Has the Algae Cavalry Arrived?

Posted by Heading Out on May 11, 2007 - 11:51am
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Editor's note by HO: There has been the occasional discussion of algae as a possible source of biofuels. The interest in this topic is continuing to increase, and thus, when ***fireangel*** *sent in this piece, it seemed to me to be appropriate to consider allowing the piece to be posted as a guest post. At the end I will have some concluding remarks (I had mentioned that I would, and this is acceptable), but for now, let me step back and yield the floor.*

The last 2 years have seen a major global push towards the use of biofuels. This has included corn, soybeans, sugarcane, sunflower and rapeseed among others. The U.S. Government has mandated an increased usage of ethanol in gasoline, which has resulted in a boom in the construction of corn-to-ethanol plants. The short-sightedness of this policy can be seen by anyone not standing for reelection to the US Senate. Soaring demand has led to a more than 60% increase in corn prices. These price increases have, however, not deterred the ethanol industry, which continues to add more and more corn-to-ethanol plants to the drawing board. While industry estimates vary it is quite likely that we could be using more than 50% of the total domestic corn production to supply less than 10% of the national demand for gasoline by 2010.

Given the relatively low overall yield of corn ethanol per acre, several alternatives have been proposed. These include the growing of soybeans, rapeseed and safflower to produce biodiesel. With some of these crops yields can range anywhere from 3-7 times that from corn ethanol per acre and have several other advantages including a much better EROEI. The one that caught my eye though was the proposal to convert algae into biodiesel. Several posts on TOD have referred to algae as holding more promise for biodiesel production, but I had yet to see any substantive proof of its feasibility. I spent several hours over the last few days researching this and I found some interesting facts that I thought I would share on TOD. The bulk of these findings are based on Dr. Krassen Dimitrov's work. I invited him to present a summary of his work at TOD but he suggested I do it. He even suggested I "link it' to me. Talk about not taking credit! My role was to verify his calculations, make a synopsis and add additional information that I learned on this subject. I also communicated with Dr.Briggs at UNH about this and his views are included.

During the oil crisis of the 1970s, Congress funded the National Renewable Energy Laboratory (NREL) within the Department of Energy to investigate alternative fuels and energy sources. The Aquatic Species Program (ASP) focused on the production of biodiesel from high lipid-content algae growing in outdoor ponds. These programs also used carbon-dioxide from coal fired plants to increase the growth rate and lipid content of algae. They estimated that under optimum growing conditions micro-algae will produce up to 4 lbs./sq. ft./year or 15,000 gallons of oil/acre/year. Micro-algae are the fastest growing photosynthesizing organisms. They can complete an entire growing cycle every few days. Based on this one can extrapolate that it would take about 10 million acres to produce 145 billion gallons of biodiesel which could supply the entire US gasoline requirements (assuming gasoline powered vehicles could be replaced over time). That is just 2.3% of total area used to grow crops in the US! So why isn't someone doing something constructive in this field?

There are at least 4 different ventures in the works, including Aquaflow Bionomic, Solio Biofuels, GS Cleantech, and GreenFuel Technologies. GreenFuel seems to be the most advanced in mass commercialization of this technology. GreenFuel Technologies along with De Beers in South Africa (no relationship to the diamond miner) have been making some rather audacious claims on this front. As mentioned here they plan to single handedly make peakists shake in their boots. Greenfield/De Beers plan to produce about 391,000 barrels per day in 5 years. That is no chump change. There are just a couple of major oil fields coming online within the next 5 years which produce anywhere close to that. So Should Chris Skrewbowski start including De Beers in his mega projects list? Not so fast.

According to GreenFuel's patent application a 1.3 sq. km. plant can generate 342,000 barrels of biodiesel per year. Now, I am not very familiar with km-acre relationship so I had to look it up. I got my wife to double check my numbers as I kept believing I screwed up somewhere. GreenFuel claims to be able to produce 45,000 gallons/ acre/ year. I have converted these to an easy to compare number to that of APS above. So GreenFuel is thus claiming to do 3 fold as well as, the highest estimate under super-optimistic conditions that has never been produced on a large scale. Also, ASP had dismissed closed photo bioreactors has prohibitively expensive but it was not clear what price of oil they were taking into their equation.

This last alliance of GreenFuel and De Beers which is making it's stand against the dark forces of peak oil is even convincing the common public that it can do this. De Beer's has sold shares to the common public (without a prospectus) and 29 franchises to build 91 plants (for 6 Million Rand each). Additionally they guarantee that each plant will produce more than 850 barrels of biodiesel per day.

Let's examine their claims in light of (pun intended) how much lipid photosynthetic organisms can synthesize.

Photosynthetic organisms (PO), such as algae, transform visible light in the 400-700 nm part of the spectrum - called photosynthetically active radiation (PAR) - into the chemical energy of carbon-containing compounds. PAR varies with latitude, seasonality and geographical factors. PAR in the southwest US is about 105w/s
The energy - in the form of biomass - that can be obtained via photosynthesis thus depends on the level of PAR and the efficiency of the conversion process Q.

Ebiomass = PAR x Q

Photosynthetic organisms use eight photons to capture one molecule of CO_2 into carbohydrate $(CH_2O)_n$ Given that one mole of CH_2O has a heating value of 468kJ and that the mean energy of a mole of PAR photons is 217.4kJ, then the maximum theoretical conversion efficiency of PAR energy into carbohydrates is:

468kJ/(8 x 217.4kJ) = 27%

This is the ideal yield on PAR energy that is: (i) actually absorbed by the photosynthetic organism, (ii) in conditions where this organism operates with 100% photosynthetic efficiency (every photon that is absorbed is effectively used in photosynthetic reactions), and (iii) the organism does not waste any energy on any life-support functions, other than building biomass. We will call this efficiency Qtheo.

If 27% is theoretical maximum, then what is most likely? Dr. Dimitrov presents reasonable evidence to suggest that Q is likely to be around 10% at best. While that to some may sound like he is being overly pessimistic, it is my belief that he is in fact being a bit optimistic.
Here are his assumptions,
90% photosynthetic efficiency i.e how well an organism avoids photosaturation ...Q= 24.3
80% conversion of this amount for us..i.e the plant uses 28% energy for its own needs...Q=19.44
70% optical efficiency of the process, which measures optical coefficient, cleanliness and reflection of light from reactor wall..Q=13.60
98% efficiency in coverting biomass to biodiesel.. Q=13.33
98% plant efficiency (2% down time) Q=13.06

I have studied these in depth and I believe that getting anything over 15% is going to be an impossible task in the near future. A more likely situation is that Q will be around 10.
Applying this to PAR of 105w/s/ sq.m or 3.3GJ/yr/sq.m. we get a maximum biofuel energy content of 0.89GJ/yr. Now, biodiesel has an energy content of 0.133GJ/gallon. Greenfuel says that they plan on getting 342,000bbl per year from a 1.3 sq km plant. That is an energy content of 1.47 GJ/sq.m/yr .

The more likely scenario is,

Now, Heading Out pointed out that the PBR design consists of inclined tubes and hence I am underestimating the yields in a given area because of that. Based on their pilot plant I have to agree that he is right. But, when you are talking about miles and miles of these then the vertical height of these individual columns acts as a limiting factor. If you picture another set of these columns behind the first one, you will see that it's proximity to the first one would affect it's access to sunlight. To access sunlight perfectly it would have to be a significant distance away. Hence GreenField cannot improve yields/sq.m by going vertical, except perhaps in its pilot plant.

So if we assume the above numbers are correct the that's 1.2 gallons/sq.m./yr or about 5000 gallons/acre/yr The other 50% is proteins and carbohydrates which would have some food value. Dr. Dimitrov assumes lower price for this portion derived from algae and based on present prices he is right. However I believe that the food and fuel markets are merging. Let me explain my position on this. Higher oil prices will result in higher corn prices (as more is used for ethanol) and this will impact food prices across the spectrum. On the other hand if we have a bad corn harvest and ethanol becomes unprofitable and companies cut back on production , it will decrease supply enough to push oil/gasoline prices higher to the point we start using corn to make ethanol again.

Hence assigning a $2.5 a gallon price on biodiesel and $1.50 on protein and food derivatives we get revenues of $4.8/sq.m/ year. Let's look at the costs of this revenue.

GreenFuel’s PBR design.

The largest cost is of course going to be the construction of the plant. GreenFuel promises to use polycarbonate tubes for its construction, which have installed costs as high as $190/sq.m. However since GreenFuel plans to build at least 91 of these massive plants I am going to give them a lower cost of $150 assuming that they can negotiate huge discounts. Polycarbonate is the best choice as it has excellent PAR transmission but blocks UV much better than acrylic or glass making it ideal for grwoing algae.

Next are the land costs. Dr. Dimitrov generously assumes they can get the land for free. If the US starts taxing carbon emissions then maybe there is a remote possibility for getting land for free next to carbon dioxide spewing power plants. I too will give them the benefit of the doubt here but we must remember that this is likely to work against them. Large amounts of land at specific locations with great sunlight and fresh water availability are not cheap.

Next we consider the operational and maintenance costs. These include personnel costs for repair and cleaning and costs for parts and repairs. Assuming 0.03 full time employee's per 1000sq.m, that translates into $1.20/sq.m/yr (assuming total costs of $40,000 per employee, including healthcare and other benefits). These costs were obtained by using the costs for maintaining sun-tracking heliostats such as those used in concentrated solar power.

The costs for operating GreenFuel's plant are likely to be about the same assuming they use neutral buoyancy spheres to clean inner surface. All other costs including administrative, parts and labour, quality testing, transesterification, water, pH control total up to about 0.60/sq.m. These are again the costs for concentrated solar power generation ($0.50) with zero costs assigned to water and pH control. Transesterification costs are assumed to be just $0.10, which is 30% lower than any number I could find from many different studies. Some put this as high as ($0.50). Suffice to say that these costs are extremely low compared to real numbers. Adding it up we get a total cost of about $1.8/sq.m/yr. That leaves gross profit of $3.00. That means at current prices it would take 50 years to just cut even on their investment. That is clearly not feasible. For one thing these polycarbonate sheets take a lot of UV damage and their useful life is almost always less than 15 years (usually 10 years). Also whoever is investing for 15 years would be crazy to want a zero return on their investment. Even if someone had some philanthropic goals it would be inflation adjusted returns of zero. Even making assumptions of 6% inflation (whoever believes the official CPI needs to get their head examined) and zero returns requires oil prices greater than $240 a barrel!! So great we have a technology which will save us once oil prices get high enough, right? That assumption too would be a mistake as at $240 a barrel, polycarbonate costs are probably going to be a lot higher. Ditto for repairs and parts. Labour may be cheaper if $240 a barrel results in massive unemployment.

Also, I would like to point out that going vertical will not affect GreenFuel's costs.

From these calculations it is apparent that the limiting factor is the cost of polycarbonate. Also, if the world tries this on a massive scale it is likely to put immense pressure on the polycarbonate market and hence its price. For a closed system polycarbonate is the best choice. Everything else reduces yields. However if there is something that gives good cost to yield trade off it might be a better idea than GreenFuel's choice.

After going through a few studies done by different institutions I have found that there quite a few technological hurdles which need to be cleared even if costs can be brought down.
1) Low yields (in spite of optimum conditions)
2) Contamination
3) Lack of water in areas with best sunlight
4) Low Lipid content of algae
5) Open small pond method is problematic due to repeated contamination and much lower yields
6) Energy required to constantly move large amounts of algae within the photo bioreactor is likely to be extensive

7) Low yields would also hurt GreenFuel's potential carbon sequestration credits, should they ever get those

I communicated with Dr Briggs at UNH about Dr. Dimitrov's work.

His position was
1) GreenFuel is drastically overstating its potential yield. He was not aware of the exact claims as the patent application is incredibly confusing in that area. I was happy to point out the exact points made.
2) However 15,000 gallons/acre is achievable
3) Q=10% is unnecessarily too low
4) More by-product credit needs to be applied for non-lipid content
5) PBR costs may be different than that used by him, but costs need to come down substantially
6) He also made an important point about meat prices which I thought was interesting. He felt that the corn to ethanol boom would result in higher meat prices and that was a good thing as meat is ridiculously cheap compared to fruits and vegetables. Since it takes 10 times as much land and energy to produce a certain amount of calories from meat as from grains, he feels meat should be priced much higher

My remarks,
1) needs no comment.
2) at what cost and how? Can this be done on a mass scale?
3) I adjusted theoretical Q to 13 based on some of his comments. But I am reluctant to adjust my base case of Q=10 to higher levels as it seems unrealistic.15,000 gallons (3x our base case yields, with Q at maximum possible) may be possible in areas where PAR is much higher. Also if we are to do this on a large scale we will be utilizing land everywhere and not just in the southwest. Hence average PAR is likely to be a lot lower. If 15,000 gallons can be achieved then too with current prices and using a modest 6% inflation return the plant is likely to be unprofitable. However with those yields at twice current prices things start looking a lot better. Even under our most optimistic scenarios at current prices things do not look too promising. As Robert Rapier's Thermal Depolymerization post showed, costs are more likely to be underestimated than overestimated.
4) I have tripled the by-product credits given by Dr. Dimitrov
5) I have reduced costs of construction by 20%.
6) I am in total agreement with him on this. As the third world countries continue increasing their meat consumption this might happen sooner than we think.

In conclusion it seems that while their intentions may be heroic, GreenFuel and De Beers have promised way more than they can possibly deliver. I am so confident of this that I would love to extend a familiar $1000 bet on this. Unfortunately as seen here, no one can verify how much any of GreenFuel's plants produce at any time.

The future may hold a lot of promise for this technology though. A cheaper replacement for polycarbonate along with setting up reactors in third world countries with more PAR and cheaper labor may make this very realistic.

Maybe we will read something like this in 2025.

"Biodiesel prices rose on the MUMEX (Mumbai mercantile exchange) as India pledged to cut production to balance out the glut in inventories. India's biodiesel minister was quoted as saying "$600 a barrel is a fair and equitable price." Saudi Arabia which just turned importer last month is complaining that the high prices are wrecking its fragile economy and threatened to finally start using its Trillion barrel of “proved“ resources to destroy the Biodiesel cartel.”

A small end note from Heading Out. If one reads the patent claims for this process that are referenced above it can be seen that the program considers the use of artificial light as part of the source of the energy input. Given that the plant is being established at a power station, this energy cost may be small, and the land may be available at the plant. There is some information on the plant that is installed in South Africa here and here and the coming US operation here . My apologies that current time constraints have limited my input to this.