FUTURE OF YOUR FUEL TANK!!!

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Abstract

Rapid depletion of fossil fuel reserves coupled with recent global economic meltdown has put tremendous pressure to search for the alternative renewable energy sources. Enormous interest has been shown for developing biofuel from non-food feed stocks. Algae being the prime candidate are currently being investigated for the production of biofuels. This paper reviews some of the promising features related to commercial production of algal fuel along with the endowment of algae to the environment.

INTRODUCTION

Energy sector plays a pivotal role in the economic growth of a country. Industry, agriculture and business are totally dependent on energy (Ahmad, 2009). It is well known that one of the key indicators of living standards of a nation is energy consumption per capita (The Nation, 2009). Adverse effects of economic meltdown in the last two years have acerbated the energy crises. This has led to an increase in energy demand in the developing countries which chiefly rely on oil. As countries develop, industry, rapid urbanization and higher living standards drive up energy use, most often of oil (Wiki, 2010). In Pakistan, economic, industrial and social sector have witnessed slow growth because of ever increasing gap in energy demand against the capacity (Pkproblems, 2009). At present the nation is facing daily electric power shortage of about 4500-5000 MW which is resulting in daily electricity outage (The News, 2010). This situation is further aggravated by time to time increase in prices of electricity, gas and petroleum that has resulted in public outcry.

According to an EIA report published in 2009 energy consumption of the world is expected to increase from 472 quadrillion Btu in 2006 to 552 quadrillion Btu in 2015 and 678 quadrillion Btu in 2030 (EIA, 2009).This suggests a total increase of 44 percent in energy need over the next 20 years time period. Based on the estimates of 1988, reporting oil production rates of 64.2 million barrels/ day, total oil reserves of the world would be equivalent of 40 years of consumable oil (IEA 2009). FAO report published in 1997 suggests that total oil reserves have been shown to be slightly greater than the proven oil reserves. Nevertheless, oil reserves are finite. Under the present circumstances there is a dire and urgent need to seek alternative fuel (FAO, 1997).

Renewable energy

Major advantage of renewable energy is that it provides diverse source of energy supplies which can potentially replace diminishing oil reserves over a long period. The use of renewable energy can reduce greenhouse gases and other pollutants (IEA, 2009). To search for clean and renewable energy sources is a gigantic task and a major challenge for mankind. This will not only keep the environment clean rather bring prosperity, stability and economic growth (Mata et al., 2010). To achieve the desired results, arduous decisions and long term planning will be required.

Sun is an infinite and renewable source of energy. Sunlight reaches this earth continuously. According to the data recorded by NASA satellite missions, 1360 watts/m^2 of solar energy reach the top of the atmosphere of the earth (Quinn and Frohlich, 1999). Most of this energy is absorbed directly and used to drive the ocean currents and weather, only a fraction (0.1–0.5%) of this is captured by biological systems via photosynthesis (Rabinowitch, 1961; Whitaker and Likens,1975) which can be utilized to produce biomass (a renewable raw material resource for the production of food, fuel and chemicals) through appropriate conversions (FAO, 1997).

Survey of literature suggests that biofuels can replace and/or supplement petroleum, diesel, oil, coal , gas etc. Biofuels can be chiefly obtained from renewable resources i.e. woody plants, short rotation coppicing, perennial grasses, crop residues, municipal solid wastes and algae (Scargg, 2005). Worldwide biofuel yield leapfrogged by 11.2 billion gallons from 4.8 billion gallons through 2000 to 2007. Yet this increase has been considered to be less than 3% of the world fuel which is used for transportation (Coyle, 2007). Moreover, there are several obstacles in the production of biofuels including competition with food and fiber production for use of arable land, cost, regional market structure, biomass transport, lack of well managed agricultural practices in emerging economies, water and fertilizer use, conservation of bio-diversity, logistics and distribution networks (IEA, 2007). In this context it is worthwhile to mention here that CEO National Biodiesel Board of USA reported 30 million gallons decline in the production of commercial biodiesel in March 2009 (NBB, 2009). Similarly a downward trend in ethanol production has been reported by Archer Daniels Midland Company (ADM) USA. According to this report the production fell down by 21%, from about 12.9 million gallons in mid-late 2008 to 10.2 million gallons in February 2009. This decline occurred even when the ethanol producers received big subsidies (Autobloggreen, 2009). To overcome such barriers it is necessary to find new and unobjectionable sources of biomass for alternative energy.

The Possible solution

Nature gave us oil from algae; perhaps we should try the nature's way again!

A famous paleo-botanist of mid 19th century Les Losqueroux claimed that the petroleum originated from marine algae in Devonian Shales. This idea was corroborated by a report written by Arnold and Anderson that appeared in a bulletin of the US Geological Survey (1907) suggesting that the only possible source for oils from Santa Maria field in California was microscopic fossil plants called diatoms (Arnold and Anderson, 1907). This belief was given a strong backing by Clarke in 1916, who presented evidence that the oil in question from the California was similar in its chemical composition to the organic composition of the diatom remains.

Although we may not realize, algae play an important role in our life by carrying out the process of photosynthesis. Photosynthesis is the basis for making solar energy available in usable forms for all organic life in our environment. Algae are accountable for the net primary production of ~52,000,000,000 tons of organic carbon per year, which is ~50% of the total organic carbon produced on earth each year (Field *et al*. 1998). These organisms use energy from the sun to combine water with carbon dioxide (CO_2) to create biomass. While the mechanism of photosynthesis in microalgae is similar to that of higher plants, they are generally more efficient converters of solar energy because of their simple cellular structure. In addition, because the cells grow in aqueous suspension, they have more efficient access to water, CO_2, and other nutrients. For these reasons, microalgae are capable of producing 30 times the amount of oil per unit area of land, compared to terrestrial oilseed crops (Sheenan et al. 1998). They are also considered to be productive in terms of supplying substrate for different renewable fuels. One of the advantages of the algal biofuel is that it is free from sulphur, is atoxic and biodegradable (Peswiki, 2010). Algae are environment friendly organisms because they feed on CO_2, wastewater and in presence of sunlight (which is sufficient in our country). Thus, algae will actually give us a solution by sequestering CO_2, and helping in treating wastewater. Microalgae are considered to be a rich source which has not been tapped. Out of >25,000 species of microalgae only 15 are in commercial use. Moreover it is believed that algal culturing technology will be lucrative business due to its practical applications (Raja et al., 2008).

Diversity in Algal Habitat

Algae of different sizes and shapes not only occupy all aquatic ecosystems but some are also capable of growing in the harsh environmental conditions, e.g. there is an outstanding salt tolerance of halophilic algae like *Dunaliella salina* (Chlorophyceae), which is capable of growing in environments that are nearly saturated with NaCl. The author further reported that cryophilic green algae like *Chlamydomonas nivalis* (Chlorophyceae) are adapted to low temperature, poor nutrition, permanent freeze-thaw cycles and high irradiation, and by the way, they color snow fields orange or red. A principal alga of hot acidic waters is the red alga *Cyanidium caldarium* (Bangiophyceae), which can grow, albeit slowly, at a pH of zero and at temperatures up to ~56°C. Aerial, sub-aerial and aeroterrestrial algae like *Apatococcus lobatus* (Chlorophyta) are normally spread by airborne spores and grow in the form of biofilms in aerophytic biotopes (bark of trees, rocks, soils, and other natural or man-made surfaces). Hypolithic algae, like *Microcoleus vaginatus* (Cyanobacteria), can live in very arid environments like the Death Valley or the Negev desert. The spectacular diversity in the living conditions of algae make them extremely enchanting for commercial utilization (Hallman 2007).

Energy crises in the 1970s triggered considerations about using microalgal biomass as renewable fuels and fertilizers. (Pulz and Scheibenbogen 1998; Spolaore et al. 2006). Particularly during the past two or three decades, algal biotechnology grew steadily into an important global industry with a diversified field of applications, and more and more new entrepreneurs began to realize the potential of algae (Hallmann 2007).

The U.S Department of Energy initiated a long term project, “Aquatic Species Program” (ASP) in 1978. The focus of the program was to develop renewable transportation fuels from algae, distinguishing it from other elements of the Biofuels Program that focused on terrestrial plants for this purpose. ASP was concerned with photosynthetic organisms that grew in aquatic environments. Extensive research was conducted on the production of biodiesel from algae grown in large raceway ponds that use waste CO_2 from coal fired power plants as a fertilizer for the algae. While the history of this program dates back to 1978, much of the research from 1978 to 1982 was focused on using algae to produce hydrogen. The program switched emphasis to other transportation fuels, in particular biodiesel, beginning in the early 1980s (Sheenan et al, 1998).

The ASP study was initiated to explore a suitable species of algae for the best output of transportation fuels. For the production of biodiesel they explored different strains of algae which would give high growth rates along with high lipid or oil content. And for this purpose over 3,000 different species of algae were available and the scientists had challenging task of analyzing the species which would be more suitable for biodiesel production. As a result of the study the researchers became able to identify around 300 strains of algae which were promising with regard to high growth rates, oil content, and some also capable of growing in harsh climates (Sheenan et al. 1998).

Many researchers rivet their efforts on using biochemistry to manipulate the algae to have higher oil content. The goal of this research was to take advantage of the “lipid trigger”, which is the phenomenon that occurs when microalgae are under environmental stress due to which many species go through a metamorphosis and begin producing very large amounts of oil (Benemann, 1996). Researchers thought that this could be done by denying the algae certain nutrients, specifically nitrogen. However in the end the researchers concluded that although the nitrogen deficiency did increase the oil content of the algae, it does not lead to increased oil productivity because it reduces the growth rates of the algae (Sheenan et al. 1998).

Table 1 illustrates some of the lipid contents from various algae which can be tried for biofuel production.

Table 1. Some Algal Strains and their lipid content:

Strain	Lipid (% of Dry Mass)	Reference
Schizochytrium sp.	50-77 %	(Chisti, 2007)
Botryococcus braunii	25-75 %	(Chisti, 2007)
Nannochloropsis sp.	31-68%	(Chisti, 2007)
Neochlaris oleobundans	35-54 %	(Chisti, 2007)
Chlorella vulgaris	14-22 %	(Becker, 1994)

Comparison of microalgae with other biodiesel feed stocks

Although the microalgae oil yield is strain-dependent, it is generally much greater than other vegetable oil crops. It is very promising to note that when the biodiesel production efficiencies and land use of microalgae and other vegetable oil crops is compared, productivity is generally much higher in case of algae even in those having low oil content (Table 2) (Mata et al., 2010).

Table 2. Comparison of Microalgae with other biodiesel feed stocks:

Plant Source	**Oil content** (% oil by weight in biomass)	**Oil yield** (L oil/ha/ year)	**Land use** (m2 year/kg biodiesel)	**Biodiesel productivity** (kg biodiesel /ha/ year)
Corn / Maize (*Zea maysL.*)	44	172	66	152
Hemp (*Cannabis sativa L.*)	33	363	31	321
Soybean (*Glycine max L.)*	18	636	18	562
Jatropha (*Jatropha curcasL.*)	28	741	15	656
Camelina (*Camelina sativa L.)*	42	915	12	809
Canola/ Rapeseed (*Brassica napus L.)*	41	974	12	862
Sunflower (*Helianthus annus L.)*	40	1070	11	946
Castor (*Ricinus communis*)	48	1307	9	1156
Palm oil(*Elais guineensis*)	36	5366	2	4747
Microalgae (low oil content)	30	58,700	0.2	51,927
Microalgae (medium oil content)	50	97,800	0.1	86,515
Microalgae (high oil content)	70	136,900	0.1	121,104

(Chisti, 2007; Teixeira and Morales, 2007; Kheira and Atta, 2008; Callaway, 2004; Hili and Feinberg, 1984; Kulay and Silva, 2005; Mobius Biofuels, LLC, 2008; Nielsen, 2008; Peterson and Hustrulid, 1998; Rathbauer et al., 2002; Reijnders and Huijbregts, 2008; Vollmann et al., 2007; Zappi et al., 2003). (Table adapted from Mata et al., 2010).

Growth Requirements of Algae

Artificial production of algae has been attempted by replicating and enhancing the optimal natural growth conditions as far as possible (Brennan and Owende, 2009). The use of natural conditions for commercial algae production has the advantage of using sunlight as a free natural resource (Anssen, et al. 2003). However, this may be limited by available sunlight due to diurnal cycles and the seasonal variations; thereby limiting the viability of commercial production to areas with high solar radiation. For outdoor algae production systems, light is generally the limiting factor (Pulz and Scheinbenbogan, 1998).

Microalgae have been reported to fix carbon dioxide from different sources i.e. from the atmosphere, from industrial exhaust gases (e.g. flue gas and Microalga Cultivation N/P-Rich Wastewater flaring gas), and in the form of soluble carbonates (e.g., $NaHCO_3$ and Na_2CO_3). Under natural growth conditions, microalgae assimilate CO_2 from the air (contains 360 ppmv CO_2). Most microalgae can tolerate and utilize substantially higher levels of CO_2, typically up to 150,000 ppm (Bilanovic et al. 2009, Chiu et al. 2009). Therefore, in common production units, CO_2 is fed into the algae growth media from external sources such as power plants (Brown,1996; Kadam, 2002; Vunjak-Novakovic et al., 2005; Doucha et al., 2005; Hsueh et al., 2007). Carbon can also be supplied in the form of soluble carbonates such as Na_2CO_3 and $NaHCO_3$ (Emma Huertas et al., 2000, Colman and Rotatore, 1995).

Microalgae can transform carbon dioxide from the air and light energy through photosynthesis to chemical energies such as polysaccharides, proteins, lipids and hydrocarbons. Compared to higher plants, microalgae have a higher photosynthetic efficiency and growth rate (Chisti 2007). CO_2 sequestration using algal reactors has been reported to be one of the most promising and environmentally benign process.The study showed an increase in CO_2 sequestration efficiency by maneuvering chemically aided biological CO_2 sequestration i.e. *Chlorella sp.* and *Spirulina platensis* showed 46% and 39% mean fixation efficiency, respectively (Ramanan et al., 2009).

Other inorganic nutrients required for algae production include nitrogen, phosphorus and silicon (Suh and Lee, 2003). While some algae species can fix nitrogen from the air in the form of NOx (David et al., 2000; Moreno et al., 2003), most microalgae require it in a soluble form with urea being the best source (Hsieh and Wu W-T., 2009).

Phosphorus is of lesser importance and is required in very small amounts during algal growth cycle (Celekli et al., 2009) but, Phosphorous must be supplied in excess of basic requirement because phosphates ions bond with metals ions, therefore, not all the added P is bioavailable (Chisti, 2007). Importance of silicon is confined to productive growth of certain groups of algae such as diatoms (Martin-Je´ze´quel et al., 2000).

Microalgae like other plant-based biofuel resources provide the mechanism for collection, conversion and storage of solar energy into chemical form. For biofuel production, the major factors cited as determining economically viable production include: productivity (viz., strain selection, photosynthetic efficiency, and productivity of lipids), production and harvesting costs (Borowitzka, 1992).

Major advantages of using microalgae for biofuel production

- Microalgae are capable of all year round production, therefore, oil productivity of microalgae cultures exceeds the yield of the best oilseed crops, e.g. biodiesel yield of 12,000 l ha^{-1} for microalgae (open pond production) compared with 1190 l ha^{-1} for rapeseed (Schenk et al., 2008).
- They grow in aqueous media, but need less water than terrestrial crops, therefore reducing the load on freshwater sources (Dismukes et al., 2008).
- Microalgae can be cultivated in brackish water on non-arable land, and therefore may not incur land-use change, minimizing associated environmental impacts (Searchinger et al., 2008), with no compromise on the production of food, fodder and other products derived from crops (Chisti, 2007).
- Micro-algae have a rapid growth potential and many species have oil content in the range of 20–50% dry weight of biomass, the exponential growth rates can double their biomass in periods as short as 3.5 h (Chisti, 2007; Metting, 1996, Spolaore et al., 2006).
- Nutrients for microalgae cultivation (especially nitrogen and phosphorus) can be obtained from wastewater therefore, apart from providing growth medium, there is dual potential for treatment of organic effluent from the agri-food industry (Cantrell et al., 2008).
- Algae cultivation does not require herbicides or pesticides application (Rodolfi et al., 2008)
- They can produce valuable co-products such as proteins and residual biomass after oil extraction, which may be used as feed or fertilizer. (Spolaore et al., 2006) and can also be fermented to produce ethanol or methane (Hirano et al., 1997).
- Varying growth conditions can modulate the biochemical composition of the algal biomass therefore the oil yield may be significantly enhanced (Qin, 2005).
- Micro-algae are capable of photobiological reduction of 'biohydrogen' (Ghirardi et al., 2000).

Above all, National Geographic documentary states "there is no magic-bullet fuel crop that can solve our energy woes without harming the environment, says virtually every scientist studying the issue. But most say that algae—single-celled pond scum—come closer than any other plant" (NGM 2007).

Endowment to the environment

CO_2 Mitigation: Life on Earth is carbon based and the light energy is used to fix atmospheric carbon dioxide into biological material (biomass); indeed fossil fuels that we consume today are a legacy of mostly algal photosynthesis. Algae have higher photosynthetic efficiencies than terrestrial plants and are more efficient in capturing carbon (Packer, 2009). The combined production of renewable energy and material resources with unique environmental applications for GHG emission mitigation and wastewater treatment is one of the hallmarks of microalgal research (Reith et al., 2004). With respect to air quality maintenance and improvement, microalgae biomass production can affect biofixation of waste CO_2 (1 kg of dry algal biomass utilize about 1.83 kg of CO_2) (Chisti, 2007).

Wastewater treatment: Algae can remove wastewater contaminants such as NH_4, NO_3, PO_4, making algae to grow using these water contaminants as nutrients (Wang et al., 2008). They also provide a pathway for the removal of chemical and organic contaminants, heavy metals and pathogens from wastewater while producing biomass for biofuel production. Photosynthetic oxygen from microalgae production reduces or eliminates the need for external mechanical aeration (Munoz and Guieysse, 2006).

The attributes like biofuel production, CO_2 fixation, biohydrogen production, and bio-treatment of wastewater accentuate the potential of microalgae. Furthermore, "microalgae have the potential to **revolutionize** biotechnology in a number of areas including nutrition, aquaculture, pharmaceuticals, and biofuels. Given the vast contributions that these solar-powered, carbon dioxide-sequestering organisms can provide to current global markets and the environment, an intensified focus on microalgal biotechnology is warranted. Ongoing advances in cultivation techniques coupled with genetic manipulation of crucial metabolic networks will further promote microalgae as an attractive platform for the production of numerous high value compounds" (Rosenberg et al., 2008).

Future Challenges

Despite the inherent potential of algae as a biofuel resource, many challenges have impeded the development of algal biofuel technology to commercial viability that could allow for sustainable production and utilization.

- Species selection must balance requirements for biofuel production and extraction of valuable co-products (Ono and Cuello, 2006).
- Attaining higher photosynthetic efficiencies through the continued development of production systems (Pulz and Scheinbenbogan, 1998).
- Development of techniques for single species cultivation, evaporation reduction, and CO_2 diffusion losses (Ugwu et al., 2008).

- Potential for negative energy balance after accounting for requirements in water pumping, CO_2 transfer, harvesting and extraction (Hirano et al., 1998).
- Few commercial plants are in operation, therefore, there is a lack of data for large scale plants (Pulz, 2001).
- Incorporating flue gases which are unsuitable in high concentration owing to the presence of poisonous compounds such as NOx and SOx (Brown, 1996).

Our Efforts

Presently a project is being executed at Department of Biological Sciences, Forman Christian College captioned as ``Production of Algal Fuel`` funded by WWF-Pakistan. The objective of this project is isolation and optimization of the native algal species containing sufficient amount of oil. Two algal species have been isolated in this context. Further efforts are being made to optimize the isolated algal species and upscale the whole process from lab to pilot scale.

Conclusion

There is urgent need to find some alternative options as our fuel resources are diminishing and the demand is growing constantly. Comparing all the available options of energy, i.e. solar, wind, geothermal, nuclear energy etc it seems that algae can be a possible solution to our energy issues which at the same time would solve many of our environmental problems as well. Though it is not cost effective yet to compete with fossil fuel without additional support (for example government subsidies) research is being done to turn it economically viable, both in academia and in industry (Kanel and Guelcher, 1999; Yokochi et al., 2003; Bijl et al., 2004). In the long term, as crude oil reserves diminish and price per barrel increases on daily basis, other alternatives must become available. Hence, it is now the time to search, develop and implement those alternative options (Mata et al., 2010). The idea of constructing buildings covered by glass tubes containing algae is not new (Inhabitant, 2009). Likewise, it is not farfetched when everyone will be having an algal culturing tank on top of the cars, fed by water, light and the CO_2 exhausted from the engine. And the time might come when someone will be able to invent a process for the *In situ* harvesting of algal biomass and its conversion into fuel.

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