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Algal Biorefinery

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Abstract—*Micro and macro algae comprises a vast group of photosynthetic, heterotrophic organisms which have an extraordinary potential for biofuel production as energy crops. Production of biofuel from both micro and macro algae is capital intensive energy consuming which involves various chemical and physical processes. Therefore production of only biofuels from algal biomass will not be cost effective and environment friendly. Therefore it is important to produce biofuel as co-products along with other byproducts through an integrated system by biorefinery approach. Integration of the emerging algal biorefinery concept with other industries can bring many environmental deliverables while mitigating several sustainability related issues with respect to greenhouse gas emissions, fossil fuel usage, land use change for fuel production and future food in sufficiency. A new biorefinery based integrated industrial ecology encompasses the different value chain of products, co-products, and services from the biorefinery industries. This paper discusses a framework to integrate the algal biofuel-based biorefinery.*

Keywords*: Algae -1; Biodiesel -2; biofuels -3; wastewater treatment -4; biorefinery concept.*

1. INTRODUCTION

The world is faced with energy challenges in the near future and it is reported that fossil fuel reserves will be depleted in half a century [1]. This will be an unprecedented vicissitude that will impact negatively on all anthropogenic activities most importantly agriculture, industry and commerce. With this in mind, it is crucial to explore renewable and cost-effective sources of energy for the future. It has been estimated that biomass could provide about 25% of global energy requirements and can also be a source of valuable chemicals, pharmaceuticals and food additives [2]. In addition, the growing of urban population poses a serious threat to the environment due to the release of much amounts of domestic municipal wastewater [3 and 4]. It seems probable that growth in human population, future climate change effects on freshwater resources, which are already stressed in some regions and eventual shortages of unutilized arable land, will encourage the ability to utilize non-agriculture land and waste water resources with few competing uses make algal biofuel production has created great interest in governments, NGOs, the private sector and the research community because of the ability of algae to grow in several condition. Micro and macroalgae are one of the most important bio-resource that are currently receiving a lot of attention due to its multiple role.

Production of biofuel from both micro and macro algae is capital intensive energy consuming which involves various chemical and physical processes. Therefore production of only biofuels from algal biomass will not be cost effective and environment friendly. Therefore it is important to produce biofuel as co-products along with other byproducts through an integrated system of biorefinery approach. The use of algae is desirable since they are able to serve a many role to sort out various climatic problems like, bioremediation of wastewater, generating biomass for integrated biofuel production with concomitant carbon dioxide sequestration [5 and 6]. There is several utilization of algae by which we can sort out the environment problems like; the major problem of global warming is CO_2 in the atmosphere which creates green house effects, so for the growth of microalgae the utilization of CO_2 is very essential, and to generates around 1 kg algal biomass requires 1kg of CO_2 which is better to sort out this problem, it can be reduce many heavy or toxic metals form waste water and this process called Phycoremediation, It can be use as biofuel to reduce the effect of our conventional fuel which is going to be finish day by day because algae have potential to produce biofuel in the form of lipid which id further processed by transesterification process get the biodiesel which has the properties same as the our conventional diesel and it can be use for the many cosmetics, food and many use in the field of pharmaceuticals. So in this paper discusses a framework to integrate the algal biofuel-based biorefinery concept.

2. ALGAL GROWTH IN THE WORLD

Piccolo [7] has reviewed some of the current developments for algae oil production in the EU countries. According to him the biggest algae investment in the EU is the £ 26 million publically funded project by the UK Carbon Trust which planned to build a large algae farm in Northern Africa. To support such development, Carbon trust launched a new £ 8 million research programme, Algae Biofuels Challenge (ABC) in 2009. The ABC has two phases [8]. Phase 1 is targeted on addressing the fundamental R&D challenges and phase 2 will focus on evolving the strategies for large-scale production of algae oil. The ABC is now led by a research team from 11 institutions including Universities of Manchester, New Castle, and South-ampton, the Plymouth marine laboratory, and Scottish association for marine sciences [9]. Lately, the Scottish government launched 6 million EU projects called BioMara [10]. The scope of BioMara project is not just limited to the single celled algae species but also includes larger seaweed species which grow quickly and can be harvested for their biomass. In another development, a Spanish renewable energy company Aurantia and Green Fuel Tech of Massachusetts (USA) formed partnership through a $92 million project in 2007 to produce algae oil. In the long run, this project will target to scale up to 100 ha of algae greenhouses, producing 25,000 ton of algae biomass per annum. The plant will obtain its CO_2 from a cement plant near Jerez in Spain. In yet another Endeavour, an Italian energy Company, has installed a 1 ha pilot facility for algae oil production, in Gela, Sicily. This project is testing the photobioreactor facility as well as open ponds. The countries with a coastline onto the Mediterranean Sea, are suitable locations for algae farms, in particular in those countries south of the Mediterranean that experience warmer climates and whose temperature do not go too much below 15-8 °C throughout the year.

This sort of warm climate of the Mediterranean region can facilitate the algae growth in the open or closed pond system. It would probably be the most efficient, economic and most suitable way to grow the algae biomass. New technologies in algae harvesting have also succeeded to set up cultivation for open pond farms to be located in slightly cooler climates by covering them with special material making them behave in a similar way as a greenhouse, this can certainly increase the latitude in which such farms can be built. In view of the above, a number of countries in the Mediterranean basin possess a great potential for algae harvesting. Some countries, e.g. Israel, have been growing and harvesting algae for non-fuel i.e. medicinal purposes as well as nutrients production for a long time and also have begun the production of several strains for fuel production recently. The southern countries that border the Mediterranean Sea, e.g. Morocco, Algeria, Tunisia and Egypt, are particularly attractive because of high temperatures and enormous unused desert land. At the same time, countries like Libya, Cyprus and Turkey could also have lots of marginal land to harvest algae. Even if some of these countries do not have plenty of water resources that is also not a constraint. It is well established now that algae do not require freshwater, rather they can grow with recycled brackish or salty water. Besides, these countries are developing countries and could strongly benefit from such an industry. Algae farming can provide jobs for locals and the transfer of technologies to developing countries can also be beneficial for the country concerned. A comprehensive survey has been carried out by Edward [11], which highlights the various aspects of the algal cultivation as well as utilization industry.

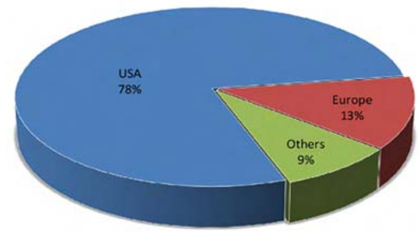

Fig. 1: Region-wise percentage of companies around the world producing algae fuels.

Fig. 1 shows a pie chart representing the percentage distribution of algal biofuel producing companies around the world in different regions. Fig. 2 represents the percentage distribution of various algae production technologies being used by the companies worldwide.

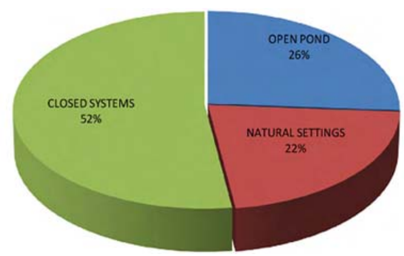

Fig. 2: Worldwide technologies being used for algae biofuel production companies.

As indicated from Fig. 2, more thrust is being made to cultivate algae in closed systems or using photo-bioreactors. These bioreactors are in fact installed near a source of CO_2, and thus serve an additional purpose of carbon sequestration. However, the natural formations are the least capital cost intensive. The open ponds are also an attractive option for the regions where sufficient land can be allocated for algae growing, without interfering with the food chain.

3. ALGAL BIOREFINERY (SCOPE AND POSSIBILITIES)

The biorefinery concept is related to today's petroleum refineries, which produce multiple fuels and products (petrochemicals) from petroleum. The various petrochemicals produced from the refineries and their applications in various industries, e.g. plasticizers, vegetable oil extraction, paints and anti-corrosive substances, and many more. The production of these petrochemicals makes the refinery process more profitable as well as practical. Industrial biorefineries have been identified as the most promising route to the creation of a new domestic bio-based industry. On the basis of correspondence with a petroleum refinery, a biorefinery may be defined as a facility that integrates biomass conversion processes and equipment to produce fuels, power, materials or chemicals from biomass. A more specific and comprehensive definition of a biorefinery has been given by IEA Bioenergy Task 42 document [12], which states, "the sustainable processing of biomass into a spectrum of marketable products and energy". By producing multiple products, a biorefinery can take advantage of the differences in biomass components and intermediates and maximize the value derived from the biomass feedstock.

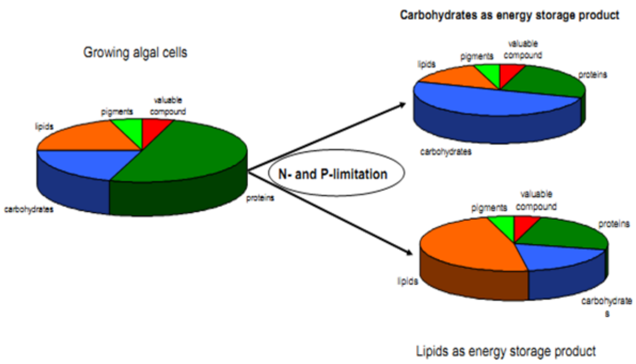

Fig. 3: Production of storage products in microalgae

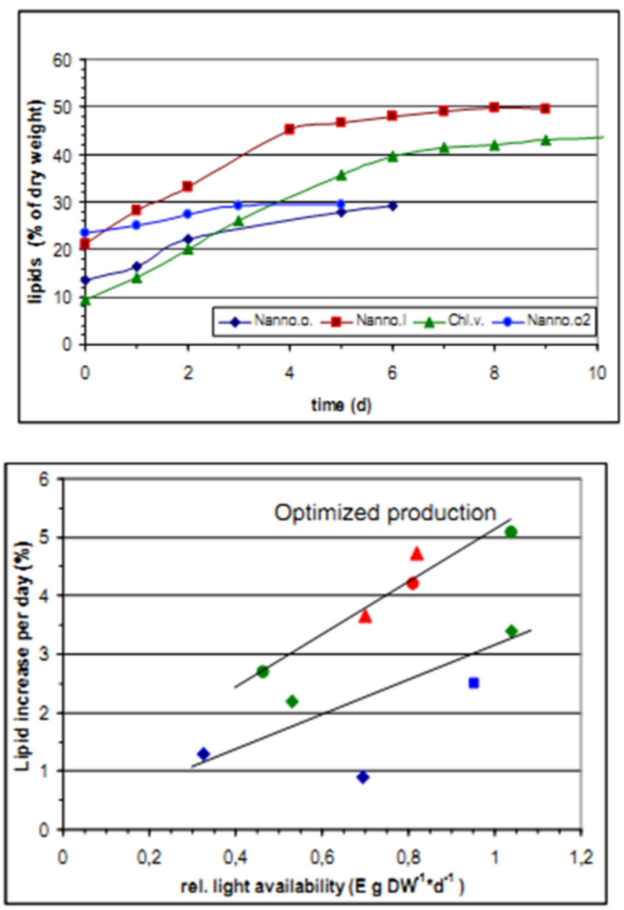

Fig. 4: Energetic use: Microalgal lipid production (Microalgal lipid production depends strongly on available light per cell)

3.1. CONCEPT OF ALGAL BIOREFINERY

The concept of algal biorefinery has the key to explore the possibility of producing biofuels at large scale from industrially grown algae. The main components of a typical algae feedstock are proteins, carbohydrates, lipids, and other valuable components, e.g. pigment, anti-oxidants, fatty acids, vitamins etc. The maximum lipid contents in microalgae are also around 40% on wt. basis, which is reasonably good. All these factors make microalgae a potential source for bio-oil production. A wide array of products can be formed from the algae [13 and 14].

These products range from the food supplements and nutrients for human, livestock feed, fine organic chemicals for pharmaceuticals, pigments and various other applications, e.g. chlorophyll, bio-butanol and acetone etc., along with energy fuels, e.g. biodiesel, bioethanol, and biomethane. Following subsections present a brief account of the various valuable products that can be obtained from various algae feedstocks.

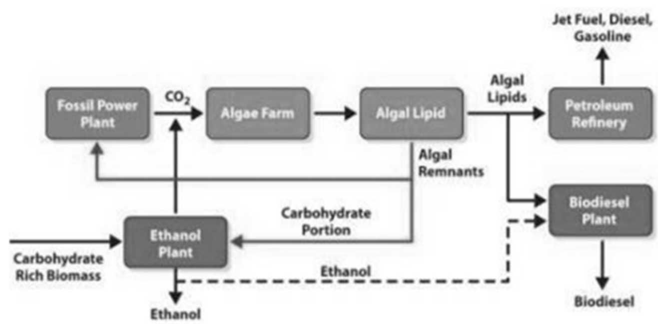

Fig. 5: Algae Biorefinery concept

4. ALGAL BIOREFINERY FOR BIOFUEL PRODUCTION

Today all over the world, energy crisis and environmental issues are the most important concern. In addition, it is projected that world energy demand will continue to expand by 45% from 2008 to 2030, an average rate of increase in 1.6%/yr (World Energy Outlook 2008). According to the available data nearly 81% of the energy is being supplied through use of fossil fuel followed by 16% of renewable energy and 2.8% through nuclear energy (Fig.6). Excessive use of fossil fuels as energy is now widely accepted as unsustainable due to depleting resources and also due to the accumulation of greenhouse gases in the environment [15]. Besides, another problem,

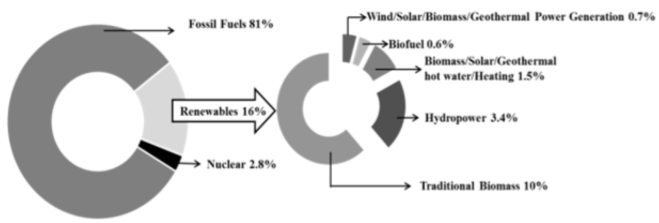

Fig. 6: Global Energy Consumption, (Renewables 2011- Global Status Report)

with the petroleum fuels is their uneven distribution in the world where 63% of the global fossil fuel resources are located in the Middle East region of the world which has several implications such as equity issues as well as environmental, economic and geopolitical concerns. Therefore, biomass based energy can serve as an excellent alternative source to meet the present and future demand. Amongst the various form of biomass energy, biofuels are the most common source of energy as transportation fuel. Although the demand for biofuel is several times higher but presently only 0.6% of biofuels are consumed globally.

5. FEASIBILITY FOR ENERGY

In Netherlands some of energy companies, studies on the production of microalgae, in which three production technologies were compared: open pond, horizontal tubular photobioreactor and a flat panel photobioreactor. Estimations were conservative, which means that for reaching estimated productivities there is no need to develop systems or processes further than what is now possible. In this analysis we also assumed that nutrients for the growth medium and CO_2 had to be bought. The end product of the process we designed is an algal paste with a dry matter content of 20%. Extraction of oil and esterification was not considered. Two different plant sizes were evaluated (1 and 100 ha). We report here the values estimated for a scale of 100 ha. Microalgae biomass can be produced cheaper in photobioreactors than in raceway ponds, but this is achieved at the expense of higher energy consumption. When comparing the two photobioreactors, the horizontal tubular reactor and flat panel show a similar biomass production cost. Regarding energy balance, flat panels perform a bit better, even though both systems have a negative balance.

There is no practical experience with cultivation of microalgae for energy purposes. Photobioreactors have only been applied for the production of biomass of high value, i.e. more than 100 €/kg DW. As a consequence, processes have never been optimized for applications where the value of biomass is less than 1 €/kg DW. Process development for the production of microalgae for energy purposes still needs to be done. In order to analyze the effect of some parameters on biomass / energy costs a sensitivity analysis was made. In this way we could determine whether and how costs could be realistically reduced. With the present status of the technology, production costs were calculated at 4.02 €/kg biomass (153.5 € / GJ) but could become as low as 0.42 €/kg biomass (16.0 € / GJ). Development of the technology combined with the usage of the remaining biomass components, which are not required for biofuel production, in other applications (a biorefinery approach in which 100% biomass is valorized) the commercial production of microalgae could become a realistic option for the biofuel market.

6. FACTS ON ALGAE

The ultimate and ideal energy carrier for durable technologies is solar irradiation. The most efficient method to benefit from solar irradiation to produce biomass is growing microalgae. Microalgal biotechnology is a relatively young field and presently the market is mainly determined by a few species (Spirulina, Chlorella and Dunaliella). It is expected that the commercial market will expand with other promising species for valuable and more diverse products. The biodiversity of microalgae is enormous and each species produces its own unique product(s). Because only 10% of the species are identified microalgae represent an almost untapped resource. It has been estimated that there are between 200,000 and several million species, compared with about 250,000 species of higher plants. Microalgae have an enormous potential. This is supported by the comparison, in terms of development, with both microbial fermentations and agriculture. Due to the development in these technologies and strains (in case of fermentation) and crops (in agriculture), the productivity of present systems is about 5000 times higher than the original natural production systems. Production of microalgae is still based on traditional technologies with wild type strains. It is a great challenge to realize breakthroughs in both photobioreactor technology and strain development. Especially marine microalgae are rich in high-value bioactive components like vitamins, ω-3 fatty acids, pigments, antioxidants and sterols. Only a small number of these compounds have been commercialized at large scale. Development of new products from microalgae has always been limited by the technology, as described above. Especially for products for which algae need to be grown as monocultures, the available technology is seen as a bottleneck. Most of the commercial systems applied are open ponds for the production of Spirulina, Chlorella and Dunaliella. Apart from that, microalgae are produced at aquaculture sites in which they serve as feed [16].

7. THE WORLD'S ENERGY CHALLENGES

As worldwide petroleum reserves diminish due to consumption exceeding discoveries, many countries are becoming increasingly dependent upon imported sources of oil. The United States, for example, currently imports a full two-thirds of its petroleum from only a few countries around the world. The demand for energy is growing worldwide especially in many of the rapidly developing countries such as in China and India. Furthermore, the continued combustion of 2 fossil fuels has created serious environmental concerns over global warming due to the increased release of greenhouse gases (GHG). Biofuels are one of the potential options to reduce the world‘s dependence on fossil fuels but biofuels have their limitations. One of the recent concerns with respect to increased biofuels production is the availability of land. It is recognized that the GHG benefits of biofuels can be offset if land with existing high carbon intensity is cleared for the production of biofuel feedstocks. Biofuels that could be produced without large increases in arable land, or reductions in tropical rainforests could be very attractive in the future. Algae may offer that opportunity.

The basic concept of using algae as a renewable feedstock for biofuels production has been known for many years. However, historical efforts in this field have been inadequate to facilitate the development of a robust algal biofuels industry. Realizing the strategic potential of algal feedstocks will require breakthroughs, not only in algal mass culture and downstream processing technologies, but also in the fundamental biology related to algal physiology and the regulation of algal biochemical pathways.

8. CONCLUSIONS

Reducing the carbon intensity of the energy sources used in various industrial sectors by transitioning to alternative fuels and energy efficient machineries could reduce GHG emissions. The complex and interconnected nexus of fuel, food and GHG emission needs a planned, integrated approach. Undoubtedly, all industrial sectors are going to require radical changes in the future to address the massive challenges of emission-related regulatory framework. An important key to limit emissions in all these processes is an integrated industrial framework. Microalgae cultivation for wastewater treatment coupled with biofuel generation is therefore an attractive option in terms of reducing the energy cost, GHG emissions, and the nutrient (fertiliser) and freshwater resource costs of biofuel generation from microalgae. The high biomass productivity of wastewater-grown microalgae suggests that this cultivation method offers real potential as a viable means for biofuel generation and oilgae biomass could be cultivated in photo-bioreactors but a favourable assessment of the economics of production is necessary to establish and is likely to be one of many approaches used for the production of sustainable and renewable energy. This review encompasses latest developments on exploiting microalgae biorefinery concept.

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