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The Grand Challenge of Carbon Sequestration

Clayton Lawrence, Norberto Martinez, Thomas Nguyen, & Mitchell Tomazin

The University of Texas at Austin

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Abstract

Carbon capture and storage (CSS) of greenhouse gases from the atmosphere is a solution to the problem of global warming. Two sequestration methods are analyzed. Industrial capture is one way to repurpose the captured carbon dioxide for its use in enhanced oil recovery (EOR). Carbon dioxide is pumped underground, restoring pressure to depleted oil wells and thus allowing more oil to be extracted. However, the potential of carbon dioxide to leak to the surface and contaminate water reservoirs poses an environmental threat where the issue of liability must be addressed. In oceanic iron fertilization (OIF), algal blooms are stimulated by dumping iron into the ocean. Upon dying, the phytoplankton sink to the bottom of the ocean, depositing carbon in the sediment. The process naturally sequesters carbon from the atmosphere, but overstimulation would lead to high marine levels of carbon and potentially disrupt the oceanic ecosystem. Both of these sequestration methods are costly in terms of money, resources, and manpower. Consequently, there is little incentive for private industries to engage in sequestration. From both an ethical and an economic perspective, more research and new technology will be needed before these methods can be safely implemented on a large scale.

Keywords: carbon capture and storage, carbon dioxide, sequestration, industrial capture, enhanced oil recovery, oceanic iron fertilization, algal blooms, ecosystem

Grand Challenges Team: Carbon Sequestration

"The concept of global warming was created by and for the Chinese," a man on a podium once exclaimed (Cillizza, 2017). This statement belongs to none other than our very own president Donald Trump, but is it true? Contradictory to his belief, NASA reports an average rise in global temperatures over a span of the last 134 years, with the hottest being in the most recent fifteen (MacMillan, 2016). Global warming is a fact and a critical issue that needs to be addressed. In response, engineers and scientists have proposed various carbon capture and storage (CCS) methods to counteract global warming at its roots. Two methods, industrial capture and oceanic iron fertilization, show potential promise. Each solution, however, is linked to certain ethical problems which cloud its justifications. In the end, neither industrial capture nor oceanic iron fertilization are viable options with the current technology available. More research and ingenuity are needed to make them safe and economically sustainable.

The challenge of global warming involves many causes and effects. Carbon dioxide (CO_2) is predominantly emitted from the combustion of fossil fuels, both through massive electric power generation plants and via smaller distributed sources such as furnaces and vehicle engines. Some extraction processes and deforestation techniques, particularly slash and burn, can also result in the immense ejection of CO_2 into the atmosphere (Rubin, et al., 2005). There is scientifically incontrovertible evidence that these vast emissions of CO_2 and perfluorocarbons (carbon-fluorine compounds commonly emitted in manufacturing electronics) have impacted the environment by invading the atmosphere at high concentrations. In doing so, they have triggered an unnatural exacerbation of the process known as the Greenhouse Effect. In this process, the added gaseous emissions of carbon absorb infrared radiation energy from the sun, increasing the total energy absorption of the atmosphere. This effect acts as a positive feedback loop that has resulted in (or at least contributed largely to) global warming.

In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was created as a result of international concern and a desire to “[stabilize] greenhouse gas concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system” (United Nations Framework Convention on Climate Change, 2017). This is the same organization that adopted the Paris Climate Accord in December of 2015. As of November 2017, 195 members of the convention have signed the agreement and 86% of those have domestically ratified it (Rubin, et al., 2005). As more nations commit to these policy changes in their industry sectors, they are effectively devoting more research—both to finding new sequestration mechanisms and to improving those that already exist. It goes without saying that placing limitations on greenhouse gas emissions is clearly a difficult task: doing so will harm industrial profits and potentially even a nation’s economy.

Effects of global warming are widely evident, with the obvious one being a rise in global temperatures. According to NASA, the additional effects are plentiful: droughts are lengthening; heat waves are growing hotter; mild winters shorten while lengthy summers scorch the earth (Callery, Jackson, & Shaftel, 2017). The Arctic as we know it may not be *arctic* by the turn of the mid-century. In addition to seawaters warming, glaciers are melting, which will force sea levels to rise by a projected one to four feet by the year 2100 (Callery, Jackson, & Shaftel, 2017).

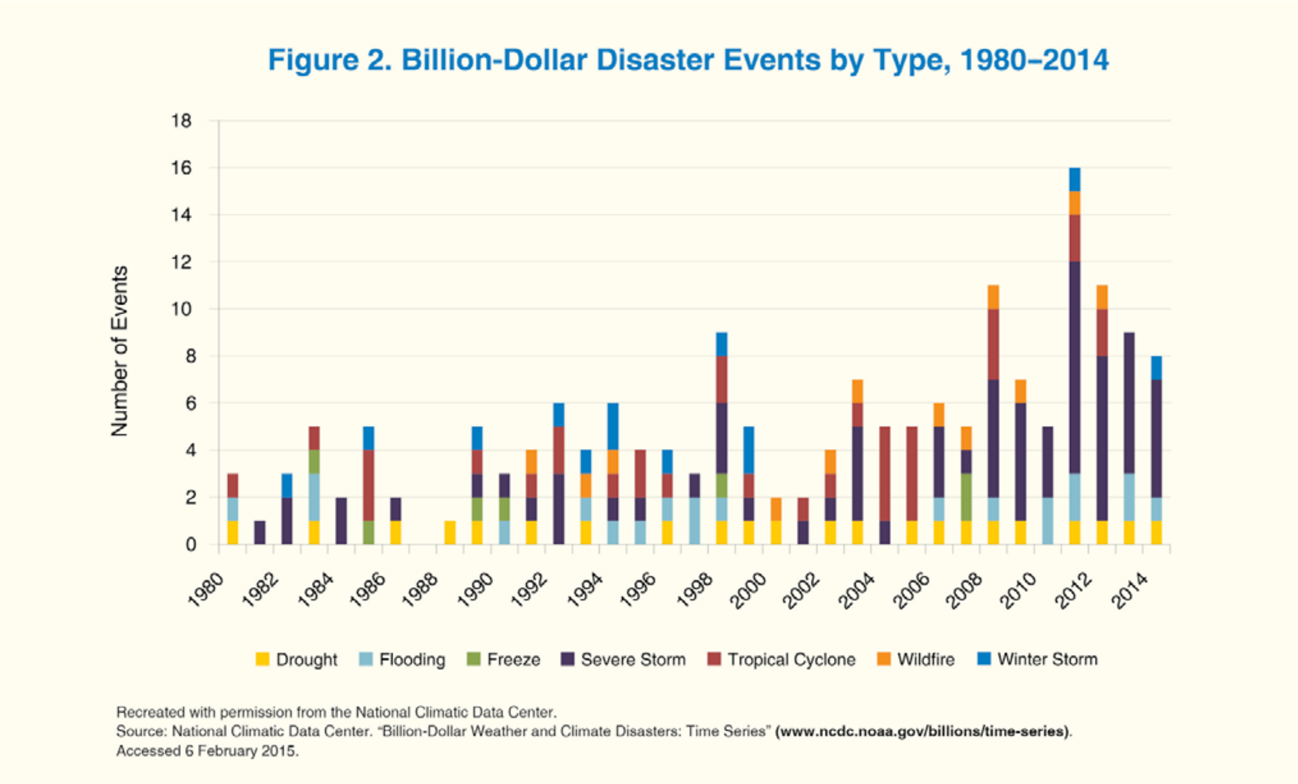

Figure 1. This data formulated by researchers from the National Climatic Data Center (NCDC) displays an observable increasing trend in incidence of wildfires, drought, severe storm, flooding, and tropical storms in the last decade. It also displays a decrease in incidence of freeze and winter storms. https://www.ncdc.noaa.gov/

As a result of these catastrophes, coastal cities and countries face not only an increased risk of flooding but also stronger tropical storms (Callery, Jackson, & Shaftel, 2017). Case in point: remember Hurricanes Harvey, Irma, and Maria. Hurricanes thrive in warmer waters; therefore, as temperatures continue to rise, so does the strength of these storms (Drash, 2017). To date, Hurricane Irma was the longest Category 5 hurricane in recorded history, "[maintaining] winds of 185 mph or above for a total of 37 hours" (Drash, 2017). In reality, limiting the amount of carbon in the atmosphere would in turn limit global warming and its effects, such as these ominous "mega hurricanes."

Today engineers are researching new solutions to combat this potential catastrophe of carbon emissions. Carbon capture and storage or carbon sequestration refers to a preemptive measure that intends to slow the extensively harmful runaway effects of fossil fuel emissions (viz. global warming and ocean acidification). It customarily does this by totally preventing carbon dioxide from leaving the point source—the central location of CO_2 discharge. This can be carried out pre- or post-combustion, depending on the type of plant and the resources available to it. After sequestration of carbon from a point source, the byproduct is converted, stored, and/or recycled in various ways. Carbon sequestration can also be theoretically done through large-scale “geoengineering projects” in which it is drawn from the general atmosphere. An example of this is the mass-cultivation of algal blooms, which will be addressed below.

Although CCS systems can hypothetically reduce CO_2 emissions by 80-90% depending on the type of generation plant, the takeaway for industrial companies is whether the captured carbon can be put to use in a manner that creates profit or at least negates the cost of capture (Rubin, et al., 2005). To this end, there are various products to which the captured carbon can be recycled, such as a catalyst in the geological extraction of fuel. In spite of all this, supplementary fuel is still required to carry out sequestration in the first place. This means that when CCS systems are involved in the plant, either substantially more fuel has to be used to yield the same amount of power (thereby increasing the amount of CO_2 emissions) or the system must be sustained renewably (Brouwer, Van den Broek, Seebregts, & Faaij, 2013). Sustaining a system renewably can be done by designing wind fields or solar farms next door to a plant that is using a CCS system. Additionally, the transportation and/or storage of the converted CO_2 requires time, effort, and resources. In short, for CCS to become a reliable, economically self-sustaining, and industrially feasible system in unclean power generation, these costs must not outweigh the benefits.

The two CCS methods to be examined are industrial capture with enhanced oil recovery, which is sequestration from a point source, and oceanic iron fertilization (OIF), which is sequestration from a nonpoint source. First, to introduce them briefly, industrial capture with enhanced oil recovery refers to the process of capturing carbon dioxide produced in factories and repurposing it to release more oil from the ground (Nettles & Conner, 2009). Because this method primarily deals with businesses, it is best to examine it from a common good and utilitarian perspective. It is important to take into account business profits and liability, the ratio between carbon captured and carbon released from recovered oil, and the possible effects on the environment.

OIF is the process of dumping iron into a portion of the ocean so as to induce larger phytoplankton blooms, as phytoplankton is a natural absorber of CO_2 from the atmosphere (Strong, Chisholm, Miller, & Cullen, 2009). As the blooms die, they sink to the bottom of the ocean, carrying with them carbon that is then stored in the sediment. One study in 2006 found that 80% of the harpacticoid copepod species died in a simulated sequestration project and successfully carried the carbon to the seafloor (Thistle, et al., 2006). Presently, however, the true long-term effects of the increased carbon and phytoplankton in the ocean are unknown, resulting in a dilemma. Looking from a utilitarian standpoint with current research, OIF remains unethical because no matter how much carbon is reduced, it is unknown how drastically oceanic ecosystems may be affected—a risk too great to be overlooked. Therefore, both CSS methods, although effective in capturing and storing carbon, inevitably cause more problems than they solve, making them ethically unjust mainly from the utilitarian viewpoint. We will examine these two methods in further depth below.

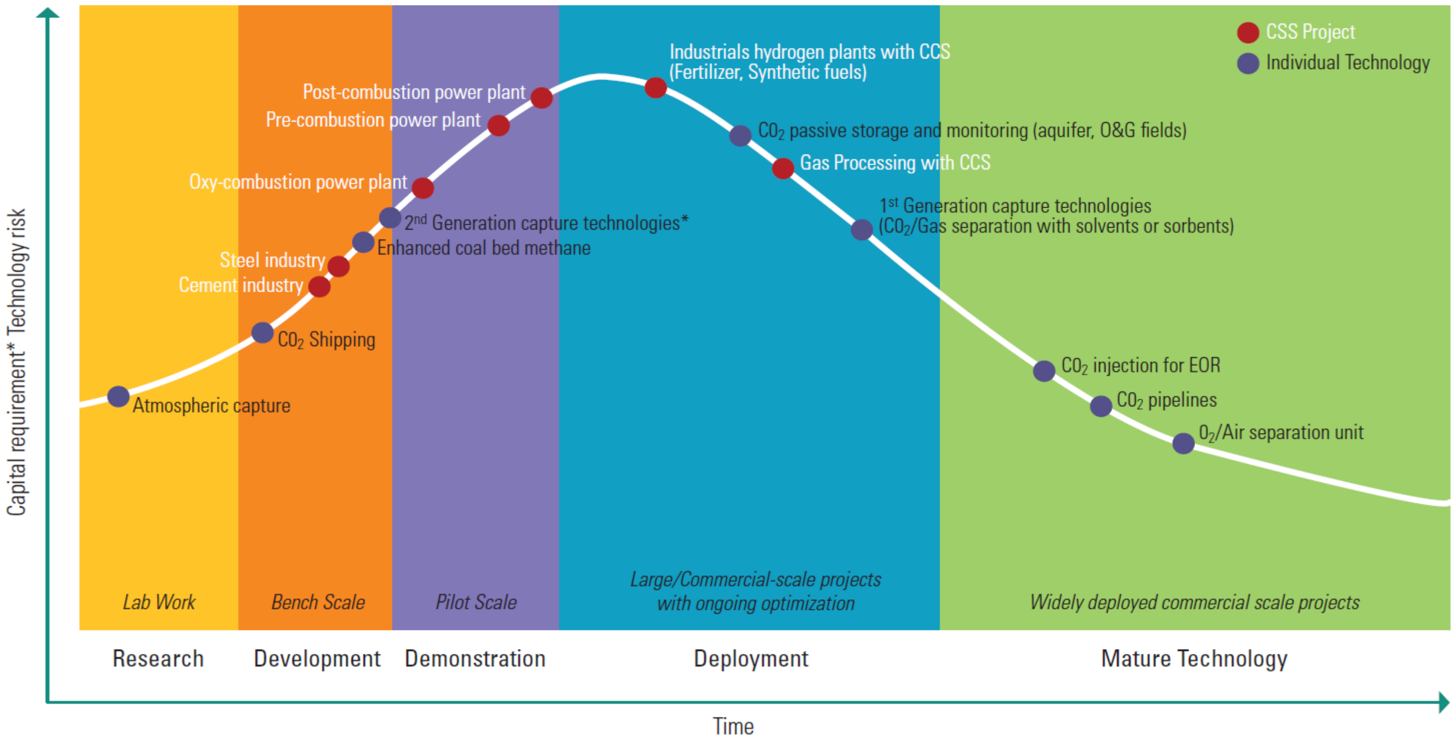

Figure 2. There is a plethora of CCS methods proposed by scientists and researchers—all of them in different levels of development. The two examined in this paper (i.e. atmospheric capture and CO_2 injection for EOR) lie on opposite sides of the developmental spectrum. https://carbonremoval.wordpress.com/2014/06/24/the-pros-and-cons-of-enhanced-oil-recovery-eor-for-commercializing-cdr/

Industrial capture quite literally involves capturing carbon dioxide from large industrial point sources, such as power plants or large manufacturing facilities. There are three techniques by which this is being done: post-combustion, pre-combustion, and oxy-fuel combustion (Nettles & Conner, 2009). In post-combustion, CO_2 is chemically stripped and captured from the exhaust of burning fuels. In pre-combustion, the primary fuel, such as coal or natural gas, is synthesized to produce CO_2 and hydrogen-rich fuel separately. This new fuel, which is devoid of CO_2, can then be combusted. The third technique involves combusting the primary fuel in pure oxygen which results mainly in a CO_2 and water vapor mixture which can be condensed to remove the water. The advantages of all of these methods is that it allows for power to be produced from the burning of fuels without releasing carbon dioxide to the atmosphere. However, all of these methods have high costs associated with them, so one challenge is finding a way to make carbon capture profitable.

The selling and repurposing of captured carbon dioxide is one way that current carbon capture methods can be made economically feasible. One of the uses of captured carbon dioxide is in the food industry. Captured CO_2 can be sold to the food industry for its use in products such as carbonated beverages (Nettles & Conner, 2009). A second, more climate-relevant repurposing of carbon is through its use in enhanced oil recovery. In this process, carbon dioxide is pumped into oil wells deep underground. This restores pressure underground, thus forcing more oil to the surface. Additionally, gaseous carbon dioxide can get into places that liquids, which have previously been used to restore underground pressure, simply cannot get to. A portion of this carbon will remain sealed deep below the earth's surface, thus being permanently stored. What makes this method so attractive is that it appeals to both environmentalists and oil companies (Biello, 2016). While it is obvious that oil companies have something to gain with this method, as they can get more oil out of depleted wells, one might wonder why environmentalists would see this method as beneficial, as it produces more unclean energy. It turns out that for every barrel of oil recovered using this method, 0.6 metric tons of carbon dioxide are pumped underground (Knight, 2010). When this figure is compared to the amount of carbon dioxide released from burning one barrel of oil, 0.4 metric tons, it is clear how this method actually creates a negative net carbon footprint, meaning carbon is removed from the atmosphere. (Knight, 2010).

Enhanced oil recovery has been a widely used method in the U.S., with about 5% of all crude oil production coming from use of this method as of 2014 (Dai, et al., 2014). However, as of late, economic problems have arisen with this method of enhanced oil recovery. With the recent fall of oil prices, Schlumberger, a huge oil company, has already shut down its carbon services unit, as it has failed to remain profitable, and other companies are considering doing the same (Biello, 2016).

While enhanced oil recovery seems like a smart way both to repurpose and to store captured carbon, it raises some troubling issues. There are potential harms to the environment that pumping carbon dioxide underground could have. For instance, what if the carbon were to leak to the surface, or even worse, if the carbon were to leak into water reservoirs? There definitely is potential for this happening, so the question becomes, who is liable for such problems? Should the private oil industry be held responsible for such incidents, or should liability be transferred to the State? If long-term liability is kept in the hands of private owners, it would discourage them from storing carbon underground. This would be unfortunate, as the underground storage of carbon is seen as a huge global benefit. If the liability is given to the state, however, some argue that this would be an unfair financial burden on the public (Nettles & Conner, 2009). This problem needs to be addressed before underground carbon sequestration can be implemented on a large commercial scale. Ideally the State should be responsible, and also perhaps should even offer monetary incentives to private industries for the storage of carbon. This would encourage the private sector to take action in helping to fix a global problem.

The other potentially promising strategy for carbon sequestration is geoengineering the earth's oceanic ecosystems on a massive scale in a process known as oceanic iron fertilization. Phytoplankton is already one of the leading components for CO_2 absorption from the atmosphere, accounting for the removal of over 48% of CO_2 emitted from the burning of fossil fuels between 1800 and 1994 (Pickrell, 2014). By introducing iron compounds into the ocean, scientists can stimulate what is known as an algal bloom, the rapid increase in algae population in an aquatic environment, thus raising the level of carbon absorption (Kintisch, et al., 2017).

Oceanic algae alone are responsible for the production of between 70 and 80% of the oxygen in the earth's atmosphere (Hall, 2012). This is due to the fact that oceans cover over 71% of the earth's surface area while algae grow at depths of up to 300 feet, meaning these organisms have a practically limitless environment in which to thrive (Anitei, 2008). Combining that with their ability to reproduce at an exponential rate (literally doubling their numbers every few hours), oceanic algae has the makings of the world's leading agent in carbon sequestration and oxygen production (Hall, 2012).

The concept of artificially inducing the bloom of phytoplankton and algae is a topic that has been widely discussed among the scientific community for some time now. The United Nations (UN) ultimately banned it due to the fear that it could cause unforeseen damages and side effects to the fragile marine ecosystem (Strong, Chisholm, Miller, & Cullen, 2009). Notwithstanding doubt from the scientific community, in 2008 researchers aboard the Royal Navy's H.M.S. *Endurance* found that icebergs melting off of the coast of Antarctica were releasing millions of ferric particles into the surrounding ocean, feeding the blooms naturally (Macfarlane, 2009). This discovery shows that the mechanism has already been operating naturally for millions of years on a large scale and therefore might be safely accelerated. This has driven the UN to give research teams the green light and allow them to delve into groundbreaking experimentation on the theory.

However, despite the fact that the process is naturally occurring, it is still not guaranteed that human interference would go without some adverse effects. The key is that the process occurs *naturally*. Through simulations and research, scientist have noted that this natural increase in CO_2 absorption has already begun to acidify the ocean and decrease the oxygen content at deeper levels (Leibniz Institute of Marine Sciences, 2007). The European Iron Fertilization Experiment (EIFEX) was conducted in February of 2004 in order to begin measuring both the long-term effects of OIF within an isolated region as well as the quality of storage (Smetacek, 2012). The OIF biomass must sink to depths deeper than normal biomass in order for this method to be cost effective. For the carbon to be sequestered successfully for centuries, the OIF biomass must reach depths that allow the sedimentation process to occur before the sequestered carbon eventually finds its way back up to the surface (Smetacek, 2012).

While this method of carbon sequestration may be promising, it raises the ethical question of priority between the limited time to solve this problem of global warming and the health of the marine environment. It is difficult to extrapolate results on the long-term effects of OIF because they could potentially take decades to become noticeable. That amount of time is unavailable when it comes to global warming (Blain, et al., 2007). Additionally, OIF is a very costly method which begs the question of who would fund it. The concept of selling carbon credits as an incentive for companies to fertilize the ocean may seem easy. However, where there is monetary profit to be had, there will be individuals and companies willing to cut corners and follow unsafe OIF practices to maximize profits (Smetacek, 2012).

The topic requires years more of research and experimentation before scientists can be certain of the effects this huge geoengineering proposal would have if implemented globally. Thus prior to its application, research teams such as Climos have proposed a code of ethics to the United Nations which mandates total disclosure of experimental findings and procedures (Kintisch, 2007). This ensures that every party involved in the fertilization of algal blooms is acting safely and respectfully towards the environment—an appropriate caution to take in such a large-scale experiment.

Global warming is certainly not a cakewalk problem. The world relies heavily on industry, which is ironically the single greatest producer of carbon dioxide. The two proposed solutions, industrial capture with enhanced oil recovery and oceanic iron fertilization, do well in the sense that they do what they are meant to do: capture and store carbon. Industries have evolved in their capability to prevent carbon dioxide from even leaving their smokestacks. Phytoplankton blooms are ideal for absorbing carbon dioxide from the atmosphere and taking it down with them to the ocean floor.

Still, with each, there are underlying ethical qualms that present an endless domino effect of further consequences. To make a significant change in carbon dioxide levels, a large swath of ocean must be fertilized, and research up to the present day has not been able to simulate the effects such an action would have on oceanic life. Perhaps key species would die out, causing a collapse in the food web intricately woven in sea and on land; perhaps not. Either way, to put the fate of all life at risk in order to slow down the dangers of global warming is not an ethical trade to make. The ethics of industrial capture with enhanced oil recovery, on the other hand, do not involve the fate of all life. The issue is rather with harming ecosystems in a single geographical area from potential gas leaks, for which no government or company wishes to be liable. To add, low profitability makes the method even less incentivizing. We conclude that as they stand, these methods are not viable in mitigating climate change, but with additional research, improving technology, and increased efficiency, they can certainly hold the key to saving our planet.

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