ChemE Cube Competition 2023

Problem Statement: Modular Direct Air Capture

Business Objective

The carbon cycle is nature's way of recycling carbon atoms from the atmosphere to the terrestrial organisms, ocean, land, and then back into the atmosphere. With the introduction of human carbon emissions, there has been a net positive increase of carbon dioxide in the air. Carbon dioxide emissions are the largest greenhouse gas (GHG) emissions globally, accounting for 76% of all GHG emissions annually[1] and reaching 34.8 billion tons in 2020.[2]

The rising CO_2 emissions leads to increasing global temperatures, rise in ocean acidification, and disruption of ecosystems. The effects of climate change can directly and indirectly impact human health. In order to take into account this global issue, the 2015 Paris Climate Change Agreement was enacted in order to combat the rise of global CO_2 emissions. Its goal is to limit global warming to preferably 1.5°C.[3]

There are different ways to reduce the amount of CO_2 emitted. Conserving energy, efficient energy use, switching fuel type, and changes in use of land and land management practices help reduce the amount of CO_2 emitted. Carbon capture and storage (CCS) can be used to capture CO_2 at the point where it is emitted to keep it from entering the atmosphere. However, even after employing all of these approaches, many external technology assessments[4] suggest that additional steps will be needed to meet stated climate goals. This includes the deployment of direct air capture technologies, where CO_2 in the air (ambient concentration of ~420ppm) is removed and sequestered.[5] This is what your design will aim to achieve.

You are tasked with creating a modular direct-air capture mini-plant that can fit inside a cube that is 1-foot in length, width, and height. Your mini-plant must capture CO_2 from surrounding atmospheric air for 30 seconds to 5 minutes. It is also important that your cube design is efficient so that the CO_2 emissions that come from the energy (used to power the mini-plant) is low. You will have a maximum budget of $1,500 for your first-of-a-kind prototype. Your design should be marketable as a modular CO_2 capture device. Ultimately, it should create an impact by demonstrating technological breakthroughs, be able to address a market, and finally, benefit humanity.

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1 https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data
2 https://ourworldindata.org/co2-emissions
3 https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
4 https://www.iea.org/reports/net-zero-by-2050
5 An updated roadmap to Net Zero Emissions by 2050 – World Energy Outlook 2022 – Analysis - IEA

Related Efforts

The following related efforts may help to provide clarity and resources to you as you develop your cube:

- The United States' National Energy Technology Laboratory Direct Air Capture (DAC) Center supports rapid development and commercialization pathways for technologies that remove CO_2 from the atmosphere.[6]
- The Justice40 Initiative[7] was enacted by President Biden to ensure that 40% of the overall benefits of certain Federal investments go to communities that are underserved and overburdened by pollution. A cube such as this has the potential to address disproportionate needs of underserved communities.
- XPRIZE hosts a competition revolved around the removal of carbon dioxide.[8] They have noted three grand challenges that come with carbon dioxide removal: 1} Massive scale required for carbon dioxide removal, 2) Current DAC solutions are too expensive, and 3) Structural incentives are lacking from both the government and markets.
- The Direct Air Capture (DAC) Coalition supports the international effort to address the climate challenge by bringing together diverse, leading global innovators to educate, engage, and mobilize DAC technology.[9]
- Carbon Dioxide Removal Primer is a new online resource on the fundamentals of carbon dioxide removal and its role in addressing the climate crisis.[10]

Technical Objectives

Cubes will be supplied with DC current only as to allow for the use of off-grid power sources such as solar or wind power. Each team must include their required electrical current (not to exceed 10A) in their team's Engineering Design Package (EDP). Regulated 12 V DC power will be provided for the competition. Your plant must use exactly 12 V. Power will be provided from standard banana jacks (socket) color coded red and back to indicate polarity. Cubes should provide suitably insulated, properly gauged leads not less than 12ft in length terminated in standard banana plugs to access the provided power.

Input

Teams will need to pull air from the atmosphere into their system. The flowrate is dependent on your design and it should be able to draw air in at a rate where it's able to capture CO_2 for a minimum of 30 seconds continuously. The duel will take place in an open area and teams should expect that the concentration of CO_2 may reach up to 1700 ppm. The required input flowrate is 500 mL/min.

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[6] https://netl.doe.gov/dac
[7] https://www.whitehouse.gov/environmentaljustice/justice40/#:~:text=What%20is%20the%20Justice40%20Initiative,underserved%2C%20and%20overburdened%20by%20pollution.
[8] $100M Prize For Carbon Removal | XPRIZE Foundation
[9] Direct Air Capture Coalition (daccoalition.org)
[10] https://cdrprimer.org/

Output

For the 2023 competition there will only be one outlet stream with a continuous CO_2 concentration meter and an airflow meter. You must use PVC tubing with ⅛ inch I.D. and ¼ inch O.D. to ensure proper connection with the CO_2 meter. The output flowrate must range from 100 mL/min to 500 mL/min as per operating conditions of the CO_2 meter.

Cube Criteria

Table 1. ChemE Cube: Direct Air Capture Criteria

Criteria	Lower Limit	Upper Limit	Point Values	How the criteria is measured
Able to continuously capture CO_2 for 30 seconds to 10 minutes (minimum output flowrate 100 mL/min)	No	Yes	100	Continuous CO_2 Concentration Meter/Ion Probe
Time before material used for capture becomes fully saturated	30 seconds	600 seconds	= Time (s) /6 (Max: 100 points -> 600 seconds = 100 points)	Continuous CO_2 Concentration Meter/Ion Probe
Energy Usage (12V Power Required)	Judged head-to-head, team with the lower amount receives the points.		20	Energy Meter
The following criteria are associated with the safety of operating your team's cube. By applying for the competition, you are indicating that your team has fully reviewed and agrees to follow the ChemE Cube Safety Program, document can be found on the ChemE Cube website.				
Weight of the Cube	Judged head-to-head, team with the lower amount receives the points.		20	Scale
Temperature of Exhaust Stream	Temperature must not exceed 75F due to safety considerations.		20	Airflow Meter
Pressure Drop		1 psi	20	Airflow Meter
Smell[11]	Smells	Doesn't smell	20	Judge's Nose
Total Points			300 per duel (2 duels, 600 total)	

[11] If not treated properly, amines have a distinct, chemical odor. In order to make sure the on-site competition is a pleasant experience, please design your cube to ensure it does not emit a foul odor. https://www.science.org/content/blog-post/amines-and-landscape-chemical-stink