**The Potential yield of Microalgal Oil. A Simple Estimation**

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**Introduction**

There have been many claims for the amount of oil that could be produced by microalgae, this brief technical note attempts to establish the maximum algae yield using a simple estimation.

**Method and Results**

In autotrophic microalgae the energy from solar radiation arriving on the microalgal surface is converted into stored biomass by photosynthesis. Unfortunately, not all of the solar energy arriving at the surface of a plant can be used in photosynthesis. “Only light within the wavelength range of 400 to 700 nm (photosynthetically active radiation, PAR) can be utilised by plants, effectively allowing only 45 % of total solar energy to be utilised for photosynthesis” (FAO, 1997). “Furthermore, the fixation of one CO2 molecule during photosynthesis necessitates a quantum requirement of ten or more, which results in a maximum utilisation of only 25% of the PAR absorbed by the photosynthetic system. The theoretical maximum efficiency of solar energy conversion is approximately 11%” (FAO, 1997). In practice, however, the magnitude of photosynthetic efficiency observed in the field, may be further decreased by factors such as poor absorption of sunlight due to its reflection, respiration requirements of photosynthesis and the need for optimal solar radiation levels.

The level of the Sun’s energy reaching the ground in South Western USA is approximately 2000 KWhr/m2yr (Maryland, 2007, Meteotest, 2009, NREL, 2009, NASA, 2009). This area has been suggested for microalgae growth and has solar insolation levels typical of many areas being commercially considered for microalgal growth and so the figure for annual total solar insolation of 2000 KWhr/m2yr was selected for the calculation. Levels in Southern England are about 50% of this level and the very highest level such as those in North West Australia and central Sahara are of the order of 25% higher. Using a maximum 11% efficiency of solar energy conversion by photosynthesis 220 KWhr or 189166 Kcal/m2yr of biomass potential caloric value of biomass could be produced per m2 per year from the 2000 KWhr/m2yr of solar energy arriving on the surface.

The calorific value of algae has been found to be between 3.58 and 5.47 Kcal/g (Paine and Vadas, 1969). The approximate calorific value of carbohydrate is 4.2Kcal/g and lipid is 9.4kcal/g with value of protein approximately similar to carbohydrate (Mcardle et al., 2006, Platt and Irwin, 1973). Using the above values it is possible to estimate the calorific value of algae for a range of algal oil contents as shown in Table 1.For a 20 % content in the algae calorific would be 5.2Kcal/g ((0.2x9.4) + (0.8x4.2)). Using the estimated calorific and the law of conservation of energy it is possible to calculate the total amount of algal biomass (potential caloric value of biomass/ calorific value of algae) displayed in Table 1. A wide range of units have been used in the past for potential algal oil production which may not have added to the clarity of information available. Table 1 gives the oil yield in Metric Tons per Hectare per year, US Gallons per Acre per year and Barrels per Acre per year to allow ease of use (A typical Specific Gravity Value for vegetable oil 0.918 was used to calculate oil volume: The standard oil barrel of 42 US gallons)

The oil content of algae can be high at over 70% with oil levels of 20% to 50% being reasonably common, but more typically 10 to 30% when grown under nutrient replete conditions (Gavrilescu and Chisti, 2005, Campbell et al., 2009).The NREL study found oil yields in certain species up to 60%, but maximum productivity levels were found at lower oil contents (Sheehan et al., 1998). Table 1 displays the results from the range oil contents in algae between 10% to 80 %.

Table 1. Calculated algal calorific value, algae yield and algal oil yield for various oil contents at a solar insolation of 2000 KWhr/m2yr and overall photosynthetic efficiency of 11%

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Algae oil Content | Calorific value | Yield algae | Yield Algal Oil | Yield Algal Oil | Yield Algal Oil |
| % Oil | Kcal/g | Metric Tons per Hectare per year | US Gallons per Acre per year | Barrels per Acre per year | Metric Tons per Hectare per year |
|  |  |  |  |  |  |
| 10.00% | 4.7 | 401 | 4667 | 111 | 40 |
| 20.00% | 5.2 | 361 | 8408 | 200 | 72 |
| 30.00% | 5.8 | 328 | 11474 | 273 | 99 |
| 40.00% | 6.3 | 301 | 14032 | 334 | 120 |
| 50.00% | 6.8 | 278 | 16198 | 386 | 139 |
| 60.00% | 7.3 | 258 | 18057 | 430 | 155 |
| 70.00% | 7.8 | 241 | 19669 | 468 | 169 |
| 80.00% | 8.4 | 226 | 21081 | 502 | 181 |

**Conclusions**

The use of solar insolation data, overall photosynthetic efficiency and estimated algal calorific values can form the basis of a simple means to calculate the maximum algal oil yield for a range of algal oil content and solar radiation levels. The overall maximum theoretical yield of algal oil is calculated between 40 and 181 metric tons per hectare per year. This is the absolute maximum yield and is unlikely to be achieved in practice, but it is a useful guide when examining suggested production figures.

A figure of 50% oil content for commercial algae has been suggested, but this is considered higher than feasible by many and a lower figure of 20% may be more realistic and is supported by initial large scale production (Campbell et al., 2009). The algae for growth in an open system will need to be “robust “and may not yield the very highest oil contents. It is suggested; therefore that actual range for the maximum potential oil yields is limited to oil contents between 20% to 50% or between 72 and 139 metric tons of algal oil per hectare per year.

The overall maximum calculated yield of algae is between 401 and 226 metric tons per hectare or 110g/m2 day to 62g/m2 day. The growth rate of a range algae have been reported at between 4 to 38g/m2day (Moheimani, 2008). The NREL in their extensive study reported single day productivities as high as 50 grams of algae per square meter per day, in areas of similar solar insolation as that used in the calculation (calculated as equivalent to 5 to 10% overall solar radiation depending on the oil content of the algae), but continuous production levels were substantially below this level with biomass productivities equivalent to a total solar energy conversion efficiency of about 2% (Sheehan et al., 1998). Seambiotic, in Israel, have reported yield 20g/m2day equivalent to 73tons of algae per hectare per year and Auburn University also suggested economically practical rates of 20 grams per square meter per day for the south eastern region of the U.S., both probably of the order of 2 to 2.5% total solar energy conversion efficiency (Putt, 2007, Ben-Amotz, 2008).

If the yields are only a fraction of the maximum calculated algae will have a considerable productivity advantage over conventional land based crop oil for production. A feasible total solar energy conversion efficiency of 2 % with oil content in the algae of 20% could yield in excess of 13 metric tons per hectare per year of algal oil or over 1500 US gallons per acre per year.

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