Cyan v1: Open Hardware Micro Direct Air Carbon Capture

Assembly Instructions

Open Source Licenses	
Hardware	CERN-OHL-P-2.0
Software	GPL-3.0-or-later
Documentation	CC-BY-SA-4.0

All the most up-to-date documentation can be found at
https://github.com/openair-collective/openair-cyan

Purpose: These are instructions to build a DIY DACC unit for home or classroom use.

Expected results: an up to 12.5% weight increase from CO_2 uptake over the course of a 16-hour period when starting with 10 g input material. This translates into about a 2.1 g CO_2 uptake obtainable during a single run. On average we are seeing a 1.7 g per run uptake.

Minimal parts cost: <$20 (unit shown above). All the bells and whistles mentioned: about $100.

A live version of this document can also be found on our Cyan Google Drive at:
https://drive.google.com/drive/folders/1jJmSW5A4CJa3Al3WlE5lJOv2GNdNztFd?usp=sharing.

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Introduction

The goal of this project was to build a high-efficiency, very low cost direct air carbon capture (DACC) system. We call the system Cyan in honor of Violet, OpenAir's moisture swing sorbent DACC, and also in honor of **cyanobacteria**, whose combined efforts transformed the early Earth's atmosphere. Similarly, we believe millions of distributed, consumer-scale DACC units could someday complement large-scale DACC efforts and make a difference when it comes to climate change. This unit will not solve the climate crisis alone, but many of these will open doors to discussion, education, behavior changes, modifications, and further R&D to improve the state of DACC. And that is what we desperately need to limit the possibility of dangerous warming.

Chemistry and Benefits

The carbonation reaction (also known as carbonatation) is being used to capture CO_2 as follows:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

This reaction takes place naturally, especially in concrete, but typically takes a very long amount of time (months to years). Cyan speeds up the reaction considerably by increasing the relative humidity and forcing this "wet" air into the reaction chamber to offset CO_2 declines as the reaction progresses.

Calcium carbonate ($CaCO_3$) is a safe output that is actually the main constituent of limestone. It can be extracted, filtered, dried, weighed, and the quantity of CO_2 taken up can be determined through calculation from the weight. No equipment is required to pressurize the captured CO_2, making Cyan a good choice for true consumer-scale DACC.

Challenges and Limitations

The carbonation reaction is slow due to the formation of a passivating layer of $CaCO_3$ around $Ca(OH)_2$ molecules. While bubbles of CO_2 were produced upon filtering, drying, and applying 5% distilled white vinegar (acid test for the presence of $CaCO_3$), it is very likely that not all the $Ca(OH)_2$ is converted to $CaCO_3$ in 24 hours. Thus we still need to quantify the amount of CO_2 that is captured per gram of $Ca(OH)_2$ to see how that depends on different variables.

To achieve true negative emissions using Cyan, you will need to start with a source of carbon-neutral $Ca(OH)_2$. Hydrated lime is a good consumer source; it is very easy to buy hydrated lime at a gardening or hardware store. However, this hydrated lime comes from calcium oxide (lime) produced through calcination, a very energy-intensive process with temperatures above 900 degrees Celsius. This energy is typically supplied mostly by fossil fuels, though renewable sources are becoming increasingly prevalent in the energy mix. There are projects underway to produce

lime through concentrated solar, but for now this is a one-way reaction to produce calcium carbonate without regenerating the lime.

Safety Considerations

$Ca(OH)_2$ comes in powdered form and although it has uses in pickling and gardening, it can do great damage if rubbed into the eyes, inhaled, or ingested. Scoop the material and avoid pouring; if you do pour, a mask should be worn so as not to inhale the dust.

Do not ingest any reactant or product, even the calcium carbonate you produce. It's never a good idea to eat the products of your chemical reactions.

Also, since the aquarium air pump does not have a grounding plug (the case for most such pumps), the safety considerations for working with electricity near water should be observed.

Parts List

The following 5 items are the minimum required parts to construct a Cyan. Total cost <$20.

Item	Use	Qty	Price	Qty for price	Per unit price	Units used	Subtotal
Sterilite 2.5 Qt FlipTop[1] 	Outer container ("humidifier box"), dimensions are 7 5/8" x 6 1/2" x 4 1/2"	1	$2.28	1	$2.28	1	$2.28
Tetra Whisper 10 Aquarium Air Pump[2] 	For airflow to let in CO_2; needs AC outlet, 1.5 watts only	1	$5.06	1	$5.06	1	$5.06
Air Tubing and Air Stone[3] 	To disperse the air from the air pump, 3/16" diameter	1	$4.99	2	$2.50	1	$2.50

[1] https://www.homedepot.com/p/Sterilite-2-5-Qt-Flip-Top-Box-18038612/203002006?irgwc=1&cm_mmc=afl-ir-78091-456723-&clickid=zEwUoH1OxxyLRSBwUx0Mo3ZxUkEUYIXsw0Wsyc0

[2] https://www.amazon.com/Tetra-Whisper-Easy-Aquariums-Non-UL/dp/B0009YJ4N6

[3] https://www.amazon.com/gp/product/B0797QFV4D

Empty Sabra Hummus Container, 10 oz[4] 	Used for spacing; coffee filter goes on the HDX Quart lid that floats on top of this container. Could potentially remove or size down to add more space for $Ca(OH)_2$.	1	$3.34	1	$3.34	1	$3.34
Lid from HDX Quart Container[5] 	Has a lid that the coffee filter holding the $Ca(OH)_2$ sits in so as not to get too wet. Also comes graduated with lines, useful for measuring and mixing materials.	1	$1.38	1	$1.38	1	$1.38

total $17.05

[4] https://www.walmart.com/ip/Sabra-Roasted-Red-Pepper-Hummus-10-oz/10850131
[5] https://www.homedepot.com/p/HDX-1-qt-Multi-Mix-Pail-2M3/202264024

Below are optional items - you may choose to put the above setup within the file box below for easy portability and to expand the amount of space available for carbon capture. Mounting the fan on the box will also allow you to dry your $CaCO_3$ faster once you are done humidifying it, though the fan also uses about 3 more watts of electricity. The fan may contribute to extra CO_2 uptake during the drying time.

Item	Use	Qty	Price	Qty for price	Per unit price	Units used	Subtotal
Bankers Box file box[6] 	Outer container ("box")	1	$9.97	1	$9.97	1	$9.97
120 mm computer fan, AC Infinity Multifan S3[7] 	Airflow, USB-powered, 3 speeds	1	$11.99	1	$11.99	1	$11.99
120 mm safety grilles[8] 	Comes in packs of 4 for screening air	3	$6.99	4	$1.75	3	$5.24
USB and AC power adapter[9] 	for everything to plug into	1	$14.99	1	$14.99	1	$14.99
		total	**$43.94**				

[6] https://www.walmart.com/ip/Bankers-Box-Plastic-Portable-File-Box/155376229
[7] https://www.amazon.com/gp/product/B00G05A2MU/ref=ppx_yo_dt_b_asin_title_o02_s02?ie=UTF8&psc=1
[8] https://www.amazon.com/dp/B08FY7QQ6L?psc=1&ref=ppx_pop_dt_b_product_details
[9] https://www.amazon.com/gp/product/B08CC6SYCH/ref=ppx_yo_dt_b_asin_title_o02_s02?ie=UTF8&psc=1

If you don't already have a scale to weigh your $Ca(OH)_2$, this is a good one, along with a source of $Ca(OH)_2$ to get you started and some coffee filters for holding your samples:

Item	Use	Qty	Price	Qty for price	Per unit price	Units used	Subtotal
Triton T2 scale[10] 	Weighing $Ca(OH)_2$	1	$18.95	1	$18.95	1	$18.95
Bonide Hydrated Lime, 5 lb[11] 	Main input; for capturing CO_2. Can also try hydrated lime from a hardware store in the cement aisle; there they have 50 lb bags for the same price as this 5 lb bag. .	1	$17.02	1	$17.02	1	$17.02
Coffee filters, 8-12 cup[12] 	Holding the $Ca(OH)_2$ - you can weigh the filter beforehand, write the weight on the filter, then add your $Ca(OH)_2$, run, dry, weigh, then subtract the filter weight to get your product weight.	1	$7.99	100	$0.08	100	$7.99
		total	**$43.96**				

[10] https://www.amazon.com/Triton-Digital-Pocket-Formula-Jewelry/dp/B00AE0GVYK
[11] https://www.amazon.com/Bonide-Chemical-Number-5-Hydrated-Lime/dp/B00BSH0U4A
[12] https://www.amazon.com/Melitta-Basket-Filters-Natural-Unbleached/dp/B00027930Y

Tools and Skills Needed

- Drill with 8/32” drill bit (for fan mounting holes)
- Scissors (useful for cutting tubing)
- Box cutter (for scoring and cutting the fan ventilation holes)
- Sharpie or other permanent marker (optional but very useful)
- Small reciprocating saw (optional - would be useful for cutting the round ventilation holes on the sides of the file box)

Optional Materials for Testing

- 5% distilled white vinegar (for testing for $CaCO_3$)
- Spoon (for dispensing $Ca(OH)_2$ without the need to pour it)

Assembly Time Required

Minimal unit assembly takes a few minutes, assuming you’ve already eaten the hummus from the hummus container. The file box + fan assembly can be done in 2 hours following the provided instructions.

Construction

Humidifier Box

Wash the Sabra hummus container (“container”) thoroughly. Create a hole in the center of the lid since you will be letting in water, otherwise the container will float within the box. You may wish to remove a few labels before placing the lid on top and placing the whole assembly within the Sterilite FlipTop box.

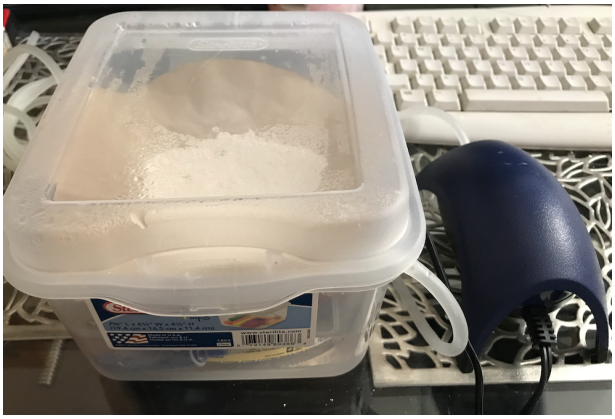
Cut about 1 foot of air tubing (this may be too short for your needs, but ideal if you are locating the pump directly alongside the box). Attach the tubing to the pump, then attach the air stone to the other end of the tubing. The air stone is the blue porous ceramic object; air blows into the stone and finely diffuses through to create many small bubbles.

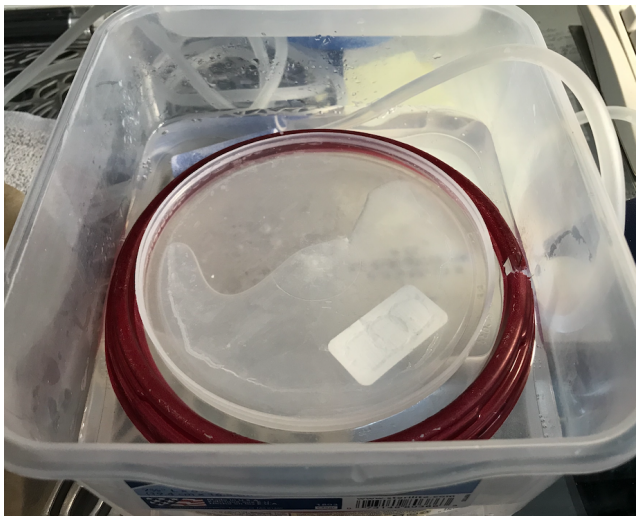
Place the container inside the box. It should fit very nicely and effectively divide the space between the upper and lower halves of the box.

Fill the box up to the level of the container lid with water. Allow the water to go into the container as well. The water level should be up to the top of the lid (the whole container should be submerged).

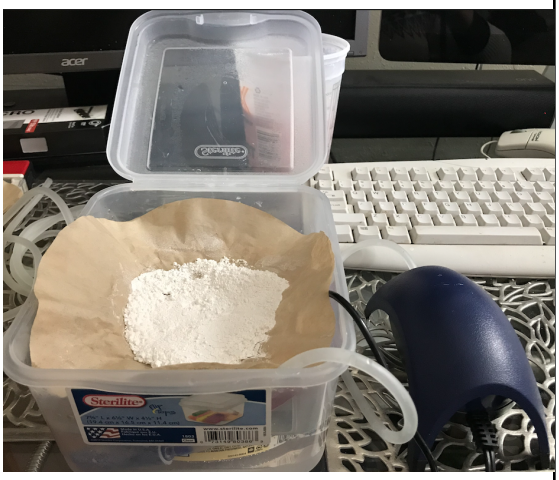
Place the air stone so that it is on its side, alongside the submerged container. One of the back corners near the box’s hinge is a good place. You may wish to drill a hole in the lid to allow the air tubing to easily pass through. We did not find a hole necessary, as the lid can be snapped mostly shut with the air tubing in place.

Place the HDX quart container lid on top of the hummus container lid. It will float in place and should not sink. This is shown at right.





When ready to do a run, you will add a coffee filter with the desired amount of $Ca(OH)_2$ onto the HDX lid, close the box lid, then plug in the air pump and let it run for your desired amount of time (upper left).

Dry Filter and Powder (initial loading)	Wet Filter and Powder (after 12 hours)
	

If you wish to speed up the drying process after you remove the coffee filter (i.e. to weigh the product and find out how much CO_2 you obtained), please go on to the next section which is the box and fan assembly.

Box and Fan: AIrflow Handling

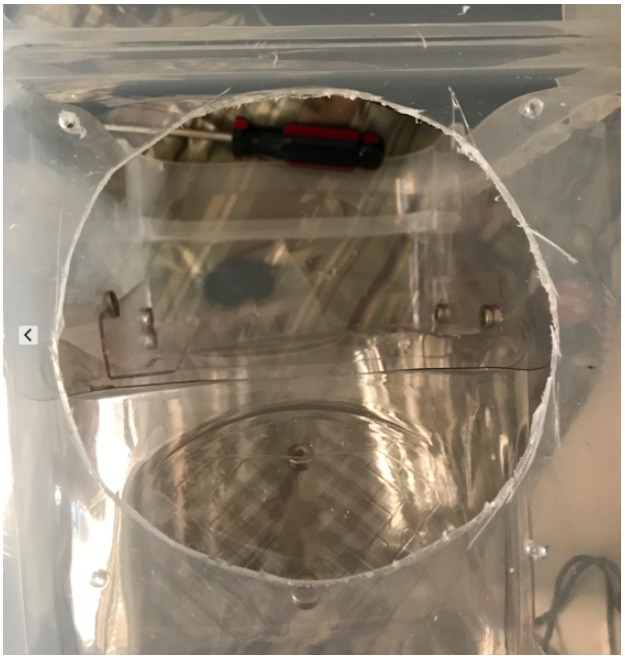
The fan has two sides, each with four corners with anti-vibration foam pieces held in place by screws. The fan grilles are also held in place with these screws. The fan will blow air in the direction of back to front, so when we mount the fan on the side of the box, we expect it to pull air from inside and push it outside.

We will use one of the fan grilles as a template for where to drill holes into the side of the box, as well as where to cut the circular hole that will let the air through.

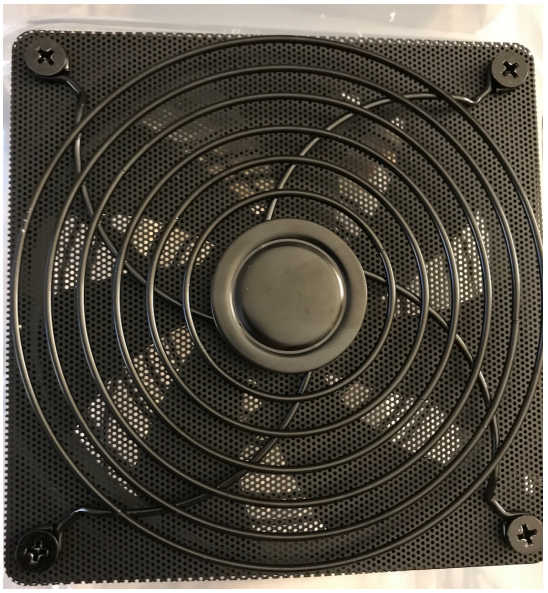
Disassemble the back of the fan to obtain just the grille by unscrewing the 4 screws at each corner. You will not need the anti-vibration foam piece at each corner for anything so those can be saved for other uses.

Once you have the back grille off, center it on the short side of the box, just under the plastic handle. You can use optional neodymium magnets to hold the grille in place by putting one magnet on the outside and one on the inside of the plastic side wall.

Next, score the plastic along the outermost circle on the grille with a box cutter blade. You may also decide to use a Sharpie to more clearly identify the hole to be cut. Instead of a box cutter blade, a small tooth reciprocating saw would be very helpful to avoid the initial breaks in the plastic caused by getting the hole started and widened.



Once the hole is cut, on the inside, take the 4 screws and back grille from the fan and slip one of the safety grilles between the back grille and the fan blade. A safety grille should also be added between the front grille and fan blade as well. One is not shown in the image below and to the right for initial airflow considerations, but it is advisable if you might have small external objects that could find their way through the front grille and into the fan blade.



Back

Front

View of the mounted fan from the inside, looking outward. Plastic at bottom is part of the front paint liner that will hold the aquarium pump.

The mounted fan on the side of the box.

For the input vent, repeat the hole-cutting process on the opposite side of the box from the fan, using the 8/32” screws and nuts provided with the safety grilles to add two safety grilles, one on the inside and one on the outside. The screws should face inward for best appearance.

Operation

Measure out a desired quantity of $Ca(OH)_2$ for your test and add it to a coffee filter that has already been weighed without $Ca(OH)_2$ added to it. Place the coffee filter onto the HDX lid that is within the humidifier box. Close the lid and run the air pump for your desired amount of time. The powder will start to clump up and form cracks as humidification takes place.

Calculating CO_2 Uptake

The coffee filter plus product should be thoroughly dried before weighing. Subtract the weight of the coffee filter and also the weight of the $Ca(OH)_2$ that you added. That will give the amount of mass change that has taken place. This change in mass is equal to the grams of CO_2 sequestered minus the grams of water that have evaporated.

The carbonation reaction once again is $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$. Since both sides of the equation must have the same mass (mass balance), the following must also be true:

change in mass = x * (mol wt $CaCO_3$ - mol wt $Ca(OH)_2$)
= x * (100.0869 g/mol - 74.09268 g/mol)
= x * 25.9942

where x = moles of $CaCO_3$ produced.

It also follows that the grams of CO_2 captured is x * (mol wt CO_2), which equals x * 44.0095 g/mol.

Thus the change in mass that is measured must be scaled by a factor of (44.0095/25.9942) = 1.693 to obtain the actual amount of CO_2 taken up.

Example: You have added **10.00 g** $Ca(OH)_2$ to a coffee filter weighing 0.86 g. The total initial weight is 10.86 g.

After your run, you measure a weight of coffee filter + product of 12.11 g.

You subtract the weight of the coffee filter to get the weight of the product, which is 12.11 g - 0.86 g = 11.25 g.

The mass change from final to initial time points is thus 11.25 g - 10.00 g = 1.25 g.

You must then increase the mass change by a factor of 1.693 to get the weight of CO_2 taken up. This is 1.25 g * 1.693 = **2.12 g**.

The above was taken from the best experimental run so far. For approximately every 5x $Ca(OH)_2$ inputted, 1x CO_2 is taken up. Making a thin layer of $Ca(OH)_2$ really seems to help.

Confirming the Presence of CO_2

You can confirm the presence of $CaCO_3$ by doing a 5% distilled white vinegar test. A positive test is the visible emission of bubbles (CO_2) upon applying the vinegar to the product. Make sure you do the test after you have made sure your sample is completely dry and you have already quantified your CO_2 uptake, as you will release some of your captured CO_2 during this test.

Storage

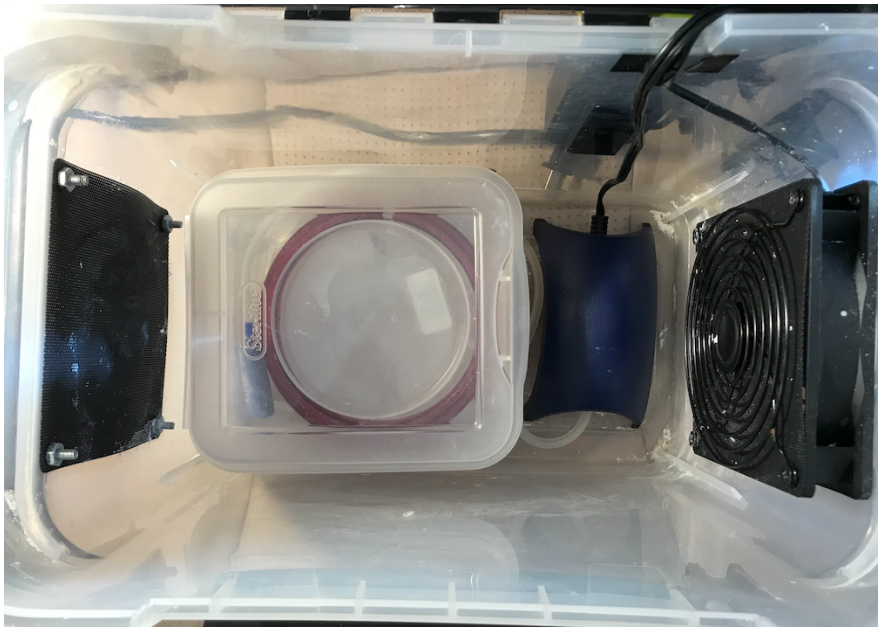
The unit is fine to sit closed for long periods of time. If you leave the water inside, the water will very slowly evaporate. For longer-term storage, empty the water, dry, and store the equipment together. As for storage of the product, partially-reacted $Ca(OH)_2$ stored in thin layers will fully react over time, and it would be educational to check the weight increase over time.

Disposal/Reuse

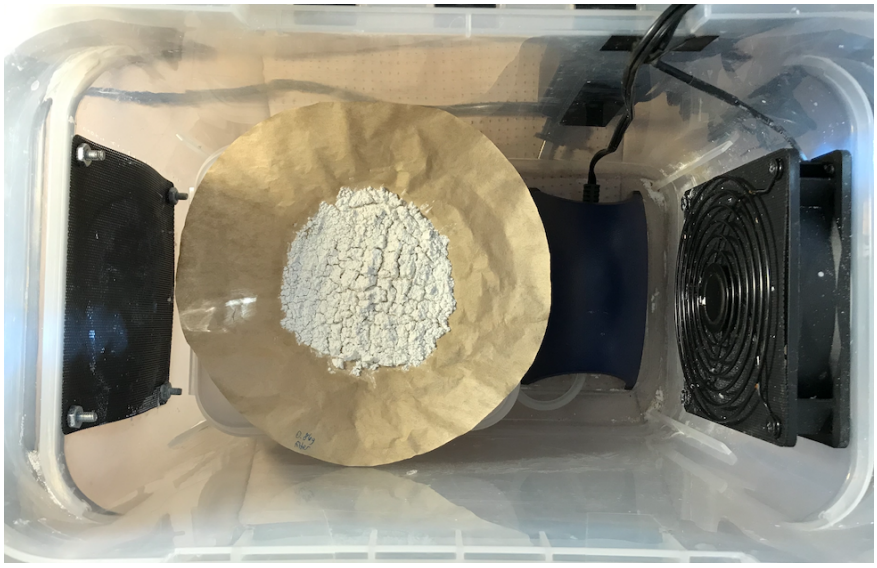
Calcium carbonate is a safe material that surrounds any unreacted $Ca(OH)_2$. Over time, even the unreacted $Ca(OH)_2$ will get carbonated. Disposal should be the same for typical soil materials. Calcium carbonate also has many uses: https://sciencestruck.com/uses-of-calcium-carbonate. Note that just because this link includes many medical applications of $CaCO_3$ does not mean you should ingest it - this rule applies for any product you might produce. However, It is fine to use it in the garden as a treat for tomatoes!

More Pictures

Filter paper removed to show unit ready for loading



Filter paper has been removed and placed on top of the humidifier box to allow the fan to dry it



It all fits! This unit can be easily carried around.