Carbon Capture/Direct Air Capture: Role in Addressing Climate Change?

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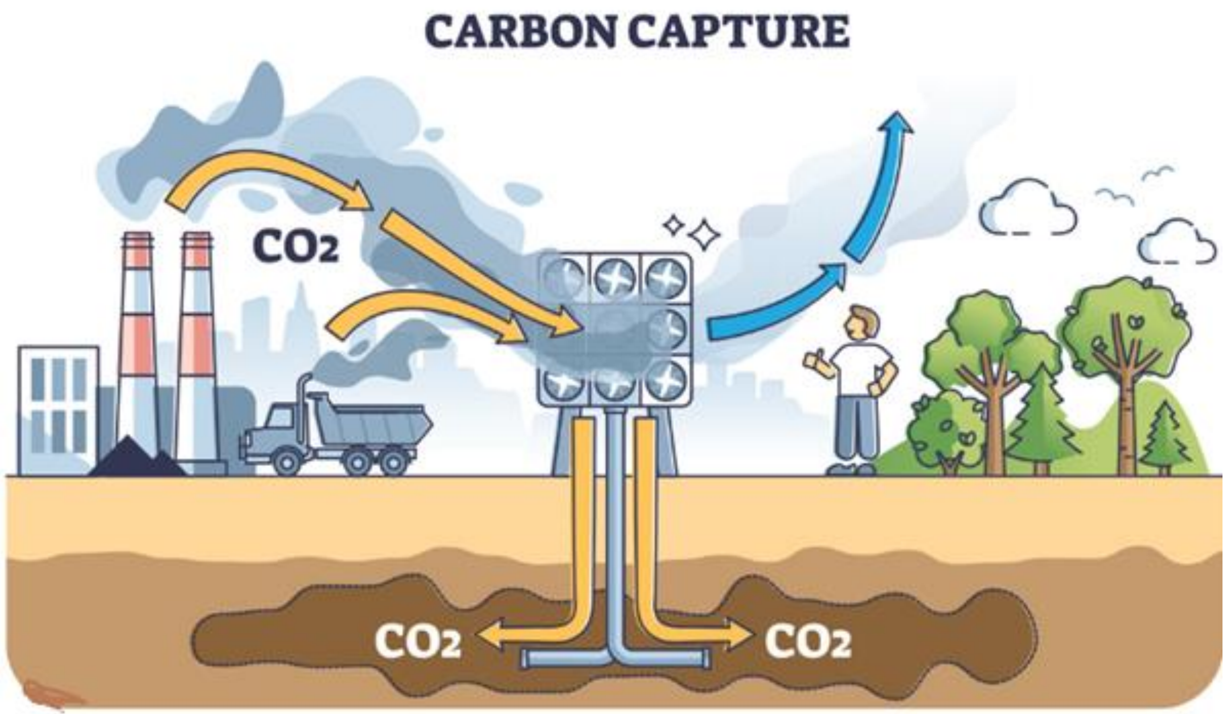


Image Courtesy of Green Recruitment Company

On December 8 – during COP28 in Dubai - there was an opinion piece in the NY Times entitled: [Carbon Capture Won't Save Us From Climate Change.](#) The writer states that "direct air capture of carbon isn't a completely bad idea…….. because in some sectors of the economy, it's impossible or extremely costly to reduce greenhouse gas emissions all the way to zero". He cites cement production as one such example. However, his main theme is that we need to focus more on avoiding the generation of CO_2 entirely rather than creating it and then trying to capture it.

His opinion is in effect matched by the final agreement approved at COP28 which said that carbon capture could be helpful in "hard-to-abate sectors" like steel manufacturing that are expected to have a difficult time eliminating their emissions, but that by itself it was not a way to eliminate the climate impact of fossil fuels.

Before getting more into the pros and cons of carbon capture, it is important to note that the Times article did not distinguish between 2 related but not identical technologies: *Carbon Capture* (generally referred to as Carbon Capture and Storage (CCS) and sometimes as Carbon Capture Utilization and Storage (CCUS)) and *Direct Air Capture* (DAC).

Carbon Capture vs. Direct Air Capture

Carbon Capture technologies are intended to essentially prevent the release of CO_2 into the atmosphere at the locations at which they are generated. In the most commonly used arrangement today, a chemical that can "grab" CO_2 is placed in or near the stream of CO_2 at a source such as a power plant, oil refinery or industrial facility. The captured CO_2 is then released and compressed so that it can be transferred (generally but not always via pipeline) and then be used - for example, as feedstock for an industrial process – or permanently stored underground.

Direct Air Capture technologies remove CO_2 from the atmosphere, even if it had been released many years earlier. Typically, air is forced over a chemical that can "grab" the CO_2. DAC and CCS can use the same chemicals, but generally there are chemicals that are better suited for each application, and the supporting equipment must be optimized for the different CO_2 concentrations involved in DAC and CCS. After capture, the process for DAC is similar to that used for CCS, and the same equipment can be used for compression, transfer, and storage. The chemical that does the capturing can be used multiple times.

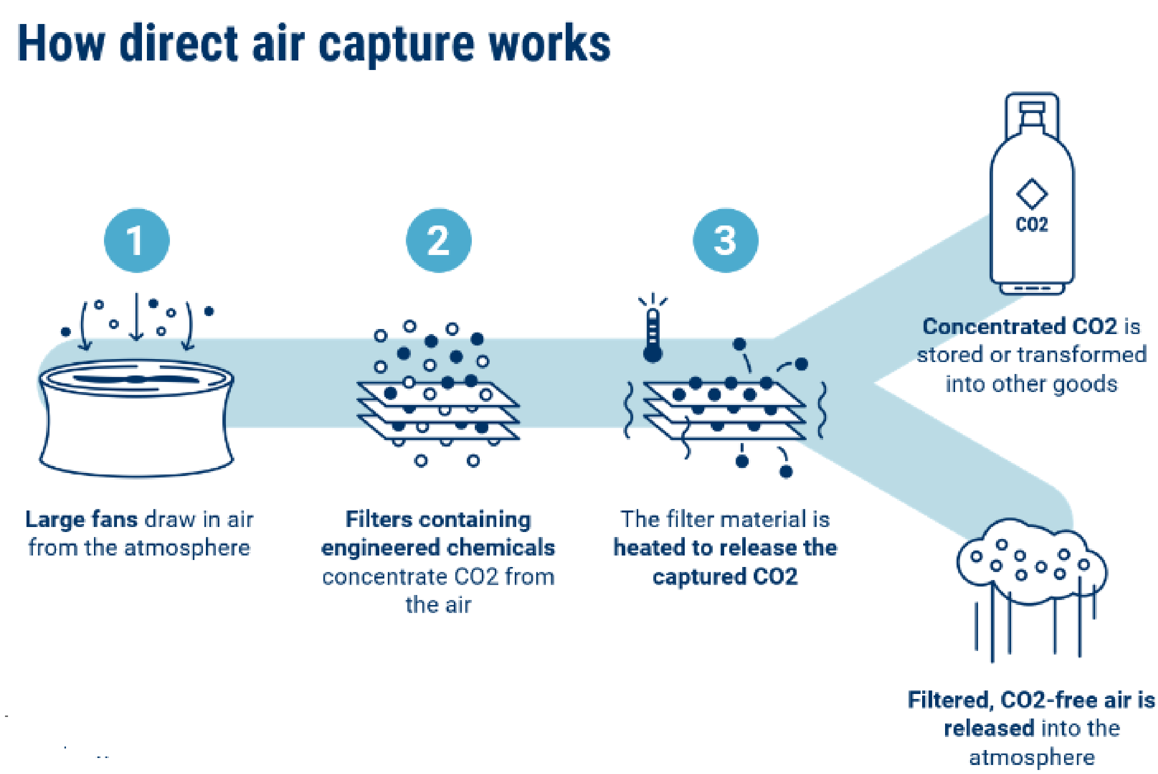


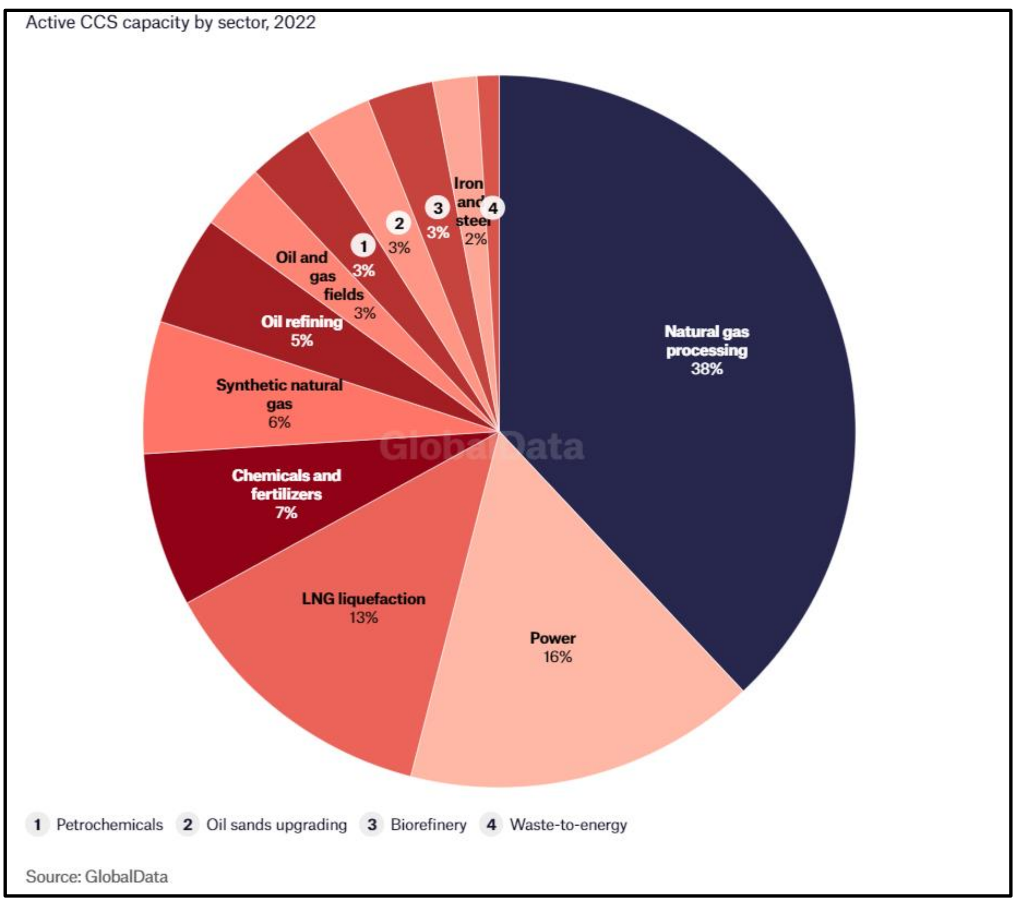
Image Courtesy of CB Insights

Two technological approaches are currently being used for DAC: solid and liquid DAC. Solid DAC (S-DAC) is based on solid adsorbents operating at ambient to low pressures and medium temperature (80 - 120 °C). Multiple technologies are used for S-DAC, differing in energy intensity, operating temperature, and cost. Liquid DAC (L-DAC) relies on an aqueous basic solution (such as potassium hydroxide) which releases the captured CO_2 through a series of units operating at high temperature (between 300 °C and 900 °C). While S-DAC can be powered by a variety of low-carbon energy sources (e.g. heat pumps or geothermal), the current high temperature needs of L-DAC does not allow that level of flexibility.

DAC plants can be deployed in a much greater number of locations than CCS facilities since they do not need to be attached to an emissions source. By placing DAC facilities close to locations where the captured CO_2 can be stored, the need for pipeline infrastructure is reduced, as is the potential for CO_2 leaks. To-date, DAC plants have operated in a range of climatic conditions, mostly in Europe and North America, but further testing is still needed in locations characterized, for instance, by extremely dry or humid climates, or polluted air.

Although the capture technologies for CCS and DAC are different, they face similar challenges; both are typically capital and energy intensive. However, CO_2 in the atmosphere is much more dilute than it is in the flue gas from a power station or a cement plant, for example. As a result, DAC requires more energy and costs more than CCS. More on this topic later.

CCS technology has been around for about 50 years. That being said, there were only about 40 operational CCS facilities operational across the world in 2023, with another 100 under development and over 100 more in the pipeline. The sectors where CCS is being used are highlighted below. An image of a Liquified Natural Gas plant with Carbon Capture and Storage follows.



The Gorgon liquefied natural gas (LNG) and carbon capture and storage (CCS) facility, operated by Chevron Corp., on Barrow Island, Australia

DAC technology has been around for a little under 25 years. A total of 27 - mostly small - DAC plants have been commissioned worldwide. Six DAC projects are currently under construction, with the largest two expected to come online in late 2023 in Iceland (see image below) and 2025 in the US. Plans for at least 130 DAC facilities are now at various stages of development. However, lead times for DAC plants range from 2 to 6 years. The Biden administration recently authorized $3.5 billion to develop four regional hubs — the first two in Texas and Louisiana — to accelerate the deployment of Direct Air Capture. The $1 trillion bi-partisan infrastructure bill approved in 2021 earmarked more than $12 billion for carbon capture projects and infrastructure**.** It also included funding for the Department of Energy's Office of Fossil Energy and Carbon Management (FECM).

Just last week FECM issued a notice of intent to provide funding for large-scale conversion of carbon emissions into environmentally responsible and economically valuable products. Projects will develop sustainable feedstocks and conversion technologies necessary to produce fuels, materials, and other carbon-based products that are better for the environment than current petroleum-derived components. If issued, the funding will support two areas of focus: (1) research and development of electrochemical conversion processes that convert carbon emissions into products such as engineering polymer/resin precursors, specialty chemicals, and commodity chemicals; and (2) feasibility studies that examine retrofitting refineries for carbon utilization and production of products such as ethane, liquid petroleum gas, and naphtha.

There are now more than 30 companies across the world that are implementing CCS and DAC technologies. Here are the 10 largest CCS and 20 largest DAC companies as reported by Carbon Herald, followed by an image of a DAC plant being opened by one of the companies on the list.

Largest CCS and DAC Companies as Reported by Carbon Herald		
CARBON CAPTURE	**DIRECT AIR CAPTURE**	
Aker Carbon Capture	AirCapture	Heirloom
Calix Limited	Capture6	Mission Zero Technologies
Carbon America	CarbonCapture Inc	Noya
Carbon Clean	Carbon Engineering	Removr
CarbonFree	Carbon Collect Limited	RepAir Carbon Capture
Carbon8 Systems	Carbyon	Skytree
Chart Industries	Climeworks	Soletair Power
Capsol Technologies AS	CO2Rrail	Sustaera
NET Power	Fervo Energy	Valiidun
Svante	Global Thermostat	Verdox

Rendering of DAC Plant Developed by Climeworks in Iceland

Pros and Cons of DAC

TreeHugger posted an article back in 2021 (Direct Air Capture Pros and Cons) outlining positive and negative sides of DAC. Here's a quick summary of the advantages of DAC that they mentioned in citing it as "one tool that shows promise for helping to slow warming":

- DAC reduces atmospheric CO_2.

- It can be deployed in a wider variety of locations than CCS.
- DAC requires a smaller footprint than CCS – or particularly bioenergy carbon capture and storage.
- It can be used to remove carbon (by creating long-lived products such as building insulation or cement) or to recycle carbon (by creating short-lived products such as carbonated beverages and synthetic fuels).
- DAC can achieve net-zero or negative emissions by creating synthetic clean fuels that could take the place of fossil fuels.

They then went on to address the downsides of both CCS and DAC:

- DAC requires large amounts of energy in order to drive the air, produce the required materials, and heat the materials for re-use.
- It's currently very expensive; the cost of removing a metric ton of CO_2 (as of 2021) ranges from $250 - $600 based on the type of energy used; whether liquid or solid sorbent technology is used, and the scale of the operation. (Note: a more recent source quotes the range as $250 - $1,000).
- There are environmental risks from the transport of CO_2 and its storage. In addition to the risk that a pipeline will leak and groundwater could be polluted in the process of injection it is possible that the disruption of geologic formations during injection will trigger seismic activity.
- Direct Air Capture enables *Enhanced Oil Recovery (EOR)* - which uses CO_2 injected into an oil well to help pump out otherwise unreachable oil. (Oil and gas companies have long performed EOR, reinjecting CO_2 generated and captured in oil and gas production into older reservoirs that are losing pressure, increasing the wells' output).

Interestingly, in 2020, the world’s largest CCS plant, the Petra Nova facility in Texas, shut down after becoming commercially nonviable. Although the plant’s technology appeared to perform relatively well, the EOR, for which Petra Nova’s captured carbon was used, fell victim to a sharp decline in oil prices caused by COVID.

TreeHugger did not fully address the issue of safety. It should be noted that in 2020, a CO_2 pipeline in Mississippi ruptured, releasing carbon dioxide that displaced breathable air near the ground and sent dozens of people to hospitals. Work is being done to improve safety of CCS and DAC.

Approaches for Improving DAC

There are a number of emerging DAC technologies that rely on innovative separation methodologies that have a goal of reducing the energy intensity (and hence the cost) of the DAC process.

- **Electro swing adsorption** - ESA-DAC is based on an electrochemical cell where a solid electrode adsorbs CO_2 when negatively charged and releases it when a positive charge is applied. ESA-DAC is currently being developed in the US and UK.

- **Zeolites** – (rare) minerals that possess a natural negative charge - are now being adopted for DAC. It is believed that their porous structure is suitable for CO_2 adsorption. The first operational DAC plant relying on zeolites was commissioned in Norway in 2022.
- **Passive DAC** relies on accelerating the natural process that transforms calcium hydroxide and atmospheric CO_2 into limestone. This process is being engineered in the US by a company (Heirloom) using renewably powered kilns to separate CO_2 from limestone.

All 3 are still in early stages of deployment.

Advocates for Carbon Capture and Direct Air Capture

There are a range of advocates of Carbon Capture and Direct Air Capture across the globe.

For example, the **Carbon Capture Coalition**, started by the Great Plains Institute, is a collaboration of more than 100 companies, unions, and environmental policy organizations aimed at building federal support to enable wide-scale deployment of carbon management technologies. They argue that wide-scale adoption of carbon management technologies is critical to achieving net zero emissions. A recent quote from the Executive Director: "What we are talking about now is taking a technology that has been proven and has been tested but applying it much more broadly and also applying it in sectors where there is a higher cost to deploy."

The **Direct Air Capture Coalition** describes themselves as supporting international efforts to address the climate challenge by bringing together diverse global innovators – from technology, business, finance, government, and civil society – to educate, engage, and mobilize around Direct Air Capture. They argue that: "Science tells us that we need to remove hundreds of billions of tons of CO_2 to avoid catastrophic climate change. Because it can be deployed quickly and located nearly anywhere there is air, Direct Air Capture has a critical role to play".

There is also a group called the **Direct Air Capture Advisory Council,** run by the Bipartisan Policy Center, which describes itself as: "bringing together Republicans and Democrats—and providing them with the space, policy insights, and evidence-based research they need to negotiate in good faith—to help turn legislators' best ideas into passable, durable laws".

And then, of course, there are the oil and gas companies.

ExxonMobil, Chevron, Shell, Occidental Petroleum, Air Products, Archer Daniels, and Talos Energy, for example, are investing billions in carbon capture technology. These companies predict big growth. For example, Occidental has estimated that the carbon capture market will hit $50 billion a year by 2030. Exxon has suggested it could go as high as $4 trillion by 2050.

A recent Associated Press article noted that the American Petroleum Institute says oil and gas will remain a critical energy source for decades, meaning that in order for the world to reduce its carbon emissions, "rapidly expanding carbon capture technology is key to cleaner energy use across the economy." The article goes on to say that "a check of oil companies' plans to get to net-zero emissions finds that most of them are relying on carbon capture".

Most of the oil companies heavily promote their carbon capture activities. Here's a screen shot taken from the Chevron website (which also has a quote: "Carbon capture makes a lower carbon future possible"):

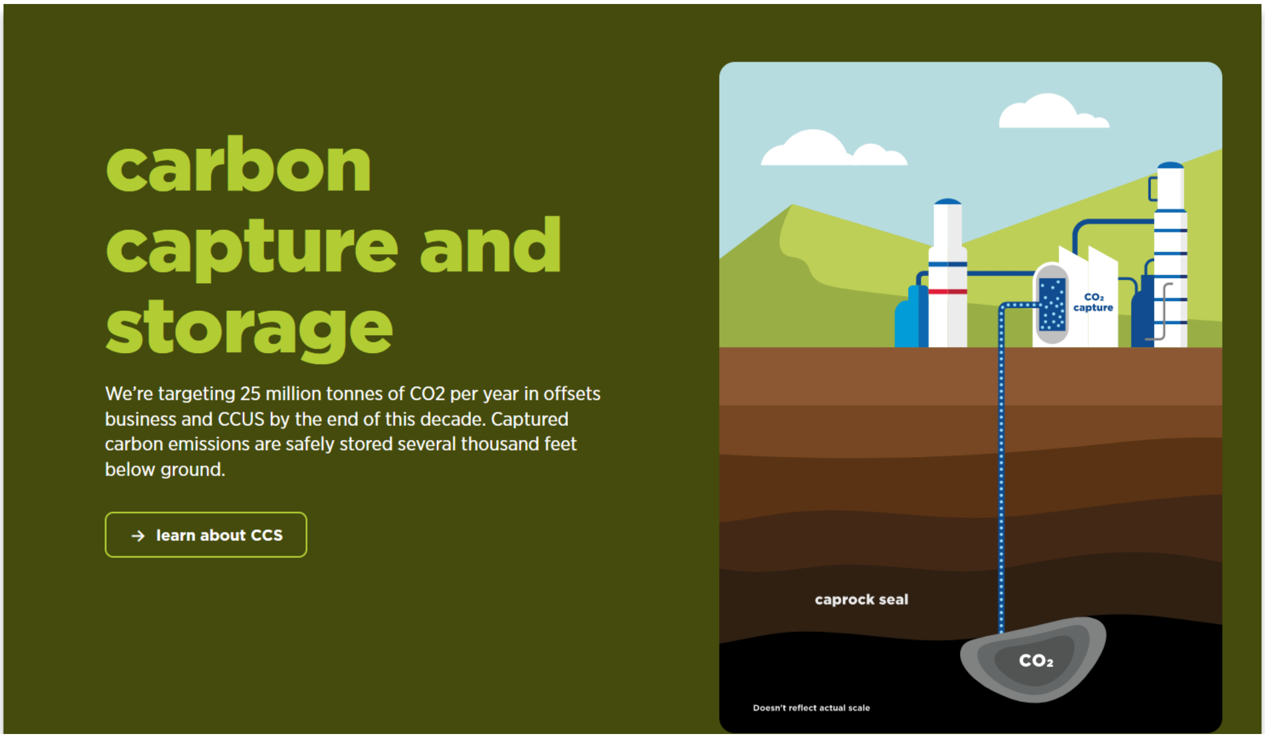


Image Taken from Chevron Website

Detractors of Carbon Capture and Direct Air Capture

While there appear to be a significant number of supporters of Carbon Capture and Direct Air Capture, there are quite a few detractors as well.

Among the detractors speaking out against carbon capture, the Swiss-based **Center for International Environmental Law** released a report in July 2021 condemning the approach. They argued that such projects provide "the fossil fuel industry with a license to continue polluting, that CCS facilities rarely capture a meaningful amount of carbon dioxide, and that they in fact worsen the climate crisis when used to boost oil production".

More recently, right before COP28, the head of the **International Energy Agency** (IEA) stated that the oil and gas industries need to let go of the "illusion" that carbon capture technology is a solution to climate change and invest more in clean energy. He went on to say:

"The industry needs to commit to genuinely helping the world meet its energy needs and climate goals – which means letting go of the illusion that implausibly large amounts of carbon capture are the solution".

An IEA report states that one of the major pitfalls in the energy transition is excessive reliance on carbon capture. Carbon capture is essential for achieving net zero emissions in some sectors, but it should not be used as a way to retain the status quo. 32 billion tons of carbon would need to be captured (for utilization or storage) by 2050 to limit climate change to 1.5 degrees Celsius under current projections for oil and gas consumption. The necessary technology would require 26,000 terawatt hours of electricity to operate in 2050, more than total global demand in 2022. It would also require $3.5 trillion in annual investment from today through mid-century.

Influence Map just issued a report that argues that most corporate advocacy promoting CCS for addressing climate change is not aligned with "science-based pathways" recommended by the Intergovernmental Panel on Climate Change (IPCC) for limiting global temperature rise to below 2°C. The report draws from InfluenceMap's platform which tracks the climate policy engagement of over 500 of the world's largest companies and 250 industry associations. It examines corporate advocacy on CCS, i.e., attempts to influence CCS-related policy or to push for CCS inclusion in climate policies. They note that corporate advocacy in favor of CCS over the past several years has been dominated by the oil and gas sector, which uses a wide range of influence tactics – from PR and advertising to regulatory lobbying – to promote the technology**.** Entities that appear most active on CCS-related policy include companies such as Occidental Petroleum, ExxonMobil, Shell, BP, Santos, and Cenovus, and industry associations such as the Australian Energy Producers Association, International Association of Oil and Gas Producers, Canadian Association of Petroleum Producers, and the American Petroleum Institute. Corporate advocacy ranges from the promotion of high-level narratives to detailed regulatory engagement. A common goal across CCS advocacy is to drive financial and regulatory support for CCS-focused pathways and to direct policy attention away from fossil fuel phase-out. In a letter to the Canadian government, for example, the Pathways Alliance advocated for large tax benefits to commercialize CCS without specifying the intended application of the technology. The Federation of Korean Industries has emphasized the need for major financial support for CCS over other decarbonization pathways.

The research identified three common claims that appear across CCS corporate advocacy: that CCS allows for continued oil and gas expansion; that CCS is central to meeting global climate targets; and that CCS can support jobs and communities.

This report also assesses recent high-level communications from 21 national governments (the G20 and UAE) on CCS and fossil fuel phase-out, finding that the positions of 17 of the 21 countries appear to reflect those of the oil and gas sector, suggesting that the industry has been successful in many of its efforts to influence government positions. Countries such as Canada, Japan, the UK, and the US – where the oil and gas sector actively promotes CCS as the primary decarbonization technology – tend to see fossil fuels with CCS as a long-term climate strategy. Countries with large state-owned oil, gas, and coal companies also tend to support CCS alongside a significant, long-term role for fossil fuels

A recent opinion piece in **Scientific American** entitled Don't Fall for Big Oil's Carbon Capture Deceptions also focused on how carbon capture and direct air capture are being touted and used by the oil industry. (The subtitle of the article was: Carbon capture technology is a PR fig leaf designed to help Big Oil delay the phaseout of fossil fuels).

The writer argues that counting on these technologies is a bad idea. He noted that industrial carbon capture projects are far too small to matter; even after decades of investment, carbon capture projects remove a small percentage of yearly greenhouse gas emissions. He points out that the planned US

Regional DAC Hubs, noted earlier, are intended to catch 1 million metric tons of CO_2 a year while the world emitted last 40.5 billion tons last year.

The writer launches into additional negatives of CCS and DAC

- They are far too expensive, costing thousands of dollars for every ton of CO_2. Other solutions, including improving energy efficiency, deploying renewable energy sources, and addressing emissions in agriculture and industrial sectors, are far more cost-effective. Industrial carbon removal costs at least $1,000 per ton removed; other climate solutions may have costs lower than $10/ton.

- Industrial carbon removal techniques consume huge amounts of energy. If carbon capture projects are powered with fossil fuels they lose much of their proposed climate benefit - but powering them with renewable energy sources provides less climate benefit than using that energy to directly displace fossil fuels.

- CO_2 captured by industrial carbon capture projects is often used to produce more oil or gas, helping fossil fuel companies to expand their output. This is being pushed by a range of oil and gas companies and may be considered a ploy by Big Oil to delay actions to phase out fossil fuels.

The writer goes on to argue that these projects allow fossil fuel companies to claim that they are taking serious climate action while they are actually continuing to build out the fossil fuel infrastructure. He notes that Occidental Petroleum which has received hundreds of millions from US DOE for carbon capture projects, stated that: "direct capture technology is going to be the technology that helps to preserve our industry over time…….. giving a license to continue to operate for 60, 70, or 80 years."

The Scientific American writer further argues that carbon capture – heavily supported by taxpayers - is being used to distract the world from the need to rapidly phase out fossil fuels. He finds it troubling that billions of tax dollars have already been spent on carbon capture – with lots of the money going to Big Oil – and that the Inflation Reduction act expands 45Q tax credits[1] for this purpose. He believes that we need to see fundamental shifts in how carbon capture technology is governed, funded, and used, and that we should not allow money from taxpayer-supported carbon capture projects to go to fossil fuel companies. Instead, he argues that carbon capture should immediately be redirected to more effective climate solutions.

Interestingly, despite the extreme negativity, the writer reaches the same conclusion as the NY Times writer; that carbon removal technology could have a role in the fight against climate change, if we limit its use to hard-to-control industrial sources like cement, steel, and fertilizers. But even here he notes that we need to lower the energy use and costs of Direct Air Capture.

Food and Water Watch posted an equally negative view on Direct Air Capture (5 Things you Need to Know About this Climate Scam), starting with this quote: "Direct air capture promises to suck carbon from the sky. But its proponents — including Big Oil — are hiding some dirty downsides. Now, DAC

[1] The 45Q tax credit is an incentive tax credit introduced by the IRS in 2008 for projects that capture carbon oxides (CO, CO2, and C_3O_2). As part of the Bipartisan Budget Act that passed in February 2018, the US Congress extended and significantly increased the 45Q tax credits.

boosters are drumming up hype that masks real problems — notably, that Direct Air Capture is a scam that won't help solve the climate crisis. With time running out on climate change, we can't waste resources on this dangerous and speculative technology."

The article outlines 5 issues with DAC:

1. DAC Wastes Tons of Cash on a Few Drops in the Bucket

Recently, Occidental Petroleum proposed a new DAC facility in Texas that could become the largest such facility in the world - at the cost of $811 million. But the facility would capture, at most, just .01% of our country's annual CO_2 emissions.

The writer goes on to note that capturing just a quarter of our country's annual emissions would cost at least $700 billion per year, with taxpayers, based on current regulations, paying more than $150 billion of that. He argues that the cash would be better spent on clean energy; noting that investing in solar and wind to reduce emissions would be fifteen times cheaper than using DAC to pull CO_2 from the sky.

2. DAC Emits More Than It Captures

Direct air capture currently uses a lot of power – and potentially more than it can remove. He cites research that finds that capturing 1 ton of CO_2 with fossil-powered DAC would emit the equivalent of 3.5 tons of CO_2. If the U.S. used all of the electricity it currently generates on DAC it would still only capture a quarter of our annual emissions.

The article notes that some proponents argue that using renewables to power DAC would solve this problem but points out – as was noted by the Scientific American writer – that this would pull renewable energy from more important and efficient uses, like household power.

3. Carbon Capture Relies on Toxic Solvents

The writer argues that DAC also threatens public health and safety because the most promising carbon capture technologies rely on two kinds of toxic solvents. The first, aqueous hydroxide solutions, can produce chlorine gas, which has been used as a chemical weapon. Scaling DAC would produce vastly more chlorine gas than we currently use, raising questions about whether it could be disposed of safely. Capturing just a quarter of U.S. annual CO_2 emissions would produce triple the amount of chlorine gas that we use globally.

The second, amine-modified solutions, release chemicals that are carcinogenic and could potentially harm human health, even at very low levels. DAC releases one kind of amine-modified solution at a rate that exceeds toxicity levels for drinking water and aquatic ecosystems.

The writer goes on to point out that we don't have sustainable or economical solutions to dispose of all these toxic chemicals.

4. "Long-Term Storage Solutions" are Super Risky

A key part of carbon capture is sequestration: burying the carbon deep underground, where it will (supposedly) never again see the light of day. But getting the carbon down there has risks — most notably leaks.

Leakage may occur from the injection of carbon into storage wells which could fracture the well – or even create minor earthquakes. Additionally, where CO_2 is sequestered near oil or gas wells, the original well bores could create pathways for leaks. Therefore, there's no guarantee that sequestered carbon actually stays sequestered.

5. DAC Projects Often Subsidize and Power More Drilling

While proponents proclaim DAC will pull our emissions out of the sky, they ignore a key fact: currently, 95% of our country's captured carbon goes to Enhanced Oil Recovery, which injects CO_2 and other chemicals into wells to flush out the last dregs of oil.

Food and Water Watch ends their article with the following:

"Right now, direct air capture isn't a climate solution — it's a climate wrecker. What's more, its greenwashing claims allow fossil fuel giants to continue drilling, fracking, and polluting — subsidized with even more taxpayer dollars. It may even net them more oil, through enhanced oil recovery. We don't need expensive, dangerous technology that doubles as a boon for Big Oil. Funding for a complete transition to renewables would be far more effective and efficient, and more people and planet-friendly".

Note: multiple other sources put the percentage of captured carbon in Enhanced Oil Recovery at approximately 60% - a far cry from 95% that Food and Water Watch cites but still quite significant. Here's a quote from the Society of Environmental Journalists:

"Every year, companies around the United States capture around 18 million metric tons of carbon dioxide from natural gas processing plants, oil refineries and power plants. As long as that CO_2— equivalent to around 4 million cars on the road for a year — is buried somewhere deep underground, it can't contribute to global warming. That's the theory, anyway. But today, the lion's share of the CO2 captured from industrial processes doesn't go back into the ground. Instead, 60 percent of it is used to extract more oil, in a controversial process known as "enhanced oil recovery."

The article with the above quote goes on to add another one from Lorne Stockman, research co-director of the advocacy group Oil Change International. "I think it's a huge problem. The oil and gas industry has done a very good job of co-opting our climate and clean energy policy."

And, to put a closing note on CCS and DAC detractors, at COP28, Al Gore said: "The current state of the technology for carbon capture and direct air capture is a research project. There's been no cost reduction for 50 years and there is a pretense on the part of the fossil fuel companies that it is a readily available, economically viable technology."

Notice any consistent attitudes towards Big Oil?

So Where Does that Leave Us?

Clearly, no one is arguing that we should cease all Carbon Capture & Storage and Direct Air Capture projects.

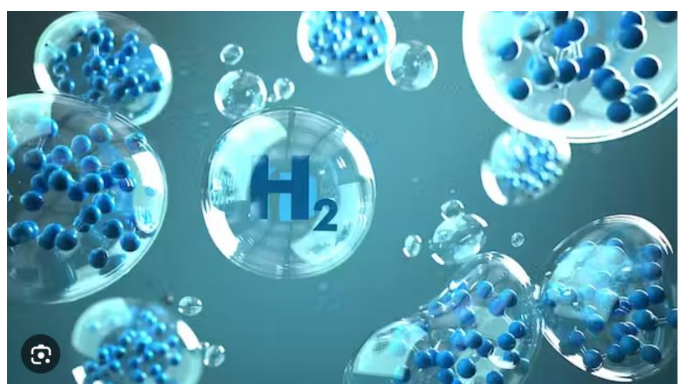
However, the detractors forcefully point out that there needs to be a greater emphasis on eliminating the generation of CO_2 than on methods for removing it after it is released. The goal of most world governments – as evidenced by COP28 - is to totally phase out fossil fuels. But how can that be accomplished?

There is enormous activity aimed at reducing and ultimately eliminating the need for fossil fuels across all segments. For example:

- In the US, there are enough renewable energy and energy storage projects in the queue to totally phase out fossil fuel for power generation – if they can all be implemented. The problem is that the electric transmission and distribution grid cannot handle the addition of all of these generation and storage sources, and there is a huge backlog of projects (known as the Interconnection Queue) waiting to be implemented – a process that is taking multiple years causing many such projects to be cancelled. The good news is that the federal government recently allocated $3.5M to help enhance the grid and there are multiple companies working on technology that can help make the grid more efficient – but this is clearly an area that needs investment at many levels.

- Progress is being made in increasing the volume and lowering the cost of Green Hydrogen, a totally clean fuel created from the electrolysis of water (using renewable energy) that can be used in industrial processes, transportation (primarily heavy-duty trucking and potentially maritime and air transport), green ammonia production for fertilizers and potentially transportation, and more. (Currently 25% of hydrogen is used for oil refining, but we won't go there). There is also considerable activity going on across the world in "mining" White Hydrogen, which is hydrogen gas that is naturally generated within the Earth's crust

  Unfortunately, Green Hydrogen costs almost 5 times as much to produce as hydrogen made with natural gas, but a significant amount of work is being done by DOE and others to address that. The Biden administration recently announced $7 Billion in funding for 7 Hydrogen Hubs to create "clean" hydrogen. However, while 4 of the sites will be producing Green Hydrogen; the other 3 will be producing what is known as **Blue Hydrogen**, which is hydrogen made from natural gas leveraging carbon capture to try to eliminate the CO_2

- While the sales of Electric Vehicles have slowed down some– at least in the US – there is a definite move to replace gas-powered vehicles with EVs across the world. Vehicle range is getting longer and charging times are getting shorter. Progress is being made in the required infrastructure to support EVs – namely charging stations - but not nearly fast enough. The Federal government approved $5 billion two years ago (under the National Electric Vehicle Infrastructure (NEVI) Formula Program) for states to build a network of fast chargers. Although some states have made progress recently, most have not yet awarded contracts or started construction. Only two states — Ohio and New York — have actually opened charging stations using this funding. A handful of others have broken ground on projects very recently. In total, 28 states have awarded contracts to build chargers or started accepting bids for projects.

- Major efforts are being made – certainly across the US – to phase out the use of natural gas in home heating, water heating, and cooking, with both mandates to exclude gas appliances from new construction and rebates for doing so. The Massachusetts Department of Public Utilities just issued an order that should encourage a transition to using electricity for heating and other functions that gas currently serves. Massachusetts is the first state to take such a clear step to phase out natural gas, but at least 11 other states (California, Colorado, Illinois, Maryland, Minnesota, Nevada, New Jersey, New York, Oregon, Rhode Island, and Washington) and Washington, D.C. have ongoing regulatory cases that are exploring ways to phase out natural gas. Of course, until we phase out the use of fossil fuels for power generation - where it is currently responsible for 60% in the US - this will not have nearly the effect that is being looked for.

- There are other activities aimed at reducing fossil fuel use, including general energy efficiency programs being pushed by utilities and others, improvements to efficiency of appliances, and more. Leading businesses are taking steps to understand and manage their greenhouse gas emissions, preparing annual greenhouse gas inventories and setting long-term targets to reduce emissions. There are a variety of very innovative technologies being developed to reduce carbon emissions. For example, a very early-stage company that I advise (and have invested in) – RainIons - has developed a new coating technology for car and industrial exhausts that has been shown in 7 third-party tests to eliminate 33% to 95% of CO_2 (and other pollutants including CO, NO, and NOx), with the amount reduced tied to the temperature used, fuel, and other factors. Technologies and activities such as these will clearly play a major role over time.

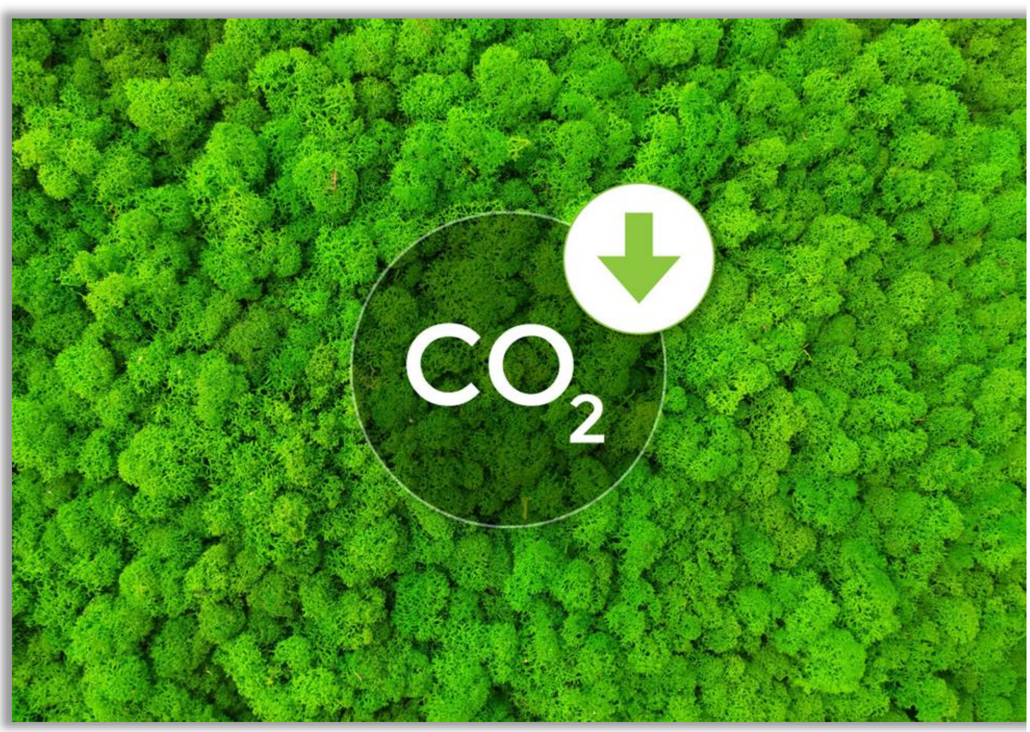


Image Courtesy of Galooli

But in the interim, CO_2 is being pushed into the atmosphere, so CCS and DAC will be required for the foreseeable future.

A very recent article in the Boston Globe about Vertex Pharmaceuticals, a very successful Boston-based biotech company, caught my attention. The article entitled: "Painkillers without addiction? Vertex hopes its experimental pill can be first in a new class of drugs" is about an experimental drug for treating pain. The article noted that anti-inflammatory drugs such as aspirin and ibuprofen work by reducing swelling at the location of pain, while opioids change the brain's perception of pain, mimicking the natural pain-relieving chemicals - endorphins - produced in the brain. In contrast, the Vertex drug is designed to interrupt pain signals *before* they reach the brain, blocking certain proteins that transmit pain to the nervous system. In other words, rather than waiting for the pain to occur and then having to deal with it, it blocks the pain from happening.

Which sounds like an apt analogy for carbon. Clearly, we need to continue to work towards removing CO_2 that has entered the atmosphere. But it will be much more effective to focus on blocking CO_2 entirely. To reach the energy transition and stated climate goals the phase out of fossil fuels needs to happen.

Therefor, here are some thought on how to move forward:

- Governments should begin to shift some of the money currently going to carbon and direct air capture to other areas - many of which are identified above - aimed at phasing out fossil fuels.

- Since CCS and DAC will be around for many years, research is needed into new technologies that can reduce the amount of energy – and costs – involved in CCS and DAC.

- Efforts should be made to constrain the oil companies from using carbon capture for Enhanced Oil Recovery and focus more on what beneficial products can be created with the captured CO_2.

- CCS and DAC require a ramp-up in regulatory oversight to confirm that capture technologies do what they're designed to do and that gases injected underground stay there.

Bottom line: CCS and DAC have a role to play, but accelerating the path to phasing out fossil fuels needs to take priority.