# AQUATIC BIOFUELS
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## 1. BACKGROUND

The production of biofuels dates back to the very first diesel engine invented by Rudolf Diesel who foresaw vegetable oil as a fuel source for his engine[1]. Henry Ford had high expectations of his Model T to also run on ethanol, another biofuels energy sources. As the story goes, petroleum then entered the equation and proved to be the most logical and "easy" fuel source. This was mainly due to its large supplies, low price and high efficiency. On a much smaller scale, some vegetable oils were being used to replace diesel fuel during the 1930s and 1940s.

Currently around 2-3% of the world's energy derives from agricultural biofuels - a figure which is predicted to increase especially with the recent rise in the cost of crude oil at US$135 (May 2008), per barrel. Already in 2007, the European Union instructed that 10% of all transport fuel consumption in the EU be sourced from biofuels by 2020 in order to help fight climate change. Biofuels produced from rapeseed (canola) oil will probably be the European Union's preferred biofuel commodity choice.

However, what impacts will that have on rapeseed and canola oil production as well as animal feedstock? A much broader question would be: what impacts will the over-production of certain biofuel commodities have on the sustainability of that commodity, and on the environment?

Recent talks on biofuels have outlined their un-sustainability in the production phase; commodities such as corn, rapeseed, palm oil and soya are being grown and harvested in a way that could have negative economic, social and environmental effects, and have a global impact on land use, food security, water resources, deforestation and global markets.

This paper will be looking at alternatives to agricultural commodities for biofuel production and focusing on 2 ways of producing oils suitable for biofuels extracted from fish waste and algae.

## 2. IMPACTS OF AGRICULTURAL BIOFUELS

### 2.1 ON BIODIVERSITY

As the world population increases, so too will its demand for energy. Many scientists fear that 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 would also see land being taken away from them to produce commodities for biofuels.

[1] http://auto.howstuffworks.com/biodiesel2.htm

### 2.2 On markets

Another concern is that as biofuels are becoming more lucrative for farmers, the farmers subsequently grow crops for biofuel production instead of food production. Lower food production increases prices and is causing 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.

### 2.3 On food security

The developing countries of Africa import about 10 MMt of maize each year; another 3–5 MMt 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.

### 2.4 Nitrogen in the environment

Another concern is that intensive farming increases the amount of nitrogen oxide released into the environment. To efficiently farm biofuels currently means using nitrogen fertilizers, as is common practice among farming communities. Fixed nitrogen is naturally present in soil but becomes $N_2O$ ($N_2O$ 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 $CO_2$)[2] when crops are harvested. 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 when they get into drinking water and killing off life in lakes and rivers.[3]

## 3. Aquatic Alternatives

The stress on land-use and food security to produce biofuels is becoming quite significant and will be even more so in years to come. Therefore looking at aquatic resources for energy production makes not only ecological sense but economic sense too. Two alternatives do exist to agricultural biofuels, these are; the extraction of oil for biofuels from micro algae and oil for biofuels from fishgut or fish waste. Although still at an experimental phase the potential is good and research is being carried out on both fronts in many countries to explore sustainable ways of producing and harvesting maximum yield of oil for biofuels from micro algae and fish gut/waste.

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[2] http://www.greencarcongress.com/2007/09/study-n2o-emiss.html

[3] http://www.iop.org/EJ/article/1748-9326/2/1/011002/erl7_1_011002.pdf?request-id=ef187622-200f-4b81-9e7b-b7ca66480f0f

### 3.1 FISH GUT/WASTE

The use of animal gut to produce bio-diesel is not a new technology; however the adaptability of this technology to aquatic resources has only attracted public interest recently. The process is simple. Fish oil is derived from the leftover gut/waste after fish fillets are produced and is mixed with methanol (roughly 10%) and other products. 1kg of fish gut/waste can produce just over 1lt of bio-diesel.

Two main companies deserve to be mentioned and are making a significant contribution to local energy production through the use of fish gut/waste. One of these is AGIFISH in Vietnam using catfish waste and the other is Aquafinca in Honduras, using tilapia

**Aquafinca**

Saint Peter Fish of Honduras, which specialises in the processing of tilapia fish, is estimated to be producing over 11 000 litres of bio diesel from tilapia fish oil per day. The company claims to have subsequently become the leader in converting oil from animal origin into bio diesel fuel. The bio diesel is used to produce electricity at its production facility as well as running its vehicles, including 10 lorries and eight buses that transport its 1 500 workers. Aquafinca operates a tilapia farming facility in the El Cajon dam as well as at Yojoa lake. It also exports some 25 million kgs of tilapia fish per year to the USA market.

**Agifish**

The leading Vietnamese catfish producer has teamed up with Saigon Petro and two local refrigeration firms and announced successful initiatives towards the large-scale production capacity of efficient biofuel from the gut of tra and basa catfish. The General Director of Agifish Mr. Ngo Phuoc Hau said that together they have agreed to set up a joint venture holding the major stakes by Agifish and Saigon Petro. A plant with the production capacity of 30 000 tonnes of fuel per year is set to be established in An Giang province, and will be provided with imported equipment.

A feasibility study is underway and negotiations on investments and possible plant-sites are still being tabled. After studying the production of fuel from fish waste for more than a year, the national scientific council and local tra and basa catfish farmers and processors welcomed the project. A co-op is to be established soon for the development of biofuel. With a consumption of 400 000 tonnes of basa and tra every year, the Mekong Delta provinces will likely provide 50 000 tonnes of fish waste.

The technology used in the production of biofuels from fish gut/waste is adaptable and transferable in many other parts of the world including developing regions in Africa and other regions in Asia and Latin America. It can provide livelihoods, and produce local energy free from green house gases and emissions. With little investment in already existing fish farms local energy can be produced at very little cost. Catfish and tilapia could be used by economic planners as income generating opportunities for rural communities. That is, the breeding of both species could provide cash on a sustainable basis to rural communities throughout the developing world. These fish farms could provide income from the production and export of fish fillets and produce relatively cost-free local energy. It could therefore have a positive impact on food security and energy security.

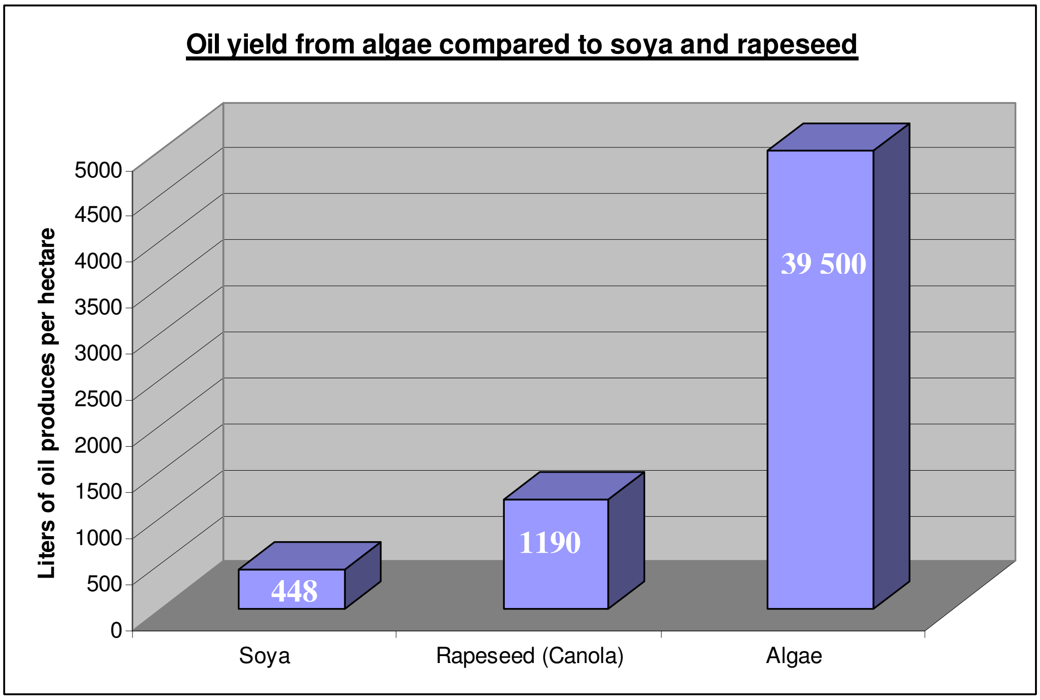
### 3.2 Micro algae:

Micro algae have been aquacultured for many years for pharmaceutical and for health food purposes but never in a large scale commercial enterprise. The oil contained in some species of micro algae is very similar to vegetable oil making it very suitable for energy production.  The main advantages with producing micro algae for energy production are:

- Does not compete with agriculture
- High per acre yield
- Contains no sulphur therefore no SO2 emissions
- Non toxic and highly biodegradable
- Does not require soil for growth
- Uses as little as 8cm of water per year
- Adaptable anywhere even at great distances from water.
- Industrial emissions of CO2 from power plants, refineries, and other stationary emitters can be productively consumed by micro algae in engineered plants and used to manufacture valuable products, thus making the whole process carbon neutral.

Furthermore the yield of oil from micro algae is much higher when compared to agricultural biofuels. For example for the same amount of land used micro algae yield 40 times more than rapeseed and 100 times more than soya.

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)[4]
Micro algae – Up to 39 500 liters yield from 1 hectare of land




[4] http://journeytoforever.org/biodiesel_yield.html

Micro algae hold great promise because they grow very rapidly, are rich in vegetable oil and can be cultivated in highly engineered re-circulating ponds of fresh or brackish water, thus minimizing the use of fertile land and irrigation water.

Micro algae can also grow in man made bio – reactors (where temperature and ideal conditions are generated, monitored and controlled to ensure maximum yield). The process works by converting sunlight into oil through the use of micro algae. Micro algae can produce more oil in an area the size of 2 garages than an entire football field of soybean. The single celled species in particular are very efficient at capturing and absorbing nutrients.

**Table 1: Various parameters showing the relativity between** open ponds vs. closed photo bio-reactors.

| Parameter | Relative | Notes |
|---|---|---|
| Contamination risk | Ponds > PBRs | Much reduced for PBRs |
| Space required | Ponds ~ PBRs | A matter of productivity |
| Productivity | Ponds < PBRs | PBR's 3-5 times more productive |
| Water losses | Ponds ~ PBRs | Depends upon cooling design |
| CO2 losses | Ponds ~ PBRs | Depends on pH, alkalinity, etc. |
| O2 Inhibition | Ponds < PBRs | O2 greater problem in PBRs |
| Process Control | Ponds < PBRs | Very important in PBRs |
| Biomass Concentration | Ponds < PBRs | 3-5 times in PBRs. |
| Capital/Operating Costs Ponds | Ponds << PBRs | Ponds 3-10 x lower cost! |

*Source Nrel:* http://www.nrel.gov/biomass/pdfs/benemann.pdf

So are photo bio–reactors better than ponds? It seems that in some cases they are, although they are often overstated. Biofuels cannot afford excessive costs, therefore a solution to grow the right kind of micro algae at minimum costs is vitally important. Hundreds of species of micro algae are being experimented with, such as *Arthrospira platensis* (spirulina) which is easy to culture and easy to harvest but does not contain a high oil content and *Haematococcus pluvialis* (red algae), which is very high in oil yield.

With the correct species in place and the right conditions the species can produce oil at near-theoretical limits. Micro algae are less than 30 microns in size and their aquatic nature makes them perfect for large scale, highly automated, closed production systems like the photo-bioreactor (PBR). These are systems that are highly tuned to provide the precise conditions for max productivity.

Algae thrive on CO2 and NO2 (pollutants of power plants) – ant these act as nutrients for the micro algae. These facilities can thus be fed exhaust gases from fossil fuel power plants reducing even more CO2 and NO2 emissions, hence making the whole process carbon neutral.

Micro algae are a feasible option for large scale energy production, although the cost of setting up plants (photo bio-reactors) is considerable high. However, the yield is high and production costs are kept to a minimum due to the limited resources required (sun + water + CO2). CO2 is a strong driving force in the photosynthetic process of micro algae and actually "feeding" $CO_2$ to the micro algae can speed up production considerably. Through minimal water use and simple sustainable operations a photo bio-reactor farm can sequester $CO_2$ from nearby industry and feed it to the micro algae plant to produce oil, plus by-products such as proteins, methane and fertilizers as well as obtaining $CO_2$ credits for effectively reducing greenhouse gas emissions. According to GreenFuel's Chief Technology Officer Isaac Berzin, an micro algae farm large enough to absorb all the $CO_2$ from a 1000 megawatt power plant (which would likely need to span 8-16km2), could potentially produce 150 million litres of biodiesel[5]

Significant hurdles have yet to be overcome however before micro algae to biofuel production becomes cost-effective and makes a difference to the world's supply of transport fuel these are:

- Capital and operational costs

- The cost of development work to increase productivity of algal cultivation and harvesting systems.

- Cost of harvesting micro algae.

Producing oil from algae is also energy intensive, requiring large amounts of energy to filter the algae for oil extraction. Recent developments in algae extraction technology however, have managed to surpass some of the problems making the process more energy efficient.

**Some of the large investors and companies experimenting with micro algae to biofuel energy production are the following:**

**A2BE Carbon Capture LLC (www.algaeatwork.com)**
The A2BE Carbon Capture solution is unique in that it addresses carbon capture and recycling as well as the production of biofuels, animal feed protein, and fertilizer in a single integrated plant. $CO_2$ can originate from stationary sources such as fossil fuel fired power or heat plants.

Ideal characteristics of a commercial solution include:

- Able to capture $CO_2$ at the source
- Capable of recycling $CO_2$ into multiple beneficial uses
- Capable of producing biofuels that displace the use of fossil fuels and their $CO_2$ emissions
- Capable of producing biofuels that do not compete with the production of human food supplies or land use.

At the core of the technology is the photo-bioreactor micro algae growing/harvesting (PBR) machine (see photo 4 for diagram). Each PBR machine is 350' (100m) long and 50' (15m) wide consisting of twin 20' wide x 10" deep x 300' long, transparent plastic "micro algae water-beds".

[5] http://www.ecosherpa.com/news/algae-co2-biofuel/

PBR attributes include the following:

- Each PBR has a closed photo-bioreactor with bio-isolation to prevent cross-contamination.
- Each is piped CO2 and NOx bearing flue gas emissions or pure CO2 plus water and nutrients.
- Each produces pure O2 and a concentrated slurry of biomass through piped manifolds.
- PBR tubes are expendable in case of wear out or culture crash and are simply unrolled over an engineered base.
- Multi-function rollers pump in both directions, re-suspend micro algae, degas media, and clean internal surfaces.
- Parallel sets of counter-rotating helical currents within the bags photo modulate the light to the micro algae as they are carried up through the photo-tropic zone.
- Fully enclosed system prevents water evaporation and percolation. Water consumption is only 3" of equivalent rainwater use per year.
- Passive control of temperature extremes is achieved through a thermal radiation-conduction switching membrane within the bioreactor tubes.
- Bio-harvesting aggregates micro algae cells into larger, more separable, organisms allowing in-situ extraction and continuous production w/o resorting to batch stressing.
- Profitability is enhanced by the production of biofuel, protein, fertilizer, and methane.

**Shell Oil**
Some of the bigger energy companies like Shell and HR Biopetroleum have formed a joint venture called "CELLANA", and are conducting a pilot project. They are looking at investing some time and money in the research and they are building a refinery in Hawaii.

The site has been leased from the Natural Energy Laboratory of Hawaii Authority (NELHA), and it is located near existing commercial micro algae enterprises, (which are being used for pharmaceutical purposes). The facility will not use up land that is suitable for conventional agriculture but will be built on coastal areas. The harvested micro algae and the extracted oil will be used for testing within the facility.

CELLANA are intensifying their micro algae production growth by "feeding" CO2 into the micro algae plants. However, they are not capturing the CO2 from nearby power plant emitters but instead are buying bottled CO2 and feeding it into the micro algae to explore the potential.[6]

**Marine Institute (IM) of Comodoro Rivadavia**
Researchers from the Marine Institute (IM) of Comodoro Rivadavia (Chubut), Argentina, researched the possibility of starting up production of bio-diesel fuel from micro algae oil, among other raw materials. The research project is a continuation of projects worked on by personnel of the Hydrocarbon, Mines and Geology Secretariat, and other bodies, together with entrepreneurs of small and medium-sized companies in Comodoro

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[6] http://www.shell.com/home/content/media en/news_and_library/press_releases/2007/biofuels_cellana_11122007.html

Rivadavia and Puerto Madryn. Marcelo Gonzalez Machin, from Puerto Madryn is among the business persons that have developed state of the art systems for oil extraction from micro algae, and according to Pesca & Puertos, has succeeded in extracting 90% of oil from seaweed. To produce industrial fuel, estimates calculate that it is necessary to produce at least 20 000 litres of micro algae oil per day. This in turn requires searching for interested investors for the project. For each hectare of micro algae production, 55 times more oil is produced than any other oil-bearing plant. Moreover, due to the superior output of micro algae, the initiative allows for exploitation of a resource that is natural to the area.

## 4. RECENT DEVELOPMENTS WORLDWIDE IN MICRO ALGAE PRODUCTION

- In **Florida**, PetroAlgae said that it hoped to reach its commercial production stage next year, as algae producers begin to differentiate over varying methods of getting past the algae "shade wall" and other issues in achieving commercial scale.

- **New Zealand**'s Aquaflow said that it has developed a scalable method for producing and harvesting wild algae in sewage treatment facilities, and envisioned expanding to a series of 1,000 acre facilities in the US and other countries.

- A research team from the University of **Texas** has developed a new blue-green algae (cyanobacteria) that secretes a soft cellulose as well as glucose and sucrose. The team told Science Daily that the microbe "could provide a significant portion of the nation's transportation fuel if production can be scaled up." The cyanobacteria is grown in sunlight and salty water at facilities on non-agricultural land. The team said that the cellulose is a soft, gel-like type that is easy to break down, and that the microbes secrete the sugars and cellulose, making it possible to continually harvest biofuels feedstock without destroying organisms and using powerful enzymes to extract sugars.

- In **California**, tests on Soladiesel from Solazyme conducted by the Southwest Research Institute concluded that algae-based bio diesel has superior performance under cold weather conditions than bio diesel derived from other feedstocks.

- The National Algae Association held its first meeting in April 2008 to discuss new ventures, and paths to profitability.

- In the **Netherlands**, AlgaeLink claimed a new process for extracting algae oil without using chemicals, drying or an oil press. The company said that its patent-pending technique uses 26 kilowatts of power to produce 12,000 gallons of algae oil per hour, with a yield of 50 percent from the initial algae paste.

- In **Texas**, the state's Emerging Technology Fund will provide $4 million to Texas AgriLife Research and General Atomics to conduct micro algae research and development.

- In **Virginia**, researchers at Old Dominion University have successfully piloted a project to produce bio diesel feedstock by growing algae at municipal sewage treatment plants. The researchers hope that these algae production techniques could lead to reduced emissions of nitrogen, phosphorus and carbon dioxide into the air and surrounding bodies of water. The planned pilot project would hope to produce up to 70,000 gallons of bio diesel per year.

- In **Minnesota**, Xcel Energy has pledged $150,000 to assist in funding an algae-to-bio diesel research project sponsored by the University and the Metropolitan Council. The grant is a follow-on to more than $4.5 million given to five other University of Minnesota projects from the Xcel Energy Renewable Development Fund.

- The US Department of Energy recently partnered with Chevron in a research effort to develop higher-yield strains of micro algae. The Defense Advanced Research Projects Agency is working on a project with Honeywell, General Electric and the University of **North Dakota**.

- In **Texas**, US Sustainable Energy is awaiting lab results from a test of biocrude production using 20 pounds of algae as a feedstock. The company recently ran its initial test of 20 pounds of 5 percent oil-content algae feedstock with 40 percent water content, which resulted in an ignitable oil product.

- In **Arizona**, PetroSun BioFuels Refining recently signed a joint venture to develop and operate a 30 Mgy algae bio diesel facility in Coolidge. Construction is projected to commence in the third quarter of this year. Late last fall, PetroSun announced a letter of intent to supply 54 million gallons of algal oil to a new 54 Mgy Bio-Alternatives biodiesel plant in south Louisiana. The initial delivery to Bio-Alternatives refinery will be in the third quarter of 2008.

## 5. ADAPTABILITY OF TECHNOLOGIES

Whereas the fish gut/waste technology is adaptable to small scale energy production, the micro algae to biofuel technology is more suitable to large scale energy production. The technology to extract oil from fish waste or gut is adaptable to almost any aquaculture farm with a medium to high productivity rate. Furthermore there is a possibility that this technology could be adaptable on large fishing trawlers. If this were the case some of the trawlers that cut up fish directly on the vessel will be able to convert the waste into oil and produce the biofuel directly on the vessel. As current fuel prices are increasing – it is becoming economically non viable for large trawlers to go out at sea and fish large quantities of fish, which they are having to sell at lower prices, the "free" fuel will help them gain back some of the income lost in the purchase of standard fuel for the vessel, as well as lowering greenhouse gas emissions. Alternatively ports could form cooperatives where all the waste is gathered and oil produced processed and bio-diesel created.

Micro algae to fuel conversion requires a high initial investment and land to grow and harvest the micro algae in the large photo bio-reactors (350' by 50' roughly 100m x 15m). The large investment would secure the purchase of the photo bio-reactors to grow the algae plus maintenance and running costs. Figures are not available to this day on costs for the large photo-bioreactor, however countries with large capital investments and vast areas of unused land could benefit from the photo bio-reactors. Alternatively as mentioned above the micro algae can also grow in highly engineered re-circulating ponds and the cost for harvesting these is considerably less (about 3-10 times).

Both technologies can contribute to increasing employment and would benefit local communities by not having considerable areas of land used for mono-crop biofuels production.

## 6. CONCLUSION

Aquatic resources that produce clean energy may not be the total solution to the world's energy needs and demands, but they do offer a partial solution, a solution which does not interfere with the production and costs of food and most importantly does not put a strain on food security. They are 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. Fish waste can contribute to securing energy for small to large fishing villages, ships and vessels, and local communities, while ponds or bio-reactors can play a part in securing larger amounts of energy once the economic hurdles are overcome. Oil will need to leave the energy market, and we need to start filling the energy gaps with biofuels and other renewable energy resources, like wind, solar, biomass and so on.

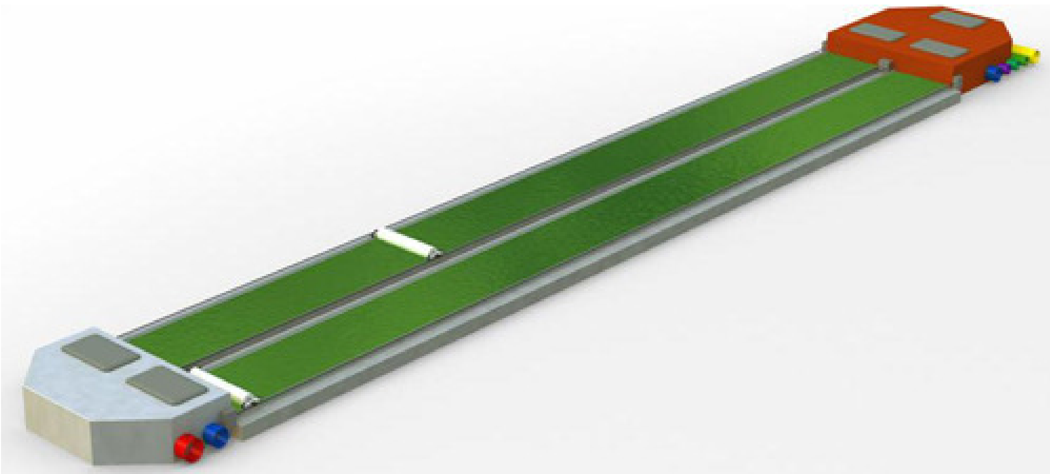
## 7. PHOTOGRAPHS

**Photo 1**: Biofuel pump outside the aquafinca tilapia farm (Honduras)

**Photo 2**: The technology to separate the fish gut from water and adding methanol to produce the bio-diesel (Aquafinca, Honduras)

**Photo 3**: Bio-diesel pump outside the Aquafinca plant in Honduras.

**Photo 4**: Example of a photo-bioreactor algae growing/harvesting (PBR) machine. Each PBR machine is 350' long and 50' wide consisting of twin 20' wide x 10" deep x 300' long, transparent plastic "algae water-beds".



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