

A Technical and Economic Feasibility Assessment of Carbon Capture and Sequestration at the UW Power Plant

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Introduction

As part of the University of Washington Climate Partnership's "Next Best Steps" project, this report was completed to investigate the technical and economic feasibility of implementing carbon capture and sequestration (CCS) processes at the on-campus power plant. The plant, which burns mostly natural gas to produce steam for campus heating and a small amount of electricity, accounts for more than 40% of the University's total greenhouse gas (GHG) emissions. Figure 1 below shows the monthly variation in CO₂ production at the power plant. The total emissions for 2006 were approximately 85,000 metric tons of CO₂ released at an average rate of 230 tCO₂/day. As a large point source, the plant is an attractive location for the implementation of CCS processes.

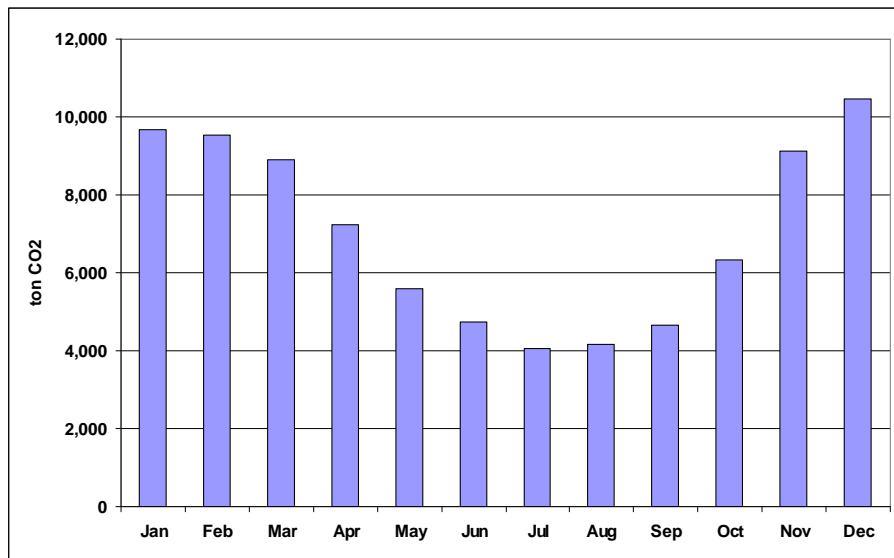


Figure 1: Monthly CO₂ emissions from the UW power plant calculated from the UW facilities services fuel consumption monthly reports for 2006

CCS processes typically consist of three major components: capture, transport, and storage. Generally there is a very large quantity of gas exiting the plant in the flue stack and CO₂ only makes up a small fraction. Because it is impractical to sequester all the flue gas, the CO₂ must instead be separated out. This is a difficult task technologically, and generally requires significant amounts of energy. This additional energy is usually generated by burning more fuel which in turn produces more CO₂ emissions. Once the CO₂ has been separated, it must then be compressed to a liquefied state in preparation for temporary storage or transport. Transport is usually accomplished via pipeline, which is widely accepted as the most economical transport method for CCS given the large quantities of CO₂. The transport distance of course depends on the location of the storage site. The most likely storage option identified in this study was injection into deep underground geologic formations. Potentially suitable formations have been identified in the Puget Sound area. The overall effectiveness of the CCS system in terms of its potential for mitigation of global warming is dependent on the efficiency of the capture, transport, and storage processes. This concept is illustrated in Figure 2.

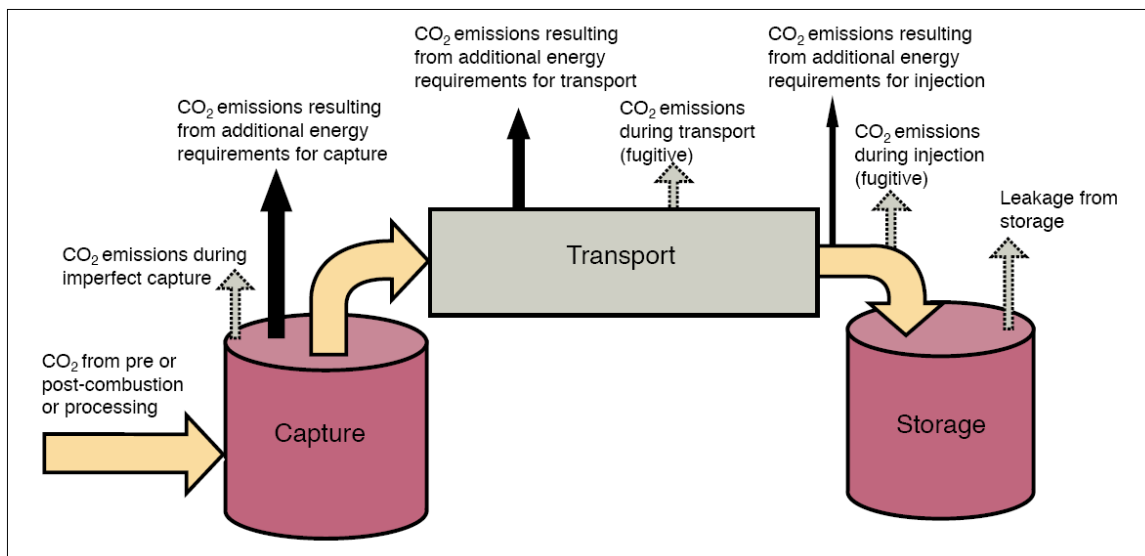


Figure 2: Additional and fugitive emissions resulting from the implementation of CCS processes (IPCC 2005)

Project Scope and Assumptions

The purpose of this report is to provide a broad overview of the currently available technologies and to identify the most promising options for the UW power plant. Because CCS processes are a relatively new topic brought about by recent studies of anthropogenic forcing and impacts, many of the applicable technologies are still in the research and development phase. Rather than attempt to predict which technologies will become successful, this report instead focuses on those which have the highest immediate potential.

Many campus facilities, such as the UW medical center, depend on the plant's continuous operation. It is therefore desirable to identify post-combustion CCS processes which operate only on the flue gases and do not require any major retrofits to the existing equipment or disruptions to plant operations. The capture process was assumed to be the most significant challenge in terms of technological difficulty, cost, energy use, efficiency, and impact at the UW campus. While all components of CCS are important and were considered, limitations in time and resources restricted the majority of the efforts towards researching the capture process.

Key Findings

Capture

Carbon dioxide concentrations in the flue gas resulting from the combustion of natural gas in air can be as low as 3% CO₂ by volume. The main technical challenge is therefore to separate the CO₂ from the other flue gases. Options for post-combustion separation processes are limited due to the high energy demands and costs. Examples include separation by liquid solvents or solid sorbents, selectively permeable membranes, and cryogenic separation. Of these technologies, processes involving the use of liquid amine solvents were selected as the most promising option. A schematic diagram depicting such a process is shown in Figure 3.

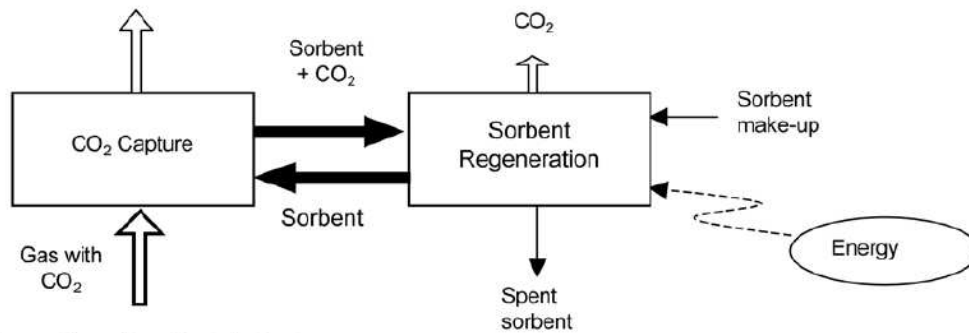


Figure 3: Schematic diagram of an amine based CO₂ capture system (IPCC 2005)

The amine separation process works by directing the flue gas through a chamber containing the liquid amine solvent which absorbs the CO₂. A typical solvent used is monoethanolamine (MEA) which is an ingredient often used in the manufacture of many familiar products such as laundry soap (Verschuere 1996). After absorbing the CO₂, the so-called “rich” solvent is then transferred to a regeneration chamber where it is heated and/or depressurized to release the CO₂ as a relatively pure stream (> 99%). The remaining “lean” solvent is then recycled back to the flue gas chamber where it is reused in a cyclic fashion. The separated CO₂ is then compressed in preparation for transport to the storage site. Typical CO₂ capture efficiencies are about 85-90% (Rao 2002).

The amine separation process is the only known post-combustion process for which there are currently available commercial systems with capacities capable of matching the CO₂ production rate at the UW power plant. Examples include systems made by Kerr-McGee, Fluor Daniel, and the Kansai Electric Power Co. (IPCC 2005). The process is capable of achieving high capture efficiencies even for flue gas streams having low CO₂ partial pressures. It also has the highest energy efficiency of all the surveyed capture processes. Even so, significant energy is required to pump the solvent streams and to heat the solvent in the regeneration chamber. This energy consumption decreases the net heating and electrical generating capacity of the plant, increases fuel consumption, and lowers the overall thermodynamic efficiency (Rao 2002). Reaction of the solvent with nitrous oxides (NO₂) in the flue gas leads to the formation of heat stable salts which must be removed (Rao 2002). The makeup solvent can be somewhat expensive while the spent solvent has associated waste disposal issues. The size of the additional equipment needed can be quite large and it is unknown if there is sufficient space adjacent to the UW power plant. Figure 4 was provided in the IPCC report and shows a 200 ton/day chemical solvent capture plant in Malaysia.



Figure 4: An example of an existing 200 ton/day chemical solvent capture plant in Malaysia (IPCC 2005)

Storage

Storage options include sequestration in geologic formations, injection into the deep ocean, mineral carbonation, and use in industrial applications (IPCC 2005). Of these options, storage in geologic formations was found to have the highest potential feasibility. Geologists working for the West Coast Regional Carbon Sequestration Partnership (www.westcarb.org) have identified coal and saline formations in the Puget Sound area which are potentially suitable for CO₂ sequestration. A pilot study is underway at the coal plant in Centralia, WA for storage in coal seams. A variety of geologic storage options are illustrated in Figure 5 below.

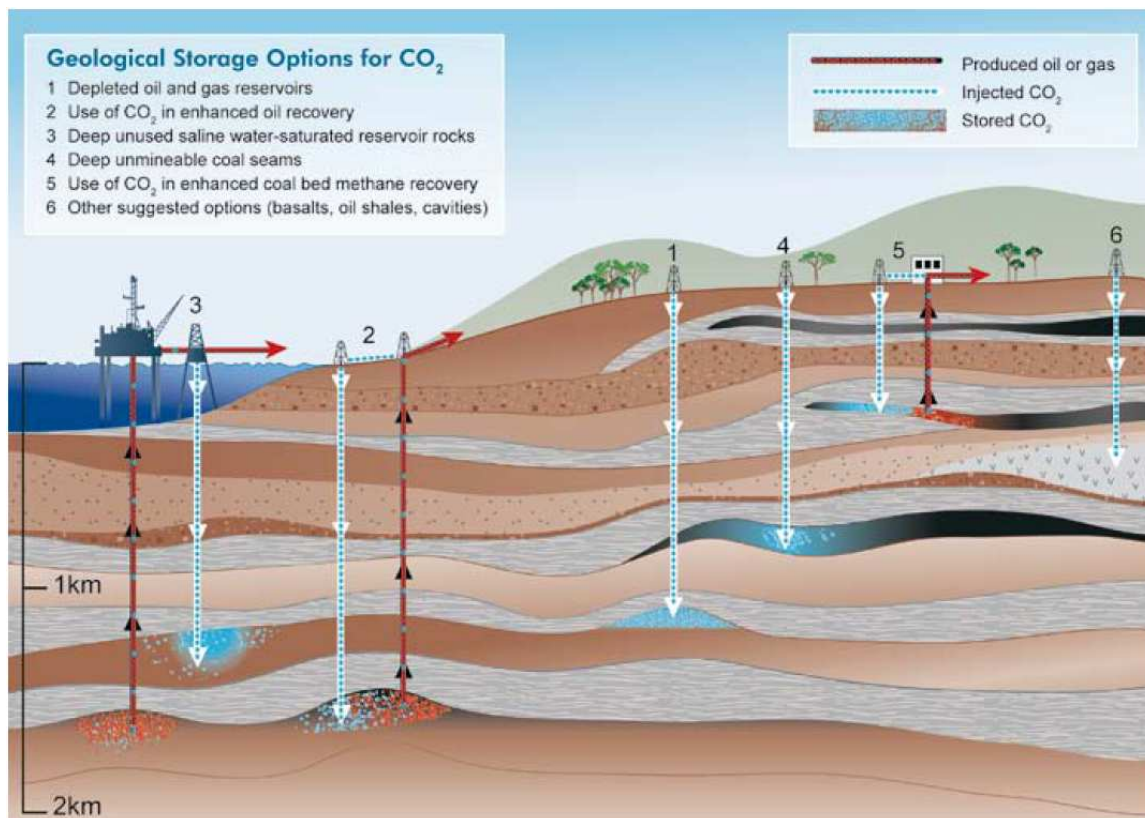


Figure 5: Deep underground geologic storage options for CO₂ sequestration (IPCC 2005)

The other storage options mentioned are either still in the research phase, or were not considered to be as cost competitive as geologic storage. Storage in the deep ocean, for example, is an option which is still under investigation for its environmental impact and long-term storability. Storage by mineral carbonation was not considered because its associated costs are an order of magnitude higher than the other options. Finally, the use of CO₂ in industrial applications is not practical due to limited capacity and short storage lifetimes (IPCC 2005).

Transport

In the best case scenario, a suitable geologic formation would be located directly beneath the UW power plant. The more likely situation, however, would be that the CO₂ would have to be transported some distance to the injection site. Transportation options include pipeline, truck,

rail, or ship. The specific transportation method used will of course depend on the location of the sequestration or storage site. Pipeline transport is currently the preferred method given the large quantities and distances involved (Zhang 2006). Pipelines are a very mature technology, having been widely deployed in various industrial applications for the transport of chemical liquids and gasses. A pipeline would also be the best option economically over the long-term.

Cost Estimation

Cost estimation was made difficult because most published research studies on CCS are for large (500-700 MWe) pulverized coal or natural gas combined cycle power plants. Such plants are very different thermodynamically from the UW power plant and more than twenty times as large. Direct cost comparisons were therefore made difficult due to the economy of scale and other uncertainties. One report was found by Chapel (1999) which detailed cost information for a 1000 tCO₂/day amine separation process. Such a plant is approximately three times larger than what would be needed at the UW power plant. The stated capture costs, however, were considered adequate given that our intended goal is only a “ballpark” estimate. The capture costs are summarized below along with estimates for compression, transport and storage.

	<u>\$/tCO₂</u>
Operating Cost	25
Capital Recovery Cost	18
Subtotal Capture Process	43
CO₂ Compression	8
Transport via Pipeline (100 km)	4
Storage and Monitoring	5
Subtotal Additional Costs	17
Grand Total	60

The above estimates for the capture system assume 3% CO₂ sulfur-free flue gas. Capital costs are based on a 20 year project life, a 15% return on investment, and 1997 pricing and technology (Chapel, 1999). Compression and transport costs were taken from Zhang (2006), and the CO₂ storage and monitoring price was given by Rao (2002). It should be noted that the assumptions behind the numbers were not fully documented. Furthermore, these costs are on a ton CO₂ *stored* basis. A better estimate should be made on a ton CO₂ *avoided* basis. The amount of CO₂ avoided is the net difference between the amount of CO₂ captured and the additional amount of CO₂ generated throughout the life cycle of the CCS process. The amount of CO₂ avoided will depend to a large degree on the assumed amine capture efficiency and the amount of additional energy required by the CCS process. This concept is modeled in Figure 6 below, which shows an estimate of the expected amount of CO₂ that would be emitted and captured if CCS were implemented at the UW power plant.

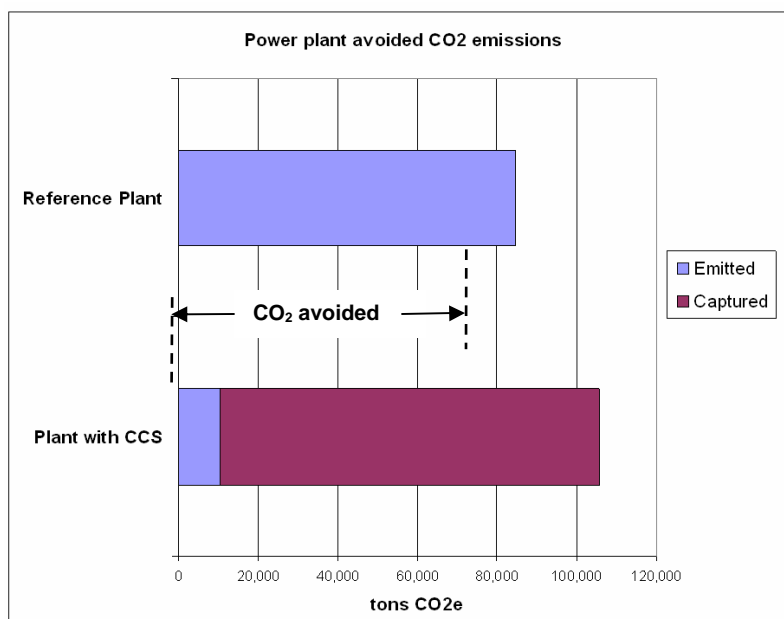


Figure 6: Example scenario for CO₂ production at the UW power plant with CCS. Reference plant emissions based on 2006 data.

Algae Bioreactor

A novel process alternative considered was proposed by Bionavitas, Inc. of Snoqualmie WA who has already expressed interest in conducting a pilot scale study at the UW power plant. I attempted to contact the company but unfortunately never heard back about their proposed project. A similar technology is being developed by GreenFuels Technologies Corporation (www.greenfuelonline.com). The GreenFuels process works by directing the flue gas through an algae bioreactor where a portion of the CO₂ is consumed by the algae during photosynthesis. The algae are then harvested and converted into fuels such as diesel oil or ethanol.

The fuels produced by such a process would later be burned to extract their energy value, perhaps ultimately releasing the captured CO₂ into the atmosphere. In order to be effective as a means of mitigating global warming, the total energy value of the produced biofuel must be similar in magnitude to the total energy value of the fossil fuel used in the original CO₂ production process. Typical conversion efficiencies for algae bioreactor systems are on the order of 1-2% (chemical energy/ sunlight energy) (IPCC 2005). In Seattle, the average solar irradiation ranges from 5.73 kW hr/m²/day in the summer, down to 0.92 kW hr/m²/day in the winter when the largest percentage of CO₂ is produced by the power plant (Stackhouse 2006). In order to capture all the CO₂ from the power plant, the area of the algae bioreactor would need to be on the order of 10-100 km² depending on the season, which is obviously not practical. Such a process is therefore not expected to be capable of significantly reducing the UW's GHG emissions. A pilot study at the power plant could, however, lead to research findings which are beneficial elsewhere.

Data Gaps

- The most significant data uncertainties in this report are associated with cost. Information found in published reports was for power plants having different configurations and thermodynamic efficiencies. Furthermore, assumptions used to generate cost estimates were not fully documented.
- It was not known how the capture equipment would be integrated into the existing power plant facilities, or whether or not this integration would cause serious disruptions to plant operations or require significant plant reconfiguration.
- Capture equipment land use was not known and could only be guessed based on photographs of existing facilities. Given the severe limitations on available space adjacent to the power plant, land use could be a significant obstacle. In addition, the large equipment used for the capture process may not fit well aesthetically in a campus setting.
- The amine separation process has several non-GHG related environmental impacts including water consumption, eutrophication, and toxicity.
- A specific location for geologic storage was not identified. This will need to be done to verify feasibility and improve the cost estimate.
- It was not known what kind of regulatory framework exists in regards to CCS or how any such regulation would affect the overall feasibility.

Recommendations

- Even with the stated uncertainties, the costs associated with CCS are still high compared to other global warming mitigation alternatives. At the time of this writing, carbon offsets were trading on the Chicago Climate Exchange for less than \$4 per ton of CO₂ equivalent. Future government regulations could make the costs more competitive.
- This report only considered currently available post-combustion capture technologies. The scope of the study should be expanded to include pre-combustion, oxy-fuel combustion, and biofuel combustion technologies which have the potential to offer lower overall system costs and improved efficiencies.
- There is some academic, government, and private research being conducted into new CCS technologies which may lead to breakthroughs resulting in substantial reductions in the associated costs. The UW should take an active roll in these research activities. Doing so would benefit not just the UW, but society in general.
- The capture process is generally considered to be the most significant challenge in terms of technological difficulty, cost, energy use, overall CO₂ capture efficiency, and impact at the UW campus. Therefore, research efforts in this area have the potential for the highest payoff.

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