GreenFuel Technologies: Case Study for Industrial Photosynthetic Capture

Follow-up Discussion

1. Convergence on Yield Estimates.

In response to the Case Study, GreenFuel Technologies has circulated a "GreenFuel Response to Errors in Thermodynamic Analysis by Dr. Kassam Dimitrov", (the Response), which is incorporated here as ***Appendix A.***

Not surprisingly, GreenFuel's response is highly confrontational. A quick scan through this six-page document finds the word "error(s)" to be used a whopping sixteen times and its synonyms ("mistake", "wrong" and "not true") additional five times.

Strikingly, however, the numbers provided by GreenFuel strongly support the main conclusion of the Case Study. This agreement in the main numbers is discussed immediately below, before getting into detailed analysis of the remaining disagreements.

There are only three things from the Response that are needed in that regard:

Page 2: "Our current data supports a more conservative oil yields closer to 1-2 bbl/ton"

Page 3: "A 4000 acre GF facility would be expected to produce approximately 350,000 metric tons of starch-combination."

Page 4: "Highest lipid accumulation for the types of algae GF currently uses would have 25% to 30% lipids with the remainder being starch-protein."

From these three references, one can easily calculate the biodiesel yields per square meter expected by GreenFuel. Here's the low range of their estimate:

Starch/protein: 3500,000t/4,000acres **= 21.6 kg/sq.m. per year**
Total algae: (75% starch/protein), 21.6/0.75 **= 28.8 kg/sq.m./yr (0.0288t)**
Biodiesel: 0.0288t x 1 bbl/t x 42 gal/bbl **= 1.21 gal/ sq.m. per year.**

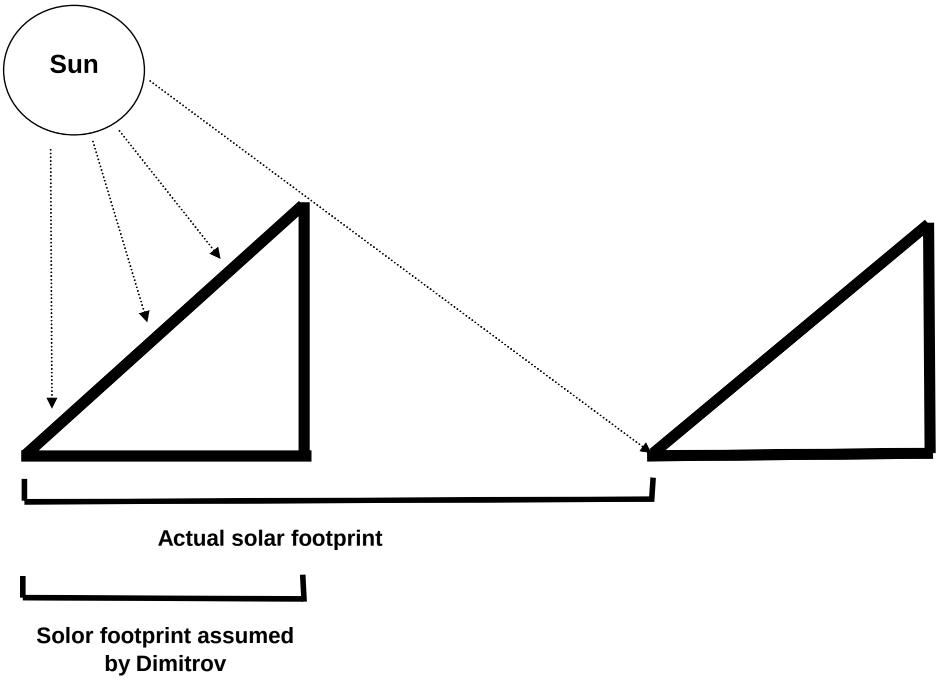
For comparison, the Case Study assumes a best-case yield of **1.24 gal/sq.m.** per year! Remarkable tightness in the estimates, and much different than the estimates **of 11.05 gal/sq.m.** in Examples 2 through 5 in the patent application.

Such agreement in the most important number makes the polemic and confrontational tone of the Response quite puzzling.

Where exactly are the remaining disagreements, who is right and who is wrong?

2. Solar footprint assumption in the Case Study:

GreenFuel claims that in analysing Example 5 of GFT's Patent Application, I have used a wrong number in calculating the solar area of the installation. They also provide the following figure to demonstrate their point:



GreenFuel's claim is absolutely incorrect. *Example 5* describes an installation of **1.3 sq. km.** or **321 acres**. My calculations generously assumed that the *entire* land area was used for solar capture: that is the solar aperture of the installation equalled its footprint. Contrary to what GreenFuel claims, no assumptions were made regarding the bioreactor geometry, as *Example 5* does not specify any particular geometry, and *Figure 4* in the patent application shows that the the photobioreactor can assume many different geometries. The point that the Case Study made was that an installation with a footprint of **1.3 sq.km (321 acres)** cannot possibly generate **342,000 barrels** of biodiesel – even assuming that the entire footprint is used for solar capture – as such annual yields would contradict the First Law of Thermodynamics. So in essence, what the figure above describes as "actual solar footprint" is exactly what has been used in my calculations.

3. Energy Flux Sources.

GreenFuel disputes the satellite PAR measurements referenced in the Case Study and have provided an alternative source for land-based PAR data, that can be found at:
http://ag.arizona.edu/CEAC/research/archive/solar-radiation_kania.pdf
Let's look into this in greater detail:

Here's what the Case Study stated:
Page 5: "As can be seen from the PAR maps, annual PAR levels vary with latitude and geographical factors. In the Southwest USA it can reach **105W/m^2** "

Looking at *Figure 3* of GreenFuel's preferred source, the maximum recorded PAR radiation for Tucson happened in 1999 at 42.1 moles of PAR photons per day. Using the common conversion factor for PAR photons of 217.4 kJ/mol, one can calculate the annual PAR radiation for Tucson in 1999 to be:

(42.1 mol/day x 217,400 J/mol) : 86,400 s/day = **105.9 J/s**, or **105.9 W/sq.m**.

In other words, the highest annual PAR flux recorded in the source cited by GreenFuel exactly matches the satellite source referenced in the Case Study. In fact, the average value for the entire 13-year period in the land-based study quoted by GreenFuel is 38.4 moles/day, which equates to **96.6 W/sq.m.**, or lower than my assumption of **105 W/sq.m**.

In their Response GreenFuel computes maximum flux of **175 W/sq.m**. by plugging the maximum observed value of 70.7 moles of PAR photons from the land-based source. However, this maximum observed value relates to a particular summer day observed in the summer in Tucson. Since *Example 5* of the patent application and all other relevant discussion relates to **annual** production volumes, the measurements associated with a particular day in the summer months is completely irrelevant, and their use in the Response is highly disingenuous.

4. Animal Feed By-product: market potential

a. *Danger of Market Saturation:*

The Case Study argued that any meaningful liquid fuel production scheme with animal feed as a by-product will ultimately lead to market saturation of this secondary market. GreenFuel's position is best summarized by this quote from their Response:

Page 3: "This is not likely, although it is an indication that Dr. Dimitrov does not understand the feed markets. The addressable market for the starch-protein combination produced by almost any of the choices of algae considered by GreenFuel is approximately 1000 million metric tons per year. A 4000 acre GF facility would be expected to produce approximately 350,000 metric tons of starch-combination. To supply just 10% of this market would require approximately 1.2 million acres of GF projects. Clearly, the risk of saturating this market is not a near term risk."

We need to quickly dispel the absurdity of this statement on most general grounds, even before getting into any details. Let's assume that a **1.2M** acres of GFT installation can indeed provide the **100M** tones of starch-protein combination that would equal 10% of the worldwide animal feed market. The same **1.2M** acres would also produce **139M bbl** of biodiesel (assuming the **1.2 gal/sq.m.** figure from Section 1 above), which equals to **380,000 bbl/day**. Considering that the world consumes more than **85M bbl** of liquid fuels a day, such production volumes would equal to **0.4%** of GFT's primary fuel market.

In other words, if GreenFuel's technology is successful in producing **0.4%** of our liquid fuel consumption, it would simultaneously dump by-product equal to 10% of the secondary feed market. This is not going to cause market saturation?

Let's get the facts straight: while the animal feed market is indeed close to **1B** tones a year, it is a low-cost, oversupplied market. We cannot even begin to compare the attractiveness of the liquid fuel and animal feed market opportunities. Liquid fuels (aka liquid gold) are the lifeblood of the world economy. When was the last time anyone have heard about an animal feed billionaire, or about a country going to war with another country over animal feed? Any approach that attempts to dump additional **100M** tones of animal feed to produce less than ½ percent of our liquid fuel needs is bound to influence the price equilibrium of the feed market. Maybe GreenFUEL should change its name to SoylentGreen.

b. DDG

Historically, the U.S. ethanol program was started as a farm-assistance initiative. The farm sector was overproducing maize, which was suppressing its market price. The ethanol subsidy helped create an additional market to soak up the excess corn production and stabilize corn prices. DDG was being produced as a by-product of ethanol and was being dumped on the animal feed market as a low-cost alternative to corn grain. As such, DDG by itself has had an effect on the pricing environment for animal feed, even before introduction of any algal meal, albeit not as much as unmitigated corn overproduction would.

With the ramp-up of the ethanol program in the last few years, we have seen increased prices for corn grain, which conceivably indicates that ethanol production is no longer just soaking up the oversupply of grain needed to maintain price stability, but is in fact driving up corn prices.

However, before we get too enthusiastic, we need to consider the threat for market saturation from by-products of other biofuels: sugarcane ethanol and cellulosic ethanol. The sugarcane ethanol produced by Brazil is very cost-competitive at current oil and corn ethanol prices. Brazil has the land capacity and intent to greatly expand sugarcane cultivation in the coming decades. This would produce substantial amounts of highly nutritious by-product animal feed. The situation with cellulosic ethanol is a bit murkier, as the technology is immature (very much similar to GFT), however any successes there would inevitably create volumes of yeast-based byproduct that will too have to be dumped on the feed market.

c. By-product price and value-add

In their Response GFT mentions an unreferenced citation by Cargill saying that algal meal can potentially be sold for **$300/ton**. I find this to be a highly unrealistic expectation. Consider that corn grain – the etalon in animal feeds - sells at around **~$160/ton** (based on $4/bu, 15.5% moisture content), even after a two year run in corn prices.

I have run several scenarios for the starch-protein by-product and here is what I would consider a mid-point case:

Mean Annual PAR Flux = **105W/sq.m**
PAR efficiency (***Q***) = **10%**
Lipid Yield = **50%** on energy equivalent (~25% on mass equivalent)
Starch-Protein energy content = **18MJ/kg**
Starch-Protein Yield (dry weight) = **9.2 kg/sq.m**.
Price for Starch-Protein Meal = **$160/t** (equal to current corn grain prices)
Moisture Content = **15.5%** (to be comparable to corn grain)
Gross Cash Yield = **$1.74/sq.m**

In comparison, the Case Study assumed **$0.62/sq.m** in **NET** by-product cash yield for the same insolation and ***Q*** base-case. The difference between net cash yield and gross cash yield is the cost of post-processing required for the by-product and includes: drying, packaging, transportation and marketing. While there are a lot of uncertainties in these numbers, I still consider them within the most probable range and GreenFuel's Response did not provide sufficient argumentation for changing them.

Depending on the composition between starch and protein, the by-product yield per sq.m could be lower than the above example (in case of higher protein content; protein has higher biosynthetic energy requirements than starch, so more energy input is needed to produce a gram of protein), however this could be offset by higher selling prices (higher protein content leads to better pricing for animal feed).

While the expenses in processing the by-product may be lower than in the above example **(~65%)**, the selling price of **$160/t** may very well be too high. In any case these numbers are so far off from making GFT's approach economically viable that even if they are exceeded by a wide margin it would not make much difference.

d. Market Growth

The prospects for substantial growth in demand for animal feeds in the industrialized world - already suffering from an obesity epidemic - are dim. Even for consumers who would not moderate their meat consumption, the preference patterns are shifting towards "*organic*" and "*grain-fed*" meat varieties. On this background meat that has been grown on algae fed with smokestack-emission would appear highly unappetizing and a hard sell for conservative farmers.

On the other hand, meat consumption is rising in industrializing nations and there may be some good growth opportunities there.

5. *Qmax*

GreenFuel disputes my estimates of maximum photosynthetic capture efficiency, without providing any evidence. Surprisingly, I have received other questions regarding my **Qmax** estimate, all of them can be distilled to: "Isn't 10% too low, why not 20%, for example?" It seems lost on the readers that my ***Qmax*** estimates are alculated based on numerous subponents discussed in Appendix A of the Case Study. Apparently, ten percent - being a round number – was assumed to be a wild guess on my part.

I have absolutely no desire to discuss ***Q*max**, as it is just a simple calculation from the assumed component efficiencies in Appendix A. If there is any disagreement, it should be directed towards the component ***Q*** assumptions or towards my good old calculator that simply multiplied them. So far I have not received a single reasonable objection regarding the component ***Q***s, in fact it appears that I have overestimated the transmittance of polycarbonate in the assumptions.

6. Nitrogen Starvation

I find this section of the Response to be convincing. It seems feasible that GFT could develop conditions of mild nitrogen starvation that would allow them lipid yields of ~25% (on mass basis, 50% on energy basis) without compromising significantly PS efficiency. This is in very good agreement with my best estimates for lipid composition and above my lower estimates.

7. Capital Cost

GFT's statement regarding capital costs is highly evasive and disingenuous. The estimates from the Case Study have been confirmed by experts in Israel. Moreover, GFT has been quoting numbers of $125-150/sq.m. at their road shows, without providing any evidence that these are achievable. Anything above **$100/sq.m** makes photosynthetic energy capture an absurdly unworkable approach, and there is no technological pathway that would even begin to approach this range for the expenses of the buildout. If GreenFuel would come out and say publicly what their estimates for capital costs are, everyone with an access to a simple DCF spreadsheet would understand that this is not something that has even the slightest chance of working.

8. Land Avilability

The response claims that: "There are over 1,700 power plants that could support at least one 250 acre GreenFuel facility". There is no disagreement here. What seems lost is that 250 acres is woefully inadequate for a commercially-viable installation. The Case Study discussed in great detail the Example cited in GreenFuel's patent application and showed that a **321** acre (1.3 sq. km.) facility will only produce **38,000** bbl per year, and mitigate only **2.2%** of the CO_2 emissions from a small 350MW power plant. even assuming optimal insolation conditions. For carbon mitigation at a more typical **1GW** power plant, and for more commercially appropriate fuel production volumes in the **10-100M gal/yr** range the land requirements will many, many, many times higher.

APPENDIX A

GreenFuel Response to Errors in Thermodynamic Analysis by Dr. Kassam Dimitrov (annotated references)

Dr. Kassam Dimitrov has presented calculations which lead him to the conclusion that GreenFuel's early photobioreactors violate the first law of thermodynamics. His analysis is based on Examples 2-5 of GreenFuel's US Patent Application 20050260553. However, the analysis has two errors, a mistake interpreting the total photobioreactor installed area, and the incorrect energy flux. Consequently his calculated input energy is too low by a factor of at least 3.5. Once the input energy is correctly calculated, there is no violation of the first law of thermodynamics.

While there are numerous small errors in the 'Case Study', we have elected to focus only on the major errors that invalidate the analysis, rather that errors that do not effect the outcome but are simply indicative of lack of rigor or understanding of specific issues. An annotated page-by-page reference is given in appendix #1. A general explanation of major errors is given below with references to detailed computations in appendicies #2 and #3.

Examples 2-5 of the cited patent are estimates of the performance of a large-scale deployment of GreenFuel's earliest bioreactor, the "triangle" design. Although we migrated away from this design in favor of more cost-effective alternatives years ago, it is important to address Dr. Dimitrov's concerns related to violating the first law of thermodynamics. The basis for Examples 2-5 is the data in Example 1 of the patent, from work conducted in 2001-2003 time period, when GreenFuel had very limited resources and of course could not attempt to build a large-scale deployment of the reactor system. Consequently Dr. Berzin extrapolated the results from testing a single-unit photobioreactor to estimate the performance of a conceptual large-scale "triangle" system. The large-scale system is comprised of many replications of this same single-unit element, and so the results for the large-scale unit should be a multiple of the single-unit system.

As Dr. Dimitrov shows, the total energy input to the system is the product of multiplying the total land area of the system by the energy flux. The first error is that Dr. Dimitrov uses the wrong value for the total land area of the system. He appears to have misinterpreted the area basis for Examples 2-5, in particular assuming that the total land area of the large-scale system is the same as the "footprint area" cited in the Examples. Closer reading of the application, particularly Figure 2 and Example 1, clearly shows that the "footprint area" is the area of the reactor system that is in direct contact with the ground. Due to the triangular shape of the bioreactors, they must be deployed over a larger area than their "footprint area", or they would shade each other and not be very effective. For the bioreactors in the Examples 2-5, one can see that the minimum spacing for capturing sunlight would result in a ratio of total land area to "footprint area" of at least 2:1. The diagram in Appendix 2 illustrates the error. Because Dr. Dimitrov incorrectly used the smaller "footprint area" in the calculation for total energy input, his results are low by at least a factor of 2. This is a common mistake. Correcting this error alone will show the system does not violate the first law of thermodynamics using his analysis.

Dr. Dimitrov makes a second error in his value for photosynthetically active radiation (PAR) energy for the Southwest. He cites satellite-based data as reported by the Department of Atmospheric and Oceanic Science at the University of Maryland, College Park (reference http://www.atmos.umd.edu/%7Esrb/par/04status.htm). From this he concludes that the maximum PAR available in the Southwest is equivalent to an energy flux of 105 W/m2 (averaged over a 24-hr day). In fact, the satellite data, which require corrections for several factors that influence PAR, underestimate the maximum PAR significantly. Kania, et al of the University of Arizona provide an analysis of PAR measurements in Tuscon over 13 years from AZMET (Arizona Metrological Network) (reference http://ag.arizona.edu/CEAC/research/archive/solar-radiation_kania.pdf). They show the maximum energy flux, using the same basis as Dr. Dimitrov, is 175 W/m2 (details of calculations in appendix 3). As a result of the incorrect value, Dr. Dimitrov's calculated energy input is low by a factor of 1.7. Again, correcting this error alone will show the system does not violate the first law of thermodynamics using his analysis.

Because the energy input calculation is based on multiplying the area and the energy flux, Dr. Dimitrov's errors are compounded, resulting in his calculated input energy being low by a factor of at least 3.5. Correcting these errors, and using his assumed 27% maximum conversion efficiency, the maximum biodiesel output using his analysis is 3.1 GJ/yr, compared to an estimated output of 1.5 GJ/yr in the GreenFuel examples. Consequently, there is no violation of the first law of thermodynamics.

These same errors are replicated in other analysis of the early GreenFuel "triangular photobioreactors." For example, in another analysis he assumes a maximum energy conversion of 10%, and applies the same incorrect energy input, leading to his conclusion that the system can not be economical. Even if these analysis are corrected for their energy input errors, it is important to note that GreenFuel's system evolved away from the "triangular design" more than three years ago. Consequently the costs estimated in Dr. Dimitrov economics analysis by are irrelevant to GreenFuel's current design basis.

One issue not addressed by Dr. Dimitrov, which GreenFuel wishes to clarify, is the yield for biodiesel per ton of algae cited in the published patent application. At that time, GreenFuel did not have its own data, and Dr. Berzin quoted the value of 3.6 bbl biodiesel/ton algae, based on the report of Sheehan (A Look Back at the US DOE Aquatic Species Program – Biodiesel from Algae, see http://www1.eere.energy.gov/biomass/pdfs/biodiesel_from_algae.pdf). Today, based on our own data, we consider a value of 3.6 bbl/ton algae to be closer to an upper range rather than an average value. Our current data supports a more conservative oil yields closer to 1-2 bbl/ton. Again, our experimental results are consistent with the first law in all data to-date.

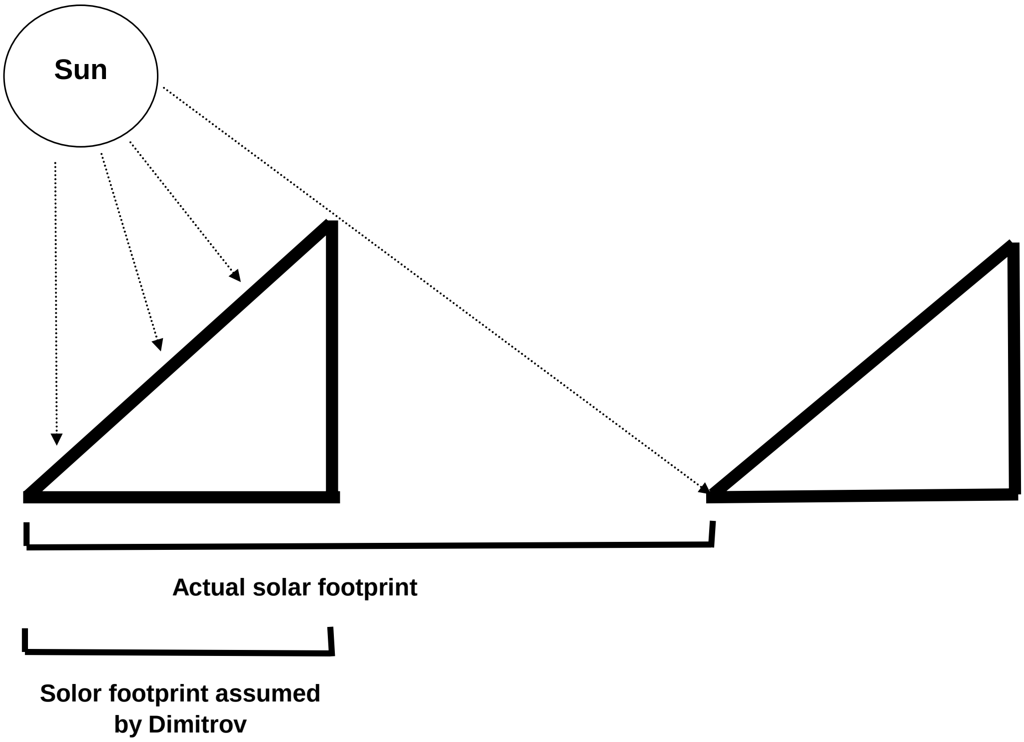
Appendix #1 – References to significant errors in the Case Study prepared by Kassam Dimitrov

Page #	Claim	Not true because
3	Danger of market saturation (algae meal) from DDG and processed soybean	This is not likely, although it is an indication that Dr. Dimitrov does not understand the feed markets. The addressable market for the starch-protein combination produced by almost any of the choices of algae considered by GreenFuel is approximately 1000 million metric tons per year. A 4000 acre GF facility would be expected to produce approximately 350,000 metric tons of starch-combination. To supply just 10% of this market would require approximately 1.2 million acres of GF projects. Clearly, the risk of saturating this market is not a near term risk. Dr. Dimitrov also seems to confuse the starch-protein associated with GF algae with DDGs, which are the residue after ethanol fermentation. These can be used as feed, but often are simply burnt for heat content. But there are some significant differences between algae starch-protein and DDGs as well as soybean meal. Most animal feeds have commonly accepted ratio limits on individual ingredients based on nutritive values. DDG is limiting in the amino acid lysine and soybean meal is limiting in the amino acid methionine. Both ingredients must be mixed with other products to achieve balanced nutrition. The market for DDGS is generally confined to locations where freight costs allow it to be competitively priced against other feed ingredients. The price of DDG (~$70/ton) will be less than the price of soybean meal because of its lower protein content. DDG is primarily used in dairy and beef cattle diets to supplement lower value silage. An acre of corn generates about 4.5 tons of grain (66% of which is starch that can be converted to ethanol) and 1.5 tons of DDG. Soybean meal is by far the most widely used protein ingredient in livestock production. Good quality swine and poultry diets will contain between 30-40% soybean meal. 36M tons of soybean meal are produced in the US/ yr. More then half is exported and that trend is expected to increase. Soybean meal does not provide all of the essential amino acids and vitamins that are required in a complete feed and therefore diets containing soybean meal must also incorporate synthetic amino acids / vitamins to make up the deficiency or more commonly include additional protein sources that are rich in the other essential amino acids and nutrients (algal meals). In any case, this is one reason algae starch-protein combinations, properly treated, are likely to have considerably more value than DDGs.
4	Q_{max} to be around 10%	While that might be the case for open ponds, it is not the case for photobioreactors. For example, Pulz et al. (Handbook of microalgal culture ISBN 0-632-05953-2, page 191) reports 130

		g/m2/d based on the photobioreactor FOOTPRINT. In any case, Dimitrov doesn't seem to understand some of the fundamental performance differences between open pond systems on which much of the photosynthesis 'rules of thumb' are based, and photobioreactors, which for many reasons are just more effective in converting solar energy into algal biomass.
5	Byproduct value 0.2 to 0.25 of the biodiesel	Simply not true. The value of the byproduct depends very much on the specific application, which is often not a technical issue but rather a regulatory issue. Oils, assuming they are refined to a RDB standard, will fetch between \$600 and \$700 per metric ton (Jacobsen), while the starch-protein of algae, properly handled, will fetch at least \$300 per metric ton (Cargill based on specific assays). Highest lipid accumulation for the types of algae GF currently uses would have 25% to 30% lipids with the remainder being starch-protein. In general, the value of the byproduct is comparable to the value of the oil. We think Dr. Dimitrov is confusing algae starch-protein with degraded DDGs associated with corn based ethanol. Also, and to illustrate the situational dependence, in jurisdictions where high premiums are paid for 'green electricity' from a biomass fired electric generator (e.g, parts of the EU), using the starch-protein as a solid fuel may be the best financial option.
6	GreenFuel Q of 44%	Dr. Dimitrov has simply misread the patent. The solar efficiency stated in GreenFuel's patent relates to the bioreactor (triangle) footprint area (20% !!!), which is clearly stated. The setup of the field layout is not described in the patent, which AT MINIMUM requires 50% spread (to prevent shading), and also depends on other geographical location and overall layout needs (service roads etc). This footprint based solar efficiency of 20% is in compliance with theoretical values of photosynthesis and published photobioreactor growth rate results. As a result of misunderstanding the areal basis of the solar efficiency numbers stated in the patent, Dimitrov's calculated Q is high by at least a factor of 2.
5	US PAR maps	Dr. Dimitrov uses incorrect PAR data. He cites satellite-based data as reported by the Department of Atmospheric and Oceanic Science at the University of Maryland, College Park (reference http://www.atmos.umd.edu/%7Esrb/par/04status.htm). From this he concludes that the maximum PAR available in the Southwest is equivalent to an energy flux of 105 W/m2 (averaged over a 24-hr day). In fact, the satellite data, which require corrections for several factors that influence PAR, underestimate the maximum PAR significantly. Kania, et al of the University of Arizona provide an analysis of PAR measurements in Tuscon over 13 years from AZMET (Arizona Metrological Network) (reference http://ag.arizona.edu/CEAC/research/archive/solar-radiation_kania.pdf). They show the maximum energy flux,

		using the same basis as Dr. Dimitrov, is 174 W/m2 (details of calculations in appendix). As a result of the incorrect value, Dr. Dimitrov's calculated energy input is low by a factor of 1.7
5	Nitrogen starvation is out of the question, as flue gas are rich in NOx	Dr. Dimitrov seems to misunderstand nitrogen reduction attendant to the triangular reactor. (By the way, this same phenomena is not as effective current reactors because the gas transfer mechanism is quite different in the current reactors.) GreenFuel uses post-compliance of flue gas with limited amount of NOx to start with. Algae can absorb dissolved form of NOx only. It is very hard to dissolve NO (which is 80% of NOx) in aqueous solution. Bubble size and gas residence time could be engineered to allow negligible amount of biologically available nitrogen, and support nitrogen starvation.
8	Capital cost	Dr. Dimitrov seems to be unaware that GreenFuel doesn't use triangular reactors for commercial systems. Triangular reactors, while an excellent research vehicle, are very expensive to build. Since inventing the triangular reactor GreenFuel has developed much more cost effective reactors. In any case, Dr. Dimitrov's cost analysis is irrelevant because it does not represent the current GF design and class of materials.
9	Land Availability	Dr. Dimitrov's assertion that there is insufficient land to support this type of system is simply incorrect. GF have used DOE and EPA databases, satellite photos, and population density maps to estimate land availability. There are over 1,700 power plants that could support at least one 250 acre GreenFuel facility. Some of them could support much more than one. The international opportunity (especially in countries like China, Australia and South Africa) is significantly greater. In any case, the perception that there is insufficient land to field this type of technology is a common misconception and generally occurs when people simply haven't done the homework to do the suverys. Fortunately, this is very easy to do today.

Appendix 2 – Use of incorrect solar footprint for triangular reactor



Appendix 3 - Energy Flux Calculations

As discussed by Dr. Dimitrov, the relevant solar energy flux is PAR. Dr. Dimitrov cited satellite data as the basis for his calculations. However, extensive land-based PAR data, which is more accurate, is available for Arizona as discussed by Kania, et al. They report maximum and average PAR of 70.3 and 38.4 mol/m2-day, respectively for Tuscon. Converting these PAR values to the equivalent energy flux units in Dr. Dimitrov's analysis requires a value for the average energy of PAR photons. Dr. Dimitrov cites a value of 214.7 kJ/mol photons. Using this value, the incident PAR energy for Tuscon is 4180 W-hr/m2-yr (computed as 70.7 mol pf photons/m2-day x 214.7 KJ/mol of photons x .277778 W-hr/KJ = 4194 W-hr/m2-day) and 2280 W-hr/m2-day (38.4 mol of photons/m2-day x 214.7 KJ/mol of photons x .277778 W-hr/KJ = 2290 W-hr/m2-day). In his calculations, Dr. Dimitrov averages the energy inputs over a 24-hr day. On this basis, the measured Tuscon PAR energy flux is 175 W/m2 (computed as 4194 W-hr/m2-day/24 hr/day) at maximum conditions, significantly greater than his cited 105 W/m2. In fact, his cited maximum value is closer to the average observed value, 95 W/m2 (computed as 2290 W-hr/m2-day/24 hr/day).

GreenFuel Technologies Corporation
April 27, 2007