A Review of Literature of

**The Benefits and Risks of Carbon Capture and Storage**

by  
*Alexandria Horne  
The Ohio State University*

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**Abstract**

Carbon Capture and Storage (CCS), also known as geologic carbon sequestration, is a technology that has been developed rather recently and has the potential to address atmospheric emissions of carbon dioxide that contribute to global climate change. This technology has been developed mostly within the oil and gas industry but may prove to be invaluable in combating global climate change. CCS has been the subject of many academic and federal studies over the past decade, and is already being used at several trial locations worldwide.

As promising as CCS appears, there are still many unknowns about this new and upcoming technology. This paper addresses two questions; first, what are the possible benefits from CCS and second, what are the possible problems of CCS. To address these questions, this paper will review the published material dealing with CCS in an attempt to summarize current known information in an attempt to help the reader better understand CCS technology.

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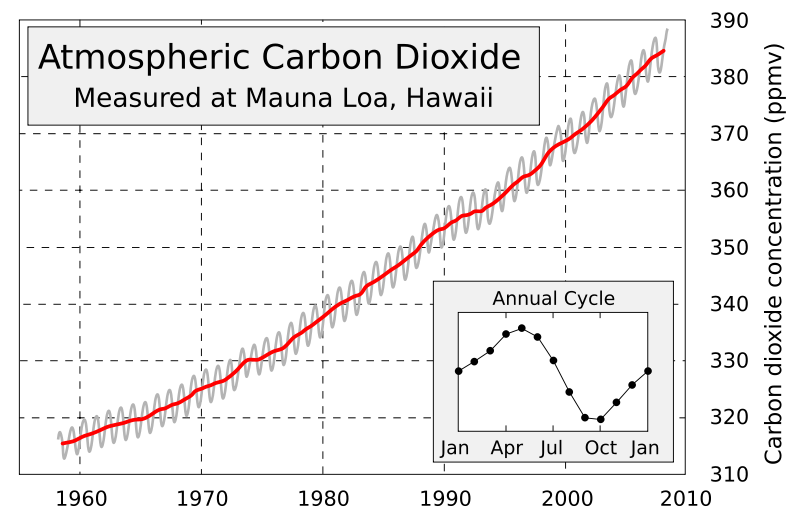
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**Introduction**

The most recent report from the Intergovernmental Panel on Climate Change (IPCC) concludes that global climate change is evident from observations of increases in global average air and ocean temperatures (Alley et al., 2007). The IPCC further states that this warming is due, in part, to increased atmospheric concentrations of greenhouse gases, of which, carbon dioxide from the combustion of fossil fuels is believed to be the largest contributor (Alley et al., 2007). Greenhouse gases are essential to maintaining the temperature of the Earth; without them the planet would be uninhabitable. However, an excess of greenhouse gases can raise the temperature of a planet to dangerous levels. Before the Industrial Revolution, atmospheric carbon dioxide concentrations were 280 parts per million. As of 2005, the concentration was 380 parts per million (Schwab, 2006). From 2000-2005, annual global emissions of carbon dioxide were estimated to be 26.4 Gt (Alley et al., 2007).

Figure 1- The “Keeling Curve” shows how the atmospheric  
 concentration of carbon dioxide has been increasing

[](http://upload.wikimedia.org/wikipedia/commons/5/51/Mauna_Loa_Carbon_Dioxide-en.svg)

(University of California, 2002)

With humans emitting ever increasing amounts of carbon dioxide into the atmosphere, we need to be able to protect our planet and its inhabitants from the devastating effects of global climate change. In recent years, a promising new technology has come about that could help ease our global climate change problems; this technology is known as Carbon Capture and Storage (CCS).

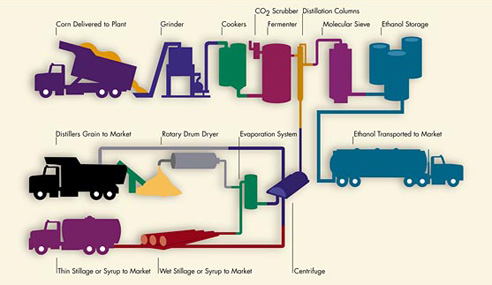
Throughout the last 20 years, there has been significant discussion on whether the benefits of CCS outweigh the risks that it presents. The purpose of this paper is to provide an unbiased overview of the known benefits and risks associated with Carbon Capture and Storage so that these factors may be looked at in further detail in the near future.

**The Carbon Capture and Storage process**

CCS is the placement of carbon dioxide into a repository in such a way that it will remain sequestered almost indefinitely, usually by injection into specific geologic formation (Beecy and Kuuskraa, 2001). CCS involves preventing carbon dioxide emissions from entering the atmosphere by capturing it, pressurizing it, then injecting it underground in order to isolate it from the atmosphere and the environment (Singleton, 2002). Using CCS, we may be able to prevent the 60% of global carbon dioxide emissions that come from power stations, industrial plants, and other large stationary point sources of carbon dioxide from being released into the atmosphere (“Can Carbon Dioxide Storage Help Cut Greenhouse Emissions?” 2006).

CCS can be a complicated process and can differ based on the type of carbon dioxide source. The most common carbon dioxide sources are coal plants, oil plants, and gas processing plants. In the United States, there are two companies that are experimenting with the ethanol process as a source of carbon dioxide (Andersons Ethanol and Archer Daniels Midland Ethanol). This paper focuses on ethanol plants as a source of carbon dioxide because they produce a very pure form of carbon dioxide during the fermentation process which is easier to capture and store. Before carbon dioxide is captured, it must first be created by the production of ethanol. A majority of ethanol plants, including the two experimenting with CCS, use a method known as “dry milling” to produce ethanol. For dry milling process, the general steps for CCS are (Renewable Fuels Association, 2005):

Figure 2- The dry milling process for ethanol production



Carbon dioxide is a by-product of the fermentation process. Once the carbon dioxide is released during fermentation, it is captured and the sequestration process begins. The steps included in sequestration are:

Figure 3- The basic CCS process

The science and technology for performing CCS testing is available, but is still experimental. For this reason, there has been great debate about the benefits and risks associated with CCS and whether it should be performed at all. Below, the benefits and risks of CCS as discussed in detail.

**Benefits of Carbon Capture and Storage**

* Prevent substantial amounts of carbon dioxide from entering the atmosphere
* Allow the atmosphere to begin to recover from high carbon dioxide concentrations
* Enhance oil and gas recovery
* Opportunity to research clean energy technology
* Carbon credits to companies using CCS.

Since the Industrial Revolution, man has been pumping increasing amounts of carbon dioxide into the atmosphere, as a consequence, the temperature of the planet has been increasing; about 0.6 degrees Celsius in the last 100 years (Schwab, 2006). CCS has the potential to take the carbon dioxide from our main fossil fuel industries that would normally be released into the atmosphere, and store it underground where it cannot contribute to global warming. Using this technology on a large scale, it may be possible to significantly decrease the amount of carbon dioxide that enters the atmosphere, therefore giving the planet a chance to repair itself and giving mankind an opportunity to search for other types of clean energy.

The fossil fuel industry has used a form of CCS technology for more than two decades. Capture and injection of carbon dioxide into oil, gas, and coal reserves have been integral parts of enhanced oil and gas recovery (Metz and IPCC, 2005). The success that the fossil fuel industry has had is very promising, and since current CCS technology is very similar to what the fossil fuel industry has already been using, there is a likely chance that CCS will be successful in other applications.

A recent study conducted by Gabrielle Wong-Parodi, Isha Ray, and Alexander E Farrell; members of the Energy and Resources Group, based out of the University of California, Berkeley, has found that global climate change is a top environmental concern for non-governmental organizations (NGOs) and that these NGOs are actively seeking climate change mitigation solutions. For some, the most feasible mitigation solution is CCS. This means that there are plenty of funding opportunities for any industry wanting to use CCS. The study further concluded that recently, CCS has become so popular amongst NGO’s mainly due to the fact that to date, nothing else seems to have been able to effectively address the problem of global climate change (Wong-Parodi, et al., 2008).

Many countries around the world are experimenting with the CCS technology. Below is a list of projects that have started, or plan to start sequestering carbon dioxide in the near future (note that plants using ethanol as a carbon feedstock are not included in this chart):

Table 1 –Current worldwide geologic carbon sequestration projects

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Project Name** | **Location** | **Leader** | **Feedstock** | **Size MW** | **Start-up** |
| Total Lacq | France | Total | Oil | 35 | 2008 |
| Schwarze Pumpe | Germany | Vattenfall | Coal | 30/300/1000 | 2008 |
| AEP Alstom Mountaineer | USA | AEP | Coal | 30 | 2008 |
| Callide-A Oxy Fuel | Australia | CS Energy | Coal | 30 | 2009 |
| GreenGen | China | GreenGen | Coal | 250/800 | 2009 |
| [Kimberlina](http://sequestration.mit.edu/tools/projects/kimberlina.html) | USA | CES | Coal | 50 | 2010 |
| NZEC | China | UK&China | Coal | Undecided | 2010 |
| Southern Energy Ferrybridge | UK | SSE | Coal | 500 | 2011 |
| ZeroGen | Australia | ZeroGen | Coal | 100 | 2012 |
| Wallula Energy Resource Center | USA | Wallula Energy | Coal | 600-700 | 2013 |
| RWE npower Tilbury | UK | RWE | Coal | 1600 | 2013 |
| UK CCS project | UK | TBD | Coal | 300-400 | 2014 |
| Statoil Mongstad | Norway | Statoil | Gas | 630 CHP | 2014 |
| RWE Zero CO2 | Germany | RWE | Coal | 450 | 2015 |
| Monash Energy | Australia | Monash | Coal | 60 k bpd | 2016 |

**(**Massachusetts Institute of Technology, 2008)

The potential reservoirs identified as being able to contain carbon dioxide have the potential to store very large amounts of carbon dioxide. Studies conducted by the International Energy Association and others indicate the following potential for underground carbon storage worldwide:

|  |  |
| --- | --- |
| Table 2 – Potential for underground carbon  storage based on reservoir type  *\** (1 Gt C = 1 Giga/billion tons of carbon) | |
|  |  |

The range reflecting optimistic estimates of absolute underground storage space on the high end and current economic restrictions on the low end (International Energy Association, 1994). Deep saline formations could possibly extend that capacity to store the world's carbon emissions for many decades if not centuries. Thus, CCS could potentially play a significant role in the solutions portfolio to reduce carbon dioxide emissions and concentrations (International Energy Association, 1994).

Another important factor is that the United States, and a majority of the world, is likely to remain dependent on fossil fuels for at least the next decade, making CCS a necessity to curb carbon dioxide emissions (Schwab, 2006).

Carbon credit trading is also a possibility for companies using this new technology. Carbon credits help to reduce greenhouse gas emissions by capping the total annual emissions allowed by a particular industry and letting the companies trade credits. In this way, industries unable to meet the emissions limit can trade or buy credits from other companies that have met the limit. On the other hand, companies that are significantly below the emissions limit can trade of sell their extra credits for profit. Credits can be exchanged between businesses or bought and sold in international markets at the prevailing market price.

As Americans deal with economy woes, rapidly fluctuation gas prices, and the ever looming fear of catastrophic global warming, CCS technology has been rapidly evolving and ready to take center stage. In fact, a general scientific consensus has found that sequestration technology is already quite advanced and likely to be very successful (Moran, 2007).

**Risks Associated With Carbon Capture and Storage**

* Experimental technology
* Risk of induced seismicity
* Groundwater acidification
* Soil acidification
* Metals mobilization
* Rapid, large scale carbon dioxide leak
* Continued reliance on fossil fuels

From past experience, we can tell that both public acceptance and sitting decisions are heavily influenced by issues of risk. Risk is an important concern for the public and it drives overall public opinion and acceptance of new technologies.

A major obstacle to the development and implementation of CCS is that there is so much uncertainty (Wong-Parodi, et al., 2008). With CCS being a relatively new process, very little is known about the potential of certain geologic formations to store and immobilize carbon dioxide. Scientists believe that chosen geologic formations (such as saline sandstone formations) will be able to sequester the carbon dioxide indefinitely, but this does not calm fears that have been raised amongst the public and certain legislators that CCS may be dangerous (Bliss, et al., 2005).

There is also the remote possibility that by pumping carbon dioxide into the ground, it may trigger seismic activity. One example of this occurred in 1966 in Denver, Colorado. A seismic event measuring 5.5 on the Richter scale occurred due to hazardous waste injection activities taking place at the Rocky Mountain Arsenal (Sminchak et al., 2002, Wilson and Keith, 2002). Seismologists know that the activity was due to the injection activities because the area was being monitored very closely with seismographs and other monitoring equipment. The damages from this incident were limited, and subsequent corrective policies were instituted to lower the injection pressure and reduce the likelihood of similar events recurring. Additionally, subsequent experiments near Rangely, Colorado have led to better understanding of the mechanisms behind induced seismicity and guidance on how it can be prevented.

Dissolved carbon dioxide can also negatively impact drinking water aquifers and the vegetation above them. It can affect the quality of drinking water in two ways: first, if carbon dioxidefrom a CCS reservoir dissolves into a drinking water or irrigation reservoir, it will acidify the freshwater making it less suitable for drinking without processing. If the roots of plants and vegetation are exposed to this acidic groundwater, it may adversely affects their root structures and result in widespread death of the vegetation (Singleton, 2002).The chemical interactions that cause the vegetation kills are not thoroughly understood, except that the cause is believed to be driven by the acidification of the groundwater (Benson et al., 2002). Second, depending on the specific characteristics of the subsurface and the mineral geology, carbon dioxide can further encourage the dissolution of additional minerals and even heavy metals into the water reservoir that had previously been bound within the rock formation. This mobilization of additional materials can contaminate the water making it unusable without processing (Singleton, 2002).

There is also a chance that the carbon dioxide that is stored underground could leak into the air above the CCS site. If a large scale leak were to occur it could possibly have catastrophic consequences; the leak could create a zone of hypoxia and suffocate humans and animals in the immediate vicinity (Union of Concerned Scientists, 2001). Scientists insist that this is a very remote possibility, but still a possibility none the less.

There are also economic issues associated with the project. CCS is a very expensive process. There are worries that millions of dollars will be devoted to projects that may not work and are potentially dangerous. This money may be used in other ways that could benefit the environment.

Another possible problem with geologic sequestration is that current tests operate on a small scale; what are the chances that this technology will be adopted on a large scale? Even if the technology is very successful, if it is not adopted on a large scale, the technology will not be very valuable. Another speculative problem is that CCS could act as a false sense of security for the fossil fuel industry. CCS may tempt the fossil-fuel based economy to continue emitting without major changes to the ways in which energy is produced and consumed; knowing that they can always rely on carbon sequestration.

The likelihood of these risks is very dependent on the site on which CCS is occurring. Some sites pose more risks than others; this is why geologic testing of a site is crucial before deciding if the site is a candidate for CCS.

**Summary and Conclusions**

While the potential environmental consequences and risks to public safety associated with CCS are generally acknowledged, they are considered minor considering the benefits that CCS could present to the world

Summarizing the benefits and risks of CCS:

**Benefits of Carbon Capture and Storage**

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Investigation of the risks and public perception of CCS found that while the overall risks were low, the uncertainty over these risks needs to be addressed by additional risk assessments (Singleton, 2002). Thus only large scale demonstrations which provide experience and data will be able to improve public acceptance and increase awareness of this technology.

**Future Research**

Currently, I am performing a carbon dioxide life cycle analysis which will analyze the efficiency of the CCS system. This study specifically examines the amount of carbon dioxide that is emitted in association with ethanol plant carbon sequestration. The study analyzes carbon dioxide output from the growing of corn, the production of ethanol, and the sequestration process and compares it to the amount of carbon dioxide that is ultimately sequestered.

There are presently many research projects examining CCS. Below are just a few of the topics being studied (USGS, 2008):

* Characterization of geological and geochemical factors controlling the capacity to store carbon dioxide in geologic formations
* Identification of potential reservoirs for geologic carbon dioxide sequestration
* New measurements of the solubility of carbon dioxide in brine reservoirs
* Characterization of the geological processes that operate in natural and man-made settings of carbon dioxide storage reservoirs, including high-carbon dioxide content natural gas accumulations, oil reservoirs undergoing long-term enhanced oil recovery with carbon dioxide, and natural gas storage reservoirs
* New methods of assessing the CO2 sequestration capacity of geologic formations

To stop global climate change, CCS, along with other up and coming technologies, must be considered. CCS has the potential to be used on a large scale to reduce emissions of carbon dioxide from large point sources (Singleton, 2002). It is essential to know everything we can about CCS so we can make the best educated decision about how to deploy this technology.

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