Carbon Capture and Storage

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According to the National Academy of Science, global temperatures have already risen 1.4 ºF since the start of the 20th Century and will likely rise 2 ºF to 11 ºF more in the next century. This warming will cause significant changes in sea level, ecosystems, and ice cover, among other impacts. With the emergence of science connecting greenhouse gases to global climate change, carbon capture and storage has been proposed as a way to reduce atmospheric accumulation of greenhouse gases and thereby mitigate global warming. The general goal of carbon capture and storage is to reduce the amount of carbon emitted from fuel combustion and other industrial processes.

Increasing Concentrations of Carbon

The Earth's climate is driven by energy from the sun and maintained by complex interactions among the atmosphere, the oceans, and reflectivity of the earth's surface. Earth's atmosphere plays a critical role in shielding the planet from damaging space matter as well as some of the sun's energy. The energy that does filter through the atmosphere is partially absorbed by the planet surface while the rest is reflected back toward space.

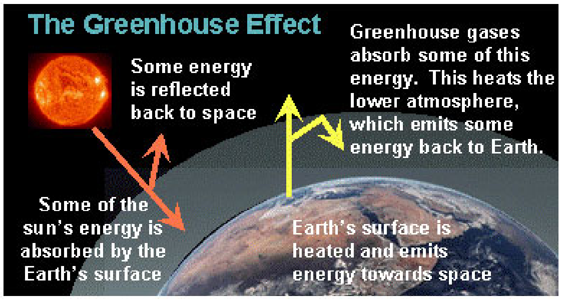

Figure 1. Summary of the greenhouse effect.

Greenhouse gases in the atmosphere naturally trap some of this reflected energy near the earth's surface and ensure a livable climate: too low of a concentration and the climate becomes too cold to support modern life; too high of a concentration and the climate becomes unbearably warm. Figure 1 summarizes the role of the atmosphere and greenhouse gases in climate control.

Scientific studies indicate that human activity has significantly increased the amount of carbon and other greenhouse gases emitted into the atmosphere. According to the Intergovernmental Panel on Climate Change (IPCC), the leading body for the assessment of climate change as established by the United Nations Environment Program and the World Meteorological Organization, atmospheric concentrations of CO_2 rose 35 percent between pre-industrial times and 2005. These increasing concentrations of CO_2 have been accompanied by increasing temperatures, as indicated in Figure 2. The National Oceanic and Atmospheric Administration (NOAA) reports that the Earth has warmed significantly over the last 140 years.

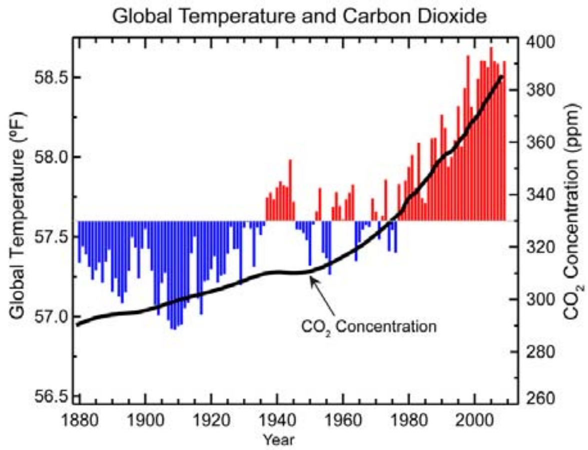

Figure 2. There is a strong correlation between CO_2 concentrations and average global temperatures. Recently, both have increased significantly.

Rapidly increasing temperatures is one of the most commonly cited indicators of climate change, but rising sea levels, receding glaciers, and decreasing snow accumulation are further signs of climate change. Climate change is nothing new; indeed it is a natural process that has been occurring for millions of years. What makes this recent evidence so alarming is the rate at which change is occurring. When compared to historic warming trends, as shown in Figure 3, the recent temperature increase is relatively rapid.

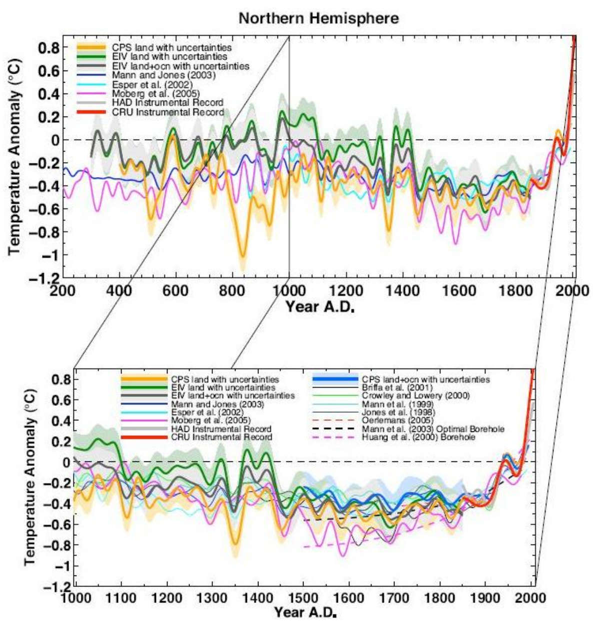

Figure 3. Temperatures are increasing at a much faster rate than any previous change.

Several factors may be contributing to current warming trends, including natural cycles and solar variation. Nonetheless, many agree natural factors alone are not sufficient to explain the rate of temperature increase and rapidly changing climate. Therefore, as NOAA paleoclimatologists observe, more and more climate scientists are coming to the conclusion that human activities are also influencing climate change with increased greenhouse gas emissions being the largest likely factor.

Greenhouse gases are a long-term, global concern because they disperse throughout the atmosphere and can remain for long periods of time once emitted. Carbon dioxide (CO_2) is the most common greenhouse gas. According to the IPCC, atmospheric concentrations of CO_2 rose 35 percent between pre-industrial times and 2005. This dramatic increase in atmospheric concentrations is shown in Figure 4. In 2006, 78 percent of anthropogenic greenhouse gas emissions in the United States was CO_2 released from the burning of fossil fuels for energy, industrial processes, and transportation.

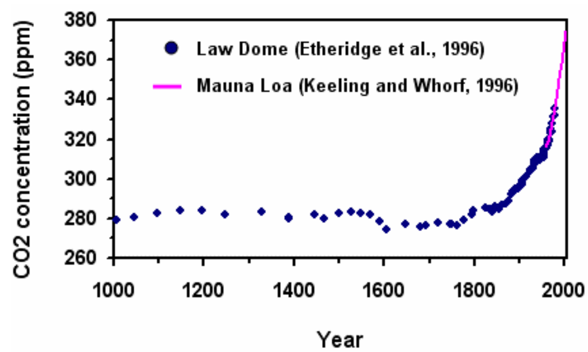

Figure 4. Atmospheric CO_2 concentrations have significantly increased since industrialization.

Increased concentrations of CO_2 in the atmosphere have increased the greenhouse effect whereby more reflected energy is trapped near the earth's surface. It is important to note that the greenhouse effect is a natural process but it has been intensified by humankind's input of greenhouse gases into the atmosphere.

Addressing increased CO_2 emissions is complicated by the heavy reliance of the United States and other countries on coal-fired power plants for electric power generation. Coal accounts for about half of electricity generation in the United States and, according to the International Energy Agency (IEA), that is the case for several other nations as well, including China, India, South Africa, Poland, and

Australia. Furthermore, several agencies are predicting increased energy demands worldwide in the future. One DOE assessment indicated a 29 percent increase in electricity sales by 2030 with business as usual policies. IEA anticipates China and India will drive increased demand for coal to meet their growing electricity demands. These predictions combined with current climate trends will likely result in a much higher atmospheric concentration of CO_2 which may cause rapid, irreversible climate change: loss of ecosystems, billions of dollars in damages from rising sea levels, millions of deaths through starvation, more frequent and severe weather, increasing water shortages, etc.

Carbon Capture and Storage

Many climate mitigation techniques exist but carbon capture and storage (CCS) is considered by many to be a crucial component of any U.S. approach because it allows for the continued operation of coal-fired power plants for electricity generation. These plants are one of the largest sources of CO_2 emissions, accounting for about one third of total CO_2 emissions in the United States. Several federal agencies have programs and responsibilities affecting CCS deployment but the primary ones are administered by the Department of Energy (DOE) and Environmental Protection Agency (EPA). DOE is the lead federal agency supporting development of clean coal technology, including CCS while, under the Safe Drinking Water Act, EPA has authority to regulate underground injections.

As summarized by the Government Accountability Office (GAO) in their September 2008 report on climate change, CCS is a process of separating CO_2 from the gases produced in fuel combustion and other industrial processes, transporting the CO_2 via pipeline to an underground storage location, and injecting it and storing it long-term in underground geologic formations. As cited in the GAO report, key barriers to CCS deployment include underdeveloped and costly CO_2 capture technology and regulatory and legal uncertainties over CO_2 capture, injection, and storage. DOE and EPA have begun addressing some of the technological and regulatory barriers, respectively.

Currently, CO_2 capture technology is demonstrated at several industrial facilities, specifically plants that purify natural gas and produce chemical products, but is not part of an emissions control plan. Instead, the CO_2 is removed to increase the value of the product. For example, removing CO_2 from natural gas prevents pipeline corrosion and increases the heating value of the gas. Because there are no requirements or market incentives to store the captured CO_2, most of the CO_2 is vented back into the atmosphere though some is used for enhanced oil recovery.

Implementing CCS technology at industrial facilities alone would account for less than 1 percent of CO_2 emissions per year from large stationary sources. Therefore, to noticeably mitigate greenhouse gas emissions, this technology will need to be expanded to coal-fired power plants and other large point sources but key differences between these two facilities make transferability of the technology difficult. One of the largest challenges is the relative concentrations of CO_2 found in natural gas applications compared to coal. Most industrial processes utilize natural gas which produces a highly concentrated stream of CO_2 as a by-product. By contrast, CO_2 is relatively diffuse in the exhaust produced by coal power plants, only about 13-15 percent by volume, making CO_2 capture substantially more energy intensive.

Acknowledging the additional complexity resulting from varying concentrations of CO_2, one of the most difficult components of expansive CCS is capturing CO_2 from power plants and other large industrial sources. Much research is being devoted to developing relatively low-energy, inexpensive methods to produce a concentrated stream of nearly pure CO_2 at high pressure so it can be transported via pipeline to a storage site. The major approaches being considered to separate CO_2 from industrial sources can be classified into three general categories: pre-combustion, post-combustion, and oxyfuel combustion capture.

Pre-Combustion Capture of CO_2

Pre-combustion capture methods separate the gas stream prior to combustion. Until recently, DOE was pursuing gasification technology as a key for reducing the environmental impact of coal-based electricity generation. This technology may be advantageous for CO_2 capture as well. Gasification methods chemically decompose fuel before combustion to provide a stream of CO_2 for separation and storage as well as a stream of hydrogen for electricity generation. This technology facilitates CO_2 capture because it provides a more concentrated stream of CO_2 at high pressure for easier separation and reduces the energy required for additional compression of the CO_2 for transport.

More specifically, DOE has been studying gasification technology as used in Integrated Gasification Combined Cycle (IGCC) plants. IGCC plants power gas turbines using synthesis gas which is made through a chemical reaction between coal and water. The synthesis gas is processed to remove most pollutants, including sulfur dioxide and CO_2, so IGCC plants may enable near-zero emission of pollutants. The hot exhaust gases from the gas turbines are then used to generate steam to power a steam turbine. Using the exhaust heat also results in a greater efficiency for IGCC plants than conventional pulverized coal plants.

Capturing CO_2 at IGCC plants imposes additional costs because capture technology is still necessary; however, assessments by DOE and international organizations conclude these costs are lower than for pulverized coal-fired power plants that remove CO_2 after fuel combustion. From DOE analysis, the cost of electricity production would increase by 35 percent for a newly constructed IGCC plant with pre-combustion capture technology compared to a 77 percent increase for a newly constructed pulverized coal power plant equipped with CO_2 capture technology.

IGCC plants with CCS technology have been planned in a number of countries but several factors have impeded their deployment. Recent assessments indicate it may be more expensive to build a new IGCC plant than a pulverized coal plant if CO_2 emissions are not captured with IEA reporting a 20 percent higher investment cost for an IGCC plant than a pulverized coal combustion plant. Furthermore, several stakeholders consulted for the GAO report expressed concerns over the reliability of IGCC plants. An MIT study indicated several IGCC power plants experienced reliability challenges in the first few years of operation; however, many of these early problems proved manageable and the reliability of the plants subsequently improved. Nonetheless, the National Coal Council identifies reliability as one continuing area of concern in which IGCC technology could be improved. Using IGCC plants for CCS also requires the construction of new coal-fired power plants but any new coal plants are subject to increasing regulatory scrutiny as a result of environmental concerns. A 2008 DOE report stated that significantly fewer new U.S. coal-fired power plants had been built than originally planned, largely as a result of regulatory uncertainty, including climate change concerns and escalating costs.

Summary of Pre-Combustion Capture
Pros:

- Produces concentrated stream of CO_2 – easier to capture
- IGCC plants have higher efficiency and fewer emissions than pulverized coal plants

Cons:

- Requires construction of new plants – requires altering energy infrastructure
- Industry has concerns about reliability of IGCC plants

Post-Combustion Capture of CO_2

Up through 2008, the DOE focused on pre-combustion technologies such as IGCC plants; however, nearly all existing coal-fired power plants are pulverized coal. Continued operation of these plants without additional CO_2 emissions requires retrofitting the plants with post-combustion capture technology. Post-combustion capture is one of the best understood capture strategies because it has been used on a small scale for many years in areas such as soft drinks and food preservation. Despite this relative familiarity, there are several significant challenges which must be overcome to scale post-combustion capture technology to commercial scale. These technical challenges greatly affect both the cost and feasibility of its deployment based on currently available technology. Nonetheless, post-combustion capture will likely be a critical method in mitigating greenhouse gas emissions because it can be added to existing plants.

Pulverized coal-fired power plants operate like regular coal plants in that the coal is burned in a large combustion chamber. Heat generated in the chamber is used to boil water, creating steam which spins large turbines and thereby produce electricity. Pulverized coal plants vary from regular coal plants because the coal is ground into a powder and burned rather than left as large chunks. The pulverized coal has a larger surface area so it burns more efficiently.

Exhaust gas from the burning coal exits the plant through a flue pipe. Scrubbers, fabric filters, and other components are added to the inside of the flue to remove pollutants from the gas before it is emitted into the atmosphere. As a result of these cleaners, the final output from the flue is mostly comprised of nitrogen, CO_2, and water vapor as well as excess oxygen from the combustion air. Although this is the source of CO_2 emissions, only about 15 percent of the flue gas volume is CO_2. Such a dilute concentration of CO_2 makes the filtration methods used to remove the other pollutants ineffective. Therefore, more advanced technology is necessary to remove the CO_2 before the flue gas enters the atmosphere.

Several different methods of post-combustion capture have been suggested but the majority of these utilize the same general approach. Flue gas is cooled and fed into a chemical solution. The make-up of this solution is quite variable and is the focus of much current research but its purpose is to bond with the CO_2, thereby filtering the CO_2 out of the flue gas. An Australian research company claims their absorber can capture approximately 85 percent of the CO_2 from flue gas. The chemical solution is then heated, thereby depositing the CO_2 and allowing the solution to be reused. Finally, the CO_2 is compressed and cooled to a liquid state so it can be piped to a storage facility.

Compressing the CO_2 represents a large auxiliary power load on the overall system. Some research companies are investigating the use of solar panels or wind turbines to supply the energy needed for compression while others use some of the electricity generated from the coal plant. If the CO_2 is compressed using electricity generated from the plant, additional coal will be needed for the same energy output. This will naturally increase the emissions and therefore the importance of capturing emitted CO_2.

Capturing CO_2 is complicated by the chemical make-up of the flue gas because research indicates that trace impurities in the gas can significantly reduce the effectiveness of some chemical CO_2 capture processes. These impurities will likely need to be filtered out prior to capturing the CO_2 or alternative capturing methods will need to be developed in order to ensure an acceptable amount of CO_2 is captured. Additionally, ash and soot in the flue gas may be problematic though it is unclear as no commercial-scale capture mechanisms have thus far been deployed.

Summary of Post-Combustion Capture

Pros:

- Can be applied to current industrial plants and power stations
- Existing technology on smaller scale – need to scale up

Cons:

- Expensive to retrofit plants – initial cost and continued purchasing of absorbing solution, etc.
- Minimal experience with commercial-scale operation

An alternative method of post-combustion capture currently being researched utilizes membranes to separate CO_2 from flue gas. In late July, the Department of Energy awarded $5.9 million in federal grant money to four projects to test membrane technology. The goal of these membranes is to separate molecules of hydrogen and CO_2 from gasified coal.

One proposal which received part of this funding was from the Connecticut-based Praxair, Inc. which will be partnering with the Colorado School of Mines and T3 Scientific of Minnesota. The three partners will use Mines' small-scale gasifier to test palladium and palladium alloy membranes.

Membranes have great potential in carbon capture technology because they can be added directly to the flue gas stream in existing coal power plants; however, one potential disadvantage is the need to regularly replace the membranes, thus increasing the overall cost of the carbon capture system. In addition, the CO_2carbon dioxide will still need to be compressed for transport to a storage facility. This is a relatively novel idea, so additional research will shed new light on both the potential benefits and costs of using membranes in carbon capture applications.

Oxyfuel Combustion Capture:

One of the less popular methods proposed to mitigate emissions, oxyfuel combustion capture, is a process in which fossil fuels are burned in pure oxygen rather than air. This results in a more complete combustion and an exhaust stream of almost pure CO_2 and water vapor. Water vapor can easily be separated from the CO_2 by condensation making CO_2 capture a relatively straightforward process.

The difficulty with this approach is separating oxygen from air. Currently, this is mainly done cryogenically but cooling the air requires large amounts of energy. A typical 500 MW coal-fired power plant supplying pure oxygen would likely require at least 15 percent of the electricity the plant generates annually to cool the air. Research is being conducted into a less energy-intensive process known as chemical looping combustion. This technique uses oxidation of a metallic compound to remove oxygen from the air. The metal is then reduced during combustion, releasing pure oxygen.

Summary of Oxyfuel Combustion Capture

Pros:

- Potential for total CO_2 capture

- Very few emissions
- May be added to existing coal power plants

Cons:

- Requires lots of additional energy to separate oxygen from air – possibly reduced with further research
- Still in preliminary stages of development

Geologic Carbon Sequestration

Regardless of the capture approach used, additional energy is required for capture and compression. As mentioned, this energy can either come from the plant itself or possibly be supplied by renewable sources. Once the CO_2 is separated and compressed, it will likely be transported to a storage site via pipes. Geologic sequestration is one of the more prevalent storage sites.

For geologic sequestration, CO_2 is injected into geologic formations well below the surface, at depths of at least 2,600 ft. The CO_2 is sequestered for hundreds to thousands of years through a combination of physical and geochemical trapping processes. CO_2 is physically trapped when the relatively buoyant gas reaches a layer of impermeable rock which inhibits further upward migration. Geochemical trapping occurs when the injected CO_2 chemically reacts with minerals in the formation, resulting in the precipitation of solid minerals. Considering these two trapping mechanisms, depleted oil and gas reservoirs and saline formations are extremely favorable sites for CO_2 storage. Estimates from DOE and IEA indicate the United States has appropriate geology to potentially store over 3 trillion tons of CO_2, equivalent to 1,000 years of emissions from nearly 1,000 coal-fired power plants.

Geochemical sequestration is the favored approach for two main reasons. First, geochemical sequestration is a relatively well understood process because it is similar to gas injection which has become a standard method for enhanced oil recovery. The first use of CO_2 injection for enhanced oil recovery took place in Scurry County, Texas in 1972. Now, over 30 million metric tones of CO_2 are injected into declining oil fields in the United States annually. The injected CO_2 increases oil recovery by restoring pressure to the reservoir and reducing the viscosity of the crude oil. Using CO_2 for enhanced oil recovery would sequester the carbon and increase the amount of oil retrieved from a given site, both beneficial. Geochemical sequestration is also favored because large volumes of CO_2 can be sequestered in a short amount of time.

Injection of CO_2 for long-term storage still contains several risks as a result of its relative buoyancy, corrosiveness in the presence of water, and the large volumes of gas being injected. Although CO_2 would be injected into a geologically favorable area, a porous formation capped with an impermeable layer of rock to prevent upward movement, it is still possible that the CO_2 may migrate. This migration could potentially endanger underground sources of drinking water. The CO_2 may cause leaching of contaminants, such as arsenic or lead, into the water or result in changes in regional groundwater flow and movement of saltier fluids into drinking water. Both these possibilities would likely degrade the quality of drinking water and therefore lead to liability under the Safe Drinking Water Act as administered by the EPA. Additionally, if stored CO_2 migrated beneath neighboring lands, it could interfere with the adjacent landowner's ability to extract minerals from the area.

Alternative Sequestration Methods

Aside from geochemical sequestration, many alternative methods have been proposed to store captured CO_2. Most of the currently researched sequestration methods enhance natural carbon sinks, such as trees, algae, etc. The three most popular alternative sequestration methods currently being researched are iron fertilization, biochar burial, and terrestrial sequestration.

Iron Fertilization

Many organisms rely on photosynthesis for energy. These organisms capture CO_2 from the atmosphere and combine it with nutrients from the sun to produce energy while emitting oxygen as a waste product. Iron fertilization intentionally introduces iron to the upper ocean to stimulate growth of phytoplankton, an algae inhabiting the upper part of the ocean surface where they have access to sunlight for photosynthesis.

Phytoplanktons already absorb CO_2 from the atmosphere but on a small scale due to population constraints. After several studies, it was found that iron was the primary element which limited phytoplankton population. Historically, iron has been carried by dust storms and deposited on the surface of the ocean. Ocean regions near desert areas therefore had a much larger population of phytoplankton. Recently however, several different studies have deliberately added known amounts of iron to the ocean surface to investigate the resulting population growth of phytoplankton and associated absorption of CO_2. These marine trials have had varying levels of success but indicate it would take somewhere between 200,000 to 4 million tons of iron to sequester 3 giga-tons of CO_2 per year (equivalent to over half of the United States' total CO_2 emissions in 2007). Even using the higher case scenario, this is equivalent to 16 supertankers of iron and a projected cost of $27 billion.

Those opposed to iron fertilization argue the possible side effects of large scale iron fertilization are not yet known. Adding iron to naturally iron-deficient areas could significantly alter ocean ecosystems. Advocates of iron fertilization respond that similar algal blooms have occurred naturally for millions of years with no observable ill effects. In 1991, the eruption of Mount Pinatubo in the Philippines deposited approximately 40,000 tons of iron dust into oceans around the world, generating an observable decline in atmospheric CO_2 concentrations and associated increase in oxygen levels but without shifting ecosystems.

Ten iron fertilization trials have been conducted since 1993, some more successful than others. Looking at some of the less successful fertilization reports, this approach may not sequester much carbon per algal bloom because the plankton is eaten rather than deposited on the ocean floor. Therefore, iron fertilization would require too many iron seedings to be practical. The counter-argument used by supporters of the iron fertilization is that trials could only monitor blooms for less than 27 days because that is all the boat time allotted but the blooms generally last 60-90 days with the heaviest precipitation of CO_2 occurring in the last two months. Therefore, the phytoplankton were likely absorbing far more CO_2 than reported. Furthermore, the trials were relatively small, less than 1000 kg of iron, so the resulting blooms were quickly devoured by zooplankton and other predators. A larger bloom would not be eaten as quickly and so would have more time to deposit CO_2 on the ocean floor. Plus, despite these constraints, some trials did report amazing sequestration results. A 2004 trial reported CO_2 to iron fixation ratios of nearly 300,000 to 1. In other words, a single kilogram of deposited iron led to growth of enough phytoplankton to sequester nearly 300,000 kg of CO_2.

One ecological concern associated with iron fertilization is Harmful Algal Blooms because it is not known exactly what type of plankton will bloom after fertilization. Certain species cause red tides and other toxic phenomena. Even the decaying of harmless plankton may be dangerous because when plankton die, they decompose and may create a situation similar to the giant dead zone in the Gulf of Mexico. A dead zone is an extremely oxygen poor area where aquatic life cannot be supported. The Gulf of Mexico dead zone is roughly the size of New Jersey and occurs where the Mississippi River feeds into the Gulf because the river has high-nutrient run-off from its drainage basin which includes the agricultural Midwest.

Nonetheless, fertilization advocates maintain that most phytoplankton are harmless and HAB is primarily a coastal phenomena which affects creatures eating contaminated shellfish. Iron stimulated plankton would occur in deep sea environments and, because the plankton only lives 90-120 days, fertilized patches would dissipate well before reaching coastal waters.

Oxygen depletion is also a concern because large algal blooms could feed more fish and bacteria than normally allowed in the natural environment. These organisms consume more oxygen so could strain the natural resources of the region. However, proposed projects are less than 10 percent the size of most natural blooms and studies of past large blooms have not shown any deep water die-offs resulting from oxygen shortages. There is still a concern over ecosystem alteration because new phytoplankton blooms may favor certain species and change the natural food chain. Then again, as proponents of iron fertilization point out, warming temperatures and increasing ocean acidity are already causing this to happen.

Biochar Burial

Biochar burial is a carbon-negative process that helps rebuild natural geological carbon sinks and is advocated by prominent scientists like James Hansen and James Lovelock for mitigation of global warming by reducing greenhouse gas emissions. Standard CO_2 capture ties up oxygen along with the carbon but biochar is unique because it breaks into the CO_2 cycle, releasing oxygen like natural coal formation has done for millions of years.

Biochar is essentially charcoal but its primary use is carbon storage and soil improvement rather than fuel. Biochar is made by exposing organic biomass material to extremely high temperatures in a process known as pyrolysis. The heat decomposes the material into a solid residue rich in inert carbon. The carbon cannot be oxidized to form CO_2 so it cannot be released into the atmosphere. Biochar can then be buried in the soil, further sequestering the carbon and significantly improving the soil. Pyrolysis can be optimized to create either biochar or energy but even when the process is designed to for char production, the amount of energy produced per unit input is higher than for corn ethanol.

Biochar burial may be extremely beneficial to the Rocky Mountain region because pine beetles have killed vast swaths of trees. As these trees die, they reintroduce large amounts of carbon into the atmosphere. Rather than allow these trees to decompose naturally, converting the dead wood to biochar would prevent substantial CO_2 emissions as well as provide a useful energy source. Similarly, the majority of agricultural waste can be turned directly into biochar, bio-oil, and syngas. Some organic matter is necessary for agricultural soil to remain productive, but using pyrolysis will prevent excess organic material from releasing CO_2 into the atmosphere.

Evidence from Amazon soil samples shows large concentrations of biochar remain after being abandoned thousands of years ago. The amount of time biochar remains in the soil depends on the type of feedstock material, how charred the material was prior to burial, soil conditions, and surface to volume ratio of the biochar particles. Estimates of residence time range from 100 to 10,000 years with most scientists concluding biochar can permanently sequester carbon for approximately 5,000 years.

Assuming biochar effectively stores carbon for an adequate period of time, serious questions still remain as to its role in combating global warming. First is a question of scale. Assuming trees absorb and release 120 billion tons of carbon per year and human-caused emissions of 8 to 10 billion a year, addressing just half of human-caused emissions with biochar would require harvesting nearly 4 percent of the world's forests every year. Furthermore, offsetting human emissions by reducing natural emissions is not a very sustainable practice and does little to address the source of the problem. The implementation of biochar would also likely require some form of market incentive because the energy produced from making biochar is still less than that produced from burning biomass. Imposing a significant price on carbon emissions could possibly provide this incentive by making biochar more financially attractive than burning.

Despite these obstacles, biochar is still an attractive process. Technology for biochar sequestration does not require a scientific advancement. Basic production technology already exists. It is simple and robust, making it appropriate for many different regions around the world. Use of biochar for energy production can be directly substituted for any application that uses coal so no change in infrastructure is required. Burying biochar improves soil quality by preventing the leaching of nutrients out of the soil, increasing water retention, and has been used to reduce soil contamination levels.

Terrestrial Sequestration

This general form of sequestration emphasizes the replanting of trees and other flora to aid in carbon sequestration through natural photosynthesis. Forest ecosystems are important to the global carbon cycle in two ways. First, plants move around 3 billion tons of anthropogenic carbon every year which amounts to almost 30 percent of all CO_2 emissions from fossil fuels. Through photosynthesis, forests are also terrestrial carbon sinks.

Reforestation may play a significant role in carbon mitigation. According to recent studies, one hectare of replanted trees, equivalent to about 2.5 acres, can sequester 38 tons of CO_2 per year. In 2000, China used 24 million hectares of new forest plantation and natural forest growth to offset 21 percent of their annual emissions. Recent research suggests almost one fifth of fossil fuel emissions are currently absorbed by forests across Africa, Amazonia, and Asia.

Although a relatively simple method for carbon mitigation, there are several drawbacks to reforestation mainly as a result of the large land area required. Reforestation competes with other land use such as food production, livestock grazing, and living space for further economic growth. There is also the risk that forest fire or insect outbreak, such as the pine beetle, will release stored carbon back onto the atmosphere.

Providing incentives for reforestation would likely encourage more land to be set aside specifically for replanting. Incentives which favor reforestation may lead regions to increase deforestation so they can replant the forest. This strategy replaces mature trees with new growth which captures far less CO_2 and is more susceptible to droughts and other dangers that may ultimately kill the tree. Therefore, it is important that incentives for reforestation must be combined with a mechanism which favors the maintenance of old growth as well.

References

All pictures courtesy of the National Oceanic and Atmospheric Administration