Updated

January 2013

Comprehensive Oilgae Report

Energy from Algae: Products, Market, Processes & Strategies

A Preview

oilgae

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The Comprehensive Oilgae Report is a detailed report on all aspects of algae biofuels. This preview provides inputs on focus areas of the report, the complete list of contents, and sample data from each chapter of the report.

The report was prepared by Oilgae, the world's leading business intelligence resource on algae fuels.

The Comprehensive Oilgae Report was last updated in the first week of **January 2013**, and has **775 pages**.

Summary of the updated Comprehensive Oilgae Report

Last updated: January 2013
Total no of pages: 775
Total number of chapters: 27
Number of companies covered: 110
Number of university and academic research efforts covered: 50
Number of tables: 110
Number of charts and figures: 50

Critical and Comprehensive Updates Provided on the Following:

- ***Company profiles*** – There are over a hundred companies worldwide making significant efforts in algae-to-fuels. Profiles and the latest updates for each of these companies are provided.
- ***CO_2 capture using algae*** – The Oilgae team had done more rigorous calculations and estimates for an effective robust algae-based-CO_2 capture model. Details of these latest evaluations are provided in this version.
- ***Costs for making different fuel products from algae*** – Updated data are provided for cost calculations and break-ups of the cost across various stages and components.
- ***Strain selection*** – The last few months have witnessed a number of companies beginning to make efforts in genetically engineering algae strains for fuel production. The latest version of the report includes details of these efforts in the Strain Selection chapter.
- ***Diverse applications and end uses for the algae meal / cake*** – The Oilgae team had done specific research in the current and emerging uses of the algae extract left over after the extraction of oil (for biodiesel) and starch (for ethanol). Insights gathered from this research effort are included in the latest version of the report.
- ***Algae grown in marine environment and saltwater*** – It is increasingly becoming clear that seawater will be the most scalable and economic medium for algae cultivation for fuel. Additional research data and analyses are included in this version of the report that will enable a better understanding of the factors involved in, and viability of using marine water as the medium for algae growth.

List of Contents

An Invaluable Guide to the Algae Fuel Industry

By providing a comprehensive collection of insights and data on all the critical aspects of algae fuels, the Comprehensive Oilgae Report is an invaluable asset that can save many years of your team's research efforts in this area.

Algae fuels present an exciting opportunity. There is a strong view among industry professionals that algae represent the most optimal feedstock for biofuel production in the long run. *It is also widely accepted that algae alone – and no other bio-feedstock - have the ability to replace the entire global fossil fuel requirements.* Such a significant opportunity has resulted in companies both large and small investing in algal energy.

Algae present multiple possibilities for fuel end-products – biodiesel, ethanol, methane, jet fuel, biocrude and more – via a wide range of process routes. Each of these process routes presents its own set of opportunities, parameters, dynamics and challenges.

Efforts into algae fuel research have accelerated in the past few years. As of December 2012, over hundred companies and about two hundred universities have begun serious exploratory efforts into algae fuels.

All these efforts will benefit enormously if a comprehensive resource is available that brings them up-to-date on the various critical aspects of the industry, status of past and on-going efforts, and critical data for assessing the technical and economic feasibility of algae fuels. Such a comprehensive resource has the potential to save many months of research and analysis.

The Comprehensive Oilgae Report was developed to satisfy this clear need.

The Comprehensive Oilgae Report is the most detailed report dealing with all aspects of the algae fuel industry. The report is divided into four main sections:

- Concepts and Cultivation
- Diverse Energy Products from Algae
- Processes & Challenges
- Industry & Market Information

Each section provides in-depth information, details and updates on the most critical aspects relevant to it.

The objective of the Comprehensive Oilgae Report is **to facilitate tangible steps for an algae fuel venture**. The emphasis hence is on providing practical data, updates and insights.

In addition, the report **has made special efforts in identifying the core challenges faced in each aspect of the algae fuels value chain.** It also provides inputs on the current efforts and possible solutions to overcome these challenges.

The report has been developed with over two years of in-depth research, and has been developed with inputs from biofuel industry experts, biotechnology researchers, and professionals who have been constantly interacting with the algae fuels industry for over four years.

The Comprehensive Oilgae Report will be an invaluable guide to those keen on venturing into one of the most exciting renewable energy domains.

Special Focus

This report has a special focus on certain unique areas in algae energy which are known to have huge commercial benefits. Owing to their in-depth understanding of the algae fuels industry with its various aspects and dimensions, the team of researchers of Oilgae continuously make important research efforts into emerging topics in algae fuels, and how businesses around the world can benefit from these topics.

Some of the topics that are of emerging interest in the context of algae fuels are provided below:

Macro Vs Micro Algae

- Microalgae have high oil content but are difficult to cultivate and harvest in a cost-efficient manner.
- Macroalgae, on the other hand, present low-cost cultivation and harvesting possibilities, but most species have low lipid as well as carbohydrate contents.
- With processes such as cellulosic fermentation (for deriving ethanol), gasification (for deriving biodiesel, ethanol and a wide range of hydrocarbons), or anaerobic digestion (for methane or electricity generation), it is possible today to use macroalgae as the feedstock for biofuels.
- Thus, both micro and macroalgae are potential feedstock for biofuels.

Which of the two feedstocks should be used? Which of the processes is most economical? The report provides insights on these critical aspects of algae biofuels.

Waste Water Treatment

- Hundreds of billions of dollars are spent worldwide on wastewater treatment.
- The present wastewater and sewage treatment methods can be significantly improved both in terms of costs and in terms of efficiency by the use of bioremediation agents such as algae.
- Algae, quite well-known as bioremediation agents, are especially good at removing nutrients and toxins from waste and sewage water.
- Can this fact be used by tens of thousands of companies around the world to choose-effectively treat wastewater while at the same time produce biofuels?

The report discusses this possibility at length and provides case studies, insights and references for this important topic.

Power Plant CO_2 Capture

- Capture and sequestration of CO_2 is one of the most critical challenges today for businesses and governments worldwide.
- Thousands of CO_2 emitting power plants and industries worldwide face this costly challenge - reduce your CO_2 emissions or pay penalties.
- One ton algae require, for their growth, 1.8 tons of CO_2; algae thus are large absorbers of CO_2. Combine their affinity for CO_2 with the fact that algae can grow practically anywhere, and we are presented with an exciting opportunity - What if these CO_2 emitting industries and power plants could use algae to absorb the CO_2 and generate biofuels in return?
- This is precisely what companies and power plants around the world are beginning to explore.

The report provides details on the concept, suitable algae strains and a number of case studies of companies already exploring algae as a medium for capturing CO2 and producing biofuels.

Other Emerging Products from Algae

- For decades, algae have been used to make a variety of products - from nutraceuticals, to pigments to organic fertilizers.
- Today, companies are able to produce many more products from algae. Some of these applications of algae (for example some high-end specialty chemicals) could fetch very high margins for the company that produces the algae biomass.
- Is it then possible for algae fuel companies to synergistically produce both fuels and non-fuel products thereby increasing their profits and prospects?

This report provides inputs on the range of non-fuel products that can be produced from algae and other emerging applications and end-uses.

Variety of Fuels and Processes

- While biodiesel is the most obvious fuel that can be considered from algae (owing to the large oil content of microalgae), it is but one of the products that are possible.
- Others include ethanol, methane, hydrogen, biogasoline and the algal biomass itself which can be used as a feedstock of combustion.

- A variety of processes exist for producing these fuels starting with algal biomass. Some of these processes are suitable for oil-rich microalgae, some for starch-rich macroalgae, some for lignocellulosic algae and some others for left-over algae extracts.

What are the processes and pathways for each of these feedstocks and for the different end-products? What are the costs and benefits of each of these products and processes? The report explains these critical aspects at length.

Latest Efforts in Cost-effective Photobioreactors

- Growing microalgae in photobioreactors results in high algae productivity, and consequently results in higher oil yields for the same area.
- However, photobioreactors are much more expensive than open ponds.
- Realizing the importance of lower cost photobioreactors, a number of companies and research teams have started working on a variety of innovative designs and concepts.

What are the statuses of these current efforts in photobioreactor designs that can lead to lower-cost and high-productivity photobioreactors? Which are the companies that are leading the efforts in this domain? What are the likely future trends in photobioreactors? The report provides inputs and details for these questions.

Chapter wise List of Contents and Sample Data

Section I: Concepts and Cultivation

CHAPTER 1

Energy from Algae Introduction

While interest in algae fuels has accelerated significantly in the recent past, contrary to popular belief, research into algae as a biofuel feedstock is not new – it is over three decades old! Similarly, biodiesel is not the only fuel that can be derived from algae. This chapter provides an overview of algae, the history and current status of algae-based fuels, and inputs on the range of fuel products that can be derived from algae.

SAMPLE TOPIC

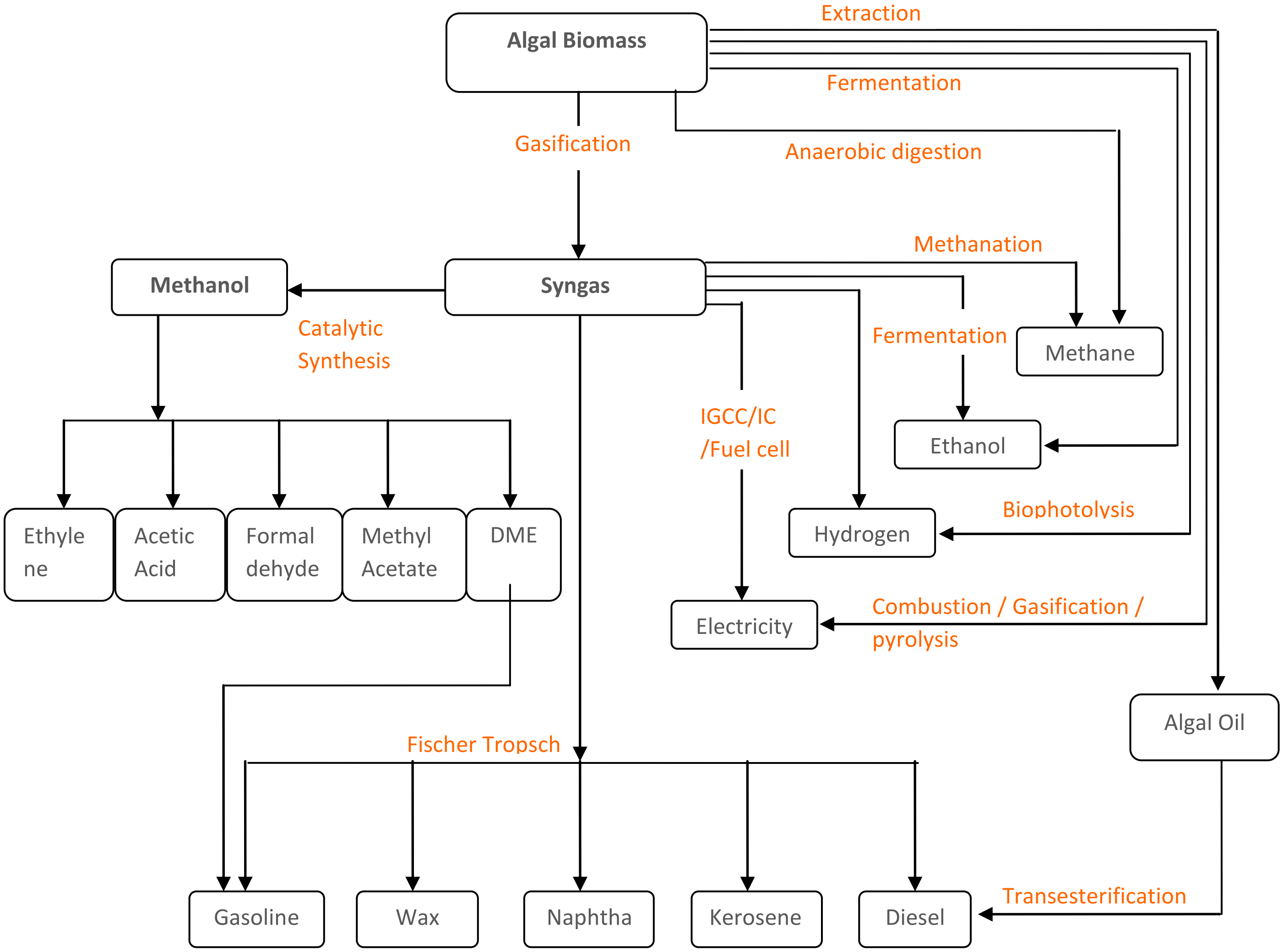
Energy "Products" from Algae

Algae to Energy – Summary of Processes for Each Energy Product

Final Product	Processes
Biodiesel	Oil extraction and transesterification
Ethanol	Fermentation
Methane	Anaerobic digestion of biomass; methanation of syngas produced from biomass
Hydrogen	Triggering biochemical processes in algae; Gasification / pyrolysis of biomass and processing of resulting syngas.
Heat & Electricity	Direct combustion of algal biomass; gasification of biomass
Other Hydrocarbon Fuels	Gasification/pyrolysis of biomass and processing of resulting syngas

Detailed descriptions on above processes, key advantages, companies, challenges & efforts, research and case studies have been provided for each of the above products

Paths to the Various Energy Products from Algae



Detailed description of each and every process is provided in various chapters.

CHAPTER 2

Algal Strain Selection

Selection of the optimal algal strain is a key component of a successful algal biofuel venture. With tens of thousands of possible strains to choose from, this is however easier said than done. A number of parameters need to be kept in mind while evaluating algal strains for their suitability as biofuel feedstock. This chapter provides comprehensive details on the parameters to be used for strain selection and also the list of strains that are high in oil (for biodiesel) and in starch (for ethanol).

SAMPLE TOPIC

Strains with High Oil Content & Suitable for Mass Production

Botryococcus braunii

A green alga, Botryococcus comes up repeatedly in nearly every forum, initiative and general information website about the potential to create biodiesel from algae. This strain specifically can produce hydrocarbons which represent 86% of its dry weight

- Ambient temperature of 23 degrees Celsius (73.4 degrees F)
- A light intensity of 30-60 W/m^2
- A photoperiod of 12 hours light and 12 hours dark
- Salinity of 8.8% (brackish waters)

With these conditions satisfied, strain cells doubled approximately every two days.
Oil content range: 25-75%

We have provided similar data for over 15 most optimal strains. We have also provided optimal algal strains for different cultivation conditions such as fresh water, salt water, sewage-based & desert-based cultivation.

Genetic Engineering Efforts of Algae Fuel Companies and Research Institutes

Exxon Mobil and Synthetic Genomics

Main line of activity: Synthetic Genomics Inc. (SGI) is a privately held company applying genomic-driven commercial solutions to address a variety of global challenges including energy and the environment, in agreement with ExxonMobil Research and Engineering Company (EMRE) aims to develop next generation biofuels using photosynthetic algae.

Genetic engineering efforts on Algae: Researchers at Synthetic Genomics are designing a synthetic gene that contains only the specifically desired DNA. They eventually created a strain of algae with desired traits that could specifically produce high amounts of oil. Also they have inbuilt suicide genes to kill the algae if they escaped from lab or fuel production facility.

Updates: In July 2010, Exxon Mobil Corporation and Synthetic Genomics Inc. (SGI) together had announced the opening of a greenhouse facility to enable them in their next level of research. The new facility, opened at SGI headquarters in La Jolla, CA are mainly aimed at testing their research in real life conditions to further analyze whether large-scale quantities of affordable fuel can be produced from algae.

In September 2012, Synthetic Genomics Inc. purchased a patent portfolio from Febit Holding GmbH which includes methods for highly parallelized, low-cost oligonucleotide synthesis and retrieval of sequence-validated DNA. Together, these technologies have the potential to drastically reduce the cost of DNA synthesis, which inturn is expected to accelerate the company's ongoing development and commercialization of a variety of products including algae based biofuels.

CHAPTER 3

Algae Cultivation

Cost-effective algal cultivation is a key requisite for success algal biofuel production. However, such cultivation of the right strain of algae, especially microalgae, in the right environment and media is a key challenge facing algae fuel companies. This chapter provides in-depth details on the various forms of algaculture and key success factors for the same. The chapter has a special focus on the critical challenges in algaculture for biofuels and the latest efforts and proposed solutions to overcome these challenges.

SAMPLE TOPIC

Best Method to Grow Algae – Ponds or Photobioreactors?

Which is the best way to grow algae - Ponds or Photobioreactors?

The NREL (National Renewable Energy Laboratory, USA) favored unlined "raceway" ponds which were stirred using a paddle wheel, and had carbon dioxide bubbled through it. The water used for these ponds is wastewater (treated sewerage) freshwater, brackish water, or salt water, depending on the strain of algae grown. The algae should be a native to the region. Other countries, notably Japan, are interested in closed systems; however these systems (at least from NREL perspective) are very expensive.

Inputs are provided on the various distinctions between ponds and photobioreactors, list of companies that are using either of these & a list of worldwide locations of algae farms / photobioreactors.

Culture Methods Followed for Different Algal Species

Botryococcus braunii

Medium: Chu 13 medium (for hydrocarbon production BG11 medium)

Procedure:

- Modified Chu 13 medium is cultured.
- Purification is done by serial dilution followed by plating.
- The individual colonies are isolated and inoculated into liquid medium (modified Chu 13 medium)
- It can be incubated at $25 \pm 1^{o}C$ under 1.2 ± 0.2 Klux light intensity with 16:8 hrs light photoperiod.
- The purity of the culture is ensured by repeated plating and by regular observation under microscope.

Culture environment: *B. braunii* grows best at a temperature of 23°C, a light intensity of 60 W/M², with a light period of 12 hours per day, and a salinity of 0.15 Molar NaCl.

Challenges and efforts: *B. braunii* is found to be able to co-exist with a wild green alga, Chlorella sp.; the presence of either alga did not negatively affect growth of the other. They form colonies/flocs which are difficult to break down. It grows very slowly: it's doubling time is 72 hours (Sheehan *et al.*, 1998), and two days under laboratory conditions (Qin, 2005).

We have provided similar data for over 10 most optimal strains. We have also provided various cultivation methods of algae in laboratory and commercial scale.

CHAPTER 4
Photobioreactors

Photobioreactors (PBR) enhance the technical feasibility of producing fuels from algae by providing an optimal controlled environment that result in higher algal productivity while preventing contamination by hostile species. At the same time, PBRs are much more expensive than open ponds, thus currently hindering the economic feasibility of biofuel production. How is the industry responding to the opportunities and challenges presented by the PBRs? This chapter provides insights and inputs that will enable a useful analysis of these questions.

SAMPLE TOPIC

Costs

For successful outdoor mass algae cultivation, photobioreactors should possess the following characteristics / properties:

- High surface-to-volume ratio
- High mass transfer rate
- High surface illumination

High Cost of Photobioreactors

Photobioreactors represent perhaps the highest cost item in algae cultivation. Photobioreactors are expensive owing to their sophistication. As of February 2011, photobioreactor costs range between \$70-150/m^2 though there some up and coming companies that claim to provide these at much lower capital costs.

This chapter talks in detail about photobioreactor, its types, parts and components, designs etc. Some sample data based on publicly available prices and costs for photobioreactors from commercial companies are also provided.

Q&A

Data, answers and insights are provided for the following questions

- What is the comparative production capacity of PBR & pond alternative, for similar area used?
- How often should the PBR be cleaned?
- What are the major parts of a PBR, and what are the parts that make it costly?
- What are closed loop photobioreactors?
- For what algae-based products are photobioreactors predominantly used?
- For what kinds of products is the use of photobioreactor economical?
- When is the use of photobioreactors mandatory for algae cultivation?
- How costly are photobioreactors when compared to open ponds?
- What are the primary cost components in photobioreactor systems?
- Is it possible to eliminate photobioreactor components without affecting the algae growth process?
- Why is it essential to pump air and CO_2 together into the photobioreactor?

CHAPTER 5

Harvesting

Harvesting, especially for microalgae, represents an important cost component, owing to the difficulties involved in the processes. It is hence important for those exploring the algae fuels industry to gain a clear understanding of the various harvesting options available, the challenges in each of the options, and the current efforts and solutions being attempted to overcome these challenges. This chapter provides inputs on all these, as well as relevant case studies that provide the reader insights on the worldwide real-life harvesting practices.

SAMPLE TOPIC

Methods of Harvesting

Harvesting Microalgae

The ease in harvesting the algae depends primarily on the organism's size, which determines how easily the species can be settled and filtered. The most rapidly growing algal species are the microalgae, very small, and often motile unicells, and these are the most difficult to harvest. Thus, it is necessary to maintain an effective interaction between the development of harvesting technologies and the selection of algal species for mass culture.

The main harvesting methods for microalgae are:

- Settling & Sedimentation
- Filtration & Related - Mechanical harvesting using filtration, by means of strong membranes, such as microscreens, and using microstrainers.
- Chemical Methods - Chemical and/or biological harvesting by means of flocculants
- Centrifugation - Algae can also be harvested using centrifugation

- Flotation - Froth flotation is a method whereby the water and algae are aerated into froth, with the algae then removed from the water.

Detailed inputs are provided for each of the above methods, with examples of companies using each and challenges faced in harvesting process. Other related methods such as polymer harvesting, ultrasound-based & vibrating separation are also discussed.

Section II: Energy Products from Algae

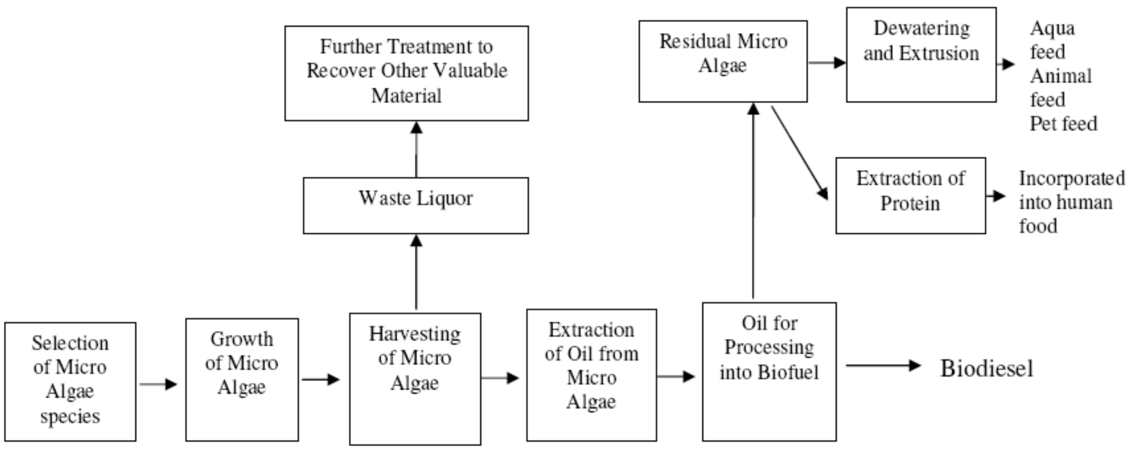
CHAPTER 6
Biodiesel from Algae

Producing biodiesel from algae provides the highest net energy because converting oil into biodiesel is much less energy-intensive than methods for conversion to other fuels (such as ethanol, methane etc). This characteristic has made biodiesel the favourite end-product from algae. Producing biodiesel from algae requires selecting high-oil content strains, and devising cost effective methods of harvesting, oil extraction and conversion of oil to biodiesel. This chapter provides comprehensive details on the methods for and latest trends in oil extraction and conversion to biodiesel.

SAMPLE TOPIC

Biodiesel from Algae

A Detailed Process of Biodiesel from Algae



This section elaborates on the advantages of algae fuels, problems and bottlenecks in each step of the algae to energy processes, case studies & research. Similar process details are given for the production of hydrogen, methane, ethanol and syngas from algae.

Increasing the Oil Yields from Algae

A Summary of Comparison of Oil and Biodiesel Yield from Main Energy Crops

Oil Source	Biomass (Mt/ha/yr)
Soy	1-2.5
Rapeseed	3
Palm Oil	19
Jatropha	7.5-10
Microalgae	14-255

Note: Mt – metric tons, ha – hectare

Yields from algae are much higher than those from other oil crops and there is a huge potential to increase this high yield even further. This chapter will discuss these important aspects and explains to what extent yields have been achieved in real-life.

Challenges in Extraction of Oil from Algae

Determining the most efficient and cost effective extraction method

The challenge here is that higher the efficiency of the extraction method, the higher is its cost. Please refer to the details provided under the "Algae Oil Extraction – Trends & Developments" for inputs on various ongoing efforts to overcome these challenges.

Reducing the energy requirements for extraction

Algae oil extraction is quite energy intensive and this is an important challenge to be recognized and addressed.

- Efforts

OriginOil's invention of a method to extract the oil from algae with high energy efficiency that builds on the company's first patent, Quantum Fracturing™, in which ultrasound from intense fluid fracturing breaks down algae cells and reduces the overall energy required for extraction.

Detailed inputs are provided for challenges in each and every step in biodiesel production, and efforts made to overcome them. Similar content are given for all the energy products that can be derived from algae.

CHAPTER 7

Hydrogen from Algae

Hydrogen is technically not a source of energy, but is a carrier of energy. Hydrogen is expected to play a major role in the future of renewable and clean energy, primarily with its potential for application in fuel cells. Hydrogen production from algae is in the research stages, but holds significant potential for the future. This chapter provides details on the scientific foundation for hydrogen production from algae and the latest research efforts worldwide.

SAMPLE TOPIC

Methodologies for Producing Hydrogen from Algae

Biochemical Processes - Under specific conditions, algae produce hydrogen, via biological and photobiological processes. Under these conditions, enzymes in the cell act as catalysts to split the water molecules. More details on this are provided in later sections of this chapter.

Gasification – Gasifying biomass gives syngas, a mixture of CO and H2. A number of methods are being researched to separate the H2 from syngas.

Through Steam Reformation of Methane – Fermentation of algal biomass produces methane. The traditional steam reformation (SMR) techniques can be used to derive hydrogen from methane.

Detailed inputs & recent research updates are provided for each of the above methods. In addition, details of hydrogen production using traditional methods are also given. This chapter focuses on efforts to use algae to produce hydrogen.

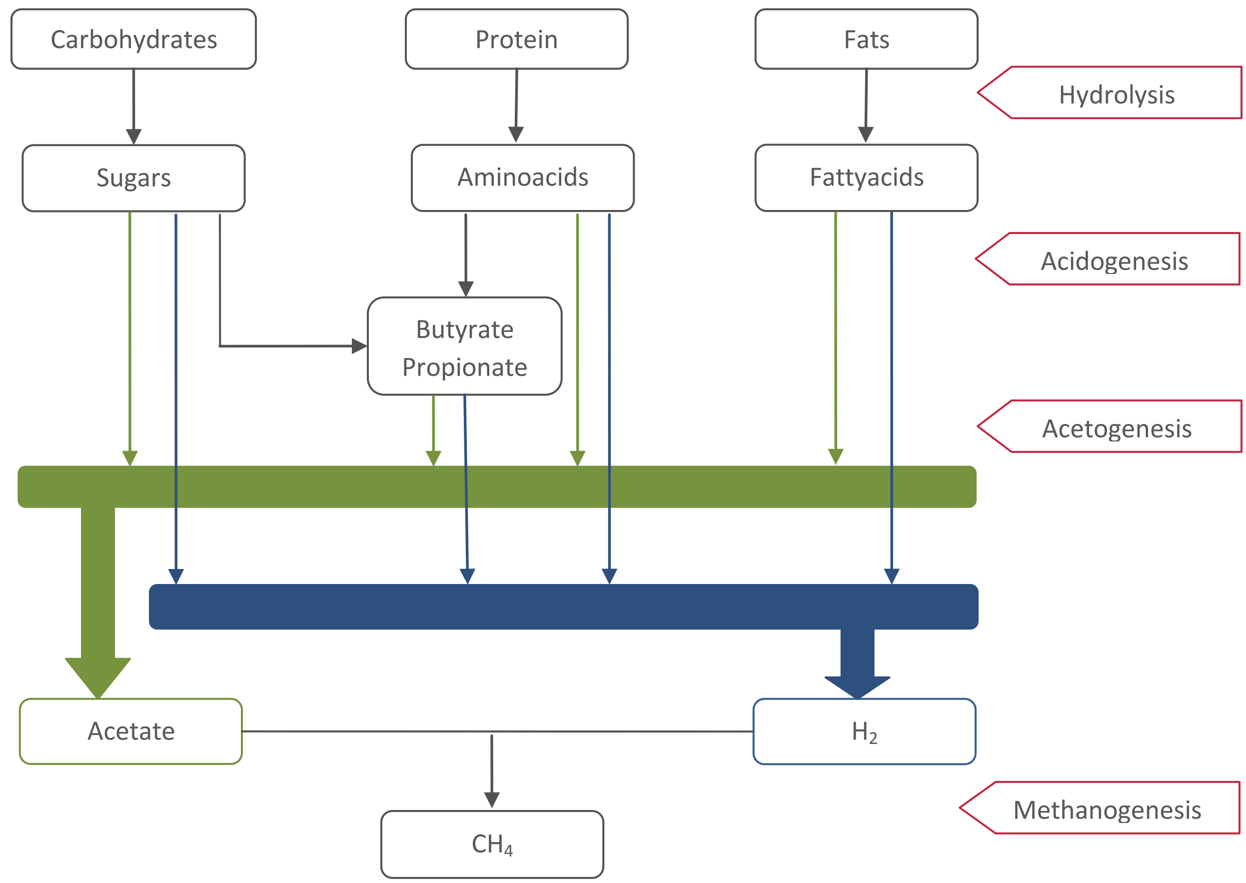
CHAPTER 8

Methane from Algae

Methane production from algae could be a viable route especially where the feedstock is algae cake (the biomass left-over after oil is extracted from algae). The possibility of methane being easily integrated with the current uses of natural gas enhances its attractiveness as a fuel. For this reason, there are a number of research and pilot efforts worldwide exploring methane production from algae. This chapter provides details on the latest efforts in this direction.

SAMPLE TOPIC

Methods of Producing Methane from Algae



In this chapter, methods of producing methane through anaerobic digestion and pyrolysis are explained in detail. In addition, references are provided for current and on-going research efforts for producing methane using algal biomass.

CHAPTER 9

Ethanol from Algae

While the initial efforts to produce biofuels from algae focused on biodiesel as the end product, many of the later efforts also have started exploring the production of ethanol from algae. The significant investments made into ethanol production and the consequent technological innovations could make ethanol production from starch and cellulose-rich algae a viable alternative. This chapter provides detailed inputs on the various processes and routes for ethanol production from algae, and case studies and updates on the latest ventures in this domain.

SAMPLE TOPIC

Efforts & Examples for Ethanol from Algae

Ethanol from Macroalgae

An exploration for producing ethanol from macroalgae (seaweed) in Vietnam

In this project, using macroalgae (Seaweed) for ethanol production was widely investigated. During this research, it was found that important and high quantity seaweeds, economically important and high quantity seaweeds, in Vietnam are:

Sargassum : Carbohydrate content ~ 48% of dry wt.
Glacilaria : Carbohydrate content ~ 45% of dry wt.
Kappaphycus : Carbohydrate ~ 35% of dry wt.
Eucheuma : Carbohydrate ~ 45% of dry wt.

The project concluded that there was a good potential for producing ethanol from seaweeds in Vietnam.

Detailed inputs are provided for fermentation of algal biomass and algae cake for ethanol production. Updates are provided on all the latest efforts in producing ethanol from micro - as well as macroalgae.

CHAPTER 10

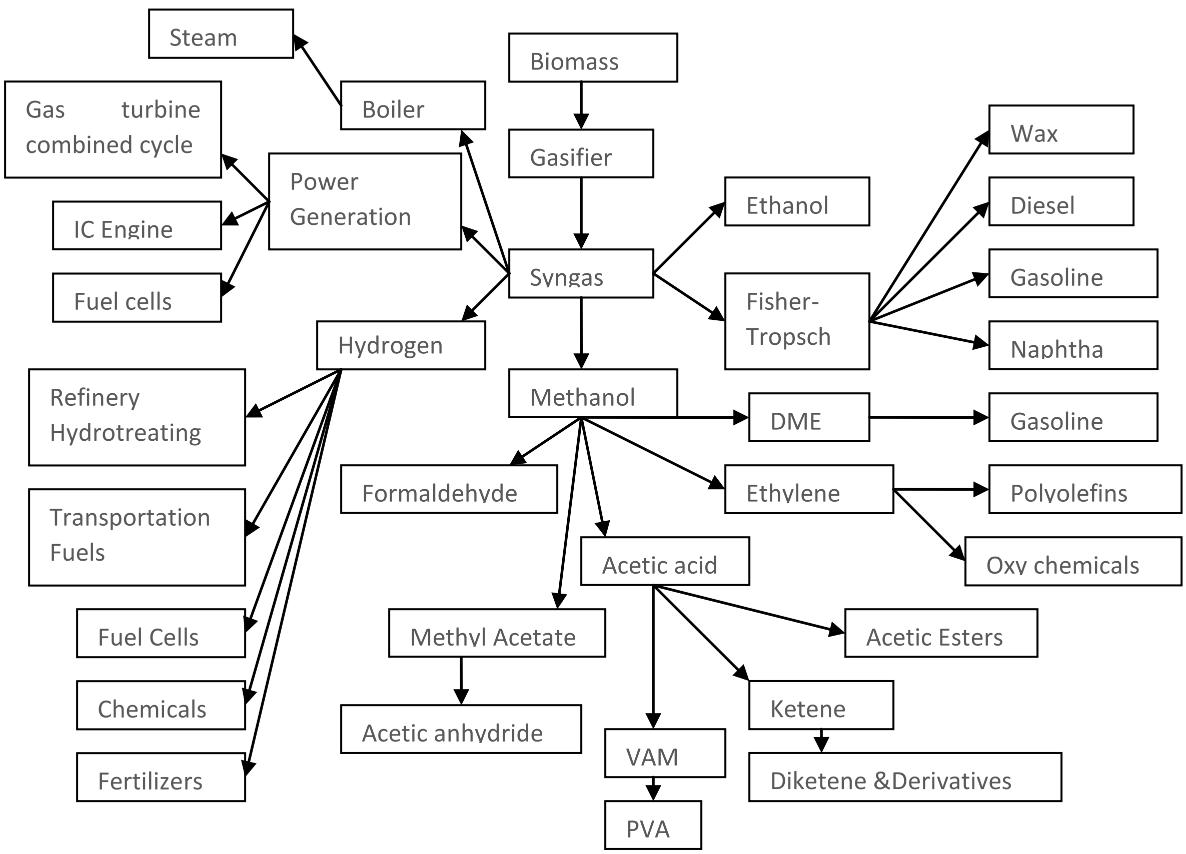
Other Energy Products – Syngas, Other Hydrocarbon Fuels, Energy from Combustion of Algae Biomass

One of the processes that is gaining significant interest worldwide is the biomass to liquid (BTL) route. This route typically comprises a gasification stage and a chemical synthesis stage. With suitable modifications of the parameters, a range of hydrocarbon fuels (and chemicals) can be obtained from biomass. The BTL route holds significant potential owing to its scalability and the wide range of end products it can produce. This chapter provides in-depth details on the BTL route for algae, in terms of technology, processes, costs and barriers.

SAMPLE TOPIC

Products from Syngas

The chart below provides the complete range of products that can be derived from syngas.



This chapter provides information on how syngas could be derived from algae biomass. Latest updates provided on research and commercial efforts in algae gasification. Other possible products such as aviation fuel, LPG, plastics, lubricants and waxes are also discussed.

CHAPTER 11

Algae Meal / Cake

Algae cake finds application in markets such as aquaculture, poultry, and agriculture, and holds future potential in sectors such as ethanol production. These end-uses and the revenues from these could make algae fuel production more economically sustainable. This chapter provides background and commercial details for algae cake.

SAMPLE TOPIC

Industries that Use Left-over Algae Cake

- Poultry - Biomass extract of algae is a good source of nutrients and biologically active substances, which in the last few years have attracted the interest of the specialists in their search for natural, ecologically and healthy sound foods for the animals.
- Aquaculture - Algae meal can be used as a major food of fish (and thus indirectly of many other animals)
- Agriculture - Algal meal is a natural fertilizer for plants. Kelp or seaweed (algae) meal is a natural fertilizer. Its high potassium content combined with other organic fertilizers makes a complete soil treatment.
- Ethanol manufacturers - Processing into Ethanol - The sugars in algae meal can be processed into ethanol.

Useful inputs provided on the various properties and uses of algae cake

Q&A

Can the algae – meal act as a protein top up for animal feed?

Obtaining at least some of the algal oil and/or protein from predominantly intact biomass is sometimes advantageous for food for high performance animals, such as sport dogs or horses.

Delipidated meal can optionally be combined with other ingredients, such as grain, in an animal feed. Because delipidated meal has a powdery consistency, it can be pressed into pellets using an extruder or expanders, which are commercially available.

Predominantly intact biomass is also useful as a preservative. Algal biomass or oil is combined with other ingredients typically found in animal foods (e.g., a meat, meat flavor, fatty acid, vegetable, fruit, starch, vitamin, mineral, antioxidant, probiotic) and any combination thereof.

In most animal diets, protein is the most expensive portion and is usually the first nutrient that is computed in diet formulation. The energy level of the diet is then adjusted to the desired level by addition of high energy supplements) which are less expensive than protein supplements.

Section III: Processes & Challenges

CHAPTER 12

Algae Grown in Open Ponds, Closed Ponds & Photobioreactor

Currently, there are three primary methods – and variations and combinations of these - followed for algae cultivation: Open Ponds, Closed Ponds and Photobioreactors. Open pond cultivation is the most economical, but it presents its own set of cultivation challenges. Photobioreactors are much more expensive than open ponds but provide significant benefits in productivity. This chapter provides the process details and latest updates for each of these cultivation systems. It also presents details on the challenges specifically faced in open pond cultivation and the efforts and solutions being attempted.

SAMPLE TOPIC

Algae Cultivation in Open Ponds – Q&A

Can open ponds for algae cultivation use CO_2 from industrial emissions?

Yes, this is possible and many companies are already running pilot projects with this method. However, considerations need to be given about the location of the ponds (they should be in proximity to power plants) and also the solubility of the flue gas components in water. The target is carbon dioxide, but the solubility of other elements (sulfur oxides, nitrogen oxides, oxygen, etc.) must be simultaneously considered.

More answers are provided for the following questions.

- Can open ponds for algae cultivation use CO_2 from industrial emissions?
- Can we have a hybrid of open pond and closed systems?

- Is a closed pond similar to green house?
- What are the materials used in closing the pond?

Detailed inputs on the methods by which flue gas can be supplied to the ponds are provided in this section. In addition, extensive details are provided on each aspect of cultivation in open and closed systems.

CHAPTER 13

Algae Grown in Sewage & Wastewater

In some parts of the world, algae are already being used for the bioremediation of sewage and waste water. Algae cultivation for biofuels in sewage or wastewater provides an opportunity to achieve twin benefits. One, it results in cost-effective treatment of waste water/sewage and two, owing to the ready availability of nutrients in the medium, it also results in lower costs of algal biomass production. This chapter provides extensive details on this exciting opportunity, and provides ready-to-use guidance for those keen on exploring this avenue further.

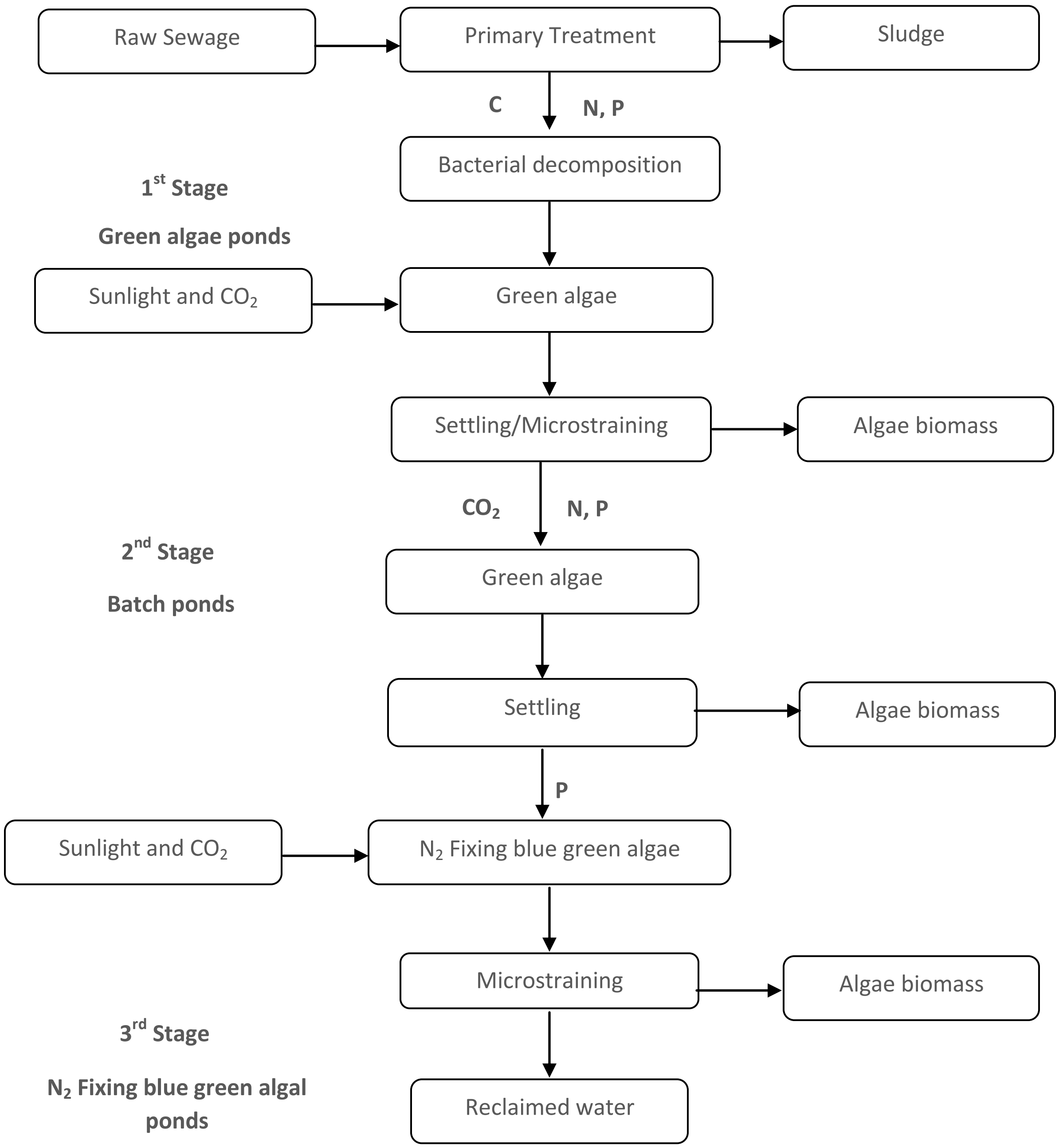
Q&A

In this section we have provided detailed answers for the following questions:

- At which stage of wastewater treatment are algae introduced?
- As sewage already contains nutrient, is there any need for additional nutrients for algae cultivation in sewage?
- Are there algae predators in sewage?
- Will toxins affect algae growth in sewage?
- Which is the best algae harvesting method for sewage cultivation?
- What are the natural microfloras in sewage?

SAMPLE TOPIC

Process Schematic for Tertiary Wastewater Treatment with Microalgae



This chapter provides detailed descriptions of the step-by-step processes of algae cultivation in municipal and industrial wastewater and strains that are highly suitable for the same.

CHAPTER 14

Algae Grown in Desert

Deserts provide algae a high amount of sunlight that has the potential to enhance photosynthesis, thus resulting in high oil yields. The availability of land in deserts is high (at low costs) thus facilitating cost-effective and scalable algaculture. These advantages make deserts an attractive environment for algae-fuel ventures. However, desert environments also present significant challenges in terms of logistics, high temperatures and water availability. What are being done by companies to exploit the advantages and overcome the challenges of desert-based algae cultivation for fuel? This chapter provides insights, case studies, data and answers to frequently asked questions in these contexts.

SAMPLE TOPIC

Algae Strains that Grow Well in Desert Conditions

- *Cyanidium caldarium* - It is a thermophilic eukaryote which can grow at temperatures below 20^{o}C and has been reported growing at temperatures up to 56^{o}C. This acid-tolerant and heat-tolerant unicellular alga is a regular member of the microflora found in acidic hot springs throughout the world (M. G. Kleinschmidt, 1970).
- Spirulina - Spirulina is a genus of filamentous alga comprising over 35 species. Spirulina is particularly attractive because of the high protein content (50-70%), lipid content (7-16%), adaption to brackish water (salt at 20-70 g/L is optimal but 1-270 g/L is tolerated), relative ease of harvest by flotation and filtration, and its ability to use animal waste as a nutrient base….

This chapter will provide inputs on the various aspects of growing algae in the desert for fuel. It will also provide examples and case studies of companies pursuing the desert-based algal cultivation method.

Q&A

Detailed answers are provided for the following questions.

- What will be the source of water in desert regions?
- How can the problem of evaporation be overcome?
- Is it possible to cultivate algae in closed loop?
- In desert environments, which is best - open pond, closed pond or PBR?
- Can PBR withstand high temperatures?

CHAPTER 15

Algae Grown in Marine & Saltwater Environment

The ocean and marine systems present an interesting opportunity for algaculture. This is owing to the availability of large tracts of ocean areas, their non-interference with land areas that could be used for food crops or to enhance biodiversity, and the possible low cost of cultivation owing to low land cost and free availability of nutrients. Research into ocean-based algae cultivation is however quite recent. This chapter provides details on the optimal strains for ocean-based cultivation, processes and challenges involved, and updates on companies that are currently involved in these efforts.

SAMPLE TOPIC

Prominent Companies Growing Algae in Saltwater

Some of the prominent companies growing algae in saltwater are:

- Green Star
- Aquatic Energy (http://www.aquaticenergy.com/)
- Sapphire Energy (http://www.sapphireenergy.com/)
- Live Fuels (http://www.livefuels.com/)
- Algenol (http://www.algenolbiofuels.com/)
- Seambiotic, Israel (http://www.seambiotic.com/)
- Biolight Harvesting and Blue Marble Algae (http://bluemarbleenergy.net/).

This chapter will provide inputs on the various aspects of growing algae in the salt water or ocean for fuel. It will also provide examples and case studies of companies pursuing the desert-based algal cultivation method.

Updates and Factoids:

- Scientists have uncovered a biochemical pathway that enables a remarkable marine alga, *Dasycladus vermicularis* to rapidly heal itself after it has been wounded. Researchers of this study claim that their work could provide clues about how to generate new synthetic adhesives that function under water –July 2011.
- An Israeli company Seambiotic cultivates a few selected species of marine autotrophic microalgae with high content of lipids and carbohydrates which aid in the production of both bio-diesel and bio-ethanol. Seambiotic has succeeded in producing oil from algae which has a yield equivalent to over 5,600 gallons/year from each hectare of land. Some of the marine species employed by Seambiotic are Nannochloropsis sp., *Phaeodactylum tricornutum*, Dunaliella sp., Tetraselmis sp. (Source: http://seambiotic.com/)
- DuPont and Bio Architecture Lab were awarded a $9 million matching grant from ARPA-E for a third generation biofuels research program to determine if sugars from macroalgae — or seaweed — can be efficiently converted to biobutanol. The project will complement the efforts under way in the Butamax™ joint venture to commercialize a multi-generational pipeline of isobutanol technologies from grain and cellulosic biomass that is the result of extensive research and technology investment by DuPont and BP.
- In Norway, Seaweed Energy Solutions has patented the first ever modern structure to enable mass seaweed cultivation on an industrial scale in the world¹s oceans. The structure, known as the Seaweed Carrier, makes a clean break with past seaweed cultivation methods that have all been based on ropes. The Seaweed Carrier is a sheet-like structure that basically copies a very large seaweed plant, moving freely back and forth through the sea from a single mooring on the ocean floor. (Apr 2010, Source - Biofuel Digest)
- Australian researchers say saltwater algae biodiesel production is at parity with petroleum diesel costs; commercial-scaling is all that is needed. In Australia, researchers at the national science organization, CSIRO, have concluded that the cost of saltwater algae production is now, based on current science, lower than the cost of diesel from fossil crude oil. In the study, the researchers focused on maximizing the value of biodiesel in economic and carbon terms by co-locating algae production with a power source – for power generation purposes more than CO2 capture. You can download the paper from here - http://www.csiro.au/files/files/poit.pdf
- In early 2008, Kansas State University researchers received a $98,560 Small Grant for Exploratory Research from the National Science Foundation to carry out a study on the potential for algae grown on solid carriers in the open ocean. Solid carriers float on the ocean surface and provide a nexus for algae to grow. The study will simulate

an ocean environment and tests numerous strains of algae to determine which strains have the optimal characteristics for oil content and ability to grow in the ocean.

- In April 2009, South Korea energy officials confirmed that the country will invest over ten years to create 86,000 acres of offshore seaweed forests that will produce over 300 million gallons of per annum of ethanol by 2020.
- In December 2012, biologists at UC San Diego demonstrated that marine algae can be just as capable as fresh water algae in producing biofuels. The scientists genetically engineered marine algae to produce five different kinds of industrially important enzymes and claim the same process they used could be employed to enhance the yield of petroleum-like compounds from these salt water algae

Q&A

Detailed answers are provided for the following questions:

- What are the challenges for marine algae cultivation?
- Are algae cultivated in marine for other purposes?
- How and why does iron fertilization help algae growth?
- How can we control algae growth boundaries in marine environments?
- Do the nutrients in seawater serve as natural nutrients for algae growth?

CHAPTER 16

Algae Grown in Freshwater

Microalgae such as Spirulina are already successfully cultivated worldwide in freshwater environments. Cultivation of oil-bearing algae strains in freshwater us not however as common. This chapter provides details on the processes, optimal algae strains required and profiles of companies involved in the freshwater algae cultivation for biofuels.

SAMPLE TOPIC

Freshwater Algae Strains with High Oil or Carbohydrate Content

There are many strains & species of algae that grow well in freshwater systems. Some of the species are: Euglenoids, Dinoflagellates, Green algae, Blue-green algae (Cyanobacteria), Diatoms, Desmids, Branching & Non-branching Forms of Algae & Red algae.

Prominent Companies Growing Algae in Fresh water

- PetroAlgae
- Solix
- Parry Nutraceuticals India
- Inventure Chemical

This chapter provides detailed inputs on algal strains suited for freshwater, prominent companies that grow algae in freshwater and latest developments in cultivation of algae.

CHAPTER 17

Algae Grown Next to Major CO_2 Emitting Industries

Power plants and other CO2 emitting industries (cement plants, iron and steel companies etc) have an urgent need to mitigate their CO2 emissions. Algae consume high amounts of CO2 for their growth (one Ton of algae requires about 1.8 Ton of CO2). Combine the two, and the result is the idea of using algae to capture CO2 at power plants and other CO2 emitting industries. Exploration into this exciting opportunity has just started, with about a dozen pilot plants worldwide. This chapter provides extensive details, case studies and data that will enable one to understand much better the nature of this opportunity and the challenges.

SAMPLE TOPIC

Business Opportunities from Algae-based CO_2 Capture

Growing algae next to CO_2 presents an interesting opportunity for companies that produce large CO_2 emissions. Many countries of the world that are signatories of the Kyoto Protocol have an existing carbon credits and trading program. The US, which even though is not a Kyoto Protocol signatory, has a carbon trading program of its own. This implies that for power plants and other entities that are large scale emitters of CO_2; sequestering CO_2 using algae provides the benefit of monetizing the carbon credits while at the same time producing biofuels.

Business opportunities exist both for companies that are CO_2 emitters as well as for external businesses such as consulting and engineering companies that are willing to work with power plants to make the algae-based CO_2 capture and biofuels production a reality.

This chapter will provide inputs on the various aspects of growing algae next to CO2 emitting industries for fuel and how algae can be grown in a cost effective way next to power plants.

Prominent Companies Using Algae-based CO_2 Capture

- Enie Technology
- MBD Energy
- RWE Energy
- Linc Energy & BioCleanCoal
- Seambiotic
- E-On Hanse
- CEP & PGE
- Arizona Public Service Co.
- Carbon Capture Corporation
- Scottish Bioenergy
- Infinifuel Biodiesel
- Energy Quest Inc.
- Stellarwind Bio Energy LLC

As of December 2012, there are about 30 key companies working on algae-based CO_2 capture.

Algae Cultivation Coupled with CO_2 from Power Plants – Q&A

Can algae withstand the high temperatures in the flue gases?

In a commercial application, flue gas from the desulphurization scrubbers would be sent to the CO_2 sequestration ponds for treatment. Temperatures exiting the scrubbers at many coal power stations are 140°F (60°C) and above – this could reach even upwards of 100°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

Can PBR withstand high temperature?

Depending on the design of the PBR and the materials used to make the system, photobioreactors can withstand the high temperatures prevalent in deserts. A wide variety of materials have been used for tubular photobioreactors , low density polyethylene film (LDPE), and clear acrylic (polymethyl methylacrylate, PMMA, also known by the trade names PlexiglasR and PerspexR). LDPE withstands temperature upto 80ºC. For acrylic plastic the maximum range is 180º F to 200º F.

Over twenty such important questions are taken up and answered for algae cultivation processes and methods

Q&A

Answers and insights are provided for the following questions

- Is there a possibility of heavy metal contamination in algae due to their presence in the flue gases?
- How do the constituents other than CO_2 in flue gas from power plants affect algal growth?
- Will NOx present in the flue gas serve as a nutrient, in addition to the CO_2?
- Can algae withstand the high temperatures in the flue gases?
- What is amount of CO_2 required for algae growth?
- Can we grow macroalgae for power plant CO_2 sequestration?
- What are the major problems faced by companies implementing algae based CO_2 sequestration techniques near power plants?
- Can power plants use waste water from their facilities for growing algae?
- 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?

Section IV: Industry & Market Information

CHAPTER 18

Cost of Making Oil from Algae

The high cost of making fuel from algae is the biggest bottleneck that is preventing quick commercialization of algae fuels. In order for entrepreneurs and businesses to explore ways of reducing these costs, they need to understand the cost components involved in the various process routes and options, and the current costs for each of the routes and options. This chapter provides detailed inputs on the costs for each stage of algae-to-fuels for every route/option viz., algae to biodiesel, algae to ethanol, algae to methane, biomass to liquids (BTL) using algae, and more.

18.1 Introduction

18.2 Cost for:

- Cultivation
- Harvesting
- Extraction
- Conversion to Fuel

18.3 Representative Cost of Biodiesel Production from Algae

18.4 Costs - Reference

SAMPLE TOPIC

Cost of Making Oil from Algae

Harvesting Costs

A number of methods are being used for harvesting microalgae and more are being experimented. We have provided the indicative capital and operating costs for the most common methods for microalgae harvesting.

Costs for:

- Drum Filtration
- Centrifugation
- Flocculation
- Flotation

The major cost components for harvesting are:

- Cost of drying algae
- Cost of harvesting infrastructure and equipments (capital expense)
- Cost of maintenance of harvesting equipments

- Cost of chemicals (if flocculation methods are used for harvesting)
- Manpower cost for all the above operations
- Electricity

(All operating costs are given for processing the medium in which algae are cultivated)

Cost of Drum Filtration

Capital Cost	Operating Cost 1	Operating Cost 2
Approximately $0.2 per 1000 annual gallons	Approximately $100 per million gallons.	Approx $120 per million gallons

Note: A 1,000,000 l / hr drum filtration system costs about $ 400,000 (drum filter, pumps and measuring equipments)

Cost of Open and closed ponds:

Indicative Costs for Open Ponds

Capital Cost	Operating Cost 1	Operating Cost 2
$125,000-$150,000 per hectare	$15,000-20,000 per hectare per annum	$27,000-35,000 per hectare per annum

Closed Ponds

Capital Cost	Operating Cost 1	Operating Cost 2
$200,000 per hectare per annum	$20,000-25,000 per hectare per annum	$40,000-45,000 per hectare per annum

Cost of Extraction Using Oil Press:

Capital Cost	Operating Cost 1	Operating Cost 2
0.5 $ per annual gallon	$ 35 / T (approx 12 c per gal)	$50/T (approx 17 c per gallon)

Thermochemical Processes

- Gasification / Pyrolysis
- Combustion

Biomass gasification and combustion technologies are evolving fast and as a result the capital and operating costs for gasification vary widely. For costs specific to your requirements, it is best to consult with suppliers of individual systems. Some indicative data are reported here

Gasification / Pyrolysis & Catalytic Synthesis

Capital Cost	Operating Cost 1	Operating Cost 2
➔ Large gasification + Large FT: varies between 2400 $/T to 1400 $/T annual diesel output, for diesel output capacities of ranging from 0.5-2.5 million T per annum ➔ Small gasification + Small FT: varies between 9000 $/T to 8500 $/T annual diesel output, for diesel output capacities of ranging from 0.5-2.5 million T per annum	Approx $0.8 per gallon of fuel produced	For large gasification + large FT: $1.5 per gallon of fuel produced For small gasification + small FT: $3.3 per gallon of fuel produced.

Indicative cost details provided for all possible algae energy products and processes – these include costs for harvesting methods, oil extracting methods and processes for conversion to energy products

CHAPTER 19

Companies in the Algae to Energy Industry

As of 2012, there are about 300 companies that have a focus on algae fuels. These companies represent a range of backgrounds, geographies and process and product platforms. This chapter provides updates profiles of all the companies that have ventured into the algae fuel industry, with a focus on the differentiating factors for each company.

SAMPLE TOPIC

Company Profiles

Aurora Algae, Inc.

www.aurorainc.com

Main line of activity	Algae Biofuels Producer
Headquartered at	1201 Harbor Bay Pkwy Alameda, CA, 94502 Phone: +1.510.748.4999
Collaboration	Aurora Algae is in collaboration with publicly traded companies, U.C. Berkeley, Stanford and Michigan State University
Funding	Aurora Algae has raised $25 million in two rounds of funding ($5 million in Jan. 2007, $20 million in June 2008 and $15 million in March 2010) from Oak Investment Partners, Noventi Ventures, and Gabriel Venture Partners. In March 2011, Aurora Algae was awarded a $2 million grant by the Australian government under its Low Emissions Energy Development Fund to support the project. In August 2011, Aurora Algae raised another $22 million and to date the company has raised $72 million.
Fuel Product derived from algae	Aurora Algae is already producing ASTM-certified biodiesel fuel on a pilot scale.
Technology employed	The company, formally known as Aurora Biofuels Inc., changed its name into Aurora Algae to reflect a new focus. Aurora Algae, Inc. is a renewable energy company exploring new sources of

feedstock for the production of biofuels. In particular, Aurora utilizes microalgae to generate bio-oil, which can be converted into biodiesel.

Aurora's technology is relatively straightforward on the aquaculture side, and its core intellectual property comes from the lab, where UC Berkeley microbiology Professor Tasios Melis developed a genetically modified strain of algae that produces extremely high yield in open ponds.

The company's patented system begins with proprietary biology. Leading scientists at Aurora Algae have screened a myriad of strains in search of microalgae that outperform others in terms of oil production and yield. Aurora has further bred its select portfolio to maximize fuel-production performance and to be cost-effective at scale. Aurora grows its optimized algae in specially engineered open ponds that provide a favorable environment for rapid algae production.

Using a proprietary hydrodynamic design, Aurora has developed pond systems operating in Florida which has a capacity of <1000 gallons of fuel per year which nurture algae with preferable conditions. These conditions include a carbon dioxide-rich environment with optimal fluid dynamic characteristics. Techniques have been developed to minimize energy demands throughout the growth and fuel production phases of the process. Once extracted, the algae oil is ready for further processing into the end product, biodiesel. In addition, the remaining algae mass becomes protein-rich animal feed. At full scale, the company's process is capable of producing fuel at $55-60 a barrel.

In Aug 2010, Aurora algae repositioned their algae products as a source of Omega-3s. They announced that they put a strong emphasis on growing algae for Omega-3 fatty acids and proteins for the dietary supplements market.

In June 2010, Oak Investment venture partner (and now Aurora chairman) Brian Hinman noted that Aurora Algae has made a significant genetic engineering achievement in doubling the productivity of its proprietary algae, and this round of funding will allow the company to demonstrate the productivity and production processes at scale.

Aurora Algae Inc. opened a demonstration-scale algae facility in northwestern Australia in June 2011. The company launched its A2 product portfolio, a series of natural products from algae (A2 Omega-3, A2 Feed, A2 Fuel, A2 Protein) and started producing samples of A2 family products in its demonstration facility.

In December 2011, Aurora Algae developed a new technique for genetic optimization to create advanced traits of algae strains for the production of biofuel, nutritiional supplements, pharma products and animal feed. The

company applied an optimization technology based on homologous recombination to Nannochloropsis sp. and the technology has the potential to rapidly advance algal functional genomics and biotechnology in a commercially relevant group of organisms.

Forecast of Commercialization

Aurora expected to have commercial-scale facilities in 2012. A commercial installation will have a production capacity of at least 10 million gallons of biodiesel per year. Installations may be linked together to form larger facilities capable of multiplying fuel production while achieving economies of scale.

Future Plans

Aurora Algae planned to complete the construction of a 1500-acre commercial-scale facility in Maitland, Australia by the fourth quarter of 2012.

Highlights

Its core intellectual property comes from the UC Berkeley lab where microbiology Professor Tasios Melis developed a genetically modified strain of algae that produces extremely high yield in open ponds. This research relationship with the lab could be a significant asset to the company.

Detailed profiles, advanced processes, specific equipments and their research are provided for over 50 companies offering products and services in the algae energy industry

List of companies for which information has been provided

1. A2Be Carbon Capture
2. Algae.Tec
3. Algae Venture Systems
4. Algaewheel
5. Algafuel Technologies
6. Algenol
7. AlgoDyne Ethanol Energy Corp
8. Aquaflow Bionomic
9. Aquatic Energy
10. Aurora Algae
11. AXI
12. Bionavitas
13. Blue Marble Biomaterials
14. Bodega Algae
15. BTR Labs
16. Carbon Capture Corporation
17. Cellana
18. Center of Excellence for Hazardous Materials Management
19. Cequesta Algae
20. Chevron
21. Circle Biodiesel & Ethanol Corporation
22. Community Fuels
23. Culturing Solutions, Inc
24. DFI Group
25. Enhanced Biofuels & Technologies
26. Fluid Imaging Technologies
27. General Atomics
28. Green Gold Algae and Seaweed Sciences Inc.
29. Green Star Products, Inc.
30. Greenbelt Resources Corporation
31. GreenFuel Technologies Corporation
32. Greenshift
33. Heliae
34. Hawaiian Electric Company
35. Imperium Renewables
36. Infinifuel Biodiesel
37. International Energy
38. Inventure Chemical Technology
39. Kai Bioenergy
40. Kuehnle Agrosystems
41. LiveFuels
42. MBD Biodiesel
43. Muradel
44. Neste Oil
45. Ocean Technology & Environmental Consulting
46. Oilfox Argentina
47. Organic Fuels
48. OriginOil
49. Parabel
50. PetroSun Biofuels
51. Phyco2
52. Renewable Energy Group
53. Revolution Biofuels
54. Sapphire Energy
55. Seambiotic
56. Solazyme
57. Solena Group
58. Solix Biosystems
59. Solray
60. Sunrise Ridge Algae, Inc.
61. Sunx Algae Oil Research Lab
62. Texas Clean Fuels
63. Alterrus Systems (Formerly Valcent Products Inc)
64. W2 Energy
65. Phyco BioSciences (formerly, XL Renewables – Sigmae)

CHAPTER 20

Industry Profile & Company Strategies

Businesses that are keen to start their efforts in algae fuels have a need to understand the underlying market dynamics of the algae fuels industry, the key factors for success, the list of do's and dont's, and steps to be taken along with resources required in order to set up an algae fuel venture. This chapter provides detailed and specific inputs that can be used as a practical guide for those on the threshold of starting their algae-fuel business.

SAMPLE TOPIC

Industry Concentration

Approximate Number of Companies Directly Involved In Producing Fuels from Algae

Year	2001	2002	2003	2004	2005	2006	2007	2008	Mid 2009	End 2009	Mid 2010	2011	2012
# of companies	1	2	4	5	10	15	25	50	100	150	200	225	300

Source: Oilgae Estimates

This chapter makes an attempt to provide inputs on some key strategic dimensions that will be of significance to entrepreneurs and investors in this industry to evaluate the current and future business potential of the industry – now and in future.

Step by Step Process to Start an Algal Energy Venture

Step 1: Evaluate your risk-taking profile. Algal energy can be classified as a high-risk high-return opportunity. If you are risk-averse, algae energy might not be a suitable entrepreneurial opportunity for you, given the nascent status of the industry and the number of uncertainties.

Step 2: Once you have decided to go ahead, your initial steps will be to chart out a plan to get an expert team in place.

Detailed guidance provided for entrepreneurs seeking to enter the algae energy domain on Sample Topics such as recommendations & suggestions on collaboration & partnerships, mistakes to avoid, setting up a pilot project and more.

CHAPTER 21

Potential for Existing Companies in Related Industries Entering Algae Energy Domain

A number of companies that are already using algae for their businesses (aquaculture, health foods etc.) are keen on understanding the potential of the algae fuel opportunity for their companies. This chapter provides case studies and analyses that will assist such businesses in understanding the nature of the opportunity, as well as insights on how companies similar to them are approaching this opportunity.

SAMPLE TOPIC

Industries with Synergistic Benefits from Algae Energy Opportunities

The list of industries for which it is attractive to explore investing in the algal energy domain owing to synergistic benefits:

1. Sewage & Water Treatment Companies
2. Agriculture & Farming
3. Companies that give out waste water
    - Meat and Poultry
    - Pesticides & Insecticides
    - Photography
4. Companies that produce animal waste (for growing algae on pork and poultry waste)
    - Pork
    - Poultry
5. Companies that are major CO2 pollutants
    - Coal Burning and Natural Gas Power Plants
    - Petrochemicals
    - Iron & Steel

Numerous case studies provided of companies from related industries entering the algae fuels industry

CHAPTER 22

Funding & Venture Funding

In the past few years, investments in algae fuel companies have grown in leaps and bounds, primarily in the form of venture capital investments. This chapter provides a detailed list of companies that have been funded, and the venture capital firms that have been active in this industry. It also provides useful inputs for an entrepreneur looking for investments in the form of tips, suggestions and strategies.

22.1 Venture Funding for Algae Energy – Introduction
22.2 Investment Firms
22.3 Government & Other Public Initiatives
22.4 List of Companies that have Received Funding
22.5 VC Perspectives
22.6 Things to Do Before Approaching a VC

SAMPLE TOPIC

Investment Firms

Venture capital firms that had made recent investments in algae fuel ventures and the companies they have invested in:

Venture Capital Firms	Algae Firms
Aardvark Investments SA (www.aardvarkinvestments.com)	Cequesta Algae
Access Private Equity	GreenFuel Technologies
Arch Venture Partners (www.archventure.com)	Sapphire Energy
BIRD Foundation (www.birdf.com)	Algatech GreenFuel

BlueCrest (www.bluecrestcapital.com)	Blue Marble Energy, Solazyme Earth2tech
Cascade Ventures (cascadeventures.netopus.net)	Sapphire Energy Cedar Grove Investments

Details and profiles of venture capital firms investing in algal fuel companies are given. Detailed lists of companies that have received venture funding are also provided.

VC Perspectives

Venture Capital Perspectives on Alt Energy & Algae

Think Big: Venture capitalists like billion $ ideas, those that can solve very big problems; they like ideas that are disruptive in nature. Algae fuels present an opportunity that has the potential to scale into a very large business in future, bigger than any other biofuel opportunity.

Think Different: There is a strong feeling in the venture capital community that the companies which have the ability to think completely out of the box have a better chance of overcoming the challenges than those companies that are merely attempting incremental changes to existing processes.

Unique VC opinions and perspectives provided, based on primary and secondary inputs, forums and interviews.

Funding & Venture Funding

Things to Do Before Approaching a VC

- Timing is important. Venture capital, like any other form of investment, is more easily available during periods of strong economic growth. For this reason, it might sometimes be best if you wait for a few months if the economic climate is not conducive.
- Decide whether you wish to go for angel funding or first round funding. For each, the requirements are different. If you are a company starting from scratch and have little or no personal resources you can utilize, angel funding might be the best (and possibly only) route.
- Spend time in deciding the quantum of funding you require

Useful insights and recommendations provided for companies seeking venture capital.

CHAPTER 23

Non-Fuel Applications of Algae

Long before algae were explored for their use as biofuel feedstocks, they have been used in a variety of industries – ranging from fish feed, cosmetics, health foods and more. A number of algae fuel ventures are exploring the synergistic benefits of producing non-fuel products from algae (some of which command high prices in the worldwide market) in order to achieve long term sustainability in algal biofuel production. This chapter provides extensive details on the various non-fuel products and applications of algae, and the market / industry information for each of the products.

SAMPLE TOPIC

Summary of Uses / Applications of Algae

A summary list of non-fuel applications of algae:

- Biopolymers & Bioplastics
- Animal & Fish Feed - Shrimp feed, Shellfish Diet, Marine Fish Larvae Cultivation
- Paints, Dyes and Colorants
- Lubricants
- Food, Health Products, Nutraceuticals
- Cosmetics
- Chemicals
- Pharmaceuticals
    - Antimicrobials, Antivirals & Antifungals
    - Neuroprotective Products
    - Slimming Related Products
    - Anti-cellulite
    - Skin Anti-ageing & Sensitive Skin Treatment
- Pollution Control
    - CO_2 Sequestration
    - Uranium/Plutonium Sequestration
    - Fertilizer Runoff Reclamation
    - Sewage & Wastewater Treatment

Food, Health Products & Nutraceuticals

Global Carotenoid Market Value by Product 2007 & 2015 ($ Million)

Product	2007	2015
Beta-carotene	247	285
Astaxanthin	220	252
Canthaxanthin	110	117
Annatto	69	95
Others	120	170
Total	766	919

Source: BCC Research, 2008

Useful details provided on various prominent companies in the non-fuel algae products. Many of the markets where algae can find applications are large and growing. Data on their market sizes and potential are also provided.

CHAPTER 24

Biofuels in Real-world

The biofuels market has been growing at a hectic pace in recent years, and the growth is expected to accelerate even further in future. This chapter provides details on the real world status of biofuels (both biodiesel and ethanol) in terms of their market potential, growth trends and challenges.

SAMPLE TOPIC

Global Biofuel Market Analysis

Global Biofuel Market Analysis- Key Findings

- Biofuels production will probably exceed the IEA predictions of 120 billion liters of ethanol and 23 billion liters of biodiesel before 2020 (Accenture 2008)
- Ethanol
    - US ethanol production is expected to dominate the global market; however, increased corn prices will be a matter of concern for ethanol production in future.

This chapter provides more inputs on biofuels, with an emphasis on their end uses, their current and future contribution, and the latest breakthroughs and advances.

Section V: Reference

CHAPTER 25

Apex Bodies, Organizations, Universities & Experts

Algae fuels is one of the most researched topics today at universities and colleges across the world. This chapter provides an extensive list of universities that have a research interest in algae-based fuels, along with details of the type of research being done by them. These details will be especially useful for those keen on forming partnerships with universities and research organizations for their algae fuel ventures.

SAMPLE TOPIC

Organizations

Country	Association	Website/Email
USA	National Algae Association The Woodlands, Texas 77381	info@nationalalgaeassociation.com
	American Assn. of Algae Biofuel Producers California	http://www.scipiobiofuels.com
	Algal Biomass Organization Seattle, WA 98104	jwilliams@algalbiomass.org
	Midwest Research Institute Kansas City, Missouri	
India	Central Salt & Marine Chemicals Research Institute Gijubhai Badheka Marg, Bhavnagar-364002, Gujarat (INDIA)	pkghosh@csir.res.in
UK	Natural Environment Research Council (NERC) Swindon	http://www.nerc.ac.uk

Organization details provided for many countries will be useful for entrepreneurs wishing to take further steps in this industry.

Universities

Auburn University, USA

Aim of the Project	Algae as a biodiesel feedstock: a feasibility assessment
Year	June 2007
Collaboration	1. Collaboration between Auburn University energy crop researchers and the USDA ARS Soil Dynamics Laboratory is working to identify optimal systems for algae flocculation, harvest, and processing to extract constituents desirable for production of liquid fuels, electrical power, nutraceuticals, etc 2. Research collaboration between Auburn University and the Alabama Department Agriculture and Industries is examining the production of microalgae as a potential source of oil for subsequent biodiesel production.
Funding	US - Auburn University has been selected to receive up to $4.9 million of federal grant money for algae to biodiesel project. (Aug 2009) Gov. Bob Riley has awarded a $10,000 grant to Auburn University to conduct a study to determine the economic and technical feasibility of cultivating pond algae commercially as a source for biofuel (2007)

Details of the project[1]

Researchers at Auburn University have developed techniques to harvest wild algae that form a nuisance at catfish farms, and convert it to biofuels. The University believes that catfish farms should form the base of the Southeastern-based algae fuel industry, because the feedstock was already in place, calling it a win-win for catfish farmers and algae fuel producers. Auburn researchers work with the leading producers of forest biomass for energy from algae in Alabama.

Researchers are proposing the development of algae farms in which carbon dioxide is received from carbon capture and biologically converted, via photosynthesis and anaerobic digestion, to CNG or LNG transportation fuels. This approach, using open ponds in the Southeastern US, could be the most competitive with petroleum-based fuels. While the technologies for lipids extraction from micro-algae for biodiesel are currently infeasible from cost and energy standpoints, anaerobic digestion of biomass to methane is a commercial reality.

There were several important innovations during the course of the program:
(1) Integration of animal litter digesters to provide nutrients and energy for the algae farms,
(2) Integration of carbonation pits and their pumps with a novel linear pond design
(3) A low-cost harvesting system
(4) A scheme for integration of algaculture with catfish aquaculture to improve the competitiveness of this industry within the state.

The experimental phase of the feasibility assessment focused on the areas which is believed to be the most important for the success of widespread algaculture in Alabama, namely algae growth rates and the harvesting process

Future plans

To capture and sequester carbon dioxide emissions from stationary point sources, particularly power plants, and vehicles using algae.

1 http://www.adeca.state.al.us/C17/ATF/Document%20Library/Algae%20as%20a%20Biodiesel%20Feedstock.pdf

Similar updates on research areas and breakthroughs are provided for research in over 40 universities worldwide.

List of universities involved in algae fuel research

1. Auburn University
2. Arizona State University
3. Brunswick Community College (BCC)
4. Clemson University
5. Cleveland State University, Fenn College of Engineering
6. CSIRO, Australia
7. Colorado State University
8. Eastern Kentucky University, Richmond, USA
9. Florida Tech University
10. The National Institute of Oceanography (NIO)
11. Iowa Power Fund, USA
12. James Cook University, Queensland, Australia
13. Massachussets Institute of Technology MIT
14. Massey School of Engineering, Wellington, New Zealand
15. Montana State University
16. NASA
17. Natural Energy Laboratory of Hawaii Authority (NELHA), USA
18. National Renewable Energy Laboratory
19. Natural Resources Defense Council
20. New Mexico State University
21. Oregon State University
22. Sandia National Laboratory
23. Southern Illinois University Carbondale (SIUC), USA
24. Texas A&M University
25. The Carbon Trust (UK)
26. Western Michigan University
27. University of Adelaide Chemical Engineering
28. University of Arizona
29. University of Arkansas
30. University of California at Berkeley
31. University of California at Davis
32. University of California at San Diego
33. University of Georgia
34. University of Florence, Italy
35. University of Nevada
36. University of New Hampshire
37. University of Texas at Austin
38. University of Virginia
39. Utah State University, USA
40. University of Washington (UW), USA

Algae Energy Developments around the World

European Union

The European Biodiesel Board - promotes the use of biodiesel in the European Union, at the same time, grouping the major EU biodiesel producers. Several algae biofuel projects have

been supported either by European Commission (EC) programmes such as FP7 or national programmes.

UK

Scottish Association for Marine Science (SAMS), which reviews the potential of marine biomass, to be anaerobically digested to produce methane which in turn can be used to generate electricity, for heat or for transport they also sequenced the genome of *Phaeodactylum tricornutum*, a well studied species of diatom.

Germany

Germany's IGV has partnered with Bioalgostral SAS (BAO) for the delivery and establishment of an industrial plant for the production of biofuels from Microalgae with a total volume of 82,000 litres in 2012. This pre-industrial pilot project aims to promote the use of Microalgae biomass for food, feed and several other products.

France

French agricultural research organisation, the Institut National de la Recherche Agronomique (INRA) has launched a 160 million Euro collaborative platform which aims at developing efficient biofuels and high added value substances by utilising micro-algae feeding on nutrients contained in waste and industrial emissions of carbon dioxide.

China

Chinese biofuel producer ENN signed a memorandum of understanding with Airbus and its parent company, EDAS, to jointly develop and test aviation fuel made from algae.

Japan

Japanese company IHI NeoG uses a type of *Botryococcus braunii* created at Kobe University through selective breeding and called Enomoto Algae, which multiplies 1,000 times faster than regular types. The company is focusing its research on developing technology to mass produce oil from the fast-growing Enomoto, for making high-priced jet fuel, among other applications.

Similar updates on algae fuel initiatives, startups, research, policies and developments are provided for over 30 countries worldwide.

CHAPTER 26

Culture Collection Centers

This chapter provides a detailed list of worldwide algae and microbial collection centres from where algae strains could be obtained.

SAMPLE TOPIC

List of algae culture collection centre

Country	Centre	Mode of ordering
Australia	CSIRO Microalgae Research Centre http://www.cmar.csiro.au/microalgae/supply.html	Fax or Mail
Canada	University Of Toronto Culture Collection http://www.botany.utoronto.ca/utcc/	Online, Fax and Phone
	Canadian Centre For Culture Collection http://www.botany.ubc.ca/cccm/	Mail, Phone or Fax
Czech Republic	Culture Collection of Algae of Charles University of Prague http://botany.natur.cuni.cz/algo/caup.html	Mail, Phone or Fax
	Culture Collection of Algal Laboratory (CCALA) Institute of Botany, Academy of Sciences of the Czech Republic www.butbn.cas.cz	Online

Similar data on algae culture collection centers for over 30 countries worldwide are provided.

CHAPTER 27

Future Trends

The algae fuels domain has a high potential for innovation and breakthroughs. Since 2002, there have been a number of approaches have been explored - some of them radically different from the mainstream concepts. It is hence essential for an entrepreneur to get a better perspective of what the future could hold for algae fuels. This chapter provides details and insights that will assist in this.

SAMPLE TOPIC

Predictions

Period	Challenges	Highlights	Dark Horses
1-4 years	• Optimal strain identification • Devising cost-effective methods for cultivation • Devising cost-effective methods for harvesting	• Ethanol from algae • Many pilot projects • Governments realizing the potential of algae biofuels and devoting higher resources for research • Reduction in costs for biodiesel production processes • Efforts to grow algae next to power plants to use the flue gases for CO2	• Growing algae in the dark • Hydrocarbons from algae gasification & catalytic synthesis • Creative sparks coming from garage & backyard inventors
4-5 years	• Innovative scientific techniques and out-of-the-box thinking to overcome what looks insurmountable • Innovative business and revenue models that factor in ground realities	• New progress from fields such as genetic engineering & biotech • Low cost photobioreactors • Growing algae next to power plants	• Integrated biorefinery for algae fuel and value added products

Inputs on similar aspects are given for the next 5-10 years for the algae energy industry. Future trends and predictions are provided for many aspects of algae energy – processes, companies and innovations & more.

List of Tables

12. Algae Grown in Open Ponds, Closed Ponds & Photobioreactor

1. Differences between Open Pond and Closed Pond Cultivation

13. Algae Grown in Sewage & Wastewater

1. **Examples of Industries Employing Algae-Based Wastewater Treatment Technology**
2. Description of Algae Production from Poultry Waste
3. Composition of Poultry Industry Wastewater
4. Content of Selected Heavy Metals in a Sample Waste Water Treatment Plant
5. Algal-Bacterial/Microalgal Consortia for Organic Pollutant Removal
6. Theoretical Sewage & Wastewater Resource Potentials By 2020

14. Algae Grown in Desert

1. Characteristics of Photobioreactor Materials and the Energy Content of Tubular Photo Bioreactors

15. Algae Grown in Marine & Saltwater Environment

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2. Detailed Composition of Seawater at 3.5% Salinity

16. Algae Grown in Freshwater

1. Macroalgae in freshwater

17. Algae Grown Next to Major CO2 Emitting Industries

1. Example of a Typical Flue Gas Composition from Coal Fired Power Plant
2. Summary of Availability and Cost of CO_2 Sources
3. Projected Global Energy Demand and CO_2 Emissions, 2000 to 2020
4. CO_2 Tolerance of Various Species
5. Energy and GHG (CO_2) Balance per Liter of Oil Produced Using Three Different Technologies.
6. Estimated Costs for CO_2 Sequestration Using Algae Grown for Six Months per Year in BC
7. Algae Project Data
8. Select List of Research on Microalgae Fixation as a Process for Post-combustion CO_2 Capture
9. Composition of Gas Mixtures
10. Solubilities of Flue Gas Components
11. Data Related to Algae-Based CO_2 Capture
12. Countries Heavily Dependent on Coal for Electricity (2006e)

13. Top Coal Importers (2006e)

18. Cost of Making Oil from Algae

1. Indicative Costs for Open Ponds
2. Indicative Costs for Closed Ponds
3. Cost of Photobioreactors
4. Cost of Drum Filtration
5. Cost of Centrifugation
6. Cost of Flocculation
7. Cost of Flotation
8. Cost of Extraction Using Oil Press
9. Cost of Solvent Extraction
10. Transesterification Cost
11. Cost of Starch to Ethanol (via fermentation)
12. Cellulose to Ethanol Cost
13. Cost of Anaerobic Digestion
14. Cost of Gasification / Pyrolysis & Catalytic Synthesis
15. Cost of Direct Combustion
16. Yield Assumptions
17. The Various Stages and the Various Options Available for Each Stage of Production
18. Cost Estimates for the Various Options under Each Stage of Production
19. The Total Cost of Biodiesel Production
20. Cost of Photobioreactors – from AlgaeWay
21. Capital Costs of Open Raceway Ponds
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23. Capital Cost Estimates of Gasification & Pyrolysis Plants
24. Costs for Biomass Energy Using Combustion
25. Typical Biodiesel Cost Break-up

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2. International Biofuels Support Policies – Ethanol
3. International Biofuels Support Policies - Biodiesel

22 Funding & Venture Funding

1. Venture Capital Firms that had Made Recent Investments in Algae Fuel Ventures and the Companies they have Invested in

23. Non-Fuel Applications of Algae

1. Pigment Composition of Several Algal Groups (During 1982)
2. Global Carotenoid Market Value by Product 2007 & 2015 ($ Million)
3. Cosmetics Market Size Forecast – Overview

24. Biofuels in Real-World

1. Current Feedstocks for Biodiesel Worldwide
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3. Global Biodiesel Production (Thousand Tonnes)
4. Annual World Ethanol Production By Country
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26. Culture Collection Centers

1. List of Algae Culture Collection Centre

27. Future Trends

1. Predictions on How Energy from Algae Industry Will Pan Out During the Next 10 Years, until about 2020.

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5. PetroAlgae's commercial micro-crop technology
6. Renewable Oil Production Process
7. AGS™ Technology – Solix Biofuels
8. Micro Organism Production System

24. Biofuels in Real-World

1. Present and Future Potential for Biofuels
2. Global Biofuel Production, 2007

Sample List of Organizations from Which Data Have been Sourced

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2. Algal Biomass Association - www.algalbiomass.org
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9. The Center of Excellence for Hazardous Material Management in Carlsbad - www.cehmm.org
10. University of Nevada - www.unr.edu
11. California Water Board
12. Old Dominion University - www.odu.edu
13. Auburn University in Alabama - www.auburn.edu
14. Middle East Technical University - www.metu.edu.tr
15. Sintef Fisheries and Aquaculture - www.sintef.no/
16. National Center for Radiation Research and Technology - www.eaea.org.eg
17. Water Environment Federation - www.wef.org
18. Royal Netherlands Institute for Sea Research - www.nioz.nl
19. Australian National University - http://solar-thermal.anu.edu.au/
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