BIOFUELS FROM MICROALGAE

MYTHS AND REALITY

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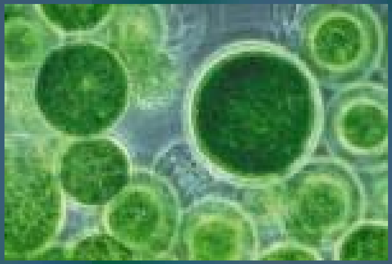
BIOFUELS FROM MICROALGAE

GENERAL CONCEPTS

BIOFUELS FROM MICROALGAE

Algae

Algae is a term which has no true taxonomic meaning, but is used to refer to a diverse group of aquatic, estuarine and marine organisms capable of photosynthesis.



These organisms range in size from microscopic (microalgae) to many meters in lengths (macroalgae).

Algae, as also terrestrial plants, are primary producers and provide the basis of energy and fixed carbon in almost every ecosystem in which they are present.

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Algae

They have additional photosynthetic pigments besides chlorophyll. This fact allows their taxonomic classification in green, bluegreens, reds and browns.

About only 50 species are currently utilized for commercial purposes. They are used for bioproducts related to pharmaceuticals and cosmetics, food, beverages, agricultural soil conditining and waste water treatment.

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Why Algae?

There are many advantages of using algae over terrestrial crops for biofuels. Some of the most significant are:

- Algae do not compete with food crops
- Algae utilize less water
- Algae require less land to produce an equivalent amount of biofuel.

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Why Algae?

Algae, depending on the species, grow in fresh or salt water.

It is very important to note that fresh water algae does not need to be grown in potable water.

This is very important because growing algae for fuel will not put added strain on the world’s potable water supply and will not compete for fertile agricultural soil, as other energy crops

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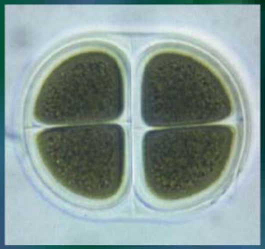
Why Algae?



Besides lipids and carbohydrates for the production of biofuels, many species of algae can be grown to produce nutraceuticals, such as astaxanthin, food supplements, fish / cattle feed and pharmaceuticals (inmunostimulants, antibiotics).

As a matter of fact, since the latter products are much higher valued products than most biofuels, it is worth to consider the potential of microalgae for the production of such products, even using costly high tech production systems (bioreactors).

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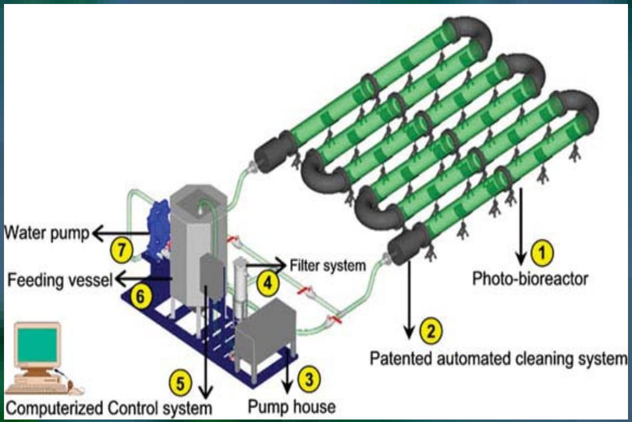
CULTURE SYSTEMS

There are 2 main systems for culturing microalge, namely photobioreactors and open ponds.



Photobioreactors

A photobioreactor (PBR or bioreactor for short) is a closed or semi-closed system in which light and nutrients are supplied to the system in an attempt to maximize algal biomass.

There are many types of photo-bioreactors: tubular vs. flat panel; airlift vs. stirred vs. sparged vs. porous difusser, and multiple combinations of such systems, to just name some of them.

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Photobioreactors (cont.)

A major problem with PBRs is that the efficiency of light collection and transmission is still very low (about 7%), so spatial heterogeneity of light intensities occurs inside them.

A critical design requirement in PBRs is to supply light efficiently. This is achieved generally by maximizing the illumination surface against the container volume. As a result PBRs are designed with tubes which are generally very narrow or panels that are very thin. Furthermore, some of the PBRs that work well in a laboratory context may not work as well when scaled up because the surface-to-volume ratio decreases, causing poor light distribution inside it.

So, efficient and economical light distribution trough a dense culture PBR is a real challenge.

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Photobioreactors (cont.)

Advantages:

1. Large surface-to-volume ratio
2. Reduction in evaporation of growth medium
3. Better control of gas transfer
4. Better temperature control
5. Better protection from outside contamination
6. Better light utilization
7. Better mixing
8. Better control of culture parameters
9. Easier to be monitored
10. Higher algal cell densities are possible.

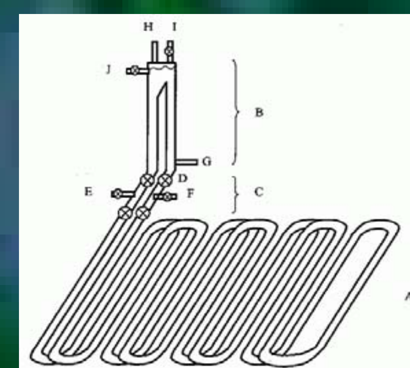

Figura 1

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Photobioreactors (cont.)

Disadvantages:

1. Higher cost

2. Higher system complexity

2. Oxygen accumulation

3. Biofouling

4. Cell damage by shear stress

5. Deterioration of materials

To produce algae-derived materials at competitive prices, efficient and economic large-scale PBRs must be designed.   However, such system has yet to be developed even thought significant advances have been made over the years. This has left commercial production of algae to open ponds.

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Open Ponds

Open ponds are structures excavated in the soil, open to the air. They share some similarities to fish ponds. Shapes can be rectangular, circular or a mixture of both geometries, which is the most favored commercial type (see figures). Besides the geometrical shape, open ponds can be lined or unlined.

Light transmission physics in a pond is the same as the aforementioned for PBRs. However, since ponds are huge flat units and knowing that an efficient system should have a high surface area-to-volume ratio, open ponds solve the light transmission problem by keeping its depth as shallow as possible.

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Open Ponds (cont.)

Advantages:

Simpler to build

- Cheaper to build
- Easier to operate and maintain

Disadvantages:

- Difficult to keep a pure culture
- Water loss (evaporation and percolation)
- Hydraulics is critical
- Difficulty in controlling light
- Difficulty in controlling temperature

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Photosynthesis: Thermodynamic principles

Photosynthesis is a biochemical process in which certain organisms utilize solar energy (photons), carbon dioxide (CO2, an inorganic carbon) from the atmosphere and water (H2O) to turn them into 2 types of carbohydrates (isomers glucose and fructose, C6H12O6, organic carbon).

The process of carbon dioxide utilization (also called carbon fixation) is really important because no other organisms (besides photosynthetics) can perform this task in the planet.

A by-product of this reaction is oxygen (O2). This “byproduct” is what keeps oxygen balance in the atmosphere within acceptable levels (about 21%) for all non photosynthetic organisms, mankind included

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FACTORS AFFECTING PHOTOSYNTHESIS

There are 4 main factors affecting photosynthesis

- Carbon dioxide concentration
- Light intensity
- Light wavelength
- Temperature.

Carbon dioxide requirements represent the largest cost (nearly 1/3) for producing biodiesel from microalgae.

Now, it is also a fact that power plants are required to reduce their emissions, which are approximately 13% CO_2 (in coal power plants).

If we pair power plants with microalgae production facilities, the operation costs could be substantially reduced for both of them.

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Q: How much CO_2 will be consumed for producing 1 Ton of algae?

A: One of the simplest ways to do it is using the stechiometry of photosynthesis, assuming that algae is all glucose. So, 1 Ton of microalgae will consume 1.47 Tons (roughly 1.5 Tons) of carbon dioxide.

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Light radiation and PAR

- All photosynthetic organisms transform the visible light (the 400-700 nm range, 47% of the entire spectrum) - also called photosynthetically active radiation (PAR) - into the chemical energy of carbon-containing compounds.

- PAR varies with latitude, seasonality and geographical factors and is expressed generally in watts /m2.

- The PAR value for Dominican Republic is between 110 to 120 (average 115 w/m2).

  This value is 9.52 % higher than SW USA (105w/m2), which is the highest irradiation zone in USA.

  The rest of USA is between 80 to 90 w/m2.

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Maximum Photosynthesis Efficiency (Theoretical)

Starting with the photosynthesis equation:

$6 CO_2 + 12 H_20 + photons \rightarrow C_6H_{12}O_6 + 6 H_2O + 6 O_2$.

This equation can be reduced to

$CO_2 + 2 H_20 + photons \rightarrow 1/6\ C_6H_{12}O_6 + H_2O + O_2$

the energy stored in 1/6 molecule of glucose is 117 kilocalories (kcal)

The energy (in kilocalories) of 1 einstein is $E = Nhc / \lambda$

$= 28{,}600 / \lambda$, where

N = amount of photons

h = Planck's constant,

c = light speed (m/s)

λ = light wavelength (in nanometers=nm; 1 nm = 10^{-9} meters)

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Maximum Photosynthesis Efficiency (Theoretical) (cont.)

The part of the solar spectrum used by plants has an estimated average wavelength of 570 nm. So, the amount of light energy used is approximately 28,600/570 = 50 Kcal

In order to know the amount of light energy involved in photosynthesis it is required to know the quantum requirement, which is the number of photons required to transfer 1 electron during photosynthesis. This number is between 8 and 9 (average 8.5).

Therefore, the estimated maximum energy efficiency of photosynthesis is the relation (or divition) between the energy stored in the final product of photosynthesis (1/6 molecule of glucose=117 kcal) and the light required for the entire photosynthesis process (50 kcal x 8.5)

= 117 kcal / (8.5)(50kcal) = 27.5%

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<u>Maximum Photosynthesis Efficiency (Real)</u>

However, the actual percentage of solar energy stored by plants is much less than the maximum energy efficiency of photosynthesis (27.5%).

For PBRs the maximum efficiency calculated efficiency has been found to be close to 10% (Dimitrov, 2007)

For open ponds the maximum efficiency has been found to be much less, 7%.

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Maximum Photosynthesis Efficiency (Real)

For comparison purposes, consider sugarcane (the terrestrial plant with most efficient photosynthetic conversion: 19 g biomass / m2 / day = 70 Ton/ Ha/year).

Its maximum yields have corresponded to practical conversion efficiencies of 1 %

Using the aforementioned we can conclude the following:

- An optimized PBR with the best found algae (yet to be found) would be 10 times more productive than sugar cane
- An optimized Pond with the best found algae (yet to be found) would be 7 times more productive than sugar cane

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Yields

Using the aforementioned data, yields can be extrapolated within a certain range based on the yields reported in the literature.

In the case of terrestrial plants, we choose sugar cane (the most efficient photosynthetic crop, the highest biomass yielder in the world) and African oil palm (the oil highest yielder crop).

For aquatic yields we use data from algae cultures (mainly Spirulina) worldwide.

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<u>Yield based on sugar cane</u>

Sugar cane average: 70 Ton / Ha / year (Brazil, Cuba and D.R.)

a) PBRs

Considering a PBR scenario the algal biomass yield would be

Maximum (70 Ton/Ha/year) (10) = 700 Ton /Ha /year

Conservative (70 Ton/Ha/year) (5) = 350 Ton/Ha/year

The agal oil yield at a moderate 20% extractability would be

Maximum : 140 ton /Ha /year = 41,098 gal / Ha / year

Conservative: 70 ton / Ha /year = 20,549 gal / Ha / year

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Yield based on sugar cane

b) Open Ponds

In an open pond the algal biomass yield would be

Maximum (70 ton/Ha/year) (7) = 490 ton /Ha /year

Conservative (70 ton/Ha/year) (3.5) = 245 ton/Ha/year

The algal oil yield at a moderate 20% extractibility

Maximum 98 ton/ Ha /year = 28,769 gal / Ha / year

Conservative 49 ton/Ha/year = 14,384 gal / Ha /year

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Yield based on African oil palm

Oil palm average: 1,500 gal /Ha/year (worldwide)

a) PBRs

Considering a PBR scenario the oil yield would be

Maximum (1,500 gal/Ha/year) (10) = 15,000 gal /Ha /year

Conservative (1,500 gal/Ha/year) (5) = 7,500 gal /Ha /year

b) Open Ponds

In an open pond the oil yield would be

Maximum (1,500 gal/Ha/year) (7) = 10,500 gal /Ha /year

Conservative (1,500 gal/Ha/year) (3.5) = 5,250 gal/Ha/year

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Yield based on existing commercial algae cultures and open field research trials

Spirulina California Ponds average 52.65 ton/Ha/year = 15,461 gallons biomass/Ha/year with efforts on quality, not quantity. At a 20% oil extractability (unreal for Spirulina) = 3,092 gallons oil /Ha /year.

The results from the Cellana test facilities at Keahole point (Hawaii) over 1 year test period indicates the following biodiesel production rates (with undisclosed species)

Maximum: 8,765 gal /Ha/ year. Average : 3,645 gal /Ha /year

NREL tests using ponds in 1987 got an average of 20 g/m2/day dry biomass, which equates to 3,857 gallons of oil/Ha/year (assuming 20% extractability) using 15 to 25 cm deep raceway ponds

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Taking into account all the aforementioned

what we should expect from microalgae cultured in open ponds may range

to be on the safe side from

3,000 to 5,000 gal /Ha/year

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OPTIMISTIC (AND MORE THAN OPTIMISTIC) CLAIMS!!!!!

There are a some reports claiming photosynthetic yields beyond 10% of PAR.

For example, the GreenFuel's patent application (a PBR-based microalgae growing system) claimed that in an experimental situation 20% of solar efficiency was achieved !!!!.

Based on the above discussion and numerical data, these reports should be taken carefully.

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OPTIMISTIC (AND MORE THAN OPTIMISTIC) CLAIMS!!!!!

Some factors can lead to exaggeration of photosynthetic yields:

a) Quoting only the peak efficiency (and not average efficiency) of the yield achieved in a short period during a light phase (not accounting for the night phase).

b) Not accounting for the role diffuse light. Only direct light is measured as the energy input in the PBRs. Generally, an isolated experimental PBR will receive substantial amounts of diffuse light that will contribute to boost the yield. In a tightly paved field of PBRs there will be no sources of diffuse light.

c) Not accounting for the role of vitamins and other growth factors in the media. In most experiments the researchers supplement the media with vitamins and other compounds, thus alleviating the biosynthetic requirements on the cell. Vitamin supplementation will be uneconomical for large scale production

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OPTIMISTIC (AND MORE THAN OPTIMISTIC) CLAIMS!!!!!

d) Supplying ammonia as nitrogen source, which does not require the cell to use energy for nitrogen fixation. In a real life situation most companies expect that the nitrogen will be supplied as NOx from the flue gas of a power plant. However, the the microalgae will require expending energy for its reduction.

e) Presenting the yield based only on absorbed light (rather than on total available light)

f) Using wrong conversions for photon flux. If the insolating light is measured as Photosynthetic photon flux (PPF) it needs to be converted into irradiance. This has been a common source of errors.

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OPTIMISTIC (AND MORE THAN OPTIMISTIC) CLAIMS!!!!!

g) Not accounting for the scaling up of the post-harvest process.

In experimental conditions, the biomass is quickly collected and then placed in a 105°C oven for determination of dry weight.

In a scaled-up plant this probably cannot be achieved.

So again, based on the aforementioned facts, the maximum value for Q can safely be assumed to be around 10% for PBR's and 7% for open ponds

A Company in the Internet once announced yields of 200,000 gal / Ha / year !!!!!!!!

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Q: Is it economically feasible to produce biodiesel from PBRs?

A: At a cost of more than US$ 100 / m2 it would be the same as producing sugar cane in a green house

Q: Is it economically feasible to produce other substances from PBRs?

A: Yes, If the cost of the final product is worth (antibiotics, inmunostimulants, etc.)

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Q: Is it economically feasible to produce biodiesel from Open Ponds?

A: At a cost of less than US$ 10 / m2 of pond certain aspects have to worked out yet, but the future is promising

Q: Is it economically feasible to produce other substances from Open Ponds?

A: Yes. That is what is currently done!!!!!! , mostly for Spirulina

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Por la atención prestada

Muchas gracias

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- FILIPINAS

- (16/04/2007) La alianza entre la compania Shell y PNOC-AFC (Compania Nacional Filipina de Petroleo – Corporacion de Combustibles Alternativos) anunciaron la introduccion de biodiesel a partir de microalgas para el 2008.

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- ESTADOS UNIDOS

- Massachusets Institute of Thechnology (M.I.T) y Massey University anunciaron basados en estimaciones que el aceite de microalgas sera más economico que el petróleo: US$ 0.41 menos por litro.

- GreenFuel, empresa nacida a partir de la investigaciones del M.I.T. ya ha conseguido 11 millones de dólares para financiar su empresa y está llevando a cabo pruebas de campo en una central eléctrica de 1,000 megavatios, propiedad de una gran empresa energética del sudoeste. Estima que alcanzara la producción plena del sistema para el 2009

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- HOLANDA

- La empresa BioKing, dedicada a la produccion de equipos para la produccion de biodiesel anuncia su primer sistema para la produccion de biodiesel a partir de microalgas.

- El sistema consta de reactores tubulares transparentes. No hacen mencion de especies en particular de microalgas. Existen datos de produccion bajo este sistema disponible en la Web.

- El mayor obstaculo para la adquisicion de dicha tecnologia es el costo. Un metro de tuberia ronda los RD$ 100,000, aunque se estima una vida util del sistema de unos 20 años

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- Otras Compañias

- A2BE Carbon Capture (http://www.algaeatwork.com/). It has patented a system for biodiesel production from algae.

- Algoil (http://213.79.36.6/algoil/index.htm). The target is also to use the rest of the extracted biomass to make food, biofuel, hydrogen, paper, or simply burning it like charcoal. The extraction of oil suitable for Biodiesel is now a confirmed success.

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- Otras Compañias

- Enhanced Biofuels & Technologies (*http://www.ebtplc.com/*) - The EBT algae process combines a bioreactor with an open pond, both using waste CO2 from coal fired power plant flue gases as a fertilizer for the algae. The biodiesel and ethanol produced can be sold, or used as an alternative fuel on site. Emissions are reduced up to 82%. U.K and India.

- •GreenShift (http://www.greenshift.com) has a license agreement with Ohio University for its patented bioreactor) process based on a newly discovered iron-loving cyanobacterium (blue-green algae)

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- Otras Compañias

- PetroAlgae (http://www.petroalgae.com/) - Commercializing an environmentally-friendly algae developed by a research team at ASU that generates over two hundred times more oil per acre than crops like soybeans. They use a modular cultivation process that can be massively scaled.

- Solazyme (http://www.solazyme.com/) The Company utilizes proprietary genetic engineering methods to develop and optimize commercially relevant biochemical pathways for production of hydrocarbons (for energy and specialty chemicals) & bioactive compounds.

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- Otras Compañias

- Solix Biofuels (http://www.solixbiofuels.com/) - A developer of massively scaleable photo-bioreactors for the production of biodiesel and other valuable bio-commodities from algae oil. Solix' closed photo-bioreactors allow fossil-fuel power plant exhaust to be captured through the growing system. The algae growth rates increase in the presence of the carbon dioxide that would otherwise be emitted into the atmosphere.

- Valcent Products (*http://www.valcent.net*) - Has developed a high density vertical bio-reactor for the mass production of oil bearing algae while removing large quantities of carbon dioxide (CO2) from the atmosphere.

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Por la atención prestada

Muchas gracias