enhancement of U.S. economic and energy security; or
   f. Promotion of U.S. advanced energy technologies competitiveness.

III. **Synergy of Public and Private Efforts**.
   a. Avoids duplication and overlap with other publicly or privately funded projects;
   b. Promotes increased coordination with nongovernmental entities for demonstration of technologies and research applications to facilitate technology transfer; or
   c. Increases unique research collaborations.

IV. **Low likelihood of other sources of funding.** High technical and/or financial uncertainty that results in the non-availability of other public, private or internal funding or resources to support the project.

V. **High-Leveraging of Federal Funds**. Project leverages Federal funds to optimize advancement of programmatic goals by proposing cost share above the required minimum or otherwise accessing scarce or unique resources.

VI. **High Project Impact Relative to Project Cost.**

VII. **Qualified Opportunity Zone (QOZ).** Whether the entity is located in an urban and economically distressed area including a Qualified Opportunity Zone (QOZ) or the proposed project will occur in a QOZ or otherwise advance the goals of QOZ. The goals include spurring economic development and job creation in distressed communities throughout the United States. For a list or map of QOZs go to: https://www.cdfifund.gov/opportunity-zones.

2. ARPA-E REVIEWERS

By submitting an application to ARPA-E, Applicants consent to ARPA-E's use of Federal employees, contractors, and experts from educational institutions, nonprofits, industry, and governmental and intergovernmental entities as reviewers. ARPA-E selects reviewers based on their knowledge and understanding of the relevant field and application, their experience and skills, and their ability to provide constructive feedback on applications.

ARPA-E requires all reviewers to complete a Conflict-of-Interest Certification and Nondisclosure Agreement through which they disclose their knowledge of any actual or apparent conflicts and agree to safeguard confidential information contained in Concept Papers, Full Applications, and Replies to Reviewer Comments. In addition, ARPA-E trains its reviewers in proper evaluation techniques and procedures.

Applicants are not permitted to nominate reviewers for their applications. Applicants may contact the Contracting Officer by email (ARPA-E-CO@hq.doe.gov) if they have knowledge of a potential conflict of interest or a reasonable belief that a potential conflict exists.

3. ARPA-E SUPPORT CONTRACTOR

ARPA-E utilizes contractors to assist with the evaluation of applications and project management. To avoid actual and apparent conflicts of interest, ARPA-E prohibits its support contractors from submitting or participating in the preparation of applications to ARPA-E.

By submitting an application to ARPA-E, Applicants represent that they are not performing support contractor services for ARPA-E in any capacity and did not obtain the assistance of ARPA-E's support contractor to prepare the application. ARPA-E will not consider any applications that are submitted by or prepared with the assistance of its support contractors.

C. ANTICIPATED ANNOUNCEMENT AND AWARD DATES

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

VI. Award Administration Information

A. Award Notices

1. Rejected Submissions

Noncompliant and nonresponsive Concept Papers and Full Applications are rejected by the Contracting Officer and are not merit reviewed or considered for award. The Contracting Officer sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. The notification letter states the basis upon which the Concept Paper or Full Application was rejected.

2. Concept Paper Notifications

ARPA-E promptly notifies Applicants of its determination to encourage or discourage the submission of a Full Application. ARPA-E sends a notification letter by email to the technical and administrative points of contact designated by the Applicant in ARPA-E eXCHANGE. ARPA-E provides feedback in the notification letter in order to guide further development of the proposed technology.

Applicants may submit a Full Application even if they receive a notification discouraging them from doing so. By discouraging the submission of a Full Application, ARPA-E intends to convey its lack of programmatic interest in the proposed project. Such assessments do not necessarily reflect judgments on the merits of the proposed project. The purpose of the Concept Paper phase is to save Applicants the considerable time and expense of preparing a Full Application that is unlikely to be selected for award negotiations.

A notification letter encouraging the submission of a Full Application does not authorize the Applicant to commence performance of the project. Please refer to Section IV.G of the FOA for guidance on pre-award costs.

3. Full Application Notifications

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

B. Administrative and National Policy Requirements

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

C. Reporting

[TO BE INSERTED BY FOA MODIFICATION IN MAY 2023]

VII. AGENCY CONTACTS

A. COMMUNICATIONS WITH ARPA-E

Upon the issuance of a FOA, only the Contracting Officer may communicate with Applicants. ARPA-E personnel and our support contractors are prohibited from communicating (in writing or otherwise) with Applicants regarding the FOA. This "quiet period" remains in effect until ARPA-E's public announcement of its project selections.

During the "quiet period," Applicants are required to submit all questions regarding this FOA to ARPA-E-CO@hq.doe.gov. Questions and Answers (Q&As) about ARPA-E and the FOA are available at http://arpa-e.energy.gov/faq. For questions that have not already been answered, please send an email with the FOA name and number in the subject line to ARPA-E-CO@hq.doe.gov. Due to the volume of questions received, ARPA-E will only answer pertinent questions that have not yet been answered and posted at the above link.

- ARPA-E will post responses on a weekly basis to any questions that are received that have not already been addressed at the link above. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.
- ARPA-E will cease to accept questions approximately 10 business days in advance of each submission deadline. Responses to questions received before the cutoff will be posted no later than three business days in advance of the submission deadline. ARPA-E may re-phrase questions or consolidate similar questions for administrative purposes.
- Responses are published in a document specific to this FOA under "CURRENT FUNDING OPPORTUNITIES – FAQS" on ARPA-E's website (http://arpa-e.energy.gov/faq).

Applicants may submit questions regarding ARPA-E eXCHANGE, ARPA-E's online application portal, to ExchangeHelp@hq.doe.gov. ARPA-E will promptly respond to emails that raise legitimate, technical issues with ARPA-E eXCHANGE. ARPA-E will refer any questions regarding the FOA to ARPA-E-CO@hq.doe.gov.

ARPA-E will not accept or respond to communications received by other means (e.g., fax, telephone, mail, hand delivery). Emails sent to other email addresses will be disregarded.

During the "quiet period," only the Contracting Officer may authorize communications between ARPA-E personnel and Applicants. The Contracting Officer may communicate with Applicants as necessary and appropriate. As described in Section IV.A of the FOA, the Contracting Officer may arrange pre-selection meetings and/or site visits during the "quiet period."

B. DEBRIEFINGS

ARPA-E does not offer or provide debriefings. ARPA-E provides Applicants with a notification encouraging or discouraging the submission of a Full Application based on ARPA-E's assessment of the Concept Paper. In addition, ARPA-E provides Applicants with reviewer comments on Full Applications before the submission deadline for Replies to Reviewer Comments.

VIII. Other Information

A. Title to Subject Inventions

Ownership of subject inventions is governed pursuant to the authorities listed below:

- Domestic Small Businesses, Educational Institutions, and Nonprofits: Under the Bayh-Dole Act (35 U.S.C. § 200 et seq.), domestic small businesses, educational institutions, and nonprofits may elect to retain title to their subject inventions;
- All other parties: The federal Non-Nuclear Energy Act of 1974, 42. U.S.C. 5908, provides that the government obtains title to new subject inventions unless a waiver is granted (see below):
  - Class Patent Waiver for Domestic Large Businesses: DOE has issued a class patent waiver that applies to this FOA. Under this class patent waiver, domestic large businesses may elect title to their subject inventions similar to the right provided to the domestic small businesses, educational institutions, and nonprofits by law. In order to avail itself of the class patent waiver, a domestic large business must agree to the U.S. Competitiveness Provision in accordance with Section VI.B.8. of this FOA.
  - Advance and Identified Waivers: For applicants that do not fall under the class patent waiver or the Bayh-Dole Act, those applicants may request a patent waiver that will cover subject inventions that may be made under the award, in advance of or within 30 days after the effective date of the award. Even if an advance waiver is not requested or the request is denied, the recipient will have a continuing right under the award to request a waiver for identified inventions, i.e., individual subject inventions that are disclosed to DOE within the time frames set forth in the award's intellectual property terms and conditions. Any patent waiver that may be granted is subject to certain terms and conditions in 10 CFR 784.
- DEC: On June 07, 2021, DOE approved a DETERMINATION OF EXCEPTIONAL CIRCUMSTANCES (DEC) UNDER THE BAYH-DOLE ACT TO FURTHER PROMOTE DOMESTIC MANUFACTURE OF DOE SCIENCE AND ENERGY TECHNOLOGIES. In accordance with this DEC, all awards, including sub-awards, under this FOA made to a Bayh-Dole entity (domestic small businesses and nonprofit organizations) shall include the U.S. Competitiveness Provision in accordance with Section VI.B.8 of this FOA. A copy of the DEC may be found on the DoE website. Pursuant to 37 CFR § 401.4, any Bayh-Dole entity affected by this DEC has the right to appeal it by providing written notice to DOE within 30 working days from the time it receives a copy of the determination.

B. Government Rights in Subject Inventions

Where Prime Recipients and Subrecipients retain title to subject inventions, the U.S. Government retains certain rights.

1. Government Use License

The U.S. Government retains a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States any subject invention throughout the world. This license extends to contractors doing work on behalf of the Government.

2. March-In Rights

The U.S. Government retains march-in rights with respect to all subject inventions. Through "march-in rights," the Government may require a Prime Recipient or Subrecipient who has elected to retain title to a subject invention (or their assignees or exclusive licensees), to grant a license for use of the invention. In addition, the Government may grant licenses for use of the subject invention when Prime Recipients, Subrecipients, or their assignees and exclusive licensees refuse to do so.

The U.S. Government may exercise its march-in rights if it determines that such action is necessary under any of the four following conditions:

- The owner or licensee has not taken or is not expected to take effective steps to achieve practical application of the invention within a reasonable time;
- The owner or licensee has not taken action to alleviate health or safety needs in a reasonably satisfactory manner;
- The owner has not met public use requirements specified by Federal statutes in a reasonably satisfactory manner; or
- The U.S. Manufacturing requirement has not been met.

C. Rights in Technical Data

Data rights differ based on whether data is first produced under an award or instead was developed at private expense outside the award.

- Background or "Limited Rights Data": The U.S. Government will not normally require delivery of technical data developed solely at private expense prior to issuance of an award, except as necessary to monitor technical progress and evaluate the potential of proposed technologies to reach specific technical and cost metrics.
- Generated Data: The U.S. Government normally retains very broad rights in technical data produced under Government financial assistance awards, including the right to distribute to the public. However, pursuant to special statutory authority, certain categories of data generated under ARPA-E awards may be protected from public disclosure for up to for up to ten years (or more, if approved by ARPA-E) in accordance with provisions that will be set forth in the award. In addition, invention disclosures may be protected from public disclosure for a reasonable time in order to allow for filing a patent application.

D. PROTECTED PERSONALLY IDENTIFIABLE INFORMATION

Applicants may not include any Protected Personally Identifiable Information (Protected PII) in their submissions to ARPA-E. Protected PII is defined as data that, if compromised, could cause harm to an individual such as identity theft. Listed below are examples of Protected PII that Applicants must not include in their submissions.

- Social Security Numbers in any form;
- Place of Birth associated with an individual;
- Date of Birth associated with an individual;
- Mother's maiden name associated with an individual;
- Biometric record associated with an individual;
- Fingerprint;
- Iris scan;
- DNA;
- Medical history information associated with an individual;
- Medical conditions, including history of disease;
- Metric information, e.g. weight, height, blood pressure;
- Criminal history associated with an individual;
- Ratings;
- Disciplinary actions;
- Performance elements and standards (or work expectations) are PII when they are so intertwined with performance appraisals that their disclosure would reveal an individual's performance appraisal;
- Financial information associated with an individual;
- Credit card numbers;
- Bank account numbers; and
- Security clearance history or related information (not including actual clearances held).

E. FOAS AND FOA MODIFICATIONS

FOAs are posted on ARPA-E eXCHANGE (https://arpa-e-foa.energy.gov/), Grants.gov (http://www.grants.gov/), and FedConnect (https://www.fedconnect.net/FedConnect/). Any modifications to the FOA are also posted to these websites. You can receive an e-mail when a modification is posted by registering with FedConnect as an interested party for this FOA. It is recommended that you register as soon as possible after release of the FOA to ensure that you receive timely notice of any modifications or other announcements. More information is available at https://www.fedconnect.net.

F. OBLIGATION OF PUBLIC FUNDS

The Contracting Officer is the only individual who can make awards on behalf of ARPA-E or obligate ARPA-E to the expenditure of public funds. A commitment or obligation by any individual other than the Contracting Officer, either explicit or implied, is invalid.

ARPA-E awards may not be transferred, assigned, or assumed without the prior written consent of a Contracting Officer.

G. REQUIREMENT FOR FULL AND COMPLETE DISCLOSURE

Applicants are required to make a full and complete disclosure of the information requested in the Business Assurances & Disclosures Form. Disclosure of the requested information is mandatory. Any failure to make a full and complete disclosure of the requested information may result in:

- The rejection of a Concept Paper, Full Application, and/or Reply to Reviewer Comments;
- The termination of award negotiations;
- The modification, suspension, and/or termination of a funding agreement;
- The initiation of debarment proceedings, debarment, and/or a declaration of ineligibility for receipt of Federal contracts, subcontracts, and financial assistance and benefits; and
- Civil and/or criminal penalties.

H. RETENTION OF SUBMISSIONS

ARPA-E expects to retain copies of all Concept Papers, Full Applications, Replies to Reviewer Comments, and other submissions. No submissions will be returned. By applying to ARPA-E for funding, Applicants consent to ARPA-E's retention of their submissions.

I. MARKING OF CONFIDENTIAL INFORMATION

ARPA-E will use data and other information contained in Concept Papers, Full Applications, and Replies to Reviewer Comments strictly for evaluation purposes.

Concept Papers, Full Applications, Replies to Reviewer Comments, and other submissions containing confidential, proprietary, or privileged information should be marked as described below. Failure to comply with these marking requirements may result in the disclosure of the unmarked information under the Freedom of Information Act or otherwise. The U.S. Government is not liable for the disclosure or use of unmarked information, and may use or disclose such information for any purpose.

The cover sheet of the Concept Paper, Full Application, Reply to Reviewer Comments, or other submission must be marked as follows and identify the specific pages containing confidential, proprietary, or privileged information:

Notice of Restriction on Disclosure and Use of Data:

Pages [___] of this document may contain confidential, proprietary, or privileged information that is exempt from public disclosure. Such information shall be used or disclosed only for evaluation purposes or in accordance with a financial assistance or loan agreement between the submitter and the Government. The Government may use or disclose any information that is not appropriately marked or otherwise restricted, regardless of source.
The header and footer of every page that contains confidential, proprietary, or privileged information must be marked as follows: "Contains Confidential, Proprietary, or Privileged Information Exempt from Public Disclosure." In addition, every line and paragraph containing proprietary, privileged, or trade secret information must be clearly marked with double brackets or highlighting.

J. COMPLIANCE AUDIT REQUIREMENT

A prime recipient organized as a for-profit entity expending $750,000 or more of DOE funds in the entity's fiscal year (including funds expended as a Subrecipient) must have an annual compliance audit performed at the completion of its fiscal year. For additional information, refer to Subpart F of: (i) 2 C.F.R. Part 200, and (ii) 2 C.F.R. Part 910.

If an educational institution, non-profit organization, or state/local government is either a Prime Recipient or a Subrecipient, and has expended $750,000 or more of Federal funds in the entity's fiscal year, the entity must have an annual compliance audit performed at the completion of its fiscal year. For additional information refer to Subpart F of 2 C.F.R. Part 200.

IX. GLOSSARY

Applicant: The entity that submits the application to ARPA-E. In the case of a Project Team, the Applicant is the lead organization listed on the application.

Application: The entire submission received by ARPA-E, including the Preliminary Application, Full Application, Reply to Reviewer Comments, and Small Business Grant Application (if applicable).

ARPA-E: is the Advanced Research Projects Agency – Energy, an agency of the U.S. Department of Energy.

Cost Sharing: Is the portion of project costs from non-Federal sources that are borne by the Prime Recipient (or non-Federal third parties on behalf of the Prime Recipient), rather than by the Federal Government.

Covered Individual: an individual who contributes in a substantive, meaningful way to the scientific development or execution of an R&D project proposed to be carried out with a award from DOE, i.e. senior/key personnel. ARPA-E may further designate covered individuals during award negotiations or the award period of performance.

Deliverable: A deliverable is the quantifiable goods or services that will be provided upon the successful completion of a project task or sub-task.

DOE/NNSA: U.S. Department of Energy/National Nuclear Security Administration.

DOE: U.S. Department of Energy

FFRDCs: Federally Funded Research and Development Centers

FOA: Funding Opportunity Announcement

Foreign Affiliation: a funded or unfunded academic, professional, or institutional appointment or position with a foreign government or government-owned entity, whether full-time, part-time, or voluntary (including adjunct, visiting, or honorary).

Foreign Countries of Concern: the People's Republic of China, the Democratic People's Republic of Korea, the Russian Federation, the Islamic Republic of Iran, Burma, Eritrea, Pakistan, Saudi Arabia, Tajikistan, and Turkmenistan.

For-Profit Organizations (Other than Small Businesses) (or *large businesses*): Means entities organized for-profit other than small businesses as defined elsewhere in this Glossary.

GOCOs: U.S. Government Owned, Contractor Operated laboratories.

GOGOs: U.S. Government Owned, Government Operated laboratories.

Institutions of Higher Education (or *educational institutions*): Has the meaning set forth at 20 U.S.C. 1001.

Malign Foreign Talent Recruitment Program: the meaning given such term in section 10638 of the Research and Development, Competition, and Innovation Act (division B of Public Law 117–167) or 42 USC 19237, as of October 20, 2022.
mCDR: marine Carbon Dioxide Removal

Milestone: A milestone is the tangible, observable measurement that will be provided upon the successful completion of a project task or sub-task.

Nonprofit Organizations (or *nonprofits*): Has the meaning set forth at 2 C.F.R. § 200.70.

PI: Principal Investigator.

Prime Recipient: The signatory to the funding agreement with ARPA-E.

Project Team: A Project Team consists of the Prime Recipient, Subrecipients, and others performing or otherwise supporting work under an ARPA-E funding agreement.

Small Business: Small businesses are domestically incorporated entities that meet the criteria established by the U.S. Small Business Administration's (SBA) "Table of Small Business Size Standards Matched to North American Industry Classification System Codes" (NAICS) (http://www.sba.gov/content/small-business-size-standards).

Standalone Applicant: An Applicant that applies for funding on its own, not as part of a Project Team.

Subject Invention: Any invention conceived or first actually reduced to practice under an ARPA-E funding agreement.

Task: A task is an operation or segment of the work plan that requires both effort and resources. Each task (or sub-task) is connected to the overall objective of the project, via the achievement of a milestone or a deliverable.

Total Project Cost: The sum of the Prime Recipient share and the Federal Government share of total allowable costs. The Federal Government share generally includes costs incurred by GOGOs, FFRDCs, and GOCOs.

TT&O: Technology Transfer and Outreach. (See Section IV.G.8 of the FOA for more information).