# Task 4 Request for Proposals:
# *Modular Carbon Dioxide Removal for Community Integration*

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**Task**

Teams will develop innovative carbon-dioxide removal (CDR) systems in modular units that can be duplicated throughout a community and across many communities. Solutions should be innovative, with teams either exploring completely new ways to implement CDR, or finding innovative ways to implement a current technology in a modular design.

**Background**

In Executive Order 14008: Tackling the Climate Crisis at Home and Abroad, the Biden Administration set a goal of reaching net-zero greenhouse gas (GHG) emissions economy-wide by 2050 [1]. The U.S. Department of State published a long-term strategy to reach this goal [2], and developed a portfolio of emissions abatement solutions. The portfolio includes, among other things, improvements in energy efficiency, decarbonization of the power sector, and solutions that remove $CO_2$ directly from the atmosphere.

Carbon dioxide removal (CDR) refers to approaches that remove $CO_2$ from the atmosphere and durably store it in geological, terrestrial, or ocean reservoirs, or in the form of long-lived products. CDR is distinguished from point-source carbon capture and storage (CCS) where $CO_2$ is captured at higher concentrations from power plants and industrial facilities. CDR addresses the trillions of tons of $CO_2$ emissions that have accumulated in our atmosphere over the past century, as well as the $CO_2$ perpetually emitted from activities that are difficult to decarbonize, such as agriculture and aviation.

CDR encompasses a wide array of approaches, including direct air capture (DAC) coupled to durable storage, soil carbon sequestration, biomass carbon removal and storage, enhanced mineralization, ocean-based CDR, and afforestation/reforestation, as outlined by the National Academies of Science Engineering and Medicine in 2019 [3] and more recently in the CDRPrimer [4] and the Carbon Dioxide Removal Mission [5]. The long-term strategy of the U.S. is to bring CDR solutions to the scale of removing one billion tons of $CO_2$ from the atmosphere per year by 2050 [2].

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Implementing CDR in Communities

The US Department of Energy Office of Fossil Energy and Carbon Management (FECM) envisions the deployment of diverse CDR approaches to facilitate gigaton-scale removal by mid-century with analysis of life-cycle impacts and a deep commitment to environmental justice. FECM prioritizes engagement with communities to encourage participation in carbon dioxide removal, including neighborhoods, disadvantaged communities, and tribal nations [6, 7, 8].

Some communities in the U.S. have expressed the desire for modular CDR units that can be integrated into the landscape and that could be scaled up as smaller designs [9]. Modular CDR units provide the opportunity for communities across the globe to actively participate in reducing atmospheric $CO_2$, and as-such could increase community education and acceptance of CDR technologies. Although one modular CDR unit will remove only a modest amount of $CO_2$ from the atmosphere, when multiplied within, or across, communities, the effects could make a significant difference in reducing the concentration of atmospheric $CO_2$.

Task-Specific Goals

Teams are urged to think outside of the box to implement CDR in modular units using an innovative idea or approach. For the purpose of this task, “modular” is defined as a single operational unit that can independently remove $CO_2$ from the atmosphere and can be easily duplicated throughout a community or across many communities. Your team is challenged to develop a solution that removes a net of 100 tons of $CO_2$ from the atmosphere per year, either through one single unit or through the accumulation of multiple units in concert. For examples and more detailed information of companies utilizing a modular approach to execute CDR projects, see [10] and [11].

To ensure maximum climate impact and integrity of carbon-removal projects, it is imperative that various aspects are considered for “high-quality” carbon removal, like those outlined by Microsoft and Carbon Direct [12]. These criteria include proper carbon accounting through life-cycle assessment (LCA), durability, monitoring, reporting, and verification (MRV) protocols, additionality and baseline assessment, environmental justice considerations, and community harms and benefits analysis.

Teams are asked to quantify the annual net removal of $CO_2$ from the atmosphere using their proposed modular CDR technology. Develop a “cradle-to-grave” carbon lifecycle assessment (LCA) to demonstrate that the carbon removal approach results in a net removal of $CO_2$ from the atmosphere coupled with durable storage for 100 years. Net removal means evaluating all materials and energy used in terms of their contribution to the carbon footprint, starting from where the materials are first taken from the earth (cradle) to where they are disposed (grave). Chapter 4 of the CDRPrimer may serve as an outline for how to conduct an LCA of your CDR solution [4].

As up-to-date information regarding global CDR projects is published, WERC will post links in the FAQs on our website.

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Teams must demonstrate that the $CO_2$ removed from the atmosphere is durably sequestered for at least 100 years. Valid demonstration methods may involve providing several credible references or a model based on defined assumptions to determine the durability. In all cases, teams must discuss the scientific mechanisms of storage and how it applies to the team's design. Additionally, teams must provide an outline of plans to conduct monitoring, reporting, and verification ("MRV") to ensure that $CO_2$ removal and/or leakage can be accurately quantified and monitored for a period of at least 100 years.

Teams must also demonstrate approaches that are "additional," meaning that they would not occur without the development and implementation of your technology or approach. Additionality should be demonstrated by comparing the removal against a counterfactual "baseline" scenario showing that the solution is not already required by existing regulations, is not "common practice" in the community, and accounts for baseline carbon flows.

It is essential to give communities a stake in your solution. To align with FECM goals, your modular system should encourage community participation and engagement (e.g., neighborhoods, campuses, NGOs, marginalized communities, and/or tribal communities). Your team's implementation outline should include 1) a plan to educate the community on how CDR works, why it is needed, and what the benefits will be, 2) partnering with the community of your choice to determine their needs and concerns (e.g., module placement, aesthetics, resources, environmental effects, health and safety concerns etc.), and 3) strategically locating the module(s) to optimize $CO_2$ removal in the community.

Teams are strongly encouraged to design their CDR processes with consideration of potential non-carbon-related social and ecological co- benefits and/or impacts such as biodiversity, habitat creation or preservation, disease vectors, wildfire risk mitigation, drought resilience, erosion and/or flood control, soil quality, co-products (food, fiber, timber, energy, etc.), community education, job creation, poverty alleviation, waste reduction, reduced noise pollution, sustainable recreation and tourism opportunities, and urban beautification (See [13]).

When teams perform the techno-economic analysis for their project, they may consider the financial incentives offered through voluntary carbon markets [14, 15] of up to $200-400/ton of $CO_2$ removed. Metrics such as average price of carbon removal sold, number of tons sold and delivered, etc., in existing carbon marketplaces are available in the literature [16].

Due to the community focus and budgetary constraints of this task, teams are encouraged to gather a multidisciplinary team that includes students of various educational backgrounds including but not limited to humanities/social sciences, business/economics, and engineering disciplines.

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**Problem Statement**

Research, design, and develop an innovative modular carbon dioxide removal (CDR) system capable of removing a net of 100 metric tons of $CO_2$ from the atmosphere per year. Your analysis must demonstrate that all sources of potential $CO_2$ emissions occurring from the operation of the modular unit are accounted for. The $CO_2$ storage mechanism should be sufficiently durable so the $CO_2$ is not anticipated to be released for at least 100 years.

The design should be simple, easy to implement, aesthetically pleasing, and motivate communities to adopt the modular system.

Teams will develop plans for scaleup to implement multiple units within a community, seeking feedback from the community to determine the number of units, placement, etc., with consideration of community concerns and needs coupled with appropriate $CO_2$ removal for that community.

**Design requirements**

Your proposed design should provide specific details and outcomes as follows.

- Interview a community of your choice to assess concerns, needs, etc. relative to CDR prior to developing your solution.
- Discuss your system's means of atmospheric $CO_2$ removal, and, if different, your system's means of $CO_2$ sequestration.
- Demonstrate an annual net removal of 100 metric tons of $CO_2$ from the atmosphere, including a "cradle-to-grave" lifecycle assessment.
- Demonstrate the durability of the $CO_2$ storage for at least 100 years and propose an outline for the monitoring, reporting, and verification (MRV) protocol.
- Discuss the additionality of the CDR solution in terms of added removal of atmospheric $CO_2$ compared to current local policies and practices.
- Address any disbenefits and/or co-benefits of the system, such as impacts on environmental health, education, economy, etc.
- Discuss maintenance of the system, such as the need for replacing/regenerating/reorienting materials.
- Propose a community adoption strategy that includes:
    - a community education plan to inform the population of the need for and benefit of CDR
    - a community engagement plan for system design that considers the needs and concerns of the community
    - clear instructions that enable residents, a neighborhood, a school, etc., to implement and maintain the system without compromising the durability of $CO_2$ storage
    - consideration of scaleup
- Discuss the considerations, both technical and community-oriented, for strategic placement of the module(s) in a community.

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- Conduct a techno-economic analysis for the community of interest, demonstrating the 1) all-in investment cost to set up and operate the modular system and remove 100 metric tons of $CO_2$ per year, 2) the marginal cost of removing one ton of $CO_2$, comparing to the goal of $100/net metric ton of carbon dioxide-equivalent outlined in DOE's Carbon Negative Shot [17], and 3) income from predicted carbon credits.
- To be considered for the WERC P2 Award, in a separate section of the report (titled "Pollution Prevention"), document success in improving energy efficiency, pollution prevention, and/or waste minimization, as it applies to your project.
- Address safety aspects of handling the CDR system and any secondary products. Safety issues for the full-scale design should be addressed in the written report. Safety issues for the bench-scale demonstration should be addressed in both the written report and the Experimental Safety Plan (ESP).

**Bench Scale Demonstration**

Bench-scale demonstrations will serve to illustrate the design considerations listed above.

In particular, your team's bench-scale apparatus will demonstrate the ability to remove $CO_2$ from the atmosphere. The apparatus should be designed as a sealed system that accepts air from a compressed gas cylinder and lowers the air pressure to 1 atm prior to entering your process.

Teams shall discuss storage in the technical report and oral and poster presentations. It may be demonstrated in the bench-scale demonstration, but this is not required.

Teams will have up to 30 hours to complete the demonstration, provided that the apparatus can safely run unattended overnight. Operational safety will be determined from the ESP review and final commissioning.

<u>Teams will provide at the contest</u>

Teams will bring their own $CO_2$ CGA 320 regulator and a minimum of 15 feet of piping needed to attach to the cylinders during the bench-scale demonstration. Bring hose clamps to ensure secure connections at barb fittings and tethers needed to restrain the pressurized piping in case of disconnection.

<u>WERC will provide at the contest</u>

WERC will provide each team with a Compressed Gas Cylinder, Size 16, with approximately 2000 liters of air at 2000 psig and CGA Valve 346, with specifications as for Breathing Air. (Cylinder size is subject to availability. Watch FAQs for late-breaking news.)

<u>Analytical Testing Procedures at the Contest</u>

Your team's success in $CO_2$ removal will be determined by appropriate analysis techniques according to your bench-scale design. For example, WERC may analyze the effluent of the air exiting your system or through chemical analysis of any products that may be formed.

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**30% Project Review**
Submission date: March 1, 2024 (you may submit earlier if you wish to receive feedback sooner).

Submit the 30% Project Review as early as possible. It should not exceed four pages. Although the review is not scored, your team will receive feedback from the judges for improving your project. You are allowed to change your plans after submitting it. Include as many items listed below as possible. The more detail provided in your review, the better direction you will get from the judges. (See Team Manual for more information.)

As available, please include:

- ***Table of Contents*** planned for the technical report (place topics in order, one line per topic)
- ***A brief description of your project:*** One bulleted list outlining: planned solution to the problem and any anticipated drawbacks.
- ***The current schematic of your planned process flow or block diagram*** with mass and energy balances, as available.
- ***Preliminary data and/or calculations that support the proposed design.*** This might include expected chemical reactions (reactants, reaction times, etc.), flow volumes and rates, etc.
- ***Any cost estimates that show feasibility of the project.*** This will give your team and the judges a chance to consider modifications that might improve feasibility of the project.
- ***Confirmation of reaching out to a community, with interview date scheduled.***

**Experimental Safety Plan (ESP)**
The ESP outlines your team's plans for safely operating your bench-scale demonstration at the contest. This document is submitted in February (see dates below). Instructions are provided in the team manual. The Team Leader, or a designated team member, shall attend a mandatory short course that outlines the ESP process. Teams will not be able to run a bench-scale demonstration if the ESP is not received by the deadline. Your team should follow your school's safety procedures while conducting tests prior to attending the contest.

**Evaluation Criteria**
Each team is advised to read the 2024 Team Manual for a comprehensive understanding of the contest evaluation criteria. As described in the manual, there are five events: a written report, a formal oral presentation, a demonstration of your technology using a bench-scale representation, a poster presentation, and a Flash Talk. Criteria used by the judges in evaluation of these five components are described in the Team Manual.

For a copy of the Team Manual, Public Involvement Plan, and other important resources, visit the WERC website: Guidelines | werc.nmsu.edu

Your response to the problem statement will include the Design Requirements listed above and consideration of the following points.

- Technical ability to remove $CO_2$ from the atmosphere during the bench-scale demonstration.
- Potential for real-life implementation (ease of operation and maintenance, affordability, etc.).
- Integration of the modular system into the community.
- Thoroughness and quality of the technical analysis.
- Thoroughness and quality of the economic analysis.
- Originality and innovation represented by the proposed technology.
- Other specific evaluation criteria that may be provided at a later date (watch the FAQs online).

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**Short Courses**

WERC is offering two short courses:

- ***Mandatory:*** Preparing the Experimental Safety Plan. The Team Leader, or a person assigned by them, must attend the course prior to submitting the ESP (and before February 20, 2024).
- ***Optional:*** Environmental Health and Safety (EH&S) Topics. The course is designed to prepare teams to complete the EH&S portion of their technical report. Course fees will be waived for contest-registered students, faculty, and judges. Watch the WERC website for schedules and registration information. Individuals who complete the course can earn a digital badge to add to their professional development portfolio.

**Dates, Deadlines, FAQs** (*dates subject to change—watch website FAQs*)

- Today: Email us to let us know you are interested in this task. We will contact you with breaking news.
- October 15 - December 31, 2023 – Early Bird Registration (discounts apply).
- December 1, 2023 - February 20, 2024: Mandatory On-demand Course: Preparing the Experimental Safety Plan. See website and Team Manual for information.
- December 1, 2023 – March 31, 2024: Optional On-demand Course: WERC Safety and Environmental Topics. See Team Manual for more information.
- February 15, 2024: Submit requests for ancillary equipment to werc@nmsu.edu
- February 15 - 24, 2024: Experimental Safety Plan (ESP) due.
- March 1, 2024: 30% Project Review due.
- March 8, 2024: Final date to register a team.
- March 31, 2024: Technical Report due
- Weekly: Check FAQs weekly for updates:
  - Task-specific FAQs: 2024 Tasks/Task FAQs
  - General FAQs: https://werc.nmsu.edu/team-info/2023-faqs.html 2024 General FAQs
- All dates or task requirements are subject to change. Check FAQs for updates online.

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