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Propositions of Sustainable Methods of Carbon Dioxide Separation and Disposal.

Intended Category: Sustainable technologies and products.

Abstract

As a result of industrialisation and a subsequent dependence on electricity, society now relies on carbon based energy sources. The minimisation of greenhouse gases to an acceptable threshold level is arguably the greatest environmental challenge that is set before us. There are a number of propositions that may be useful in achieving this challenge. This paper summarises a number of carbon dioxide separation and disposal options. There are emerging lines of research that could sustainably reduce levels of carbon dioxide emissions to the atmosphere. Carbon separation from flue gases by the method of amine scrubbing during the electrical generation process is costly. Developments in the areas of membrane separation, molecular sieves and desiccant adsorption may assist in a more sustainable approach. Current propositions of direct injection of carbon dioxide into geologic or oceanic sinks are recognised as short sighted and not sustainable. This paper develops the argument that the natural process of photosynthesis, given further advances in bioreactor technology, could be utilised to produce useful by-products of biomass, oxygen and hydrogen and to reduce carbon dioxide emissions to the atmosphere.

Introduction

The Kyoto protocol set forth a recommendation that Australia slow the rate of carbon dioxide released into the atmosphere per year to 108% of the 1990 levels by the 2008-2012 period (Australian Greenhouse Office, 1999). This protocol was established in recognition of the detrimental environmental effect a growing layer of carbon dioxide around the earth's surface would have in terms of increasing average surface temperatures. This phenomenon is commonly referred to as the Greenhouse Effect.

Traditionally Australia has been dependant on high carbon intensive energy production methods specifically coal-based electrical generation. In recognition of this dependency, the Australian government chose not to ratify the recommendation set forth by the Kyoto protocol. This dependency is highlighted by the fact that in the 1995/96 period, coal mining accounted for 1.9% of the Gross Domestic Product (Mark & Worral, 2000). From the year 1990 to the year 2000, Australian greenhouse gas emissions grew from 503.3 to 535.3 Mt CO_2 – equivalent, representing an increase of 6.3% (Australian Greenhouse Office, 2000).

The issue of reducing greenhouse gas emissions is problematic especially in view of the fact that around 33 per cent of Australia's total emissions are due to electricity and heat production (Australian Greenhouse Office, 2000). There are numerous methods of separation and disposal of carbon dioxide each with associated drawbacks. An optimal solution should remove and retain carbon dioxide from the atmosphere in a self-sustaining manner.

Carbon Dioxide Separation Options

There are a number of methods available to separate carbon dioxide from flue gases emitted from the electrical generation process. Table 1 highlights some of these options:

CAPTURE METHOD	DESCRIPTION
MEA Scrubbing	A chemical absorption process whereby a monoethanolamine (MEA) solvent comes into contact with flue gases in the absorber. The carbon dioxide rich MEA solution is sent to the stripper where it is heated releasing an almost pure stream of carbon dioxide (Herzog, 1999).
Membrane Technology	This process involves the forcing of carbon dioxide molecules that are normally adhered to a type of solvent, through a membrane. The design only allows the penetration of specifically sized molecules, namely the carbon dioxide molecules, through the surface of the membrane (Patil et al., 2002).
Molecular Sieve	A molecular sieve specifically allows molecules of a certain weight or size to be adsorbed. One type of sieve allows free flowing fluid containing carbon dioxide to pass through. The carbon dioxide is adsorbed to the sieve structure and can be released upon passing a low voltage across the adsorbent (Judkins & Burchell, 2001).
Desiccant Adsorption	Zeolite used as a desiccant has been found to adsorb carbon dioxide effectively over a temperature range of 50-100^{O}C. As the adsorbent is heated, carbon dioxide can be regenerated under depressurisation (Ishibashi et al.,1996).

Table 1: A description of carbon dioxide separation options.

Drawbacks of the carbon dioxide separation options

The MEA amine process to separate carbon dioxide is viewed as uneconomical due to the need for high levels of energy inputs for regeneration and for equipment sizes (Mark & Worral, 2000).

Membrane technology has been used by the Kvaener Group[1], not specifically to separate carbon dioxide from flue gases, but instead to increase mass transfer areas in a given volume, and to avoid problems associated with vapour-liquid contact surfaces. This has reduced costs associated with energy production (Herzog & Falk-Pedersen, 2000).

An adequate molecular sieve capable of processing the volume of flue gas emitted from a coal driven electrical generator has not yet been developed. A problem identified with the desiccant adsorption has been the reaction of sulphur dioxide with the desiccant (Ishibashi, et al., 1996). These technologies are promising methods of sustainable carbon dioxide separation but are still under development and are yet to be applied to a large-scale electrical generation process.

Carbon Dioxide Disposal Options

Once the carbon dioxide has been separated from the atmosphere a further problem arises – what to do with the carbon dioxide. Some have argued that compressed carbon dioxide could be used in industrial processes. Upon consideration of this option, there would likely be an over supply of carbon dioxide to industry and the manner in which the carbon dioxide is utilised would not necessarily reduce carbon dioxide levels in the atmosphere. Some of these disposal options been summarised in Table 2.

DISPOSAL OPTION	DESCRIPTION
Geologic Injection	Separated carbon dioxide is injected underground. The expected residence time of the carbon dioxide is in the magnitude of thousands of years (Herzog, 2001).
Enhanced Oil Recovery	Carbon dioxide is pumped into an oil reservoir, which combines with the oil, promoting the extraction process. The carbon dioxide is then recaptured and reinjected until as much oil as possible has been recovered (Lake, 1989).
Coal Seams	Another form of geologic injection an abandoned coal seam, can be used to dispose of carbon dioxide. As the carbon dioxide diffuses through the porous structure of the coal, adsorption occurs, thus retaining the carbon dioxide on a permanent basis (Herzog, 2001).
Oceanic Injection	Separated carbon dioxide can be injected into the sea by means of a long pipe line or frozen blocks. The expected residence time of the carbon dioxide is in the magnitude of hundreds of years (Herzog, Caldeira & Adams, 2001).
Oceanic Fertilisation	This method can be used to enhance oceanic injection by fertilisation of the ocean with nutrient. Photosynthetic organisms absorb and break down carbon dioxide into organic products in a process of re-mineralisation (Brewer, et al., 1999).

Table 2: A description of carbon dioxide disposal.

[1] An international engineering and construction entity.

Drawbacks of the disposal options

Geologic injection, enhanced oil recovery and using coal seams for storage all have similar drawbacks – the carbon dioxide would be expected to leach back into the atmosphere over thousands of years (Herzog, 2001). Although this would assist to reduce the immediate levels of carbon dioxide in the atmosphere, injection of carbon dioxide into a geologic structure could not be seen as a long-term sustainable solution.

Oceanic injection could potentially hold up to 10 times more carbon dioxide than geologic injection (Herzog, 2001). It has been estimated that up to 80% of today's anthropogenic emissions would be absorbed by the oceans. Direct injection into the ocean would arguably speed up this process thus reducing peak concentrations and rate of increase of carbon dioxide (Herzog, Caldeira & Adams, 2001). Using this method though, could potentially alter the pH of the oceans adversely affecting non-swimming marine organisms such as plankton (Lake, 1989).

Oceanic fertilisation experiments using iron have been successful on a small scale. Large scale projects though have limited potential, high costs and a high level of uncertainty (Brewer et al., 1999). In addition to this, changes to plankton levels could have long-term adverse effects on the oceanic eco-system. It could cause methane to be formed as the sinking organic mass sinks to the ocean floor thus negating the beneficial effect of carbon fixation (Graeber, 2000).

A sustainable approach – the photo-bioreactor solution

A sustainable approach to the capture and disposal of carbon dioxide should remove and retain carbon dioxide from the atmosphere in a self-sustaining manner. Clearly the development of membrane, molecular sieve and desiccant technologies are leading in the right direction. The question of what do with the captured carbon dioxide still remains.

One solution would be to create a bioreactor capable of fixing the carbon dioxide by using photosynthetic microorganisms in a controlled environment. Table 3 gives a summary of some of these microorganisms, their requirements and products.

TYPE	STRAIN	REQUIREMENTS	PRODUCT
Bacterium	Rhodovulum sulfidophilum	Anaerobic + light + eliminating N_2.	Hydrogen
Cyanobacteria	Synechococcus	CO_2 + dark condition.	Starch, Hydrogen
Green-algae	Chlamydomonas	Light + $CO_2 \rightarrow$ starch + O_2. Anaerobic + dark conditions $\rightarrow H_2$.	Starch, Hydrogen, Oxygen
Micro-algae	Botryococcus braunii.	Light + CO_2.	Hydro-carbon
Micro-algae	Chlorella	Light + CO_2.	Starch

Table 3: Summary of photosynthetic microorganisms (Scragg et al., 2002), (Kajiwara et al., 1997), (Miura et al., 1997), (Marukami, et al., 1997), (Hirata et al., 1996),(Melis et al., 1999).

Some of the products from these photosynthetic reactions would be very useful. Hydrogen could be used as fuel whereas starch could be used as a pulp substitute for the paper manufacturing process (Hon-nami et al., 1997). Figure 1 describes the conceptual process of a solar energised photo-bioreactor.

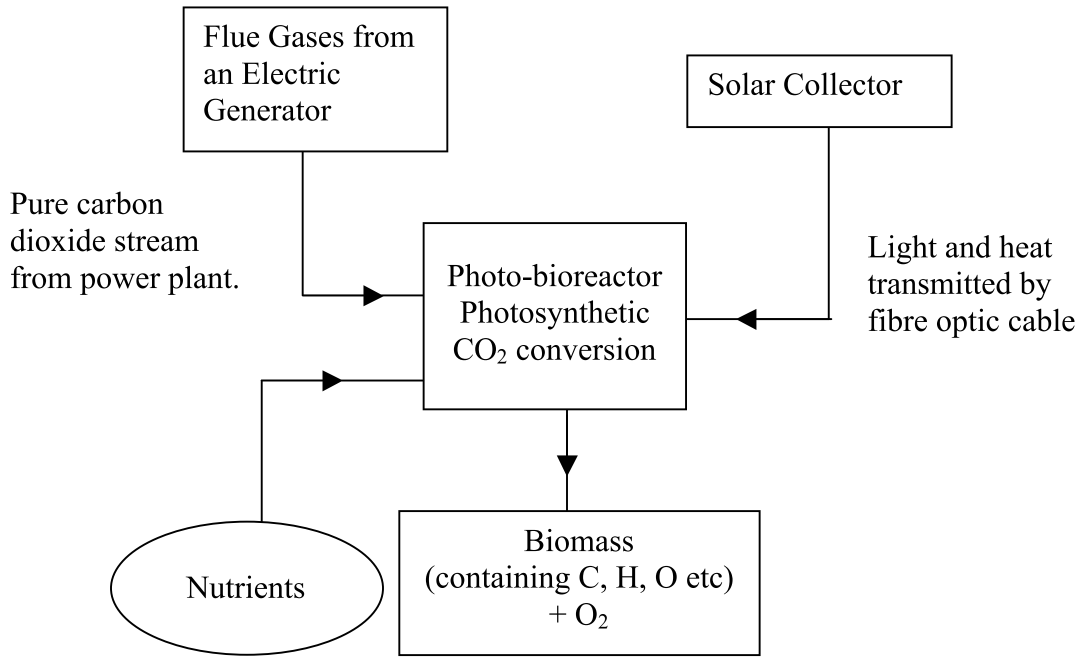

Figure 1: Photosynthetic conversion of carbon dioxide to biomass.

The first step to study the characteristics of photosynthetic microorganisms would be to design a solar energised laboratory scale photo-bioreactor. This apparatus could be used to test variations such as would be due to light cycles, light intensity and temperature fluctuations. This testing would assist in identifying robust microorganisms with high carbon fixation rates. There are essentially three components that a solar energised laboratory scale photo-bioreactor would need. These are described in Table 4.

COMPONENT	**METHOD**
Collection	Use of a solar collecting device such as a parabolic mirror or trough, to concentrate solar radiation that would be used as a light source for the micro-organisms to photosynthesise.
Transmission	A bundle of fibre optics the size of the focal area of the solar collecting device could be used to transmit the light source to the photo-bioreactor.
Distribution	The light coming from the fibre optics could be distributed in a number of ways. One way would be to interface the fibre optic output with the rectangular edge of a glass plate that sits inside the medium. The distribution plate with a triangular cross-section would be designed to disperse the light evenly throughout the bioreactor.

Table 4: Components of a solar energised photo-bioreactor (Stewart & Hessami, 2004).

At this point in time most photo-bioreactors are on a laboratory scale making no real impact on greenhouse gas emissions. It is envisaged that a large scale application be located near to a supply of flue gases from an electrical generator and would consist of a number of solar ponds capable of sustaining the optimal photosynthetic carbon fixing microorganisms. Based on an existing carbon fixation rate for a specific photosynthetic microorganism, a 4000 $metre^3$ solar pond during a natural day-night cycle could sequester up to 2.2 kilo-tonne of carbon dioxide per year (Stewart & Hessami, 2004). More research needs to be done to identify photosynthetic microorganisms that are robust to environmental fluctuations, low levels of sulphur dioxide, have high carbon fixation rates and produce useful products.

Conclusion

There is no easy solution to the increasing rate at which carbon dioxide is being released into the atmosphere. Sustainable methods of separating carbon dioxide, such as through desiccant adsorption and molecular sieves, have been identified. Yet the separation process does not address the issue of where to put the carbon dioxide. Methods of geologic and oceanic injection are plausible but will not sustainably remove carbon dioxide from the atmosphere in the long run. More research needs to be conducted into identifying photosynthetic microorganisms capable of sequestering carbon on a large scale that would potentially assist Australia in contributing to a sustainable solution to the reduction in greenhouse gases.

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