Powered by Pond Scum: Could biodiesel from algae be a viable transportation fuel?

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Introduction

There are over 26 million cars on the roads of the UK and the vast majority of these are fuelled by fossil fuel derived oil. As well as the price of fuel steadily increasing, climate change and geopolitical issues have also hastened the search for more sustainable sources of oil. Biodiesel has the potential to be an alternative as it is derived from pure vegetable oil and can generally be run in conventional diesel engines without modification or as a blend with standard diesel. However there are several environmental and ecological issues such as competing land use especially concerning food crops.

Algae are similar to plants in that they produce lipids through photosynthesis which can be recovered to produce oil. They have the potential for higher yields as they require less surface area to grow and more of the oil is recoverable. They could potentially be grown, harvested and converted into biodiesel on marginal land without displacing food crops. The biofuels lecture given at the A4 module showed that transport energy requirements represent a large proportion of total energy use in the UK which is growing yearly. Alternatives such as algae have the potential of reducing dependence on fossil fuels which may be extremely beneficial both politically and environmentally.

I am going to begin this essay with an introduction to biodiesel and some associated environmental issues. I will then discuss algae, looking at the history over the course of the 20th century. I will also look at current and future technologies before seeing whether this micro-organism could be the fuel to keep our transport system running.

What is biodiesel?

The use of the prefix "bio" when related to energy denotes that the material matter was living matter relatively recently (Boyle 2004) in contrast to fossil fuels which have taken millions of years to form. As such, biofuels are a term for liquid fuels produced as substitutes for crude oil products.

The earliest diesel engines were built to run on pure vegetable oils; the inventor of the diesel engine, Rudolf Diesel, ran his first car on peanut oil. However the entry of cheaper crude oil derived products into the market in the 1920's meant that motor manufacturers modified their engines for the lower viscosity of petrodiesel. Subsequently the use of pure vegetable oil fell out of use. Biodiesel solves this problem as a process called transesterification is used to convert the pure vegetable oil by adding methanol or ethanol. This transforms the triglycerides in the oil into esters, leaving only a glycerol by-product. Most existing diesel engines will run without modification on biodiesel although this depends on the type and viscosity of oil used.

What are the environmental problems?

It may initially seem like a positive environmental step to use crops rather than depleting our finite resources of oil to produce fuel but there are several problems. First is the competition on land use for growing food crops. The International Food Policy Research Institute predicts subsidies to promote biofuels will "drive food prices 20-40% higher between now and 2020" (Leahy 2007). Subsidies have been used in the US to promote biofuels and this shift in crop has been blamed for the "tortilla crisis" in Mexico when rapid increases in corn prices quadrupled in 2006, meaning poorer Mexicans could no longer afford to buy their staple food (Roig-Franzia 2007). As George Monbiot (2004) said "the market responds to money, not need. In a contest between the demand for fuel and poor people's demand for food, the car owners win every time." So despite appearing like a green solution, it does seem like the current policy for biofuels may be more driven by economics.

There has been an evolution of biofuels over the last decade or so. It started during the 1990's with the so-called "first generation" of biodiesel which was derived mainly from rapeseed, palm or soybean oils. This is now regularly blended with diesel in parts of Europe. The European Union has a non-binding target that road fuels should use a 5.75% blend of biofuels in both petrol and diesel products by 2010. However even a 5% switch to biofuels would take up 20% of European cropland (Strahan 2007) as traditional biofuels produce low yields per hectare. These land restraints mean that biofuel imports are cheaper than home grown production with the consequence that ancient forests and jungles are being destroyed to grow monocultures such as palm oil. Recent research also suggests net increases of carbon emissions will occur by replacing natural ecosystems to grow these crops (Jha 2008).

More recently, proponents of "second generation" biofuels have attempted to push for the acceptance of crops such as the Jatropha plant. This plant can apparently be grown on marginal shrub land leading to claims that food agriculture will not be displaced. However these crops have only been grown in non-commercial situations and Strahan (2007) calculates that 3.5 million hectares of land would be needed to replace world diesel demand. Although this is less than first generation crops it remains to be seen if there is actually this much unused non-arable land available. There are many unanswered questions regarding this crop which is why some suggest that the best solution may be to skip a generation and move to the "third generation" of biofuels which includes algae.

Green Pond Scum?

When mentioning the word algae to most people they tend to think of the contents of a "dirty" fish tank which has gone green. In actual fact these organisms range in size from seaweed down to unicellular structures and there are hundreds of thousands of different species. Despite their diminutive size, some species of algae contain up to 75% of their dry weight in oil (Edwards 2006) creating biomass by photosynthetically converting the sun's energy along with CO_2 and water. Due to higher proportions of lipid content, algae fuel tends to use microalgae which can be up to a few millimetres in length.

In contrast to land based crops, these micro-organisms have the advantage of being aquatic and therefore submersed in their nutrient supply. They are also able to grown in both brackish and fresh water (Sheehan et al 1998). As the biomass that is produced contains triacyclglycerols, biodiesel can be produced in the same way as other oilseed crops as mentioned earlier.

The main perceived benefit of algal crops is a much smaller cropping area than "traditional" biofuel crops as shown below in Table 1. The land area shows the number of hectares required to replace current worldwide diesel demand.

Crop	**Oil Yield (litres per hectare)**	**Land Area (million hectares)**
Maize	172	462
Soybean	446	178
Jatropha	1892	42
Algae (30% oil)	59000	1.3
Algae (70% oil)	137000	0.6

Table 1 - Crop Yields and Land Area (Chisti 2007)

The History of Algaculture

Despite the current hype surrounding algae based fuel by venture capitalists in the USA, research in algae has been taking place for most of the last century. In 1919 scientists theorised that algae had at least one order of magnitude more productiveness per unit area than terrestrial plants (Huntley and Redalje 2004). However it was during the oil crisis of the 1970's when research by NASA into microalgae began to take place. The Aquatic Species Program was launched in the USA in 1978 and during the 18 years that this programme existed they examined over 3000 strains of algae looking for the most productive oil bearing algae (Sheehan et al 1998). Working in desert regions in Hawaii, California and New Mexico using algae farms based on an open, shallow pond setup, they concluded that diatoms and green algae were the best for this purpose. The ponds as shown in diagram 1 had a paddle to provide flow and CO_2 and other nutrients were fed into the pond. The shallow imprint of the pond allowed sunlight to penetrate and the flowing water allowed all the algae to receive enough light. Algae grows fast and can be harvested in just a few days with the correct conditions. (Danielo 2005)

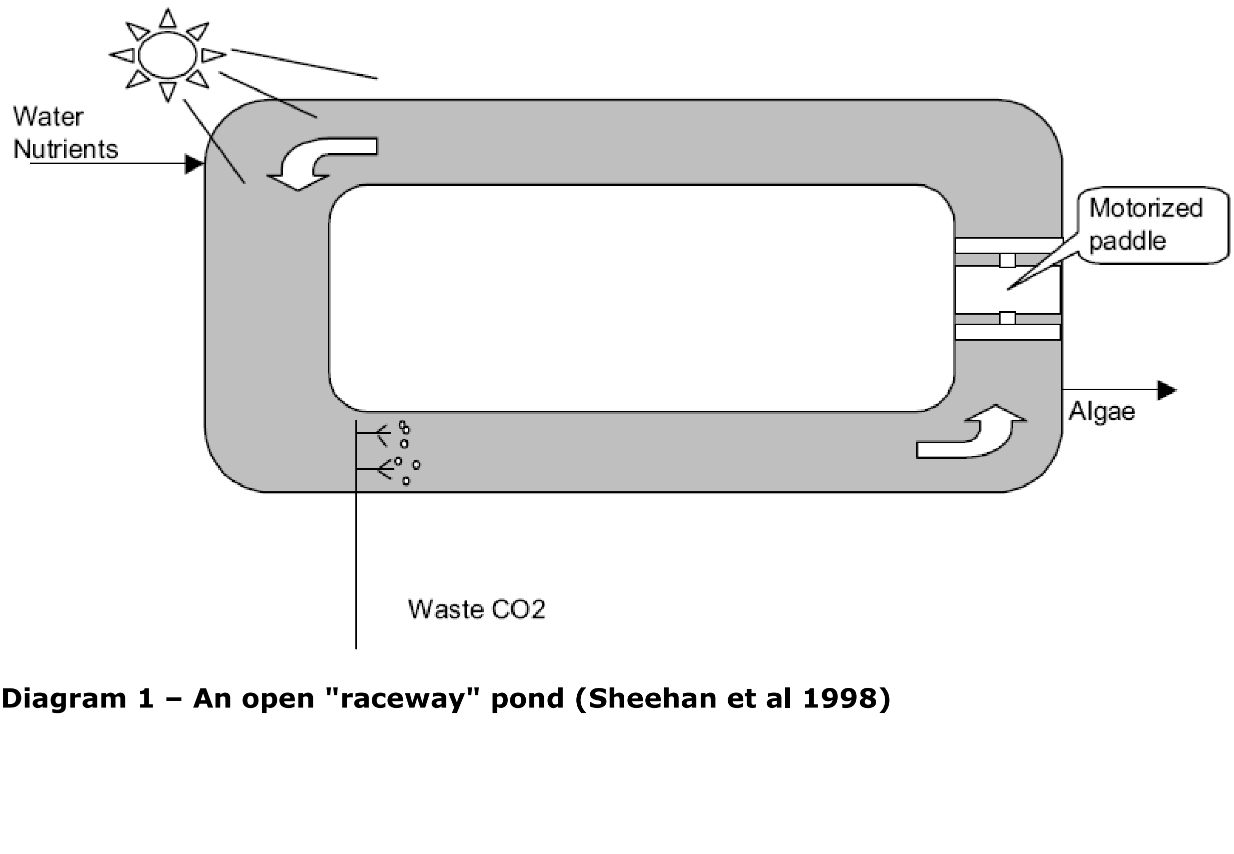

Diagram 1 – An open "raceway" pond (Sheehan et al 1998)

When funding was cut in 1996, the programme summary outlined many issues with this type of system. An open pond layout means that the water is susceptible to invasive species entering and taking over the algae that you are producing especially when breeding algae optimised for lipid growth. Laboratory conditions are much harder to scale up in this system as you have no control over temperature or external influences. Algae also needs a higher level of CO_2 than is found in normal air which generally needs to be pumped through the water, increasing costs and reducing energy returns. One solution to this which I will examine later in more detail is to locate the algae farms near to factories or power stations. The programme concluded that high cost and unpredictability of yield in pond algae farms meant it was uneconomic. Similar conclusions emerged from trials in Japan and France during the same period of time (Schulz 2006).

There are however some specific situations where this technology might work. Benemann et al (2002) have shown that the Salton Sea in Southern California suffers from huge inflows of nitrogen and phosphate fertilisers from agricultural land which in turn produces huge algae blooms. To stop eutrophication of this inland sea, the algae could be harvested and converted into biodiesel. Scenarios like this are however uncommon and harvesting native algae is likely to be a niche activity as most naturally occurring algae species have very low lipid content.

Evolving Technologies

The main alternative to the pond system is a unit known as a photobioreactor which uses a series of sealed transparent polycarbonate tubes. In a system developed by Greenfuel and MIT, the system allows gas to enter from one direction whilst liquid circulates in the opposite direction. The triangular structure is shown in diagram 2 where "A" shows a cross section of a tube and "B" is a demonstration array of 30 tubes. The direct solar radiation hits the hypotenuse and the algae circulates at an optimised speed absorbing light, moving into darkness in the other 2 sides of tubing as algae needs both light and dark to grow (Danielo 2005). Their test system is linked to a power plant giving a "free" supply of CO_2 and other nutrients. Vunjak-Novakovic et al (2005) found that the algae absorbed nearly 82% of CO_2 on sunny days.

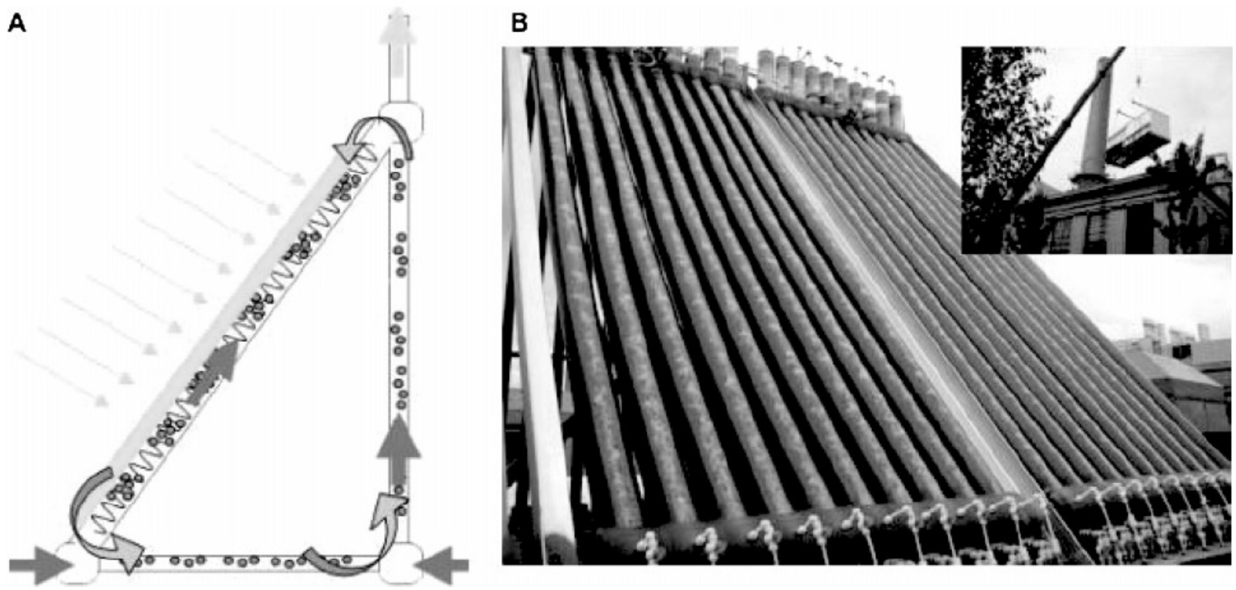

Diagram 2 – Photobioreactor design (A) and picture (B) (Vunjak-Novakovic et al 2005)

In contrast to the open pond farm, in this system all the inputs can be regulated but this comes with a hugely increased cost; both to actually produce the reactor and the connection to external systems. There are several firms who have released details of this type of production onto the market, but generally they have only given details through press releases. Some scientists are attempting to investigate these claims and look beyond the hype. In several exchanges with GreenFuel, Dimitrov (2007a) has argued that this technology is not economically feasible. In fact he says it would require oil to be $800 before being commercial viable. His paper also criticises Greenfuel for "breaking" the second law of thermodynamics. Working through the principles of photosynthetic energy collection he shows that the yields they claim would be impossible in reality. In late 2007 GreenFuel conceded that they are no longer using the triangular design of bioreactor but have yet to release details of any new reactor designs (Dimitrov 2007b).

There are other problems with bioreactors. Edwards (2006) argues that as the algae grow, the light available in the system becomes reduced, inhibiting growth. Another problem is one of too much light, or photoinhibition. If the algae do not circulate correctly, those on the outside of the tube will receive too much radiance, affecting their growth rate whilst those near the centre will not receive enough. The Aquatic species programme also rejected photobioreactors outright due to the high capital costs (Putt 2007).

Harvesting the crop is another problem. It is much easier to harvest traditional land-based crops as all the machinery and technology exists. Bio-flocculation and centrifugal flocculation can be used but are expensive and again have not been done on a large scale (Schulz 2006). GreenFuel claims to have produced algae at a power plant in the US with a yield 37 times greater than a corn crop (Cornell 2007) but this was only a two week field test at the height of summer. Most algae will stop growing during the cold winter months so a full year's data would be required before the yield could be compared.

Is this technology viable?

If, as Dimitrov argues, algae biodiesel is commercially unviable until $800 barrel oil arrives, then it is unlikely that this biodiesel will be able to compete commercially especially as other sources have generous government subsidies.

Both current solutions have their own advantages and disadvantages. Combining the best parts of the two may be another way of increasing yields and reducing costs. Huntley and Redalje (2006) have suggested a coupled photobioreactor-open pond cultivation system. In this system, the sterility of photobioreactors is combined with the low cost of ponds. By breeding in the bioreactors and then moving the algae to the open pond for a limited period of time, issues such as native species invasion are reduced whilst also allowing rapid growth to occur. Once again this system is just a proof of concept so it is too early to know whether this could be commercially viable.

Algae farms may however have an environmental advantage over other biofuel crops through their potential for capturing and recycling CO_2 and N_2O. Carbon capture and storage (CCS) technologies are being discussed for new coal fired power stations, but an algae photobioreactor next to a coal station could absorb most of the CO_2 equivalent gases and a lower cost (Edwards 2006). They would of course be released when the fuel is burned in the vehicle but is still better than the current way of burning fossil fuel. The excess heat from the power station could also keep the algae warm, meaning the technology could potentially be used in colder climates such as the UK. Although low levels of sunlight would reduce the speed of algal growth.

Conclusions

There does seem to be a lot of hype surrounding algae fuel. For instance in late January 2008 a company called Solazyme launched an algae fuelled demonstration car and has entered into research with Chevron. They haven't yet released details on how they are producing the oil so once again time will tell if the company can make things commercially viable. This seems to be the current stage of play in this re-emerging industry. When initially reading various press releases about algae powered cars, the process seemed too good to be true. It probably is. Most of the technology has existed for decades and during that time nobody has managed to scale up the systems to a commercial level. Depending on the system chosen it will either perform badly at a low cost or work reasonably well but be far too expensive.

Media interest and hype in biofuels is going to increase as governments try to remove their dependence on foreign owned fossil fuels whilst not looking like they are complicit in destroying woodland and forests. Therefore it will be very important to focus on the yields that these companies report over longer periods of time and to see whether they can trade up from laboratory tests to full scale industrial units. Only time will tell if this is the case.

One implication for the future is the possibility of legislating to make carbon negative biofuels the only way of selling these fuels. As Mathews (2007) discusses, by returning a portion of biomass to the soil, the biofuel can be rendering carbon negative. This is one huge advantage biofuels have over petrochemical based fuels. There are a few different ways this can happen and is something I would like to investigate further.

Biodiesel from algae may have some environmental advantages over other crops but does not appear to be economically viable at the current time, this is shown from the failure of over 30 years of large scale research to commercialise production. Without some technological improvements to improve this over the next few years such as genetically modified algae within photobioreactors, it seems that for the time being the majority of our vehicles are going to be fuelled by the world's finite supplies of crude oil.

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