The Comprehensive Guide for Algae-based Carbon Capture

about

Oilgae is the definitive resource for algae energy. In addition to being an online hub for all aspects of algae fuels, the Oilgae team is also a regular contributor to various online and offline forums. The Oilgae team members have been invited to speak and present at numerous international conferences and seminars.

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Preface

Global warming due to increased carbon dioxide concentration in the atmosphere has been receiving a great deal of attention lately. Research affirms that atmospheric increases of carbon dioxide are positively correlated with the amount of fossil fuels being burnt. In an attempt to retard this increase and, therefore, the greenhouse effect, most industrialized countries have taken initiatives to hold their carbon dioxide emission levels.

This increasing awareness for the need for pollution control introduced the concept of carbon credits. Carbon credits were one of the outcomes of the Kyoto Protocol, an international agreement between 169 countries. The Kyoto Protocol created legally binding emission targets for developing nations. To meet these targets, nations must limit CO_2 emissions. It was enforced from February 2005. This can be accomplished by either reducing emissions or by absorbing emissions through processes such as tree-planting.

Carbon credits are a tradable permit scheme to counteract the greenhouse gases that contribute to climate change and global warming. Carbon credits create a market for reducing greenhouse emissions by giving a monetary value to the cost of polluting the air.

Carbon credits can be created in many ways but there are two broad types:

- Sequestration (capturing or retaining carbon dioxide from the atmosphere) such as afforestation and reforestation activities.
- Carbon dioxide saving projects such as use of renewable energy sources.

Conventional sequestration techniques, despite all its advantages are second only to the vastly effective and attractive option of biological sequestration. Because, plants naturally capture and use carbon dioxide as a part of their photosynthetic process, the process of biological sequestration employs simple and easy technology providing ways to utilize the sequestered carbon.

Algae-based carbon capture is one of the latest methods of biological sequestration vastly exploited in CO_2 emitting industries. Algae, the third generation feedstock researched for bio energy production is the best agent for capturing carbon dioxide from large-scale emitters such as power-plants and industries. Algae are also a sensible choice with regard to their fast proliferation rates, extensive tolerance to wild, extreme environments, and their potential for comprehensive cultures. These advantages promise high performance in the reduction of carbon dioxide. After harvesting, microalgae can further be used as a product to offset some of the costs that have been incurred in the sequestration process.

However, there exist significant challenges for the abatement of carbon dioxide using algae despite all its application potential and advantages. These challenges are present along the entire value chain, and comprise both engineering and biological challenges.

This report provides inputs on four major aspects of the algae based carbon dioxide abatement, such as:

- Concepts of Algae-Based CO_2 Capture
- Processes & Challenges
- Industry & Market Information
- Algae for Fuels

The report comprises relevant inputs, data and statistics for all the sections mentioned above. It also includes real life case studies to assist the reader in gaining a more practical perspective of the industry status.

This is a preview for the report prepared by Oilgae, an authoritative source of information and data for the energy from algae domain. The report was last updated in the 3rd week of February, 2011.

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Why you should buy this report

- It helps you understand all aspects of the algae-based carbon capture
- It includes a number of real life case studies to assist the reader in gaining a more practical perspective of the industry status.
- It has been developed with inputs from authoritative sources.
- Special emphasis is on inputs that will facilitate businesses to quickly take further steps.
- Developed by Oilgae (www.oilgae.com), the leading resource for all information for energy from algae.

Highlights of the Report

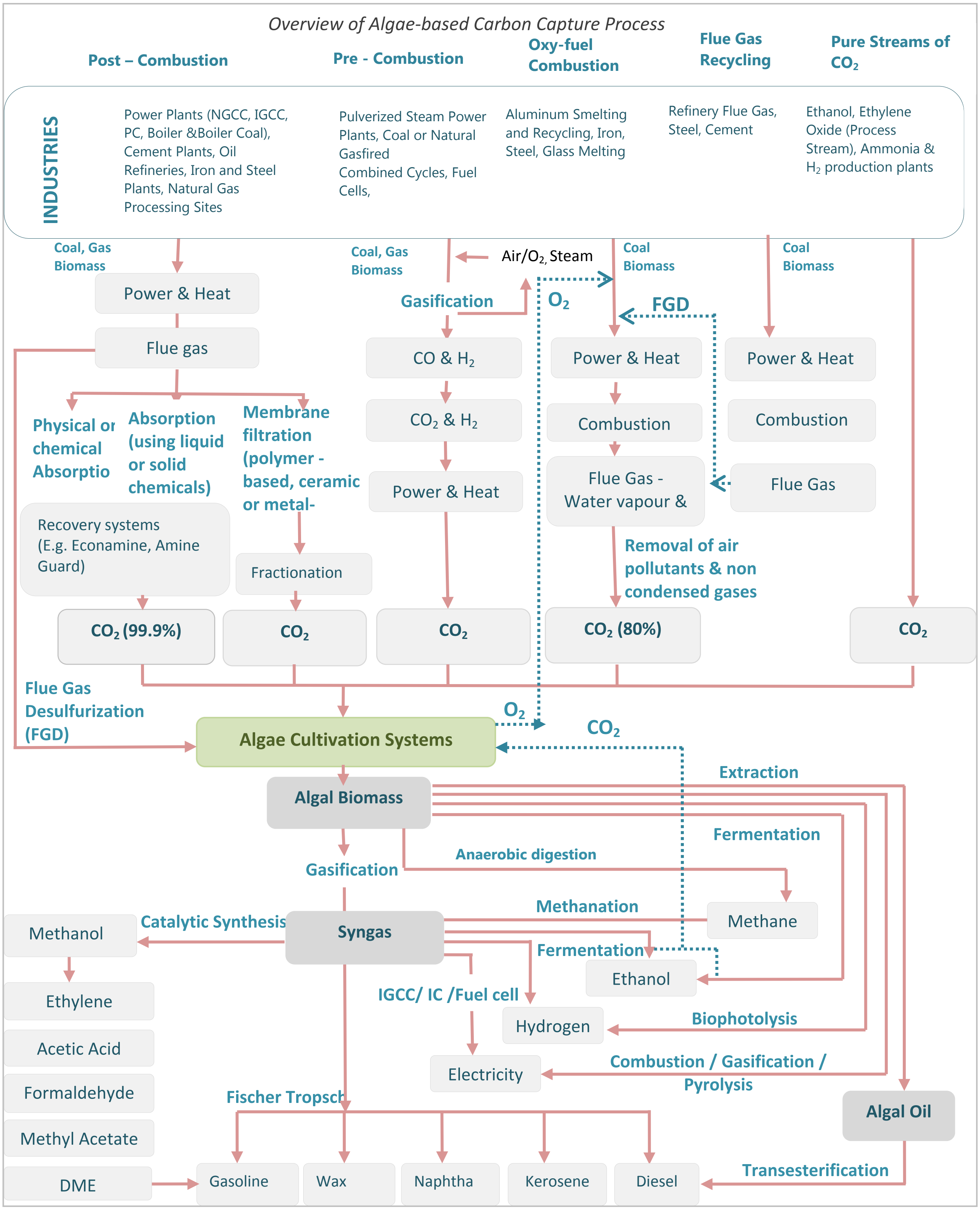
- It answers the most important questions that entrepreneurs, investors and businesses have regarding algae CO_2 capture.
- The report focuses on carbon dioxide sequestration opportunities using algae and offers recommendations on needed research and development to bring cost-effective competitive sequestration technologies to the market.
- It helps you understand the challenges and the possible efforts while using algae for CO_2 sequestration.
- It lists the companies involved in algae based CO_2 capture and commercial research, enabling students and researchers to get in touch with them for industrial collaborations.
- It showcases case studies on algae research efforts in the CO_2 sequestration at power plants, cement plants, coal burning and natural gas power plants, petrochemicals, Iron & Steel, cements, sugar, paper, inorganic chemicals, fertilizers and breweries.
- It provides current and future research areas in algae-based CO_2 capture domain.

1 Algae-based CO_2 Capture - Introduction and Concepts

This chapter provides insights into the basic concepts of carbon capture & sequestration and highlights the need for the process in today's industrial world where emission cuts are emphasized. It also provides basic information about the conventional carbon capture methods along with biological sequestration. The attributes and advantages of algae-based carbon capture are also concisely dealt with.

Key Sections

Sample Content: Overview of Algae-based Carbon Capture Process



2 Algal Strain Selection for CO_2 Capture

In this section, we highlight the importance of the strain selection process. We also provide basic information about the vital algal strains employed for the process of algae-based CO_2 and their significant attributes with regard to both micro and macroalgae. The criteria employed for selection and the factors which influence the selection process are also concisely presented. We have also accounted the carbon concentrating mechanisms in algae for the people interested in the molecular biology of the process.

Key Sections

Sample Content: **Algal Strain Selection for CO_2 Capture**

Carbon-Capture Efficiency and Characteristics for Some Microalgae Species

Some species of algae prefer more acidic cultures, like *Galderia* sp. and *Viridella* sp., while others grow best in neutral or slightly basic media, such as *Chlorococcum* and *Synechococcus lividus*. The species that survive best in acidic conditions are generally more tolerant to high CO_2 concentrations, since CO_2 lowers the pH of a solution. The microalgae with the shortest doubling times, like *Chlorella* and *Synechococcus lividus*, generally show higher productivity than other strains. The following table shows evidence that different microalgae species require different growth conditions.

Growth Parameters for Algae

Species	Temp (^0C)	pH	CO_2%	Doubling time(hr)	Features
Chlorococcum sp.	15 – 27	4 -9	Up to 70	8	High CO_2 fixation rate Densely culturable
Chlorella sp.	15 – 45	3 – 7	Up to 60	2.5 - 8	High growth ability High temperature tolerance
Euglena gracilis	23- 27	3.5	Up to 100	24	High amino acid content Good digestibility (effective fodder) Grows well under acidic conditions Not easily contaminated
Galdieria sp.	Up to 50	1 -4	Up to 100	13	High CO_2 tolerance
Viridiella sp.	15 - 42	2 -6	Up to 5	2.9	Accumulates lipid granules inside the cell High temp and CO_2

Some organisms have been isolated using flue gas, but studies to date have only been performed at a bench-scale (currently, no commercial ponds use flue gas). Two very promising organisms are *Chlorella sp. and Spirulina platensis.*

Genetic Screening

Genetic screening is getting increasingly important as new molecular tools are being developed to gain information about the genes in the algal genomes, particularly through the analysis and modulation of gene function *in vivo*. The genomes of a number of algae have now been fully sequenced. These include *Chlamydomonas reinhardtii, Cyanidioschyzon merolae, Ostreococcus lucimarinus, Ostreococcus tauri,* and *Thalassiosira pseudonana* (Waters and Rioflorido 2007). The genome analysis of *Chlamydomonas reinhardtti* has uncovered hundreds of genes that are uniquely associated with carbon dioxide capture and generation of biomass. Among the 15,000-plus genes revealed in the study are those that encode the structure and function of the specialized organelle that houses the photosynthetic apparatus, the chloroplast, which is responsible for converting light to chemical energy. The project was led by the U.S. Department of Energy Joint Genome Institute (DOE JGI);

In this section, we throw light on the enormity of carbon dioxide emissions from fossil fuel power plants and the need for power plant carbon capture. We briefly discuss the plant operations followed by the feasibility of using algae for carbon capture in power plants. The strategies and the steps involved in algae based carbon capture in power plants, latest technologies in desulphurization, carbonation and cultivation systems are dealt with in detail. We also provide a list of specialized applications of algae-based carbon capture.

Key Sections

3.1 Introduction

3.2 Need for Power Plant CCS

3.3 Thermal Power Plants - Operation and Classification

3.4 Algae for Power Plant Carbon Capture

3.5 Strategies in using Algae for Carbon Capture in Power Plants

- 3.5.1. Direct Use of Flue gas with Flue Gas Desulphurization (FGD)
- 3.5.2 CO_2 Transportation
- 3.5.3 Carbonation System
- 3.5.4 Cultivation Systems
- 3.5.5 Conventional Methods for Algae-based CO_2 Capture

3.6. Specialized Applications

- 3.6.1. Process of Algae-based Carbon dioxide Abatement Coupled with Waste Water Treatment
- 3.6.2 Production of Microalgae Biofuels with Large Volume Co-products

Sample Content: Algae for Power Plant Carbon Capture

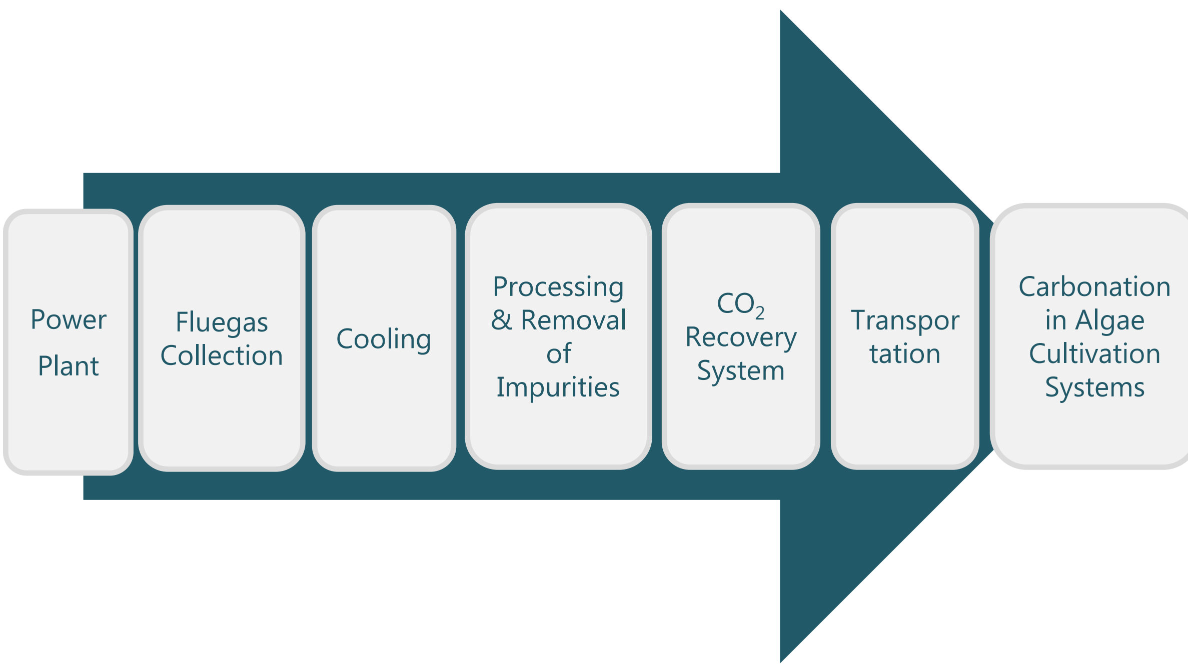
Direct Use of Flue gas with Flue Gas Desulphurization (FGD)

Flue gas can be used directly after pre-treatment, for algae cultivation due its high content of CO_2 and nitrogen. Some species of algae may not be compatible with this method due to the possibility of sulphur toxicity. Hence, it is always preferable to pre-treat the flue gas employing Flue Gas Desulphurization (FGD) method before use. The direct use of flue gas with FGD helps minimize the costs incurred.

The algae-based carbon capture involves the following steps:

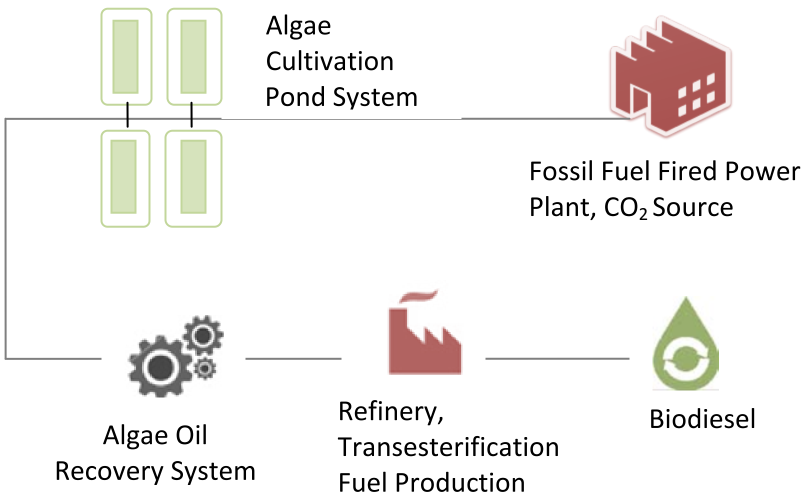
- Fluegas collection from power plants
- Cooling
- Processing & removal of impurities
- CO_2 recovery system
- Transportation
- Carbonation in algae cultivation systems

Algae Power Plant Carbon Capture Value Chain



This chapter provides deep insights into each stage of the value chain.

Flow Diagram for Microalgae Production with Introduction of CO_2 from Fossil Fuel Fired Power Plants



Source: www.oilgae.com

This chapter lists the suitable algal strains for algae-based carbon capture in power plants, while describing the processes involved.

4 Prospects for Companies and Industries to Reduce CO_2 Emissions

Here, the major carbon emission sources and the prospects for companies and industries to reduce carbon emission will be discussed in great detail. This chapter is built on extensive research done on the strains, processes, designs and end product recovery processes that can cater to the specific needs of every industry. Case studies and latest technologies are provided at the end of each section for better understanding of the implementation processes.

Key Sections

Sample Content : Algae-based CO_2 Capture for Prominent CO_2 Emitting Industries

Algae-based carbon capture has been optimized for only few industries. For others, the process is still under development. Industry specific strain selection and optimization is a laborious process and further genetic improvements may be necessary before each industrial sector is matched with the suitable algal strain.

This chapter aims to consider the emission sources of CO_2 and their suitability for capture and techniques employed for subsequent reduction of their emission. In addition, it will look at an alternative algae-based CO_2 capture and at how the future development of this technology might affect the global emission sources of CO_2 and the prospects for a clean technological future.

Sources of CO_2 in Industries

- Coal burning and natural gas power plants
- Cement industry
- Petrochemicals
- Sugar
- Breweries
- Paper and Pulp
- Iron & Steel
- Inorganic Chemicals
- Fertilizers
- Aluminium
- Mining
- Carbon Black & Tyre

Carbon Capture in CO_2 Emitting Industries - On global scale industry accounts for nearly one-third of the energy use and for approximately 10 Gt of CO_2 emissions per year including direct (67%) and indirect (33%) emissions. Iron & steel, cement and (petro) chemicals are the most energy intensive industrial sectors accounting for 30%, 26% and 16%, respectively. Manufacturing process such as ethylene, ammonia and direct reduced iron (DRI) production may offer early and cheap opportunities for industrial CCS demonstration projects as they are large and highly-concentrated sources of CO_2. However, they account for only 3-4% of the total. Blast furnaces and cement kilns also are important sources of CO_2, but they are usually smaller sources and thus imply higher capture costs ($/t$CO_2$).[1]

Sample Content : Case Studies - Cement Industry

[1] *http://www.etsap.org/E-techDS/PDF/E14_%20CCS%20draft%20oct2010_%20GS-gc_OK.pdf*

Case Study 1

Aug, 2010

Siemens, USA, has joined A2BE Carbon Capture LLC's "Algae@Work Alliance Network" to develop and commercialize a cost effective system to recycle industrial CO_2 emissions. A2BE Carbon Capture's photobioreactor system is designed to capture and recycle the CO_2 without releasing it into the atmosphere. Algae inside the PBR absorb the CO_2 and convert it into biomass during photosynthesis. This biomass is then used in the production of fuel, food, fertilizer and other useful products. Siemens along with A2BE has received $175,000 funding from the State of Pennsylvania to establish the nation's first integrated Coal-Biomass-to-Liquids (CBTL) pilot plant using A2BE Carbon Capture's PBRs.

Case Study 2

Mar, 2010

Beckons Industries in Chandigarh, India seems to have developed a modular system for Light Dependent phase of photosynthesis in a low cost PBR with indigenous material and a photosynthesis light independent phase vessel to increase its efficiency. The Company has also developed a medium for mass culture of a selected strain of microalgae. The company has planned for testing its prototype for flue gases sequestration in a coal fired cement plant in the near future. We are not sure about the pros and cons of the technology that this company employs. As of now, BIL seems to have a promising role in capturing CO_2 in India.

Case Study 3

Nov, 2008

GreenFuel Technologies Corporation and Aurantia, SA announced the second phase of their joint project to develop and scale algae farming technologies in the Iberian Peninsula. Initiated in December 2007 at the Holcim cement plant near Jerez, Spain, the project's goal is to demonstrate that industrial CO_2 emissions can be economically recycled to grow algae for use in high-value feeds, foods and fuels.

The project began with a Field Assessment Unit from GreenFuel for the construction, delivery, and initial operation, which has successfully grown a variety of naturally occurring algae strains in the Jerez sunshine using Holcim flue gases. The second phase of the project commenced with the successful inoculation and subsequent harvests of a 100 m^2 prototype vertical thin-film algae-solar bioreactor.

In May 2009, GreenFuel announced that it was closing operations owing to a number of reasons. The details provided above are based on the data obtained during the company's operations prior to its closure announcement.

5 Cost of Algae-based CO_2 Capture

In this chapter, we will discuss elaborately the challenges that the industries are likely to face in algae based carbon capture and the efforts that have been taken to overcome them. A few of them are technical while others are associated with regulations or overall process difficulties.

Key Sections

Sample Content: **Provision of CO_2 in Water**

As compared with other food crops, algae require higher concentrations of CO_2 due to which more concentrated CO_2 must be supplied artificially. The supply of carbon dioxide in accordance with its actual consumption by the microalgae is of great importance. The problems in supplying CO_2 into the photobioreactor include:

- pH and salinity of the algal culture rise due to sodium carbonate accumulation during the supply of CO_2 as carbon source
- Extremely low absorption of CO_2 - The main reason for the extremely low utilization of CO_2 during cultivation of micro-algae in open pond is the short gas-liquid contact time caused by the shallow culture solution. Therefore the CO_2 gas overflows without being absorbed sufficiently.

Efforts

There are essentially three methods of introducing carbon dioxide to the culture system:

- Natural diffusion of the gas into the liquid
- Forced introduction of the gas via sparging or bubbling
- Presaturation of the liquid with carbon dioxide using a low pressure mixing device.

There are a number of operational concerns with each of the above methods; however, they all share one significant hurdle in the tremendous volumes of gas that must be processed and the vast quantity of water required to contain the carbon dioxide at the low solubilities expected. The advantages of one method over the other are connected to the algae culture system selected (sparging and natural diffusion are ideal for open ponds, while bubbling and presaturation are ideal for PBRs).

CO_2 can be bubbled into the ponds via an automated control system whereby the CO_2 added to the medium will maintain dissolved gas levels and pH at a constant level.

Becker (1994) reported that absorption efficiency of the CO_2 was in the range 13-20%, if CO_2 was supplied in bubbles into a layer of algal culture. In a project completed by the Department of Autotrophic Microorganisms, Czech Republic, additional mass transfer area for the CO_2 in the channel was created under overflow of algal culture into channel from upstream growth surface. Unabsorbed CO_2 had been continuously mixed back under the overflow into the layer of culture in channel.

Researchers at Odense University devised a photobioreactor with a minimum maintenance requirement for continuous production of photosynthetic microorganisms. The reactor is without moving parts and equipped with two different spargers operated in dual sparging mode. Sufficient mixing to keep the cells in suspension is obtained by sparging air through two single orifice spargers which deliver large bubbles, and pure CO_2 is supplied through a perforated membrane sparger in a pH controlled environment, which delivers small bubbles that give an efficient mass transfer of CO_2 from gas to liquid phase, which is a fivefold increase relative to conventional sparging. The photoautotrophic microalga *Rhodomonas sp.* has been produced continuously for up to 415 d with a dilution rate of 0.6/d and a steady state cell number of 107 cells/mL. The productivity of Rhodomonas culture in the dual sparging photobioreactor was identical to the productivity of cultures grown with mechanical mixing.

In a project done by researchers at Department of Agricultural and Biosystems Engineering, South Dakota State University, USA, mixing is enhanced by small bubbles with high velocity. This also enhanced the gas transfer.

A research done by M.Olaizola *et al.*, supported by the Department of Energy in U.S. showed that microalgae are able to capture anthropogenic CO_2 from a wide variety of simulated flue gas and from actual coal and propane combustion gases. Microalgae are able to capture anthropogenic CO_2 under a wide variety of pH and gas concentrations.

The efficiency of CO_2 capture by microalgae is directly dependent on the pH of the culture but is not affected by differences in gas composition. The process is scalable to industrially significant scales.

6 Cost of Algae-based CO_2 Capture

This chapter deals with the cost and revenue involved in algae based carbon dioxide capture and summarizes the cost reference briefly. Comparison of the cost of algae based carbon capture with other conventional capture techniques is presented. The breakup of the expenses involved in each step of the process is provided for easier estimation of implementation costs.

Key Sections

Sample Content : Cost of Algae-based Carbon Capture and Production of Biodiesel and By-products

Cost of production has been computed taking in to account the following expenses

- Cost for cultivation
- Cost of nutrients
- Cost of harvesting
- Cost of oil extraction
- Cost of conversion of extracted oil to biodiesel and other by-products.

This section discusses the capital costs and the operation & maintenance costs involved in each stage of the algae-based carbon capture value chain.

The following table presents the levelized costs and total revenues for some of the combinations

Variable	Scenarios
% of CO_2 capture by algae	75% (base case = 100%)
Economies of scale	10%, 25% (base case = No economies of scale included)
Price of final algae biomass extract	$0.2/Kg, $0.3/Kg (base case = $0.1/Kg)
Carbon credits	At 50% realization, $18 per T of algae biomass is realized (base case = no carbon credits included)
Pretreatment	A scenario is considered where no pretreatment is required. This will reduce the total cost by $54 per T of algae biomass. (base case = pretreatment cost considered)

In this section, the levelized costs and revenues are listed based on combinations of several parameters and scenarios discussed above.

7 Companies Involved in Algae-based CO_2 Capture

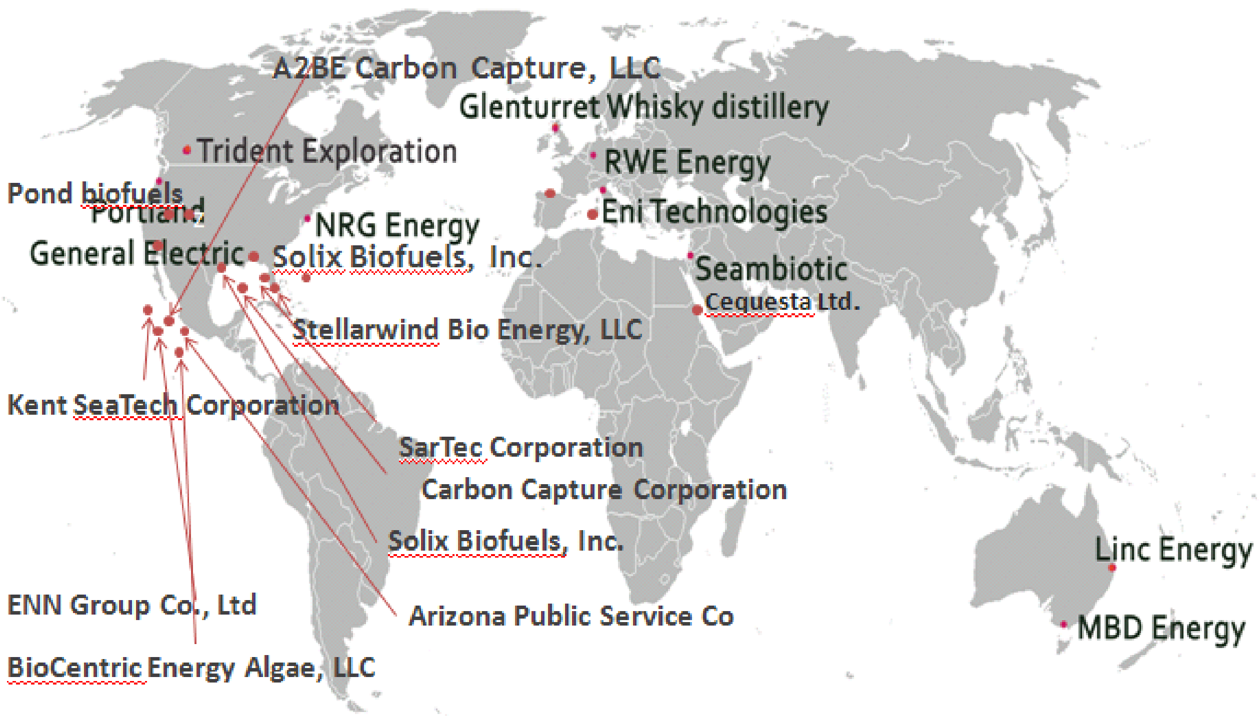
Here, we will focus on the companies which are involved in algae based carbon capture with a brief overview of their profiles. The technology employed by them, business ventures and collaborations, future plans and forecast of commercialization are also presented.

Key Sections

Sample Content: Companies Involved in Algae-based CO_2 Capture

Until a few years back, there was hardly any company working on algae CCS. Of late, the awareness has spread regarding the potential benefits associated with algae CCS and companies are investing considerable money to set up algae CCS system as part of their business. The current chapter deals with companies that have initiated efforts towards algae based CO_2 sequestration.

Global Distribution of Algae CCS Companies



Source: *www.oilgae.com*

Detailed profiles, projects, process and their research are provided for over 10 prominent companies that have ventured into the algae-based carbon capture industry.

Sample Content : MBD Energy, Australia

Main line of activity	Carbon Capture Recycling
Headquartered at	East Melbourne, Australia
Website	www.mbdenergy.com
Background	MBD Energy is a leading solutions provider assisting with adoption of safe, commercially and environmentally sustainable Carbon Capture and Recycling (CCR). MBD Energy is working in concert with the operators of a number of major coal-fired power stations, and other major CO2 emitters, to implement solutions that will enable broad industrial-scale deployment.
Technology employed	MBD employs a technology called "fuel synthesizer" which allows algae to capture half or more of the greenhouse gases emitted by a power station, at virtually no cost to the utility.
Collaboration	(1) MBD Energy has made an agreement with Eraring Energy to build a plant that will use algae processes to capture flue gases - including CO_2 and recycle them with waste water. (2) MDB Energy has made an agreement with Loy Yang Power to investigate and establish a pilot plant at Loy Yang. (3) MBD Energy is collaborating with James Cook University to establish the first algae-to-biodiesel pilot plant using algae photo-reaction technology
Future Plans	MBD Energy is collaborating with James Cook University to establish the first algae-to-biodiesel pilot plant using algae photo-reaction technology adjacent to the Tarong power station. The one hectare proof-of-concept pilot plant has the potential to capture up to 700 tons of carbon dioxide annually and has been supported through a $1 million 2010 Smart Futures fund grant. These initiatives use algae to reduce greenhouse gas emissions, reduce fossil fuel dependence at the same time as delivering sustainable, biodegradable livestock feeds, biodiesel and bioplastics. If the concept is approved in 6 to 12 months, MBD will move ahead to build a commercial pilot plant over 80ha.

Algae-based CO_2 Capture - Companies & Updates (as of December 2010)

Company	Location	Power plant	Type of work	Status
RWE Energy	Germany	Niederaussem power station	Produces 6,000 kg algae biomass using photobioreactors which are currently erected on an area of 600 sq.m.	Pilot Stage
Linc Energy & BioCleanCoal	Australia	Chinchilla	Sequestering carbon dioxide emissions from power stations to be used as fuel or fertiliser, even re-burning it to produce additional energy.	Pilot Stage
Seambiotic	Israel	Israel Electric Company, Ashkelon	Eight shallow algae ponds are filled with the same seawater used to cool the power plants and a small % of power plant flue gas will be channeled to these farms. An unusual strain of algae, skeletonema - a variety believed to be very useful for producing biofuel - was noticed growing in the pools.	Pilot Stage
E-On Hanse	Germany	Hamburg Power Plant	It uses marine microalgae as a natural carbon dioxide sink for the flue gases of a 350-MW coal-fired power station in the Bremen precinct of Farge. The aim is to capture 1% of the total emissions of this power station in a closed reactor system within five years. Two different strains of algae, one strain's biomass is suitable as animal feed and the other one for oil.	Pilot Stage
CEP & PGE	USA	Boardman, Ore Power plant	First phase is to find if algae can feed on the CO_2 from the 600 megawatt Boardman facility. Seattle-based BioAlgene LLC is providing the algae strains for this portion of the project. A full-scale operation is to include 7,500 acres of open air algae ponds.	1st phase of the 3 phases

Sample Content: Case Studies

Case Study 1

Columbia Energy Partners LLC, USA

Oct. 2008

Columbia Energy Partners LLC (CEP) announced that it was planning to convert carbon dioxide from a coal-fired electricity plant into algal oil.

The project would be divided into three phases. Results from the first phase were declared to be available sometime in Dec 2008. At that point, if the results are positive, the company planned to move forward with engineering details and the construction of larger, in-ground algae tanks while continuing to research on the process. A commercial-scale project can be estimated to be ready by 2013.

Some of the challenges that the team would have to deal with are - keeping open-air algae ponds free from contamination and the actual process of squeezing oil from the algae.

Website: http://columbiaenergypartners.com/

Case Study 2

Trident Exploration, Canada

2007

Trident Exploration Corp a natural gas exploration company has teamed up with Menova to find ways to reduce its CO_2 emissions by growing algae in photobioreactors.

Menova's Power-Spar system uses solar concentrators to focus the sun on photovoltaic solar cells, which produce electricity, and fluid-filled channels that capture the sun's heat. The system goes one step further, capturing the sunlight and redirecting it where necessary through fiber-optic cables.

Menova’s photobioreactor - heat and light are concentrated in a relatively more confined area, allowing for the high-density growth of algae without the need for acres and acres of land.

Apart from this, any algae system using Menova's collectors can produce electricity that can be used for their own power needs.

Website:
http://www.tridentexploration.ca/index.html

8 Business Opportunities from Algae-based CO_2 Capture

This chapter involves the algae carbon capture value chain and the entities involved in each segment of the chain. The people and companies who can benefit from the involvement are presented along with a list of available business opportunities, and ways to achieve greater benefits from the process.

Key Sections

Sample Content: Business Opportunities from Algae-based CO_2 Capture

A wide range of companies are involved in the carbon capture sector. The figure below shows the key segments of the sector - services that are needed for the successful completion of algae-based carbon capture projects.

R&D	Feasibility	Design and Planning	Manufacture	Construction and Installation	Operation and Maintenance	End-product Utilization
Training	Consulting	Algae strain selection	**Original equipment:**	Component testing	Training	Harvesting
Environmental Assessment	Market research	Engineering	Equipments for flue gas cooling	Skilled labor	Reliability management	Extraction and refining
Technical research	Financial analysis	Machining	Condensers	Logistics	Repair and maintenance	Logistics
Investment analysis	Customized research based on CO_2 emitter industry	Automation	Equipments for flue gas processing - Desulfarizers, precipitators, Scrubbers, Absorbers, Dryers, Sorbent injection systems		Process control and optimization	Biodiesel
Risk assessment	Retrofitting possibilities	Geo-technical services	**Components**		Environmental monitoring	Biomass utilization
	Project planning	Process design	Electrical components - Generators, cables		Software tools	
	Risk assessment	Norms conformation	Components for transportations- Pipes, Valves, Pumps			
	Concept Selection		Storage components - Tanks			
	Legal assessment		Components for carbonation- Pumps, Membranes			
	Socio-economic assessment					

This section elaborates the business opportunities available in each sector in the value chain described above.

9 Status of Current CO_2 Capture and Storage (CCS) Technologies

This section of the report will focus on the current trends in CCS and other emerging concepts and processes for carbon capture and sequestration.

Key Sections

Sample Content: Problems Faced in Current Methods Used for CO_2 Sequestration

Challenges in Geological Sequestration

There is a significant difference between sequestration of CO_2 in the gas phase and as a supercritical fluid and both are known to present significant challenges. At low gas pressures of gas phase CO_2, the capacity of all geologic storage is estimated to be only decades of fossil fuel use. Moreover, the gas phase CO_2 will remain in the gas phase and ready for release in case of unexpected accidental penetration occurs.

Unfortunately, supercritical CO_2 is far more problematic for storage than gas-phase CO_2. Supercritical CO_2 is an extreme solvent and attacks concrete, which is the material of choice for capping wells: And, while the time-scales for dissolution of the concrete seals may be decades, the supercritical CO_2 will be present for time scales of centuries since geochemical reactions that form carbonates are very slow. As a result, the possibility of leakage through capped wells is potentially high. Aquifer poisoning is another significant concern. Supercritical CO_2 is mobile, and should an underground fissure lead to migration of the CO_2 from its proposed storage formation to a potable aquifer, the potential exists for formation of significant quantities of carbonic acid in potable water sources. As much as we must make deep geological sequestration work, the potential problems, liabilities, and costs are not minor and it is clear that other alternatives must be pursued to mitigate risk.

10 Appendix

This chapter lists the frequently asked questions about algae-based carbon capture and storage techniques that have been discussed so far.

Key Sections

Sample Content: **Algae-based Carbon Capture – Q&A**

Q: Can *algae withstand the high temperatures in the flue gases?*

A: In a commercial application, flue gas from the desulphurization scrubbers would be sent to the CO_2 sequestration ponds for treatment. Exiting temperatures in the scrubbers at many coal power stations are typically 140°F (60°C) and above – this could even reach as high as 100^{o}C. Although most organisms cannot survive at these higher temperatures, some cyanophycean algae have been shown to grow at 176°F (80°C).

Since the temperature of waste gas from thermal power stations is high, the use of thermophilic, or high temperature tolerant species are also being considered (Bayless *et al.*, 2001). Thermophiles can grow in temperature ranging from 42-100^{o}C. An obvious advantage of the use of thermophiles for CO_2 capture is reduced cooling costs. In addition, some thermophiles produce unique secondary metabolites (Edwards, 1990), which may reduce overall costs for CO_2 storage. A disadvantage is the increased loss of water due to evaporation. *Cyanidium caldarium*, which can grow under pure $CO_{2,}$ is a thermophilic species (Seckbach *et al.*, 1971). Miyairi (1995) examined the growth characteristics of *Synechococcus elongatus* under high CO_2 concentrations. The upper limit of CO_2 concentration and growth temperature for the species was 60% CO_2 and 60ºC (Miyairi, 1995). Currently, an unidentified thermophilic species isolated from Yellowstone National Park has been examined by a group of researchers supported by the U.S. Department of Energy. Although less tolerant than thermophiles, some mesophiles can still be productive under relatively high temperature (Edwards, 1990). Such species also can be candidate species for the direct use of flue injection.

Q&A

Specific questions to which answers are provided in the report:

- How are algae different from other energy crops?
- How does algae productivity compare to other energy crops?
- Which of the two methods – open ponds or photobioreactors – has higher productivity for microalgae growth?
- How much CO_2 can algae consume?
- What is amount of CO_2 required for algae growth?
- Can algae withstand the high temperatures in the flue gases?
- Can we grow macroalgae for power plant CO_2 sequestration?
- Is there a possibility of heavy metal contamination in algae due to their presence in the flue gas?
- How do the constituents other than CO_2 in flue gas from power plants affect algal growth?
- Will NO_x present in the flue gas serve as a nutrient, in addition to the CO_2?
- What are the methods by which flue gas can be cooled before passing it into algae systems?
- Is it necessary that algae ponds need to be constructed right next to power plants?
- What is the average area required for the construction of algae ponds for each power plant?
- What are the major problems faced by companies implementing algae based CO_2 sequestration techniques near power plants?
- What is the approximate cost of cultivating algae next to power plants for CO_2 capture and biofuel production?
- Can power plants use waste water from their facilities for growing algae?
- Is flue gas CO_2 capture using algae net CO_2 sequestration positive?
- Transfer of flue gases from power plant to PBR
- CO_2 emission equivalent for algae cultivation in a PBR (by way of power requirements)
- Which is the best way to use the algae cultivated using flue gas?
- How large must an algae farm be to mitigate emissions from a typical power plant?

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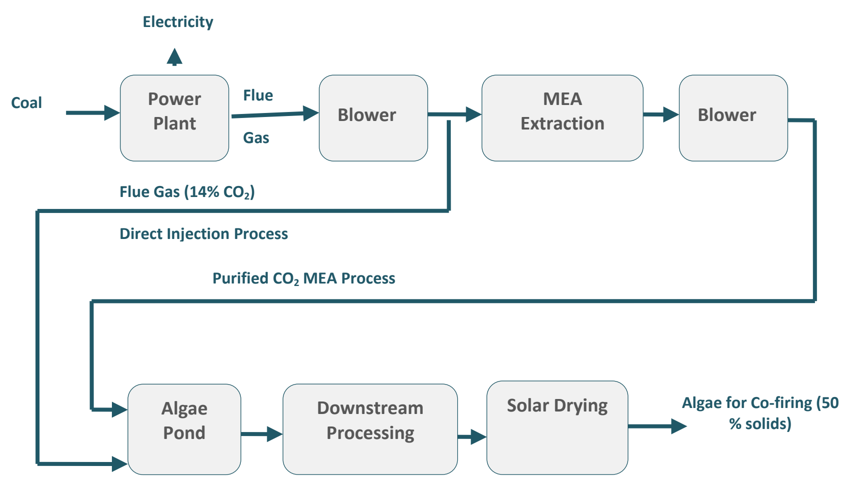
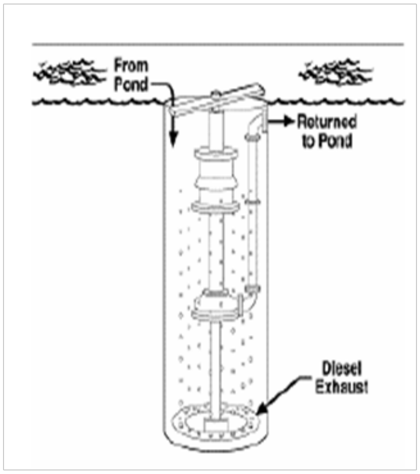
Monoethanolamine (MEA) extraction of CO_2 from flue gas



Note: Monoethanolamine (MEA) extraction is a commonly used method for the extraction of CO_2 from flue gas
Source: http://www.bmu.de/files/english/pdf/application/pdf/reccs_ii_en.pdf

In-ground Carbonation Pit



Source: http://www.nrel.gov/

Prospects for Companies and Industries to Reduce CO_2 Emissions

Companies Involved in Algae-based CO_2 Capture

Business Opportunities from Algae-based CO_2 Capture

Status of Current CO_2 Capture and Storage (CCS) Technologies

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Projected Global Energy Demand and CO_2 Emissions, 2000 To 2020

Energy source and use	Demand (EJ/year)			Emissions(GtC/Year)		
	2000	2010	2020	2000	2010	2020
Oil – electricity[a]	14	15	18	0.27	0.31	0.35
Oil – transport[b]	69	97	119	1.60	2.16	2.65
Oil – other[c]	64	71	75	1.25	1.38	1.47
Total oil[d]	147	182	212	3.12	3.85	4.47
Coal – electricity[a]	65	85	106	1.68	2.19	2.73
Coal – other[e]	27	22	17	0.70	0.57	0.43
Total coal[d]	92	107	123	2.38	2.76	3.16
Natural gas – electricity[a]	29	43	62	0.44	0.66	0.95
Natural gas – other[f]	55	71	91	0.84	1.09	1.39
Total natural gas[g]	84	114	153	1.29	1.74	2.34
Total fossil fuels	323	403	488	6.79	8.35	9.97
Fossil Electricity	108	143	186	2.39	3.16	4.03
Non fossil electricity[a]	38	43	45			
SRES scenario AIT[h]				6.90	8.33	10.00
Total energy demand	361	446	533			

Source: Mark E. Huntley (University of Hawaii) and Donald G. Redalje (University of Southern Mississippi)

Sample Table: *Assessment of CO_2 Capture Technologies for Cement Industries*

Capture Technology	Availability on Scale			Applicability in the cement industry	Reduction of
	Research	Demo	Industrial		
Pre-Combustion					
Reforming/ Gasification	X	X	X	Yes (new kilns)	Only fuel CO_2
Oxyfuel	X		(X)	Yes (new kilns)	Fuel & process CO_2
Post-Combustion					
Absorption	X	X	X	Yes (process re-design)	Fuel & process CO_2
Membranes	X		(X)	?	Fuel & process CO_2
Solid sorption process	X		(X)	?	Fuel & process CO_2
Hybrid Systems					
▪ Solar Cement plant	X			"Yes but" (new kilns)	Only fuel CO_2
▪ Carbonate looping (cement / power plant)	X			Yes (one-field application)	Fuel & Process CO_2

Source:
http://gcep.stanford.edu/pdfs/2RK4ZjKBF2f71uM4uriP9g/Volker_Hoenig_Stanford_2008_upload.pdf

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Other Energy Products – Syngas, Other Hydrocarbon Fuels, Energy from

Non-Fuel Applications of Algae

Apex Bodies, Organizations, Universities & Experts

Future Trends

Price of the Comprehensive Guide for Algae-based Carbon Capture

The price of the comprehensive guide for algae-based carbon capture report is US $200.

Purchasing Using Credit Card
The report can be purchased using credit card. Use the following link for the same:
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