Journal of Petroleum Technology and Alternative Fuels Vol. 3(1), pp. 1-4, January 2012
Available online at http://www.academicjournals.org/JPTAF
DOI: 10.5897/JPTAF11.029

Review

Potentials of microalgal biofuel production

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Accepted 30 November, 2011

Microalgae can potentially be employed for the production of biofuels in an economically effective and environmentally sustainable manner. The production of these biofuels can be coupled with fuel gas CO_2 mitigation, wastewater treatment and the production of high-value chemicals. The efficiency is low but there is much room for improvement. The use of microalgae is seen as, at least, a partial solution to climate change and energy problem.

Key words: Microalgae, biofuel, CO_2 mitigation, biomass, bioenergy.

INTRODUCTION

It is well known that the concentration of carbon dioxide is increasing in the earth's atmosphere (Hanson et al., 1981; Stepan et al., 2001; Scheffer et al., 2006). It is also well known and understood that temperature of the earth's surface and the amount of energy in the earth's atmosphere increases with the amount of carbon dioxide therein (Hanson et al., 1981; Joos et al., 2001; Zeng et al., 2004). Also still, it is without question that humanity has been using the hydrocarbon fuels, which releases and therefore increases the carbon dioxide concentration in the earth's atmosphere (Barker and Ross, 1999; Stepan et al., 2001; Dicken, 2004). It also, increases the amount of energy in the earth's atmosphere and a significant factor to climate changes within the atmosphere of the earth (Petterssen, 1969; Hansen et al., 2005; Trenberth and Fasullo, 2010; Wikipedia, 2011). This is only common sense; as, an increasing level of energy in the earth's atmosphere would increase the atmospheric temperature gradients, thereby causing the earth's oceans and atmosphere to lose more energy. All the while, the temperature in space just outside the earth's atmosphere is near -185°C.

Therefore, regardless of increased temperature gradients at earth's surface, humanity should be very cautious about altering or allowing earth's atmospheric temperature gradients to change. Humanity cannot be certain of what a new atmospheric balance is, for example, temperature gradients and energy levels, would mean the ability of the earth to support life as known at this time. Humanity should be very cautious in regard to climate change, regardless of its primary cause. Therefore, it is only rational and reasonable for humanity to manage or mitigate climate change as much as possible. Biologically produced fuels, biofuels, are seen as at least a partial solution to climate change. This is because, biofuels are made with carbon dioxide from earth's atmosphere and as a carbon source in the biofuel (Chisti, 2007a; 2007b; Li et al., 2008), which when combusted, places carbon dioxide back into earth's atmosphere. This biological-combustion carbon cycle is a means by which humanity's carbon dioxide in earth's atmosphere can be managed or reduced (Watanabea et al., 1992; Wang et al., 2008; Brennan and Owende, 2010). Microalgae can potentially be employed for production of biofuels in an economically effective and environmentally sustainable manner (Yanqun et al., 2008). Microalgae have been investigated for production of a number of different biofuels including biodiesel, bio-oil, bio-syngas and bio-hydrogen (Muller-Feug et al., 2003; Chisti, 2007a). The production of these biofuels can be coupled with flue gas CO_2 mitigation, wastewater treatment and the production of high-value chemicals (Hossain and Salleh, 2008). The efficiency with which microalgae performs its function depends on many factors, such as light intensity, temperature, pH, and availability of nutrients (Neish, 1977; Hardiman, 1993; de-Bashan et al., 2005; Luz et al., 2005; Chisti, 2007b; Groom et al., 2008; Mata et al., 2010). Light is critical to autotrophic growth of algae. Sunlight fluctuates in intensity and quality, both daily and seasonally. There are

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also significant differences in sunlight between southern and northern latitudes. On a sunny day, the light intensity for photosynthesis at noon inhibitive the algae in the surface layer of a water column, as the light intensity is simply too high; while, on the other hand it reduced its sufficient intensity in middle of the water column; and then insufficient at the bottom of the water column. This is due to, for example, blockage of light transmission by layers of the algae. Both, photo inhibition and low light decrease biomass production (Vonshak et al., 1994; Chen et al., 2009).

Light intensity is, therefore, a decisive factor in support of algae growth and productivity, which required quantification (Sorokin and Krauss, 1958; Anderson, 2004; de-Bashan et al., 2005; Kommareddy Solovchenko et al., 2007; Solovchenko et al., 2008). Therefore, high sunlight intensity causes photsaturation and photoinhibition, which leads to reduction or cessation of photosynthesis. Usually, this type of damage is reversible after 2 to 3 h of optimum light intensity (Samuelsson et al., 1985; Rodolfi et al., 2009; Brennan and Owende, 2010; Tredici, 2010). The optimum light intensity of microalgae depends on the type of microalgae. In certain species it is as low as 1.5 $W.m^{-2}$ (Sorokin and Krauss, 1958); and in some species, it may be as high as 48 $W.m^{-2}$ (Kommareddy and Anderson, 2004; Goemé, 2008). The average annual productivity of microalgal biomass in a well designed production system located in a tropical zone is measured as low as 1.5 $kg.m^{-3}.d^{-1}$ (Miron, 1999; Chisti, 2007a; 2007b) and, as high as near 4 g.kg $culture^{-1}.d^{-1}$ (Cuaresma et al., 2011); while, 2.8 $g.m^{-2}.d^{-1}$ (1,200 $gal.ac^{-1}.y^{-1}$) has been practically measured (Woertz, 2007). These values are comparable to 3.5 $g.m^{-2}.d^{-1}$ (1,500 $gal.ac^{-1}.y^{-1}$) (Wald, 2008). Much higher productivities of 3.0 to 24.1 $g.m^{-2}.d^{-1}$ (1,300 to 10,780 $gal.ac^{-1}.y^{-1}$) (Benemann and Oswald, 1996; Schenk et al., 2008) were also reported. Yet highly optimistic values of 14.8 to 34.7 $g.m^{-2}.d^{-1}$ (6,340 to 14,880 $gal.ac^{-1}.y^{-1}$) were anticipated by Chisti (2007b) and D'Elia et al. (2010).

It should be noted, however, that the majority of lipid producing microalgae are slow growing, with a doubling time exceeding seven days. In addition, high hydrocarbon concentrations exist only in non-growing, senescent and even decaying cultures, as the hydrocarbon content of growing algae is fairly low (FAO, 1997). From the above values, a conservative average productivity of 3.1 $g.m^{-2}.d^{-1}$ (1,430 $gal.ac^{-1}.y^{-1}$) is "reasonably" calculated. Considering the density of algal biodiesel (0.864 $kg.L^{-1}$), this productivity will be 4,571 $kg.ac^{-1}.y^{-1}$. The caloric value of each kilogram of algal biodiesel ranges between 33 to 41 $MJ.kg^{-1}$ (Elsayed et al., 2003; Hofma, 2003; HA&S 220c, 2004; Vijayaraghavan and Hemanathan, 2009; Wang et al., 2009), depending on the process and algal species used. This gives an average of 37 MJ. kg^{-1}. Most of the lipids produced are neutral, such as triacylglycerols (containing mainly 16:1 and 18:1 fatty acids) (Piorreck et al., 1984; Piorreck and Pohl, 1984) and in certain algae species of a very-long-chain (C23 to C40) and hydrocarbons, that are similar to those found in petroleum, can be obtained (Banerjee et al., 2002; Basova, 2005; Hu, 2008). Peak intensity of the sunlight reaching the surface of the earth is 1,366 $W.m^{-2}$ (Willso and Mordvino, 2003) giving an average of 341.5 $W.m^{-2}$. This includes visible (wavelength of 400 to 700 nm, photosynthetically active radiation, PAR), ultraviolet (UV) and infra red portions.

The visible portion makes only 43% of the total sunlight spectrum (Arjan, 2008). Photosynthetic processes can only utilize the visible portion. In plants, the theoretical maximum efficiency of solar energy conversion is approximately 11%. In practice, however, the magnitude of photosynthetic efficiency observed in the field is 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 net result of overall photosynthetic efficiency is between 3 and 6% of the total solar radiation (FAO, 1997). In comparison, reported microalgae photosynthetic efficiency varies tremendously. Values of 2.3% (Molina et al., 2001), 4.7% (Carlozzi, 2000), 5.6% (Hsueh et al., 2007), 6.9% (Doucha et al., 2005), 8.1% (Converti et al., 2006), 9.4% (Zittellia et al., 2006), 9.6% (Chini et al., 2006), and 15% (Hall et al., 2003) have been reported. These values are lower than the maximum practicable storage of total solar energy by algal biomass growth *in vitro* of 18% (Pirt et al., 1980). Variation in the photosynthetic efficiency may be due to different algal species tested under varying experimental conditions. If the highest value of photosynthetic efficiency (15%) is considered, only 51 W. m^{-2} of average sunlight energy (341.5 $W.m^{-2}$) are then converted to chemical energy. Assuming that microalgae can fully make use the 51 $W.m^{-2}$, although in reality a great deal of the photon energy is absorbed in the topical layer is wasted due to the fact that it exceeds photosaturation (Solovchenko et al., 2007; Tredici, 2010), then the daily (12 h) of usable sunlight energy (51x3600x12) will be 2,210 $kW.m^{-2}$ (3,291,000 $MW.ac^{-1}.y^{-1}$).

The amount of energy utilized by microalgae (2,210 $kW.m^{-2}.d^{-1}$ or 3,291,000 $MW.ac^{-1}.y^{-1}$) should be enough to produce 0.06 $kg.m^{-2}.d^{-1}$ (244.8 $kg.ac^{-1}.d^{-1}$ or 89,352 $kg.ac^{-1}.y^{-1}$) of lipid (based on 37 MJ biodiesel energy content). This value is much bigger than any of the values reported above. It implies that there still are great opportunities to improve microalgal biodiesel productivity by improving sunlight utilization. This can mainly be done by improving photosynthetic efficiency and minimizing energy loses, particularly when considering the significant average amount of sunlight reaching the earth's surface (43.9 x 10^6 MW. $ac^{-1}.y^{-1}$, from a sunlight intensity of 341.5 $W.m^{-2}$) (Willson and Mordvino, 2003). In light of this, there is still a significant potential (potential in magnitudes) for improvement despite the fact that a great deal of the solar energy is wasted or utilized by the algal cell to perform its physiological operations and that a maximum utilization of only 25% of the PAR absorbed by the photosynthetic system is converted (FAO, 1997). Theoretically speaking, if the 15% efficiency is considered, a productivity equivalent to about 140 $g.m^{-2}.d^{-1}$ or 60,000 $ga.ac^{-1}.y^{-1}$ is achievable. Of course, this value is out of reach with any of the current photo bioreactor designs, such as raceway, open pond or tubular, due to irresolvable limitations such as aforementioned light intensity, contamination, temperature, water loss and many other technical issues (Chisti, 2007b; Sastre et al., 2007; Kram, 2011). However, a three dimensional photo bioreactor design that takes care of all the problems facing other designs will get closer to achieving an ideal efficiency and therefore the theoretical limit of 60,000 $ga.ac^{-1}.y^{-1}$ is attained (Haase, 2008).

CONCLUSION

Nature is still in our side and ready to give us much more than we have yet obtained. Humanity needs to develop improved means for microalgal utilization of sunlight. This improved means would reduce land use, save capital, effort and offer an efficient, yet practical, means of converting solar energy to chemical energy, in addition to reducing humanity's carbon footprint. Such a means could reduce Earth's atmospheric carbon dioxide concentration, thereby allowing earth's atmosphere to recover and thereby make global climate change an item of the past.

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