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The dream of 'direct air capture'

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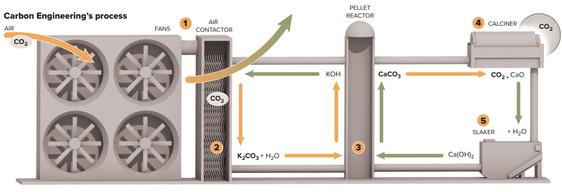
One of the least efficient, most expensive and still-speculative approaches to reducing carbon in the atmosphere — direct air capture — is collecting support among some lawmakers who support fossil fuel industries. The idea: Use technology to suck carbon dioxide out of the air, long after CO_2 exits a smokestack or vehicle tailpipe.

A University of Michigan review, however, found consensus among scientists that DAC won't be a significant option for removing greenhouse gases until after the energy sector has been de-carbonized. A 2011 American Physical Society analysis reached a similar conclusion: "Coherent CO_2 mitigation would appear to require only limited deployment of DAC until CO_2 is captured from nearly all large centralized facilities." But costs for DAC have fallen since then, to the extent that the price of the technology might be worth the social and environmental benefits.

DIRECT AIR CAPTURE

A variety of processes are being explored to capture and concentrate atmospheric carbon dioxide. The American company Global Thermostat uses an amine process, allowing one of its plants to potentially capture 4,000 metric tons per year. Carbon Engineering's pilot plant in Canada currently produces one ton of CO_2 per day, converting some of it into fuel:



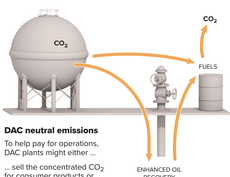
1 Large fans, driven by renewable energy sources, suck ambient air into the system, forcing it past an air contactor coated with a solution containing potassium hydroxide (KOH).

2 The potassium hydroxide reacts with carbon dioxide (CO_2), forming water and pellets of potassium carbonate (K_2CO_3).

3 Pellets enter a reactor where they undergo a chemical reaction with calcium hydroxide ($Ca(OH)_2$) forming calcium carbonate ($CaCO_3$) and potassium hydroxide, which is sent back to the air contactor.

4 In a high-temperature calciner, calcium carbonate is converted into calcium oxide (CaO) and concentrated carbon dioxide, which is either utilized of sequestered.

5 A slaker combines the calcium oxide with water to create calcium hydroxide, which is sent back to the pellet reactor.

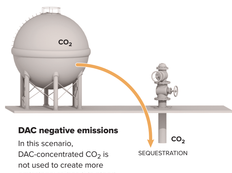


DAC neutral emissions

To help pay for operations, DAC plants might either ...

... sell the concentrated CO_2 for consumer products or enhanced oil recovery, or ...

... use the CO_2 as a feedstock for creating fuels.



DAC negative emissions

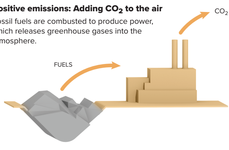
In this scenario, DAC-concentrated CO_2 is not used to create more emissions; rather, it is piped deep into the ground for sequestration.

THE GIVE AND TAKE OF ATMOSPHERIC CARBON

Carbon emissions can be either added to or subtracted from the atmosphere, or be carbon-neutral, both adding and subtracting equal amounts.

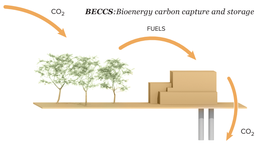
Positive emissions: Adding CO_2 to the air

Fossil fuels are combusted to produce power, which releases greenhouse gases into the atmosphere.



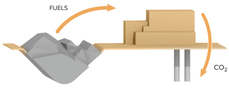
Negative emissions: Removing CO_2 from the atmosphere

Carbon dioxide is absorbed from the atmosphere by vegetation, which is harvested for biofuels. The carbon from combustion is captured and sequestered.

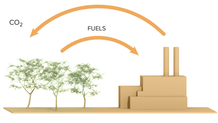


Neutral emissions

1 - Emissions from fossil fuel combustion are captured and sequestered by pumping deep underground, where they may be used to enhance oil recovery.



2 - Photosynthetic organisms (plants, phytoplankton, etc.) absorb carbon dioxide from the air, so emissions released by combustion of biofuels are considered to be offset by the carbon captured by plants used in the production of biofuels.



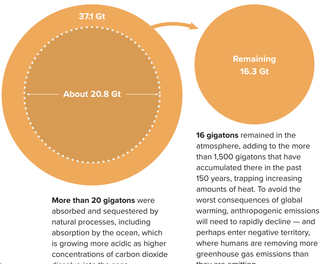
Comparing carbon removal strategies

In 2017, a group at University of Michigan's School for Environment and Sustainability reviewed the literature on atmospheric carbon dioxide removal options and their costs. The figures depicted here are median values from the studies they analyzed.

ANTHROPOGENIC EMISSIONS

Human activity released **37.1 gigatons** of carbon-dioxide-equivalents into the atmosphere in 2018.

IN GIGATONNES OF CO_2 EQUIVALENTS

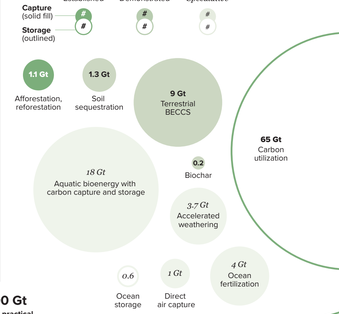


More than 20 gigatons were absorbed and sequestered by natural processes, including absorption by the ocean, which is growing more acidic as higher concentrations of carbon dioxide dissolve into the seas.

16 gigatons remained in the atmosphere, adding to the more than 1,500 gigatons that have accumulated there in the past 150 years, trapping increasing amounts of heat. To avoid the worst consequences of global warming, anthropogenic emissions will need to rapidly decline — and perhaps enter negative territory, where humans are removing more greenhouse gas emissions than they are emitting.

POTENTIAL FOR MITIGATION, PER YEAR

A variety of strategies for removing CO_2 from the atmosphere. Explanations for each strategy are listed below.



3,900 Gt
Available practical geologic storage

THE COSTS OF CAPTURE AND STORAGE

Reduction of atmospheric carbon will require a broad mix of strategies with a wide range of costs. Some methods might be relatively inexpensive, but are only speculative or offer limited potential for mitigation.

2017 dollars per metric ton of CO_2e captured or stored, median value — IN KILOGRAMS OF CO_2 EQUIVALENTS CAPTURED OR STORED PER 2017 DOLLAR, MEDIAN VALUE

Soil sequestration
Better management of pastures/cropland
$8 per metric ton of CO_2e captured or stored — 125 kilograms per dollar invested

Geologic storage
Estimated effectiveness of sequestering carbon dioxide underground without using the gas as a resource
$15 — 66.7 kg

Aquatic bioenergy carbon capture and storage (BECCS)
Aquatic biomass is used to generate energy after it captures and stores CO_2
$18 — 55.6 kg

Ocean storage
Crop residues are dumped into the sea, or CO_2 is pumped deep into ocean recesses
$26 — 38.5 kg

Ocean fertilization
Nutrients are added to the ocean to stimulate growth of marine microscopic organisms, which absorb CO_2
$30 — 33.3 kg

Afforestation, reforestation
Planting trees in areas with no previous tree cover, and replacing trees in forests with tree loss
$30 — 33.3 kg

Carbon utilization
Enhanced oil recovery; use of CO_2 in consumer products
$40 — 25 kg

Biochar
Charcoal added to soil as an amendment
$40 — 25 kg

Terrestrial BECCS
Land biomass is used to generate energy after it captures and stores CO_2
$60 — 16.7 kg

Accelerated weathering
Exposure of certain CO_2-absorbing minerals to large land areas
$70 — 14.3 kg

Direct air capture
Mechanical/chemical removal of CO_2 from the atmosphere
$345 — 2.9 kg

Some DAC developers claim they can now achieve more than 10 kg CO_2e/dollar, at less than $100 per metric ton. Others say $50 per ton is achievable.

10 kg

$100

New U.S. federal tax credits
$50 per ton of CO_2 captured and sequestered underground.
(Not reflected in the costs at left)

A 2017 analysis of natural climate solutions published the Proceedings of the National Academy of Sciences estimated the social cost of a metric ton of CO_2e to be $100 by 2030.

POST-COMBUSTION CAPTURE

The concentration of carbon dioxide in the flue gas from a coal-fired power plant is about 300 times higher than that of ambient air.

$80 avoided cost by removing CO2 from the atmosphere, 2007 (increasing to $100 by 2030)

16.1 kg
$62

Capturing CO_2 at the source

A 2007 NETL estimate of the capital and operating costs of capturing a ton of CO2 from a coal-fired power plant.

An APS report says DAC does have some cost advantages relative to post-combustion CO_2 capture:

- Lower intake temperature
- Fewer feed contaminants
- Flexibility in siting, allowing lower-cost energy resources.

However, those advantages, the analysis said, "are unlikely to outweigh the severe concentration penalty."

Sources: "Carbon Dioxide Removal Options: A Literature Review Identifying Carbon Removal Potentials and Costs," Derek Martin, Katelyn Johnson, Andrew Stolberg, Xilin Zhang, and Carissa De Young, University of Michigan; Proceedings of the National Academy of Sciences; American Physical Society; National Energy Technology Laboratory; Global Carbon Project