



## **Overview of CO<sub>2</sub> Sequestration Opportunities in New York State**

New York State Energy Research and Development Authority

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## PREFACE

This document was prepared by the New York State Energy Research and Development Authority as a technical appendix in the New York Power Authority's 2006 solicitation for the Advanced Clean Coal Power Plant Initiative (ACCPPI). Substantial contributions to the report were made by the New York State Museum (Section D), with some input from WorleyParsons (Sections C1 and C2).

The geological data presented in this document as it pertains to New York State is *preliminary* data and should be used accordingly and with caution. NYSERDA and the New York State Museum are currently refining and updating these data and assumptions.

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## NOTICE

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## A. Background

Many scientists theorize that anthropogenic climate change is caused or exacerbated by several pollutants known as greenhouse gases (GHG). If the theory is correct, these gases trap energy from the sun, warming the earth's atmosphere and causing changes in climate patterns worldwide. Carbon dioxide is the GHG of most concern because it is emitted in enormous amounts worldwide and is thought at this time to be the greatest contributor to the greenhouse effect. According to the U.S. Environmental Protection Agency, in 2004 CO<sub>2</sub> accounted for 84.6 % of all GHG emissions in the U.S.; of that amount, approximately 40% of the CO<sub>2</sub> emitted was attributed to fossil-fuel-fired power plants<sup>1</sup>.

In the United States, no federal regulations regarding greenhouse gasses have been enacted thus far, but individual states are taking their own actions. In the Northeast, nine states, including New York, are members of the Regional Greenhouse Gas Initiative (RGGI), whose goal is to reduce CO<sub>2</sub> emissions from power plants by implementing a mandatory emissions cap-and-trade program. The RGGI timeline begins in 2009, and carbon capture and sequestration may be one method used by power plants to reduce their emissions to compliance levels.<sup>2</sup>

Several options have been identified to help reduce greenhouse gas emissions, and it is likely that a combination of these will need to be implemented to significantly reduce greenhouse gas emissions. The list of options includes increasing energy efficiency and energy conservation; switching to non-carbon-based fuels such as renewable energy sources, nuclear power, or hydrogen power; and carbon capture and sequestration.

## B. Sequestration Options

In general, carbon sequestration reduces net CO<sub>2</sub> emissions by storing CO<sub>2</sub> instead of releasing it into the atmosphere. More specifically, sequestration activities generally fall into one of two main categories: terrestrial and geological.

The U.S. Department of Energy defines terrestrial sequestration as “the enhancement of CO<sub>2</sub> uptake by plants that grow on land and in fresh water,” and carbon storage in soils<sup>3</sup> as well as “the prevention of CO<sub>2</sub> net emissions from the terrestrial ecosystems into the atmosphere.”<sup>4</sup> Successful terrestrial sequestration, then, can be achieved by manipulating natural processes to maximize CO<sub>2</sub> uptake and by protecting areas that naturally have high uptake of CO<sub>2</sub>, like forests.

This could involve, for example, changing management of agricultural lands to low- or no-till farming methods, which decreases the decomposition of organic material, keeping carbon in the soil; planting winter cover crops that would continue to use CO<sub>2</sub> from the atmosphere, rather than leaving cropland empty during times of the year when economic crops are not normally grown; conversion of marginal cropland to forests or grasslands; reclamation of abandoned mine lands through reforestation, choosing tree species that are fast growing and long lived and would therefore use a large amount of CO<sub>2</sub> over their lifespan; and planting grazing lands with grass species that will maximize CO<sub>2</sub> uptake.

Another terrestrial sequestration option being developed is the concept of the algae farm. In this process, CO<sub>2</sub> is separated and captured from the exhaust stream. The CO<sub>2</sub> is then passed through colonies of algae, which use the CO<sub>2</sub> in photosynthesis, effectively storing the carbon. The algae can later be converted to biofuels. This concept is currently in the very early stages of development.

For geological sequestration, CO<sub>2</sub> is separated and captured at the source—for power plants, this can occur either pre- or post-combustion—and then transported to a location where it is injected into a suitable geological formation deep underground.

## C. State of the Technology

Carbon capture, transport, and geological sequestration are all developing technologies, with some forms closer to commercial implementation than others.

### 1. Carbon Dioxide Separation & Capture <sup>a, 20</sup>

The goal of CO<sub>2</sub> capture is to concentrate the CO<sub>2</sub> stream from a CO<sub>2</sub>-emitting source for future transport and injection at a storage site. It is necessary to achieve a highly concentrated, highly pure CO<sub>2</sub> stream for practical and economic reasons. Large volumes of dilute CO<sub>2</sub> would require large compression and transport equipment and would result in very high energy costs to compress the gas to storage conditions. As a result, it is necessary to concentrate the carbon dioxide stream prior to compression and transport. Capture processes are currently used commercially in industrial chemical production and natural gas separation processes. These processes demonstrate concept feasibility and lend credibility to future plans to capture large quantities of CO<sub>2</sub> from power plants. However, it should be noted that CO<sub>2</sub> capture is not currently deployed at any large power plants.

There are several major methods of capturing CO<sub>2</sub> from a power plant, each of which can be characterized as either pre-combustion or post-combustion capture technology. Using these methods, carbon dioxide is removed from the plant process either before or after the fuel has been combusted to reduce or eliminate the carbon dioxide emissions entering the atmosphere.

#### *Pre-Combustion*

Pre-combustion capture technologies include gasification technologies and are practiced widely in ammonia production plants. Gasification technologies enable the production of a synthesis gas, or syngas, composed mainly of hydrogen and carbon monoxide. This syngas is converted to a mixture of hydrogen and CO<sub>2</sub> by reacting the carbon monoxide in the syngas with steam and passing the mixture through a “shift” reactor. The result is a mixture of hydrogen and CO<sub>2</sub>, which can be passed through a CO<sub>2</sub> removal system. The CO<sub>2</sub> is removed from the mixture by passing the gas through a solvent in an absorber column. The solvent is regenerated and reused in the process. While the process is multi-stepped and more complex than post-combustion methods, the higher concentration of CO<sub>2</sub> (roughly 50%<sup>5</sup>) and the higher operation pressures of these processes result in a more efficient removal of CO<sub>2</sub>. Pre-combustion technologies would be employed at integrated gasification combined cycle (IGCC) facilities. Studies have concluded that the addition of CO<sub>2</sub> capture at IGCC plants would result in a cost-of-electricity (COE) increase of 20-70%<sup>6</sup>.

#### *Post-Combustion Methods (Flue-Gas Separation)*

Post-combustion capture technologies involve the removal of CO<sub>2</sub> from combustion exhaust flue gases, at atmospheric pressures. Carbon dioxide is absorbed from the flue gas by using a liquid solvent. Post-combustion capture uses either air combustion or oxy-fuel combustion. The removal of the carbon dioxide is similar in each method; the difference lies in the composition of the exhaust gas that is treated.

A pulverized coal power plant would typically require post-combustion technology to remove CO<sub>2</sub>. Post-combustion capture technologies remove CO<sub>2</sub> from the flue gas with the use of a solvent. For systems considered in advanced pulverized coal power systems, monethanolamine (MEA) is a typical solvent that would be used to remove CO<sub>2</sub>. This solvent process was developed over 60 years ago to remove CO<sub>2</sub> and H<sub>2</sub>S from natural gas streams. In this process, flue gas is passed through an MEA solution in an absorber column. The MEA solution absorbs the CO<sub>2</sub> from the flue gas, and the solution is then sent to a stripper column. The solution is boiled in the stripper column, and the CO<sub>2</sub> is released from the MEA solution, resulting in a highly concentrated CO<sub>2</sub> stream leaving the stripper, while the MEA solution is recycled back to the absorber.

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<sup>a</sup> This section was in large part contributed by WorleyParsons. Specific statistics are from other sources, where noted.

The efficiency of this process is highly dependent on the concentration of the CO<sub>2</sub> in the flue gas. Higher concentrations of CO<sub>2</sub> result in greater removal efficiencies. Because conventional pulverized coal power plants use atmospheric air for combustion, there is an abundant amount of nitrogen in the flue gas, resulting in a dilute CO<sub>2</sub> stream (typically only 3-15% of the flue gas<sup>6</sup>). The combination of the dilute CO<sub>2</sub> stream and the large volumetric flow of gas to be treated (due to atmospheric pressure) results in the need for a large and high-energy-consumption facility to remove CO<sub>2</sub> from this type of plant. Capture costs have been investigated in numerous engineering studies, and the addition of CO<sub>2</sub> capture to an advanced pulverized coal plant is estimated to result in a cost-of-electricity (COE) increase of about 34-87%.<sup>(e.g. 6, 7)</sup>

Because conventional coal power plants use atmospheric air for combustion, CO<sub>2</sub> removal technologies must be designed to treat diluted flue gas streams. An alternative to these technologies is an oxy-fuel combustion technology, which is currently in the early stages of development. This technology requires an air separation plant to provide high-purity oxygen for coal combustion. The result is a flue gas stream with a higher CO<sub>2</sub> concentration (>80%<sup>8</sup>), with the remainder of the gas composed of water vapor. The water vapor is removed by cooling the mixture, and the resultant highly pure CO<sub>2</sub> stream is compressed. Further purification of the gas stream may be required to remove components such as nitrogen and air pollutants from combustion.

## **2. Carbon Dioxide Transport**<sup>b, 20</sup>

Transport of CO<sub>2</sub> is necessary when storage locations are not in the immediate vicinity of the capture site. For ease of transport, CO<sub>2</sub> is generally compressed to approximately 95 atm (9.6 MPa).<sup>9</sup>

### *Pipeline Transport of CO<sub>2</sub>*

Carbon dioxide has been transported long distances by pipelines since 1970.<sup>9</sup> In the United States, over 2,500 km of pipeline transports more than 50 metric tons of CO<sub>2</sub> per year from sources to sites mainly in Texas, where CO<sub>2</sub> is used for enhanced oil recovery.<sup>9</sup> A pipeline also transports CO<sub>2</sub> 320 km from the Great Plains Synfuels Plant in Beulah, ND, to Weyburn, Saskatchewan, where the CO<sub>2</sub> is also used for enhanced oil recovery.<sup>10</sup> These pipelines are operated at high pressures, sometimes employing booster compressor stations at intermediate locations.

### *Pipeline Design*

Moisture-laden CO<sub>2</sub> is highly corrosive and would require pipeline designs with stainless or corrosion-resistant alloys. Dry (moisture-free) CO<sub>2</sub> is required to prevent corrosion of carbon steel piping, which is tolerant of other contaminants such as oxygen, hydrogen sulfide, and sulfur and nitrous oxides.

### *Monitoring and Pipeline Safety Considerations*

CO<sub>2</sub> could leak to the atmosphere during transport. As a result, pipeline transport of CO<sub>2</sub> through populated areas requires a design approach similar to that of natural gas, namely detailed route selection, over-pressure protection, leak detection, and other design factors.

## **3. Carbon Dioxide Sequestration**

CO<sub>2</sub> storage as a response to climate change has been developing since Marchetti proposed ocean sequestration in 1977.<sup>11</sup> Although CO<sub>2</sub> injection for the purpose of enhanced oil recovery (EOR) has been occurring since the 1970s, the concept of long-term geological sequestration of the gas is relatively new, proposed in the early '90s.<sup>12</sup> Research into both areas has been occurring globally in recent years.

Several international organizations have been recently focused on the sequestration issue. The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization and the United Nations Environmental Programme in 1988 to “assess on a comprehensive, objective, open and

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