Note on Algae

Background

We have been working on Straight Vegetable Oil (SVO), biodiesel and biogas as possible sustainable solutions for the energy problem. In all three cases, the issue finally boils down to availability of raw material – without having to compromise on the available food. Although we know that the biofuels can be produced without creating any negative impact on food, it can still attract political views and could create difficulties. Hence, one has to think of some other options, which could potentially bypass such problems. Use of Algae as raw material for fuels could be one such option.

Introduction

Major Study on Algae was conducted in the US in the decades of 80s and 90s under the Aquatic Species Program (ASP) funded by the Department of Energy (DOE). Algae were collected from sites in the west, the northwest and the southeastern regions of the continental U.S., as well as Hawaii. At its peak, the collection contained over 3,000 strains of organisms. After screening, isolation and characterization efforts, the collection was eventually winnowed down to around 300 species, mostly green algae and diatoms. The collection, now housed at the University of Hawaii, is still available to researchers.

Algae Production Systems

Over the course of the program, efforts were made to establish the feasibility of large-scale algae production in open ponds. In studies conducted in California, Hawaii and New Mexico, the ASP proved the concept of long term, reliable production of algae. California and Hawaii served as early test bed sites. Based on results from six years of tests run in parallel in California and Hawaii, 1,000 m^2 pond systems were built and tested in Roswell, New Mexico. The Roswell, New Mexico tests proved that outdoor ponds could be run with extremely high efficiency of CO_2 utilization. Careful control of pH and other physical conditions for introducing CO_2 into the ponds allowed greater than 90% utilization of injected CO_2. The Roswell test site successfully completed a full year of operation with reasonable control of the algal species grown. **Single day productivities reported over the course of one year were as high as 50 grams of algae per square meter per day (the numbers translate as follows: 50 grams/sq. m/day → 182.5 T/ha/year → if 35% lipids i.e. oil then → 63.9 T/ha/year oil as against 0.9 T/ha/year jatropha oil → yield could be 71 times).**

Attempts to achieve consistently high productivities were hampered by low temperature conditions encountered at the site. The desert conditions of New Mexico provided ample sunlight, but temperatures regularly reached low levels (especially at night). In tropical countries like India, such problems are minimal and excellent consistent results can be expected.

The Technology: Biological Concepts

Photosynthetic organisms include plants, algae and some photosynthetic bacteria. Photosynthesis is the key to making solar energy available in useable forms for all organic life in our environment. These organisms use energy from the sun to combine water with carbon dioxide (CO_2) to create biomass (food). These include macroalgae, microalgae and emergents.

Macroalgae, more commonly known as “seaweed,” are fast growing marine and freshwater plants that can grow to considerable size (up to 60m in length). Emergents are plants that grow partially submerged in bogs and marshes. Microalgae are, as the name suggests, microscopic photosynthetic organisms. Like macroalgae, these organisms are found in both marine and freshwater environments.

In the early days of ASP, research was done on all three types of aquatic species. As emphasis switched to production of natural oils for biodiesel, microalgae became the exclusive focus of the research. This is because microalgae generally produce more of the right kinds of natural oils needed for biodiesel.

The study of microalgae represents an area of high risk and high gains. Biologists have categorized microalgae in a variety of classes, mainly distinguished by their pigmentation, life cycle and basic cellular structure. The four most important types (at least in terms of abundance) are:

The Diatoms (Bacillariophyceae): These algae dominate the phytoplankton of the oceans, but are also found in fresh and brackish water. Approximately 100,000 species are known to exist. Diatoms contain polymerized silica (Si) in their cell walls. All cells store carbon in a variety of forms. Diatoms store carbon in the form of natural oils or as a polymer of carbohydrates known as chyrsolaminarin.

The Green Algae (Chlorophyceae): These are also quite abundant, especially in freshwater. (Anyone who owns a swimming pool is more than familiar with this class of algae). They can be as single cells or as colonies. Green algae are the evolutionary progenitors of modern plants. The main storage compound for green algae is starch, though oils can be produced under certain conditions.

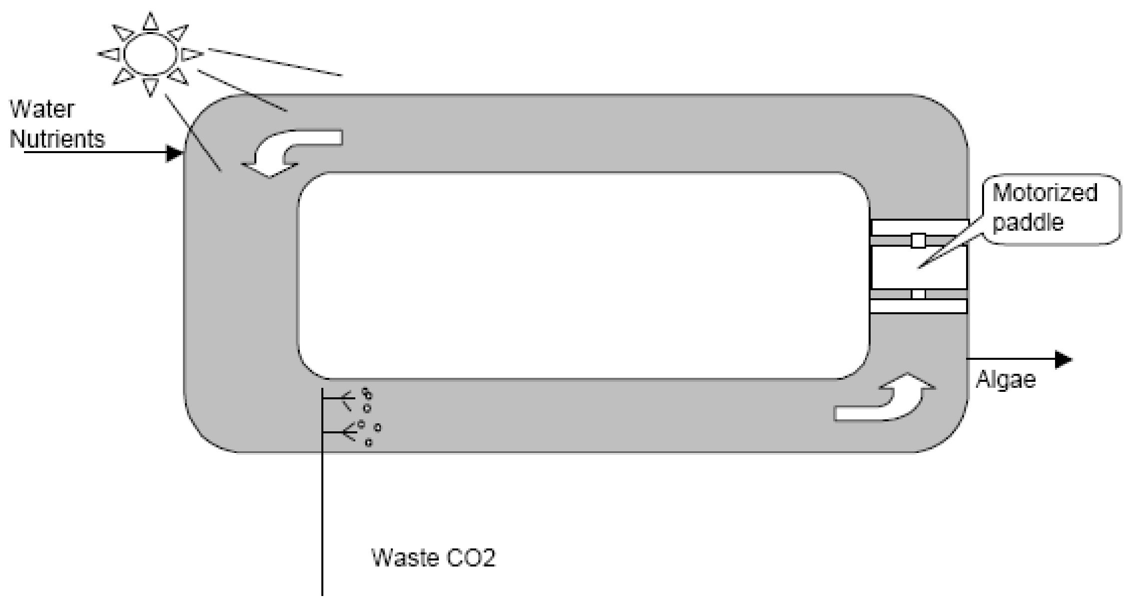
The Blue-Green Algae (Cyanophyceae): Much closer to bacteria in structure and organization, these algae play an important role in fixing nitrogen from the atmosphere. There are approximately 2,000 known species found in a variety of habitats.

The Golden Algae (Chrysophyceae): This group of algae is similar to the diatoms. They have more complex pigment systems, and can appear yellow, brown or orange in color. Approximately 1,000 species are known to exist, primarily in freshwater systems. They are similar to diatoms in pigmentation and biochemical composition. The golden algae produce natural oils and carbohydrates as storage compounds.

The bulk of the organisms collected and studied in ASP fall in the first two classes—the diatoms and the green algae. Microalgae are the most primitive form of plants. While the mechanism of photosynthesis in microalgae is similar to that of higher plants, they are generally more efficient converters of solar energy because of their simple cellular structure. In addition, because the cells grow in aqueous suspension, they have more efficient access to water, CO_2, and other nutrients. For these reasons, microalgae are capable of producing at least 30 times the amount oil per unit area of land, compared to terrestrial oilseed crops.

Put quite simply, microalgae are remarkable and efficient biological factories capable of taking a waste (zero-energy) form of carbon (CO_2) and converting it into a high-density liquid form of energy (natural oil). This ability has been the foundation of the research program funded by the Office Fuels Development.

Such algae farms would be based on the use of open, shallow ponds in which some source of waste CO2 could be efficiently bubbled into the ponds and captured by the algae (see the figure below).



The ponds are “raceway” designs, in which the algae, water and nutrients circulate around a racetrack. Paddlewheels provide the flow. The algae are thus kept suspended in water. Algae are circulated back up to the surface on a regular frequency. The ponds are kept shallow because of the need to keep the algae exposed to sunlight and the limited depth to which sunlight can penetrate the pond water. The ponds are operated continuously; that is, water and nutrients are constantly fed to the pond, while algae-containing water is removed at the other end. Some kind of harvesting system is required to recover the algae, which contains substantial amounts of natural oil.

Fuel Production Concepts

There could be three main options for fuel production using algae:

- Production of methane gas via biological or thermal gasification
- Production of ethanol via fermentation
- Production of biodiesel

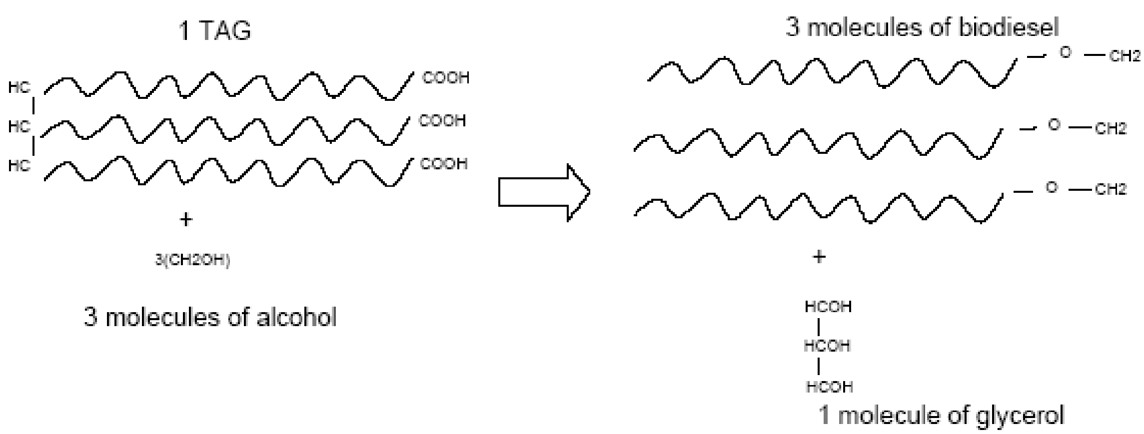
And the fourth possible – but not necessarily the most appropriate ways would be – direct combustion of the algal biomass for production of steam or electricity

Algal biomass contains three main components:

- Carbohydrates
- Protein
- Natural Oils

The economics of fuel production from algae (or from any biomass, for that matter) demands that we utilize all the biomass as efficiently as possible. To achieve this, the three fuel production options listed previously can be used in a number of combinations. The most simplistic approach is to produce methane gas, since the both the biological and thermal processes involved are not very sensitive to what form the biomass is in. Gasification is a somewhat brute force technology in the sense that it involves the breakdown of any form of organic carbon into methane. Ethanol production, by contrast, is most effective for conversion of the carbohydrate fraction. Biodiesel production applies exclusively to the natural oil fraction. Some combination of all three components can also be utilized as an animal feed.

The bulk of the natural oil made by oilseed crops is in the form of triacylglycerols (TAGs). TAGs consist of three long chains of fatty acids attached to a glycerol backbone. The algae species studied in this program can produce up to 60% of their body weight in the form of TAGs. Thus, algae represent an alternative source of biodiesel, one that does not compete with the existing oilseed market.



High oil-producing algae can be used to produce biodiesel, a chemically modified natural oil, that is emerging as an exciting new option for diesel engines. At the same time, algae technology provides a means for recycling waste carbon from *fossil fuel combustion. Algal biodiesel is one of the only avenues available for high-volume re-use of CO_2 generated in power plants. It is a technology that marries the potential need for carbon disposal in the electric utility industry with the need for clean-burning alternatives to petroleum in the transportation sector.*

Terrestrial versus Aquatic Biomass

Algae grow in aquatic environments. In that sense, algae technology will not compete for the land already being eyed by proponents of other biomass-based fuel technologies. Biomass power, biodiesel, biogas and bioethanol all compete for the same land and for similar feedstocks – trees and grasses specifically grown for energy production. More importantly, many of the algal species can grow in brackish water – that is, water that contains high levels of salt. This means that algae technology may not put additional demand on freshwater supplies needed for domestic, industrial and agricultural use. The unique ability of algae to grow in saline water means that we can target areas of the country in which saline groundwater supplies prevent any other useful application of water or land resources.

In a world of ever more limited natural resources, algae technology offers the opportunity to utilize land and water resources that are, today, unsuited for any other use. Land use needs for microalgae complement, rather than compete, with other biomass-based fuel technologies.

A multi-faceted effort was carried out to isolate microalgae from a variety of saline habitats (including oceans, lakes, ponds, and various ephemeral water bodies), screen those isolates for the ability to grow under a variety of conditions, and analyze the biochemical components of the strains (especially with respect to lipids). Some interesting strains are:

Table II.A.2 Fastest growing strains from Arizona State University collection.

Strain	Genus	Class	Growth Rate (doublings•day^{-1})	Medium
OSCIL2	*Oscillatoria*	Cyanophyceae	4.23	I/55
OSCIL3	*Oscillatoria*	Cyanophyceae	3.50	I/55
CHLOC4	*Chlorococcum/ Eremosphaera*	Chlorophyceae	3.47	I/55
SYNEC5	*Synechococcus*	Cyanophyceae	3.25	II/55
ASU0735	*Oscillatoria*	Cyanophyceae	3.06	I/55
AMPHO46	*Amphora*	Bacillariophyceae	2.81	I/55
NANNO13	*Nannochloris*	Chlorophyceae	2.78	I/55
POLYC1	*Synechococcus*	Cyanophyceae	2.73	I/55
CHLOR23	*Chlorella*	Chlorophyceae	2.66	I/55
SYNEC3	*Synechococcus*	Cyanophyceae	2.51	II/55

An Integrated System for the Conversion of Solar Energy with Sewage-Grown Microalgae

Algae require CO_2 for growth. They can also be used for cleaning up wastewater. Large ponds for wastewater treatment could be an excellent synergy between waste minimization and energy solution.

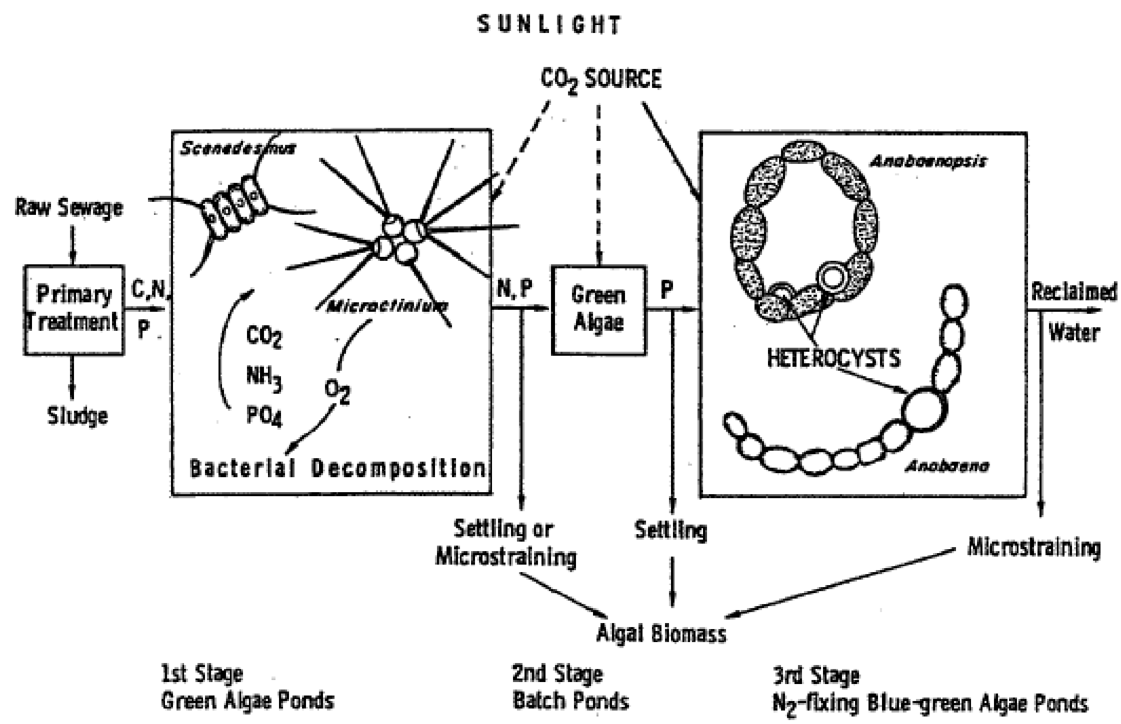


Figure III.A.3. Process schematic for tertiary wastewater treatment with microalgae.

This schematic for an advanced wastewater treatment process uses a multi-stage pond system for complete organic waste degradation and nutrient removal. The initial wastewater treatment ponds are shown, followed by a smaller intermediate “green algae” pond for N depletion and a final pond for cultivating N-fixing blue-green algae and removing residual phosphates. CO_2 supplementation would be required in the last two ponds, and could increase productivity in the initial pond. (Source: Benemann et al. 1978.)

Large-Scale Freshwater Microalgal Biomass Production for Fuel and Fertilizer

From a large number (39) of experiments, a correlation of Tmax, Tmin, and total insolation with productivity reduced the variance in the prediction of productivity by about 50% when using any single variable, but not in combination. This suggested that one of these three factors generally dominated (e.g., too high or too low a temperature or too little insolation). Similar experiments were carried out with the other microalgae in combination with the study of variables such as mixing speed, O_2 outgassing, CO_2 addition, and N limitation (for lipid induction).

The main conclusions of the extensive experimental program were:

1. Productivities of 15 to 25 g/m2/d were routinely obtained during the 8-month growing season at this location. However, higher numbers were rarely seen.
2. Continuous operations are about 20% more productive than semi-continuous cultures, but the latter densities are much higher, a factor in harvesting.
3. Culture collection strains fare poorly in competition with wild types.
4. Temperature effects are important in species selection and culture collapses, including grazer development.
5. Nighttime productivity losses increased to 10% to 20 % in July, when grazers were present; nighttime respiratory losses were high only at high temperatures.
6. There is a significant decrease in productivity in the afternoons, compared to the mornings, in the algal ponds.
7. Oxygen levels can increase as much as 40 mg/L, over 450% of saturation, and high oxygen levels limit productivity in some strains but not others. Oxygen inhibition was synergistic with other limiting factors (e.g., temperature).
8. Increasing TDS from 0.4 to 4 ppt decreased productivity, depending on strains.
9. Mixing power inputs were small at low mixing velocities (e.g., 15 cm/s) but increased exponentially. Productivity was independent of mixing speed.
10. The strains investigated in this study did not exhibit high lipid contents even upon N limitation.
11. The transfer of CO_2 into the ponds was more than 60% efficient, even though the CO_2 was transferred through only the 20-cm depth of the pond.
12. Harvesting by sedimentation has promise, but was strain specific and was increased by N limitation.