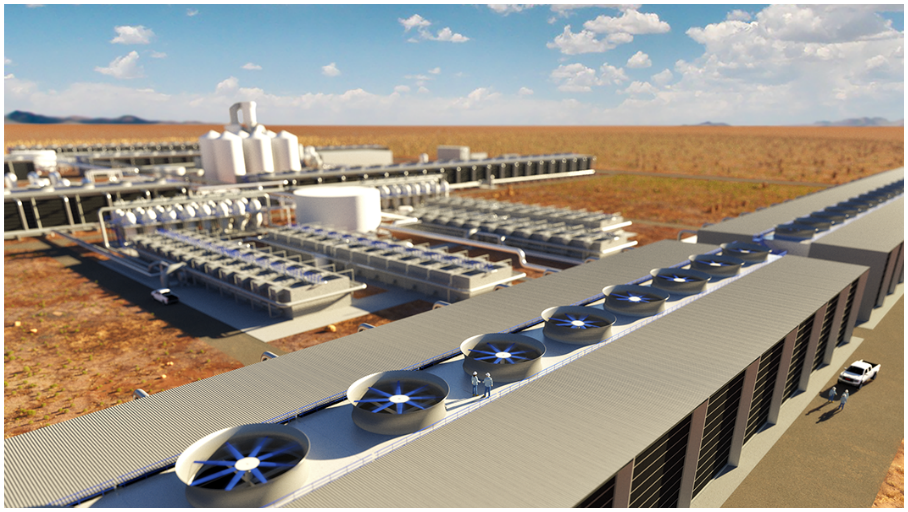
Could Direct Air Capture (DAC) and storage be the answer to solving climate change?

ENVS 145: In-Depth Q&A



By Anna Tackabery
March 2023

Questions:

What is DAC and how does the technology work to remove CO_2? How does carbon storage work?

Direct Air Capture (DAC) is a process that captures carbon dioxide from the atmosphere. There are two types of sorbents or filters used in DAC currently, solids and liquids. DAC technology for the most part works the same with both solid and liquid sorbents. Liquid DAC is more complex than Solid DAC because it uses chemical reactions to desorb the CO_2 and release it from the machine once it's captured. Solid DAC absorption starts with air going through the contactor, where the CO_2 is absorbed, and then is released as CO_2 free air. Then when the contactor is saturated with CO_2, the unit can release the CO_2 by closing the air entry, and heating to 80-100ºC in a process called desorption. Once the contactor is heated the CO_2 is released and can be either stored or utilized. In Liquid DAC the process is similar to S-DAC because air goes through contactors which filters the CO_2 out of the air. Then, L-DAC uses a chemical process to extract the CO_2 from the contactor using potassium hydroxide to bind with the CO_2 and create potassium carbonate. Then the potassium carbonate goes through the system outlined in Figure 2 and is heated to 900ºC where it completes a decomposition reaction, and the CO_2 can be obtained.

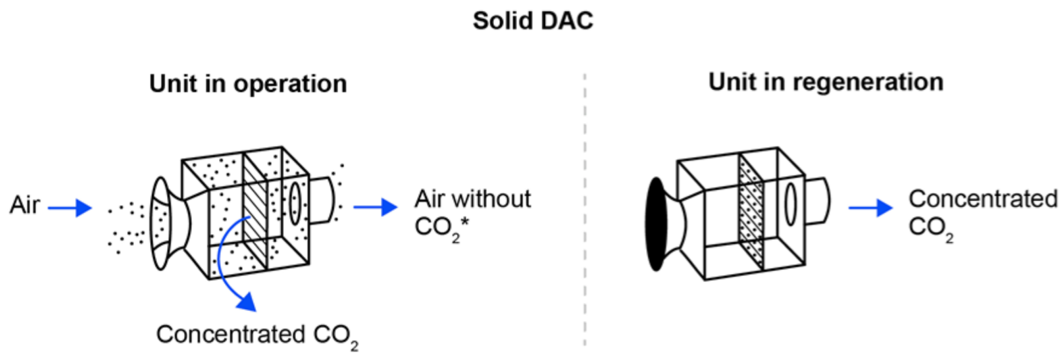


Figure 1: This figure shows a diagram of how Solid DAC works. The air enters the unit in operation and the solid sorbent collects the concentrated CO_2 before the air is released back into the atmosphere. The CO_2 can be released from the filter when it is saturated by closing the unit and heating it. The second diagram shows the unit in regeneration.

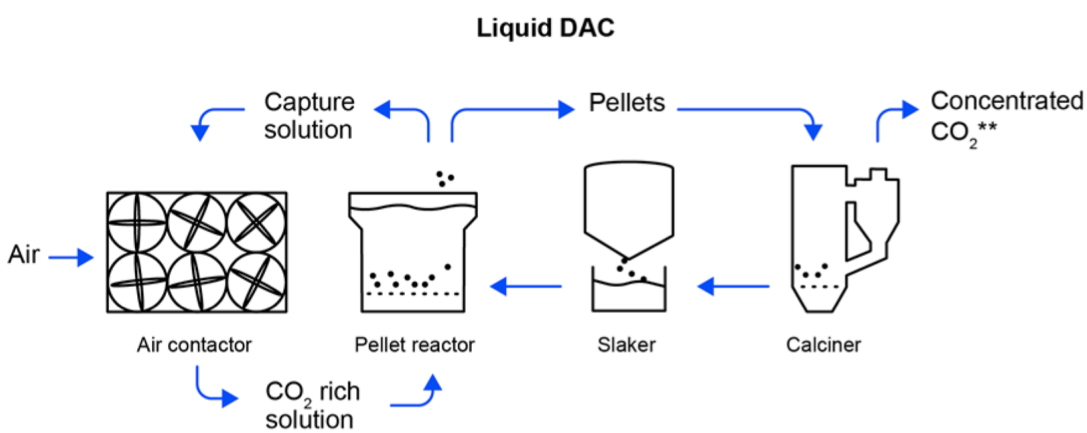


Figure 2: This figure shows a diagram of the technology of a liquid DAC plant. There are two loops within the liquid DAC, one with the air going through the contactor to absorb the CO_2 and the other forms the CO_2 into CaCO3 using chemical reactions to extract the CO_2 in the desorption reaction. In Liquid DAC it takes about 10 units of liquid air contactor to capture 1MtCO_2/yr.

	S-DAC	L-DAC
CO_2 separation	Solid adsorbent	Liquid sorbent
Specific energy consumption (GJ/tCO_2)	7.2-9.5	5.5-8.8
Share as heat consumption (%)	75-80%	80-100%
Share as electricity consumption (%)	20-25%	0-20%
Regeneration temperature	80-100°C	Around 900°C
Regeneration pressure	Vacuum	Ambient
Capture capacity	Modular (e.g. 50 tCO_2/year per unit)	Large-scale (e.g. 0.5-1 $MtCO_2$/year)
Net water requirement (tH_2O/tCO_2)	-2 to none	0-50
Land requirement ($km^2/MtCO_2$)	1.2-1.7	0.4
Life cycle emissions (tCO_2emitted/tCO_2captured)	0.03-0.91	0.1-0.4
Levelised cost of capture (USD/tCO_2)	Up to 540	Up to 340

Table 1: This table shows the comparison of Solid DAC (S-DAC) and Liquid DAC (L-DAC). It shows that L-DAC has less energy consumption, electricity consumption, can sequester on a larger scale, has less land use, life cycle emissions, and less levelized cost. L-DAC uses higher temperatures than S-DAC and uses much more water.

S-DAC captures around 50 tCO_2/year per unit and L-DAC captures around 0.5-1 $MtCO_2$/year. Once the CO_2 is sequestered it can either be stored geologically which is permanent or utilized and marketable. Injecting CO_2 into the deep saline aquifers in the earth is a permanent storage and removal of CO_2 from the atmosphere. Out of the 18 currently operating DAC plants only two are storing CO_2 underground while the other 16 are utilizing the CO_2 in other industries. CO_2 can be injected into saline aquifers, rock formations or into depleted oil or gas wells. When CO_2 is injected into depleted oil wells it can be used in a process called enhanced oil recovery. This helps lubricate the left-over oil particles and replace the oil with CO_2, pushing the oil out of the well. Enhanced oil recovery is controversial because it's sequestering CO_2 to extract more fossil fuels which is defeating the point of direct air capture which is trying to reduce fossil fuels in the atmosphere. The other use of CO_2 after it's been captured is utilization in the food industry and yield boosting for crops. Yield boosting crops is a process where greenhouses will be pumped with captured carbon dioxide to help increase the growth of the crops. It's shown to increase the yield by 25-30%. Carbon utilization has more incentive than carbon storage because there is a market for captured carbon. Carbon can be sold to companies to make carbonated drinks and to make packaging. This could be very beneficial to the industry because if there is a market for carbon dioxide then that could encourage more companies to invest in DAC.

What are the potential benefits of DAC in terms of the environment?

DAC has many environmental and economic benefits. The sequestration of carbon dioxide through DAC is beneficial to the environment because it captures carbon dioxide, a greenhouse gas. Greenhouse gasses are detrimental to the atmosphere because they cause a 'greenhouse effect.' The 'greenhouse effect' is an insulation of the earth's atmosphere. Greenhouse gasses include carbon dioxide, methane, nitrous oxide, and water vapor. When they are released into the atmosphere at unprecedented rates by humans it traps heat on earth's surface, contributing to rising global temperatures. When heat from the sun hits earth, most of it is reflected into the atmosphere and space, but when greenhouse gasses sit in the atmosphere, they reflect the heat back to earth in a loop. While the greenhouse gasses sit in the atmosphere, they also deplete the ozone layer which is a layer of the atmosphere that filters UV rays. Animals and humans need some UV radiation to live, but too much can be detrimental to living beings because it causes cancer. Using DAC to remove carbon dioxide, a greenhouse gas, from the atmosphere will help to mitigate the effects of greenhouse gasses and climate change. Carbon capture is a crucial step to limiting the earth's warming to 1.5-2ºC by 2050.

How much DAC is needed to reach net zero?

The United Nations created a goal of reaching net zero by 2050. Net zero doesn't mean that greenhouse gas emissions would decrease to zero, but that some emissions would be canceled by negative emissions. Negative emissions are the reverse of releasing gasses into the atmosphere and can be created through the sequestration of carbon dioxide. One way that carbon is sequestered from the air is through Direct Air Capture (DAC). Currently DAC is done on a small scale globally, there are only 18 plants in Europe and North America. To reach net zero by 2050, there would need to be a large increase in the amount of DAC plants operating. According to the IEA report by 2030, there is expected to be an increase in DAC's potential by a multiple of 700, but it's a fraction of the amount that would be needed to reach net zero. DAC plants are still not fully technological ready, so this would make it difficult to increase the use of DAC quickly. Of the 18 plants that are currently operational, the CO_2 capture capacity ranges from 1-4,000 tCO_2/year. The three companies that produce DAC facilities are Global Thermostat, Climeworks, and Carbon Engineering. The company Climeworks has the most DAC plants currently, owning 15 out of the 18 facilities operating. There needs to be a large increase in DAC facilities if net zero can be reached.

Currently DAC is not ready to be used at this great level and will need to be supplemented with other forms of carbon dioxide removal to reach net zero. For every 1$GtCO_2$ captured using DAC about 6 EJ will be required to power the process. The amount of energy needed to run DAC makes it difficult for the technology to be scaled up. Solid sorbent-based DAC costs about \$600/tCO_2, but it is expected to be lowered to \$200-\$300/tCO_2 by 2024. Not only are DAC plants expensive and energy-exhausting, but they also require extensive land for the facilities. It is estimated that for a solid sorbent-based DAC facility to sequester 1$MtCO_2$/yr it would require 2 km^2 for the DAC plant. To reach net zero it will require around 26,000 to 32,000 km^2 of land, low-carbon energy, and funding to see the goal realized.

Supplementary Information

$$\frac{240 \text{ MW power}}{1 \text{ MT } CO_2} \times \frac{1 \text{ MW install cap solar PV}}{0.2 \text{ MW power}} \times \frac{10^3 \text{ MT}}{\text{GT}} \times 1 \text{ GT} = 1.2 \times 10^6 \text{ MW solar cap.}$$

$$\frac{300 \text{ MW power}}{1 \text{ MT } CO_2} \times \frac{1 \text{ MW install cap solar PV}}{0.2 \text{ MW power}} \times \frac{10^3 \text{ MT}}{\text{GT}} \times 1 \text{ GT} = 1.5 \times 10^6 \text{ MW solar cap.}$$

$$\boxed{1.2 \times 10^6 - 1.5 \times 10^8 \text{ MW}}$$

$$1.2 \times 10^6 - 1.5 \times 10^6 \text{ MW} \times \frac{1 \text{ km}^2}{50 \text{ MW}} = 24{,}000 - 30{,}000 \text{ km}^2$$

of land for electricity generation only

$$\frac{2 \text{ km}^2}{1 \text{ MT } CO_2 \text{ removed using solid sorbent}} \times \frac{10^3 \text{ MT}}{1 \text{ GT}} = 2{,}000 \text{ km}^2$$

of land for just DAC plant assuming solid sorbent based DAC

$$24{,}000 - 30{,}000 \text{ km}^2 + 2{,}000 \text{ km}^2 = \boxed{26{,}000 - 32{,}000 \text{ km}^2}$$

Total land used (DAC Plant + Solar PV energy generation) for removing 1 GT of CO_2 using DAC

This calculation shows the land requirements in km^2 of DAC plants and Solar PV as the energy source to sequester 1GT CO_2.

Sources for Calculation:

- 240-300 MW power per 1 MT CO_2
- 1 GT of CO_2 removed to reach net zero
- Solar capacity 20% (gross assumption because it differs by geographic location)
- Install 50 MW Solar PV per 1 km^2
- Remove 1MT CO_2 per year requires 2 km^2 of land for solid sorbent-based DAC plant