2023 ChemE Cube™ Problem Statement

Document Revision History

Version (Date)	**Comment**
1.0 (January 2023)	Initial release of 2023 competition rules
2.0 (February 2023)	Updates to 2023 competition rules • Clarified Power Requirements • Clarified Input/Output Concentration Requirements • Cubes now weighed before each Duel, not at beginning of onsite competition • Pressure drop criteria changed from 1psi to 1psig. • Added Flow Diagram • Added Duel Timings
3.0 (May 2023)	Updates to 2023 competition rules • Fixed language regarding time to capture in business objective • Changed language regarding input
4.0 (August 2023)	Updates to 2023 competition rules • Fixed language regarding pressure drop • Added link to CO_2 meter used during duel

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 10 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

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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. For safety reasons, cubes may not exceed 10A or 120 watt. Cubes operating at a higher wattage will not pass safety inspection and therefore will not be able to compete. 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 black 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. There is no technical criteria associated with regeneration however, teams may want to consider how they would incorporate/explain a regeneration step as part of the technical poster/judging process.

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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/

Cube Input

- Teams will need to pull air from the atmosphere into their system. The duel will take place in an open area therefore the inlet concentration is not standardized and teams should expect that the concentration of CO_2 may be higher than 400 ppm at certain times.
- Connection Point Requirement: You must use a connection point so that PVC tubing with ⅛ inch I.D. and ¼ inch O.D. (or have an adapter) to ensure proper connection with the CO_2 meter and flowmeter.
- Input air will be regulated and will be pumped out of the meter at 500 mL/min. Ensure that your fan/compressor does not go over this flowrate.
- Link to CO_2 meter: Multi Gas Sampling Data Logger | CO2Meter.com (A 1% CO_2 sensor will be used)

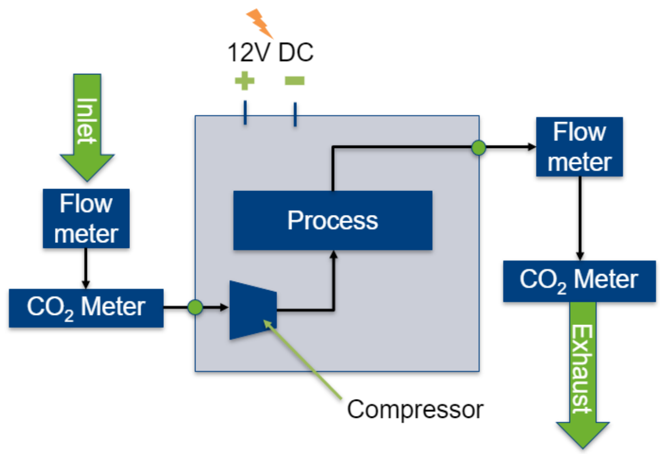

Figure 1. Depiction of Cube Hookups for Input, Output, and Electricity for onsite competition.

Cube Output

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

Link to buy PVC tubing with ⅛ inch I.D. and ¼ inch O.D.: DERNORD PVC Tubing 1/8"ID X 1/4"OD Flexible Clear Vinyl Hose 50 Feet for Food Grade: Amazon.com: Industrial & Scientific

Cube Criteria

Definitions:

1. "Capture CO_2" is defined as actively capturing CO_2 so that the outlet concentration is at least 25% lower than the inlet (Ex: If the input concentration is 400ppm, then the outlet needs to be 300ppm or less to be considered as actively adsorbing.)

2. “Fully saturated” is defined as when the outlet concentration matches the inlet concentration after at least six seconds of time where the outlet concentration of CO_2 was lower than the inlet concentration of CO_2.

Table 1. ChemE Cube: Direct Air Capture Criteria

Criteria	Lower Limit	Upper Limit	Point Values	How the criteria is measured
Able to capture CO_2 for 30 consecutive seconds.	No	Yes	100	Continuous CO_2 Concentration Meter
Time (s) before material used for capture becomes fully saturated	6 seconds	600 seconds	= Time (s) /6 (Max: 100 points -> 600 seconds = 100 points)	Continuous CO_2 Concentration Meter
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	Prior to each duel, Cubes are weighed on scale
Temperature of Exhaust Stream	Temperature must not exceed 75F due to safety considerations.		20	Airflow Meter
Pressure Drop*	1 psig		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

- The pressure drop listed as a criterion is there for safety measures. Due to the nature of the size of the process, we do not anticipate a large pressure drop across the system. Note that the input air will be at standard temperature and pressure.

Duel Timing

Format: Each team will compete in two head-to-head duels; each takes place over 20 minutes.

- The first 5 minutes will be setup/startup of the cube.
- The next 10 minutes, the cube will run autonomously.
- Final 5 minutes will be the shutdown of the cube.