# Aquatic Biofuels:

## New Options for Bioenergy

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DECLARATION:
I CERTIFY THAT THIS IS MY ORIGINAL WORK; EXCEPT WHERE SOURCES ARE ACKNOWLEDGED, AND THAT THIS DISSERTATION HAS NOT BEEN SUBMITTED IN PART OR IN WHOLE TO ANY OTHER BODY.

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# ABSTRACT
## MR. ANTONIO PICCOLO
# AQUATIC BIOFUELS – NEW OPTIONS FOR BIOENERGY

Recent talks have outlined the disadvantages of land based (agro-fuels) as feedstock for biofuels. This final dissertation for the MBA in Energy and Sustainable Development looks at these disadvantages and proposes an alternative scenario, i.e. The potential of aquatic alternatives. **Aquatic Biofuels – New Options for Bioenergy** looks at the potential of micro-algae and fish waste as feedstock for biofuel. Micro-algae come in different strains, strains differ in their composition some have more lipids/oils, others have more proteins and others yet have more carbohydrates. The chosen strain will determine what kind of biofuel can be produced or if the strain contains less lipids and more carbohydrates or proteins, the algae can produce bio-gas. Current technology in algae extraction is also covered in the report, the most advanced systems exist in the US who claim they will commercialize algae to fuel extraction in the next 3-4 years. Israel too is one of the main countries producing micro-algae however their main focus has always been on *spirulina* (high in protein) as a health supplement. Most recently Israel too has had some major developments in producing fuel from micro-algae. Fish waste (the waste from the fishing industry) has been used by fishermen for centuries, when oil prices went up fishermen would produce their own diesel from the waste of their catch. This concept is therefore not at all new. What would be innovative would be the scale up process. There are a few companies worldwide that are producing bio-diesel from the waste of the fishing industry, these are found predominantly in developing countries, Honduras and Viet Nam, but also in Canada and the state of Alaska, USA. Bio-diesel from fish waste plants could be set up in aquaculture farms, fishing ports, or even on large fishing trawlers, to allow fishermen to economise on fuel, which is becoming an economic burden. In fact due to this worldwide fish prices have increased drastically in the last 5 to 10 years. It is clear at this stage that algae alone is not yet an economically viable solution to the liquid energy needs of the world. Economic viability could be achieved when science and technology will be able to give us mechanisms to improve lipid/oil extraction and improve mass production of algae. In the meantime however, by-products from the algae cultivation and the revenue obtained from the sequestration of $CO_2$ can make the system worthwhile. The other alternative is if we can combine the potential of micro-algae and fish waste. The Integrated Aquaculture Energy System (IAES) described in Chapter 16 combines the 2 systems i.e. algae and fish waste into one. This is a fully sustainable synergistic system, that makes use of all the possible resources for energy creation. The system not only addresses fuel needs, but also food security, job creation, climate change, $CO_2$ sequestration and treatment of waste water. Aquatic Biofuels and the IAES system offer in part a solution to the liquid fuel problem which the world will have to face in the coming decades.

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**PHOTO CREDITS: Antonio Piccolo (Aquatic Biofuels)**

# 1. WHAT ARE AQUATIC BIOFUELS?

## 1.1. Background

Aquatic Biofuels embrace a relatively new concept which involves the extraction of energy, predominantly liquid fuels (bio-diesel or ethanol) and bio-gas from aquatic resources such as, micro-algae and fish waste from the fishing/processing industry.

The production of biofuels in the last decade or so has been mainly driven by first and second generation feedstock. Agricultural products have been used to produce mainly liquid fuels and this has had a considerable impact on agriculture, food security, biodiversity, land use and the environment.

First-generation feedstock for biofuels production include:

- Sugar cane
- Maize
- Cassava
- Rapeseed
- Palm oil
- Soybean

Second-generation feedstock for biofuels production include:

- Non food parts of currently used crops (stems, leaves and husks)
- Switch grass
- Jatropha
- Wood chips
- Skin and pulp from fruit pressing

## 1.2. Types of Aquatic Biofuels

The primary feedstock for the production of Aquatic Biofuels are micro-algae, these are one of the most ancient organisms living on Earth and one of the tiniest plants which alone produce about 60 percent of the Earth's oxygen. They have survived some of the Earth's harshest conditions for several billions of years, are incredibly robust, and in ideal cultivation conditions, algae produce protein and energy biomass between 30 to 100 times faster than land plants.

Waste from the fishing industry is another valuable feedstock for Aquatic Biofuels. It may be converted into fish oil then into bio-diesel, which runs perfectly in any diesel engine.

Other marine or aquatic organism can be included in the concept of Aquatic Biofuels, but for the purpose of this report, only micro-algae and fishing industry waste are covered. Macro-algae is referred to but not covered in the report.

## 2. WHY AQUATIC BIOFUELS

Aquatic Biofuels (AB) is a term coined by me and as mentioned above it involves the extraction of energy, either in liquid form (biofuel/diesel/ethanol) or as gas. It is clear why investments should be made in AB because both algae and fish waste are totally carbon neutral and algae-culture sequesters Carbon Dioxide (from now on referred to as $CO_2$) from nearby plants and converts it into biofuel. 1 tonne of algae captures and stores almost 2 tonnes of $CO_2$ (1.8tonnes). Bio-diesel from the fish waste is also greenhouse gas neutral and fully sustainable.

Both systems require little water. In the case of algae culture water can be saline, brackish or fresh water, whereas with the fish farm that will predominantly depend on the type of fish being aquacultured. In both cases the water is recycled and no extra water is required.

Algae require nutrients and $CO_2$ to thrive and the $CO_2$ can be sequestered from nearby emitting plants as well as cement production facilities. Nutrients can be either purchased and fed to the algae, or a better solution is to use waste water that is rich in nutrients. This would also solve a second problem of what to do with local waste water.

Aquaculture is the main dominant skill required in both systems. Growing algae or growing fish is a similar process so no specific skill set is required by the producer. Building or buying systems to extract the oil on the other hand can be a little more complex but many companies who are developing such systems provide guidance as well as training.

Aquatic resources that produce clean energy may not be the total solution to the worlds energy needs and demands, but they do offer a partial solution; a solution which is carbon neutral, and producing and using them has little or no impact on the environment. As a society we must slowly move away from our dependency on fossil fuels. We must look at local sustainable and clean alternatives and start producing energy locally. This will not only reduce costs but it will also help secure a cleaner environment, free from greenhouse gases. Fish waste can contribute to securing energy for small to large fishing villages, ships and vessels, and local communities, while algae ponds or bio-reactors can play a part in securing larger amounts of energy once the economic hurdles are overcome.

## 3. AGRO-FUELS AND THEIR IMPACTS:

Biofuels (mainly agro-fuels) can be divided into first-generation and second-generation biofuels. First-generation biofuels are biofuels that derive from food products. These food products are often seeds or grains. For example food products such as wheat which contains starch can be fermented to produce bio-ethanol or pressed sunflower seeds can yield a vegetable oil that can be converted into a bio-diesel. The main issue here is, if these products are used to produce energy then there will be less wheat and fewer sunflower seeds for food. The main cause of the downfall of first-generation biofuels is the fact that they have been strongly criticised for diverting food away from the human and animal food chain, leading to food shortages, soaring food prices and riots.

First-generation biofuels can be produced in either liquid and/or gaseous form. In order to produce liquid fuel, crops high in sugar (sugar cane, sugar beet, and sweet sorghum) or starch based crops like maize/corn are grown, then yeast is used in a fermentation process to produce ethanol. The second method is to grow oil rich plants like oil palm, soybean jatropha and extract the vegetable oil. These vegetable oils are very thick and their thickness is reduced mainly by heating, thus making them suitable for a diesel engine, they can be further chemically processed and made into bio-diesel. The bio-gas can be produced consequently after oil or ethanol production, the left over biomass can be anaerobically (without air) processed and bio-gas produced

These biofuels at first seemed to be the answer to the liquid fuel production and for many years attracted great investments both in the EU and in the US.

Second-generation biofuels, are those biofuels that can be generated sustainably from biomass and do not consist or constitute a food part. This may include stems, leaves and husks of plants which are residue from food crop production, or other crops that are not used for food, such as switch grass, jatropha, cereals that have little grain content, as well as industry waste such as wood chips, skins and waste from the fruit industry. The process involved in second-generation biofuel production is similar to first-generation and the feedstock is treated in more or less the same way.

In the long run agricultural biofuels will have the following impacts;

### 3.1. ON BIODIVERSITY:

As the world population increases, so too will its demand for energy. Many scientists fear that the greater adaptation of land used to produce crops for biofuels the greater the loss of habitats will be for animals and wild plants especially in the large rainforest areas of the world. For example, Asian countries could sacrifice their rainforests to build more oil plantations, as too would the Brazilian forest give way to sugar plantations for ethanol.

The replacement of local crops with monoculture energy crop plantations could threaten agro-biodiversity as well as the extensive knowledge and the traditional skills of smallholder farmers in the management, selection and storage of local crops. This knowledge is often held by women who would not only lose these traditional skills, but also see land being taken away from them to produce commodities for biofuels.

### 3.2. ON MARKETS:

Another concern is that as biofuels become more lucrative for farmers, the farmers subsequently grow crops for biofuel production instead of food production. Lower food production increases prices and causes a rise in inflation. Some farmers will benefit from the high prices of the biofuel crop; in contrast, urban and rural poor in food importing countries will pay much higher prices for basic food staples.

### 3.3. ON FOOD SECURITY:

The developing countries of Africa import about 10 million metric tonnes of maize each year; another 3–5 million metric tonnes of cereal grains are provided as humanitarian aid.

We are in a world where more than 800 million people are already undernourished and the demand for crop commodities may soon exceed supply. In the last 30 years hunger alleviation has mainly been tackled through poverty alleviation and equitable food distribution programmes. However, in the future this may no longer be the case, as humanitarian food aid is threatened by soaring commodity prices. Future food security will also depend on accelerating the rate of gain in crop yields and food production capacity at both local and global levels. The rate at which food will be produced will have to drastically increase to avoid expected shortages and allow for the increase in world population.

### 3.4. ON THE ENVIRONMENT:

Another concern is that intensive farming increases the amount of nitrogen and nitrogen oxide released into the environment. To farm biofuels, currently means using nitrogen fertilizers, as is common practice amongst farming communities. Fixed nitrogen is naturally present in soil but becomes $N_2O$ (nitrous oxide). $N_2O$ is a by-product of fixed nitrogen application in agriculture and is a greenhouse gas with a global warming potential (GWP) 296 times larger than an equal mass of $CO_2$. Nitrogen is also naturally present in the atmosphere but chemically fixing nitrogen interferes with the natural equilibrium and life cycle of nitrogen. Nitrogen fertilizers are also water soluble and therefore can be washed away into rivers causing health problems to the life in lakes and rivers, and can also enter potable water systems.

Each acre of agricultural production adds about 2.25 tones of $CO_2$ to the air[1], and corn production adds additional nitrous oxide which is a worse greenhouse gas than $CO_2$.

### 3.5. ON AGRICULTURAL DEMAND AND PRODUCTION:

In the following 2 decades world population is predicted to increase by about 1.14 percent and most of that increase is expected to be in developing countries with a focus on China and India and other middle income developing countries. This will mean a significant increase in demand for meat and dairy products. Cereals are of direct concern here and competition will arise with the production of ethanol.

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[1] Dias de Oliveria, Marcelo E., Burton E. Vaughan, and Edward J. Rykiel Jr. "Ethanol as Fuel: Energy, Carbon Dioxide Balances, and Ecological Footprint." BioScience 55:7 (2005):593-602

### 3.6. ON LAND USE:

Around 1.6 billion ha of land are being used currently for crop production, and almost 1 billion ha of that is in developing countries. Africa and Latin America have the most arable land expansion potential, whereas there is very little scope of expansion in Asia which is home to some 60 percent of the world's population.

In a scenario made by IIASA for OFID in "Biofuels and Food Security" projected global use of cultivated land increases by about 200 million ha between 2000 and 2050 in total, however most of that increase is in developing countries whereas developed countries remain fairly stable. Africa and South Africa account for 85% of the increase of land use for agricultural produce. These scenarios include crop demand for biofuel production and the results illustrate that about 150 million ha of additional arable land will be required by 2050 to meet the demand.

**Table 1. Cultivated land worldwide in millions of hectares**

| **Cultivated land (million hectares)** | | | | | |
|---|---|---|---|---|---|
| **YEAR** | **2000** | **2010** | **2020** | **2030** | **2050** |
| North America | 234 | 236 | 238 | 241 | 245 |
| Europe & Russia | 339 | 339 | 338 | 337 | 332 |
| Pacific OECD | 57 | 59 | 58 | 60 | 63 |
| Rest of the World | 42 | 41 | 40 | 39 | 37 |
| Africa | 225 | 245 | 265 | 287 | 316 |
| Asia, East | 147 | 146 | 146 | 146 | 145 |
| Asia, South | 274 | 282 | 289 | 295 | 300 |
| Latin America | 174 | 194 | 213 | 230 | 247 |
| Middle East & N. Africa | 67 | 69 | 70 | 72 | 73 |
| Developed | 673 | 675 | 674 | 677 | 678 |
| Developing | 887 | 937 | 984 | 1030 | 1081 |
| **World** | **1560** | **1612** | **1658** | **1707** | **1759** |

*Source: IIASA world food system simulations; scenario, December 2008*

## 4. ALGAE GROWTH HARVESTING AND YIELDS

Some algae strains contain up to 60% lipids and produce over 50% net oils that can be converted to high-powered jet fuels or bio-diesel.

Many algae producers began algae culture purely by chance either because they had surplus tanks that spontaneously produced algae, that they then began to grow as a food substitute for feed corn, or because they found an open pond that naturally grew algae. Many companies who have actively ventured into algae production for fuel are listed in Chapter 9. Some of these US-based companies claim they will be able to commercialize algae oil by 2010-2012. The EU is taking a stand back approach and has put down a probable goal of commercialization by 2020[2].

Algae can be either sexual or asexual creatures. Their sexual reproduction system is rather complex but very efficient and in one day a plant may produce up to several million descendents. Asexual propagation on the other hand is a combination of three different strategies:

- Cellular division (divides the cell in two and the cells separate)
- Fragmentation (pieces break off the parent and start growing individually)
- Spores (creates zoospores which break off and start growing independently)

Algae can grow in either way depending on their structure and in some cases use both systems to reproduce. In some variants of algae, like the green algae for example, reproduction could be altered if the environment changes or certain conditions in the environment change, if, for example, nutrients change or if moisture levels change. **Stressing** is a commonly used term amongst algae producers and is a process whereby environmental conditions are purposely changed in order to allow algae to grow with special characteristics. With the correct stress technique in place algae could either grow faster, or produce more oils or more proteins or more carbohydrates.

Micro-algae are tough little creatures and have the ability to grow quickly when conditions are favourable. If the conditions change and the plants die, they always leave behind cells or spores that are capable of revitalizing once conditions are once again fit for growth.

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[2] European Algae Biomass Summit EABA – Executive Director Mr. Raffaello Garofalo at the EABA first meeting on June 3-4 Florence, Italy

Algae, similar to land plants also use the carrier strategy where fragments of their parts are carried away by animals.

### 4.1. BIOMASS PRODUCTION:

Basically micro-algae are plants and the primary requirements for a plant are sunlight, water and nutrients. Algae that are cultivated are no different except their productivity can be controlled. In some cultivation systems algae can double or triple in volume in just one day[3]. Their growth rate slows down on a cloudy day and shuts down at night making way for the rest and respiration phase.

### 4.2. NUTRIENTS AND NUTRIENT STRESS:

Algae just like any other plant require nutrients and fertilizers to grow productively. There exist various mediums and recipes for each algae strain and these recipes can be found on the University of Texas website http://web.biosci.utexas.edu/utex, where algae strains can also be purchased. Some of these nutrients are provided to the algae through the water itself and others have to be dissolved into the water. It is important to recycle the water in order to save on wastage and also to make use of every little amount of nutrients available through the system.

When algae culture is deprived of a certain nutrient or fertilizer, it goes into defense mode and begins to chemically change in order to build a protective mechanism. This in turn alters the composition of the cell and hence certain characteristics of the cell may emerge while others may diminish, but never totally disappear from the cell. In these cases algae usually increase in lipid storage.

This adaptability to the local environment enables and has enabled micro-algae to survive through millions and millions of years and to continue living and evolving.

Whether the algae naturally undergo a stress or are forced to by man, the fact that the composition of the strain will be affected is certain. Under certain conditions algae can accumulate neutral lipids up to 50% of their dry weight, mainly in the form of

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[3] Hu, Qiang. "Industrial Production of Micoalgal cell-mass and secondary products – Major Industrial Species" Handbook of Micoralgal Culture Biotechnology and Applied Phycology. Ed. Amos Richmond. Oxford, England: Blackwell Science, Ltd., 2004; 264-73.

triacylglycerol (TAG)[4]. These TAGs do not form part of the structure of the cell but serve as storage for carbon and energy. TAGs are what bio-diesel are made from.

In principle the concept is the same as in other plants, however in land plants the lipids are stored in tissues or organs such as seeds or fruit. Algae have the ability to store several types of lipids in one single cell. The ability to store certain lipids under stress conditions is strain specific and not genus specific and some algae such as cyanobacteria do not accumulate lipids under stress.

Fatty acids are what form and produce lipids in algae strains; they can be either saturated or unsaturated and can be a medium, long or very long chain. The quality of the bio-diesel is determined at large by the structure and component of the acid esters. There are several ways to alter the cell in order to force it to produce the right amount of lipids or carbohydrates or proteins.

- **Chemical and physical mechanisms** can stimulate changes and fatty acid composition of the cells.
- **Nitrogen limitation** – this affects lipid metabolism and algae. Deficiencies in other elements such as phosphate and sulfate also (to a minimum degree) increase lipid accumulation.
- **Temperature** has a large effect on fatty acids – decreasing temperature increases fatty acids and tends to make the algae produce more saturated fatty acids, whereas temperature increase tends to increase lipid content.
- **Light intensity** – causes changes in the chemical composition of the cell. Low intensity induces polar lipids while high intensity increases storage of TAGs.

### 4.3. CULTIVATION OF ALGAE:

There are 3 ways to grow and harvest micro-algae for mass production;

1. **Photo Bio-Reactors (PBR)** – Man-made machines especially designed to grow algae in optimum conditions. These can be either horizontal or vertical tubes placed in such a position to absorb the maximum light intensity. Nutrients and $CO_2$ are fed through the pipes and the water is completely recycled. No loss of water due to no evaporation. Industries are constantly working on the materials to build and

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[4] Edwards Mark Green Algae Strategy Tempe, Arizona; Edwards, 2008

improve the tubes. Problems that have arisen are that some algae tend to stick to the inside of the pipe, hence covering the inside and not allowing sunlight to enter.

2. **Open Pond System** – Small lakes where algae are grown in open air. A moving paddle wheel is set in place to allow the algae to circulate in order to obtain sunlight, and to absorb maximum nutrients whether from the waste water or from the environment.

3. **Closed Pond System** – Similar to small lake, but with a cover to protect it from contamination and extreme weather.

Growth and reproduction of algae cells occurs when a variety of variables are in place. These variables are required not only to induce growth but can also change the chemical composition of the cell itself.

- **Light** – both natural light and artificial light can be used. Some photo bio-reactor systems have light inside the tubes for night time growth and reproduction.

- **Mixing** – Most growth takes place on the top layer because that is the area that faces the sun more frequently, therefore in order for the rest of the algae to take in the sun intensity mixing is required. Each cell needs to move about and take in light and go to the dark as well as taking in $CO_2$ and release $O_2$.

- **Nutrients** – Algae are just like any other plant and require the same kind of nutrients as any other land plant. They do require less per kilogram of biomass, and because the nutrients are dissolved in the water and the water is recycled – none are wasted.

- **Water** – Any kind of water is suitable, brackish, saline or freshwater, particularly efficient is the use of waste water that contains nutrients.

- **$CO_2$** – This is what makes algae thrive. They grow exponentially with $CO_2$, which can be fed to them through tanks similar to oxygen tanks for underwater scuba diving or as a flue gas from large nearby emitters.

- **pH** – Controlling the acidity of the water (pH) means also making sure the algae is not changing its chemical composition. If the pH is kept at the correct amount, invasive and competing algae will not take over.

- **Stability** – When the algae grow too fast it is difficult to maintain a high stability. They may retain too much of any nutrient or retain $O_2$, causing stress on the algae and forcing a change in their chemical structure.

### 4.4. CULTIVATION OF ALGAE – CHALLENGES:

Algae grow very quickly to a maximum until they hit a limitation on mineral, chemical, nutrient, light or temperature. If one of these nutrients is absorbed to the maximum the plant will stop growing and wait until more of the minimum is again available. One of the major challenges of algae culture is making sure that there are continuous nutrients available. One other problem is that algae do not graze; they cannot move and hence they have to rely on food that comes to them. Rich, thick biomass grows very quickly and at times impedes the mixture of nutrients and sunshine making it a challenge for all the cells to receive the right amount of nutrients.

The world requires about 80 million barrels of oil a day. A square metre of water (given that the right nutrients and $CO_2$ and sunlight are available) yields roughly over 60gr of algae, which means that 1 hectare should be able to yield about half a tonne. Therefore to completely replace the 80 million barrels of crude oil with algae oil we would require 30 million hectares of land. That equates to an area the size of the Philippines or one tenth of India.

This is not an impossible achievement if the technology is available costs are lowered and yields are improved with strain selection, stressing the algae and perhaps genetic modification of the strain itself. However, the European Union (EU) would probably not accept the GMO's because of their tough regulations on Genetically Modified Organisms (GMO's). Furthermore, we would have to be careful with using GMO's especially if the algae biomass is used as animal feed after the oil extraction. This would mean that the GMO would somehow enter the human food chain.

# 5. ALGAE OIL AND BIO-DIESEL PRODUCTION

Once the algae have grown they need to be harvested, this is generally done in the late morning period of the day when the algae have maximum cell density. Not all the algae are harvested however (roughly ¼ is left), to allow continuous growth and harvesting the following day.

There are 3 main ways to harvest algae: froth floatation, settling and flocculation. Depending on the strain and species one way may be more suitable than the other.

- **Settling:** This is a simple process whereby the algae are allowed to settle overnight (without mixing) to the bottom of the pond (open pond system) where they can be removed and dried. Alternatively the water can be passed through a fabric or filter and the algae can then be simply scraped off and dried.

- **Flocculation:** This is a process where particles are suspended in the form of floc or flakes. Small solids form in clusters and aggregate which makes it easier to see and to remove with filters. $CO_2$ deprivation causes algae to flocculate spontaneously – auto-flocculation.

- **Froth floatation:** This is a process where the water is aerated allowing froth together with algae to float and be skimmed off just like the froth on hot milk.

Once the algae have been harvested using one of the above systems, they require drying. This is usually the most expensive step in the algae oil extraction process because it requires a lot of energy if the drying is done with current available technology. These are machines that either centrifuge or de-moisturize the algae so that only about 5% of water remains. Alternatively the sun is the best drier and certainly the most economical; the more efficient the drying process is the maximum number of products can be extracted from the biomass[5].

As already mentioned the algae cell wall is very robust and hard to crack in order to extract the oily lipids. Various methods exist from pressing to using chemicals and sound. Some of the most common are listed below.

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[5] Edwards Mark Green Algae Strategy Tempe, Arizona; Edwards, 2008

- **Chemical solvents –** Usually benzene is used to extract the oil. These solvents are dangerous to work with so care is needed when using them. Vapours and direct contact with skin can cause damage. Benzene is flammable and is a carcinogen.

- **Soxhlet –** This method of extraction through a washing process with chemical solvents like hexane or petroleum ether.

- **Enzymatic –** Extraction is obtained by degrading the walls of the cell by using enzymes, the water then acts as the solvent and eases the extraction of the oil.

- **Expeller press –** Crushes and pushes the oil out of the dry algae biomass very much like juice is crushed out of grapes and oil out of olives.

- **Osmotic shock –** If there is a sudden reduction on osmotic pressure[6] the cell walls can rupture. The oil surfaces and it can be skimmed off the top.

- **Ultrasonic extraction –** This process creates bubbles in a solvent. When these bubbles burst near the cell they create shock waves which cause the walls to break and release the oil.

Science and technology are making great progress in this field and new ways and methods of extracting oil from algae are being invented and patented on a regular basis.

## 6. ALGAE STRAIN SELECTION AND BY-PRODUCTS

Micro-algae are one of the smallest, most ancient and robust organisms living on Earth and one of the tiniest plants, which alone produce about 60 percent of the Earth's oxygen. They have survived some of Earth's harshest conditions for several billion years due to their incredible and robust cell wall. Ironically, it is this very same thick cell wall that is very energy intensive to break into (in order to extract the oil) and is one of the reasons that full scale commercialization and production of algae oil has not yet been achieved.

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[6] **Osmotic pressure** is the pressure that must be applied to a solution to prevent the inward flow of water across a semipermeable membrane – www.wikipedia.org

Micro-algae come in a variety of strains (variants) and each strain has different proportions of lipids (fats), starches and proteins. Depending on this proportion the algae can be used to produce oil for bio-crude or if the variant contains more carbohydrates and less oil it can be fermented to make ethanol or biogas. It is interesting to note however, that many algae species have been found to grow very fast and to produce great amounts of oil (up to 50%). These are called oleaginous algae and are suitable for the production of liquid fuels.

**TABLE 2. SOME ALGAE STRAINS – COMPOSITION OF ALGAE (% OF DRY MATTER)**

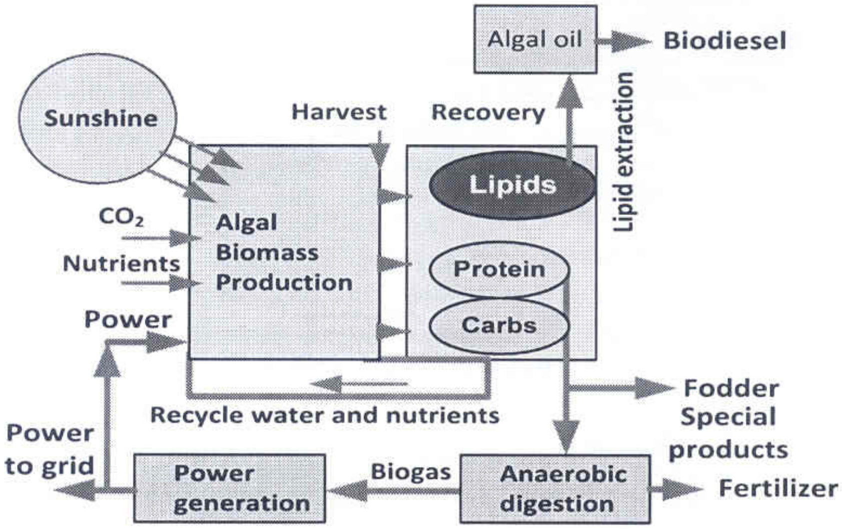
| ALGAE | LIPIDS | PROTEIN | CARBOHYDRATES |
|---|---|---|---|
| ANABAENA CYLINDRICA | 4-7 | 43-56 | 25-30 |
| APHANIZOMENON FLOS-AQUA | 3 | 62 | 23 |
| ARTHROSPIRA MAXIMA | 6-7 | 60-71 | 13-16 |
| BOTRYOCOCCUS BRAUNII | 86 | 4 | 20 |
| CHLAMYDOMANAS RHEINHAR | 21 | 48 | 17 |
| CHLORELLA ELLIPSOIDEA | 84 | 5 | 16 |
| CHLORELLA PYRENOIDOSA | 2 | 57 | 26 |
| CHLORELLA VULGARIS | 14-22 | 51-58 | 12-17 |
| DUNALIELLA SALINA | 6 | 57 | 32 |
| EUGLENA GRACILIS | 14-20 | 39-61 | 14-18 |
| PRYMNESIUM PARVUM | 22-38 | 30-45 | 25-33 |
| PORPHYRIDIUM CRUENTUM | 9-14 | 28-39 | 40-57 |
| SCENEDESMUS OBLIQUUS | 12-14 | 50-56 | 10-17 |
| SPIRULINA PLATENSIS | 4-6 | 4-630 | 13-16 |
| SPIRULINA MAXIMA | 6-7 | 60-71 | 13-16 |
| SIROGYRA SP. | 11-21 | 6-20 | 33-64 |
| SYNECHOCOCUS SP. | 11 | 63 | 15 |

*Source: Edward, Green Algae Strategy*

As we have seen from the various strains and their cell structure, algae come in a variety of forms. Some have a very high lipid content like *Botryococcus braunii* or *Chlorella ellipsoidea* others are rich in proteins *Spirulina platensis* (effective in aids patients). Therefore depending on the strain chosen we can chose to produce either biofuels or ferment the algae to produce bio-gas.

If we take one particular strain, for example *Botryococcus braunii* we can see it is very suitable for oil production because of its high lipid content. From this particular strain we could probably obtain about 50% oil content from its dry physical state. Once the oil is extracted (various technologies to extract the oil can be found in chapter 5 of this document) the dry left over matter can take several pathways from which valued by-products can be made. For a start the dry left over biomass can go through an anaerobic process and hence produce bio-gas to generate energy for the algae farm itself. The left over fodder and fertilizers can still further be used. Another alternative is to use the left over dry matter which is still rich in omega3 as a food supplement for fish.

**Figure 1. Algaeculture Production System**[7]



*Source: Edward, Green Algae Strategy*

The Integrated Algae Energy System (IAES) (explained in detail in chapter 15) would make use of this left over dry matter to give to the fish aquaculture farm which will generate food and with the waste from the production of fillets produce another bio-diesel + glycerine as a valued by product.

## 7. $CO_2$ ABATEMENT AND CLIMATE CHANGE MITIGATION

Besides sun and water the other two fundamental requirements for algae production are $CO_2$ and waste water. The $CO_2$ allows the algae to thrive whereas the waste water carries all the nutrients available for the algae cells. The $CO_2$ can be taken from power stations or from other emitters like cement making facilities.

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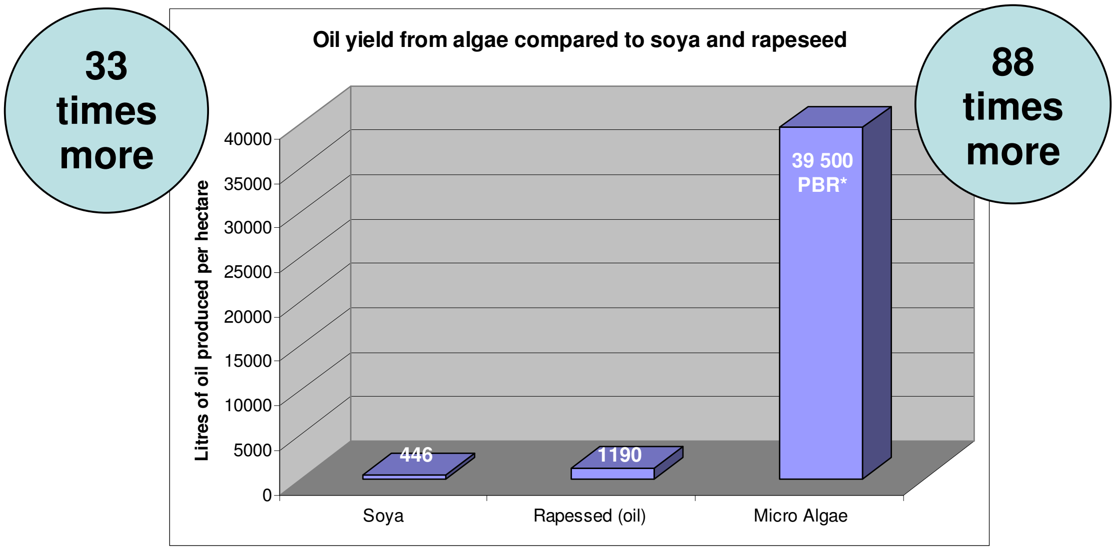
[7] Edwards Mark, Green Algae Strategy Tempe, Arizona; Edwards, 2008

The process for algae to absorb $CO_2$ is called bio-fixation; bio-fixation is particularly advanced in algae because of their cell structure. Most of the other plants (particularly land plants) are not good at this and are only capable of fixing about 1-2% of the energy they receive from the sun to allow the photosynthetic process to take place. Algae, as a result of this incredible capacity to fix $CO_2$ can grow faster and can almost double their weight in a day (under optimum conditions even triple). Furthermore this process of exponential growth can continue forever[8]. It may very well be possible that storing $CO_2$ in algae cells can be a cheaper way at reducing carbon dioxide emissions compared with other methods like storing it in tanks underground or underwater.

Algae culture can mitigate climate change very effectively; this is because it captures the $CO_2$ and stores it in the plant cell. Now it is true that when the algae dies it will return that $CO_2$ into the atmosphere, however if we turn some of that carbon fixed into the cell into oil then the process takes a different fold. One tonne of algae can sequester almost 2 tonnes of $CO_{2.}$ Some strains of algae have half their weight in lipids and are more productive at producing oil than conventional land plants covering the same area. For example with the same land use algae can produce 88 times more oil than soy beans.

Soya – 446 liters yield from 1 hectare of land (mainly used in the US)
Rapeseed – 1190 liters yield from 1 hectare of land (mainly used in EU)[9]
Micro algae – Up to 39 500 liters yield from 1 hectare of land

**Figure 2. Yields per hectare of microalgae compared to other land based feedstock**



**PBR* photo bio-reactor**

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[8] Goodall Chris, The technologies to save the planet London, UK; Goodall, 2008
[9] http://journeytoforever.org/biodiesel_yield.html

Burning the algae diesel in an engine may seem to be emitting carbon dioxide and indeed that is what is happening, however the car that runs it will be essentially carbon neutral, because the gas that has been emitted will have been taken (sequestered) previously. In terms of net affect it would be the same as storing the $CO_2$ in tanks underground i.e. there are zero $CO_2$ emissions into the atmosphere. The $CO_2$ is either bubbled through the ponds or bio-reactors or it is fed through the systems from tanks.

## 8. WASTE WATER FOR ALGAE GROWTH

Nutrients are very important to the growth and reproduction of the algae cell, in particular nitrogen and phosphorous, N and P. These nutrients required by the algae cells actually can be found in waste water; waste water in fact can act as a nutritional base for algae.

Waste water from human, animal and some industries can contain enough nutrients for algae growth. The algae provides the waste with oxygen and therefore lowers the biological oxygen demand (BOD) of the waste itself. These wastes, however, need to be collected in very large amounts and above all need to be liquefied.

Human waste (please keep in mind that this is region specific due to dietary habits of various populations) contains roughly 3kg N per capita/per year and is equal to a potential 30kg of algal biomass per capita year. This would mean that for a 100 tonne/ha/year productivity we would require 3,000 people (3,000 multiplied by 30kg = roughly 100 tonne), based on the fact that N levels in the biomass would be at 9%. Standard sewage treatment ponds reduce only the BOD but do not remove nutrients from the waste.

Similar achievements can be obtained from pig waste and cow manure, however there are considerably fewer pigs and cows in the areas where algae farms could be established, but the N levels in their waste are much higher than humans. Pigs in actual fact excrete 16kg of N per year and cows 70kg of N per year.

A typical 10 hectare algae pond therefore would have to collect waste from a population of about 30,000 people, 5,000 pigs or 1,200 cows.  Both pig and cow dairy slush although more manageable, would be much harder to collect unless the algae pond was in proximity to a farming area, in which case the sludge would be easier to collect. Odours would however be a major concern.