PRB 05-89E

Library of Parliament
Bibliothèque du Parlement

CARBON CAPTURE AND STORAGE: TECHNOLOGY, CAPACITY AND LIMITATIONS

Tim Williams
Science and Technology Division

10 March 2006

PARLIAMENTARY INFORMATION AND RESEARCH SERVICE
SERVICE D'INFORMATION ET DE RECHERCHE PARLEMENTAIRES

TABLE OF CONTENTS

Page

CANADA

LIBRARY OF PARLIAMENT
BIBLIOTHÈQUE DU PARLEMENT

CARBON CAPTURE AND STORAGE: TECHNOLOGY, CAPACITY AND LIMITATIONS

INTRODUCTION

Vast deposits of oil, gas and coal that took hundreds of millions of years to accumulate are being extracted and burned in the geological blink of an eye. The rapid release of carbon dioxide (CO_2) from the combustion of fossil fuels has led to a build-up of this gas in the atmosphere. This in turn is affecting how plants grow and use water, causing the oceans to acidify and, most importantly, causing an imbalance in the manner by which solar energy is trapped in the atmosphere.

Anthropogenic climate change is now seen by most governments as something that needs to be addressed. Technologies are available that can reduce emissions, but none has the capacity to address the problem single-handedly. One of the options that is gaining interest is carbon capture and storage. The following paper describes this technology, its capacity to address emissions reductions and some of the problems associated with it.(1)

WHY THE NEED?

The only real long-term way of reducing greenhouse gas emissions, assuming that energy use will continue to grow, is to uncouple energy use and CO_2 release. This can be done by moving to low-carbon-energy sources such as hydro, nuclear, wind, solar, geothermal, and tidal energy. However, currently available low-carbon-energy sources and technologies cannot fully substitute for fossil fuels, particularly given the numerous ways in which such fuels are used and the current economic framework for energy.

---

(1) For more details on the technology, see the Intergovernmental Panel on Climate Change (IPCC) special report, *Carbon Dioxide Capture and Storage*, September 2005, http://www.ipcc.ch/activity/ccsspm.pdf. For information on the economics of carbon capture and storage, see Frédéric Beauregard-Tellier, *The Economics of Carbon Capture and Storage*, PRB 05-103E, Parliamentary Information and Research Service, Library of Parliament, Ottawa, 13 March 2006.

The result is that fossil-fuel-dependent energy infrastructure is currently being planned that will remain for decades, continuing to increase atmospheric CO_2. It has been estimated that lifetime emissions from power plants projected to be built for the next 25 years are equivalent to all emissions for the last 250 years.(2)

An alternative possibility, however, is that fossil fuels can continue to form the basis of our energy infrastructure, but that CO_2 can be captured from the emissions and stored away from the atmosphere for very long periods of time. The atmosphere has been a convenient repository for such wastes, but there is no technical reason why this has to be. Other parts of the Earth, notably geological formations and the oceans, can also be used to store CO_2.

CARBON CAPTURE AND STORAGE

Before carbon can be stored in a manner that prevents it from entering the atmosphere, it must first be removed from the emissions emanating from the burning of fuel. Removal of CO_2 from widely distributed and/or mobile emission sources such as residential heating, automobiles and airplanes, is impractical but must be addressed.

A. Mobile and Distributed Sources

If fuels for mobile and distributed energy needs continue to be carbon-based, then CO_2 must be dealt with after the emission has taken place. This could be through increasing biological sinks (e.g., forests), or indirectly through displacing fossil fuel-based electricity with carbon-free sources such as wind. The latter option is likely to be the most viable, since biological sinks are limited in capacity. Other technological approaches such as capturing atmospheric CO_2 in carbon-absorbing chemicals have been suggested but not as yet demonstrated.(3)

---

(2) Robert Socolow, "Can we bury global warming?" *Scientific American*, Vol. 293, 1 July 2005.

(3) Klaus Lackner, "A Guide to CO_2 Sequestration," *Science*, Vol. 300, 13 June 2003.

B. Large Stationary Sources

Carbon capture and storage is mostly used to describe methods for removing CO_2 emissions from large stationary sources, such as electricity generation and some industrial processes, and storing it away from the atmosphere.

1. Capture

There are three basic methods for capturing CO_2 from such emission streams: pre-combustion; post-combustion; and oxyfuel combustion.

- Pre-combustion reacts a primary fuel with air or oxygen and steam to produce hydrogen and carbon monoxide which can be further treated to produce more hydrogen and CO_2 (15%-60% by volume), which can then be separated. The hydrogen (synthesis fuel) can be used for energy, with water as a by-product; the CO_2, at relatively high pressure and concentrations, is more amenable to capture than would have been the case if the fuel were combusted as is. This type of technology is used in Canada in four coal-fired integrated gasification combined cycle (IGCC) plants, although none capture the CO_2. The production of synthesis gas is relatively old technology but has been used in combination with pre-combustion capture only in specific circumstances.

- Post-combustion processes generally use a recyclable solvent to trap CO_2 in the emission stream, though some projects are attempting to demonstrate biogenic capture through photosynthetic algae. Post-combustion capture has been used only in specific circumstances.

- Oxyfuel combustion burns the primary fuel in almost pure oxygen to produce a very pure CO_2 stream which then can be compressed for storage purposes. This process, however, requires a fairly elaborate mechanism to purify the oxygen. Oxyfuel technology is in the demonstration phase. In other cases, such as fertilizer production (ammonia), CO_2 is separated as part of the chemical process of producing the product. These latter types of operations operate already in a mature market, though once again not in combination with storage.

All technologies as applied to energy generation effectively reduce efficiency, increasing the amount of CO_2 created (and therefore necessary to capture) per unit of energy produced. The Intergovernmental Panel on Climate Change (IPCC) has estimated that the increase in energy required to capture the CO_2 is between 10% and 40% depending on the technology; the natural gas combined cycle requires the least and pulverized coal requires the most.[(4)] Capturing CO_2 is the most energy-intensive phase (and therefore the largest contributor to CO_2 releases and costs of energy production) in a complete carbon capture and storage mechanism.

---

(4) Intergovernmental Panel on Climate Change (2005).

It should also be noted that since biofuels such as ethanol and biodiesel are derived from plant material that uses atmospheric CO_2, the capture and storage of CO_2 from the combustion of these fuels would actually remove CO_2 from the atmosphere.

2. Transportation

Many point sources of captured CO_2 would not be close to geological or oceanic storage facilities. In these cases, transportation would be required. The main form of transportation envisioned is pipeline, though shipping would be a possibility should there be a need. Trains and trucks are thought to be too small-scale for projects of this size.

Pipelines would require a new regulatory regime to ensure that proper materials are used (CO_2 combined with water, for instance, is highly corrosive to some pipeline materials) and that monitoring for leaks and health and safety measures are adequate. However, these are all technically possible, and pipelines in general currently operate in a mature market.

3. Storage

Storage of CO_2 is mostly discussed in terms of geological storage, though oceanic storage has also been noted as a possibility. Geological storage can take place in oil and gas reserves, deep saline aquifers and unminable coal beds. The injection of CO_2 at pressure into these formations, generally at depths greater than 800m, means that the CO_2 remains a liquid and displaces liquids, such as oil or water, that are present in the pores of the rock.

Liquid CO_2 is lighter than water and therefore tends to travel upward; thus, suitable geological formations must have a "cap" rock to act as a barrier to its movement. If the cap rock is insufficiently wide, CO_2 could leak out around the edges. In this case, mechanisms would be required to prevent such leakage. The viability of any such project would have to be established on an individual basis.

There is also the possibility of injecting CO_2 into the deep ocean. CO_2, however, reacts with water to produce carbonic acid, which makes the water more acidic. Many aquatic organisms are highly sensitive to changes in acidity, making oceanic storage more problematic than geological storage from an ecological standpoint. Models assuming that oceans are used to contribute 10% of CO_2 emission reductions toward a stabilization of atmospheric CO_2 at 550 ppm (it is currently at 380 ppm; the pre-industrial level was 280 ppm) estimate that this approach would increase the acidity of 1% of the ocean volume by 2.5 times (a decrease in pH of 0.4 units) – an acidification significantly greater than pre-industrial variation.[(5)]

---

(5) *Ibid.*

a. Estimated Capacity

One of the main goals of the IPCC study was to examine the global capacity for carbon storage. The IPCC report concluded that, from a technical standpoint, there is a lower limit of about 1,700 Gigatonnes (Gt; one Gt equals one thousand million tonnes) of CO_2 capacity, with very uncertain upper limits (possibly over 10,000 $GtCO_2$). From a more realistic (economic) point of view, however, the report suggested that there is almost certainly a minimum of 200 $GtCO_2$ capacity and likely 2,000 $GtCO_2$.[(6)] At the lower estimate, all current emissions could be sequestered for approximately 9 years, and for 90 years at the upper estimate. Of course, by those dates the definition of what is economically viable and/or the need for capture could be very different.

There are currently three major carbon storage operations in the world, storing approximately four megatonnes of CO_2 per year (0.004 Gt/year). One of these is the Weyburn Canada enhanced oil recovery project in Saskatchewan. The project increases oil recovery by pumping CO_2 (from the United States) into the oil field. The CO_2 remains in the ground, thereby displacing oil and facilitating its extraction.

b. Storage Times

Once CO_2 has been injected into the ground, storage times depend not only on the propensity of a geological formation to leak, including through seismic events, but also on the substance's chemical properties. CO_2 can dissolve over hundreds or thousands of years into the surrounding water, which then becomes heavy and tends to sink, rather than rise. In addition, chemical reactions over millions of years can permanently trap the CO_2 as carbonates, provided the rocks have suitable minerals. CO_2 may also displace methane in some coal beds and adsorb (stick) to the coal. Storage times for geological formations are generally measured in many hundreds to thousands, and even tens of thousands, of years.[(7)]

Oceanic storage times depend on depth of injection. After approximately 100 years, about 20% of injected CO_2 would be expected to leak if the injection depth were 800m, while at a depth of 3,000m only 1% would leak.[(8)]

---

(6) The IPCC defines "virtually certain" as 99% or more, and "likely" as between 66% and 90% certain.

(7) Lackner (2003).

(8) IPCC (2005).

c. Impacts of Leaks

Currently the world emits approximately 6 Gt of carbon (roughly 22 Gt of CO_2) per year. If carbon storage is to play a significant role in reducing CO_2 emissions, presumably some hundreds of Gt of carbon will need to be stored over a period of 100 years. Leak rates of even 1% per year would mean that over 1 Gt of carbon would be emitted per year; in that case, future generations would have to either sequester it, much as non-point sources must be dealt with now, or live with its consequences.

Catastrophic leaks – due, for example, to seismic events or other failures of geological storage or broken pipelines – would not only release large amounts of a greenhouse gas, but create possibly lethal CO_2 concentrations in the locality of such an event. All of these considerations must be taken into account in deciding where to store CO_2. They also suggest that only very deep ocean sequestration should be considered as a viable oceanic option.

The IPCC concluded that aggregate leakage rates of 1-10% over 100 years or 5-40% over 500 years would maintain storage as a viable option for reducing emissions. In an extreme case, however, if coal is to remain a significant portion of the world's energy mix and is mostly combusted, approximately 5,000 Gt of carbon would need to be stored and could potentially leak. The greater the reliance on storage, the greater the absolute need to minimize leakage rates in order to minimize efforts required of future generations.

CONCLUSION

Technologies are available that can make incremental and very important contributions toward reducing greenhouse gas emissions over the next few decades.[(9)] The IPCC concluded in its special report on carbon capture and storage that this technology is one of them. The capacity is significant, if not well constrained. Geological storage is preferred over oceanic storage, as it is a more mature technology with fewer ecological implications. Each project, however, must be examined for its viability, in particular with regard to limiting leakage rates to acceptable levels. In an extreme case, the burning of biofuels and subsequent capture and storage of CO_2 would lead to removal of CO_2 from the atmosphere.

---

(9) S. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years With Current Technologies," *Science*, Vol. 305, 13 August 2004.

Capture technology alone increases energy inputs from 10% to 40%, which would be reflected in energy costs to the consumer. Any significant implementation of carbon capture and storage, therefore, will require public support in order to create the political will to act. As the IPCC concluded:

> at least two conditions may have to be met before CO_2 capture and storage is considered by the public as a credible technology, alongside other better known options: (1) anthropogenic global climate change has to be regarded as a relatively serious problem; (2) there must be acceptance of the need for large reductions in CO_2 emissions to reduce the threat of global climate change.[10]

(10) IPCC (2005), p. 33.