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Algal Biofuels : A Review

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ABSTRACT

The fossil fuels have their adverse effects on nature. So, environmentalists advise to minimize the use of fossil fuels. The natural and artificial resources other than fossil fuels can meet world energy demand. An energy mix consisting of fossil fuels, hydrogen, bio-fuels, and renewable energy sources seems to be a good initiative. Microalgae have additional advantages over terrestrial plants. The major challenges towards using microalgae for biofuel production include strain isolation, nutrient sourcing and utilization, production management, harvesting, coproduct development, fuel extraction, refining and residual biomass utilization. Algae have the potential to produce a number of secondary metabolites which can be used a source of biofuel for energy needs of the world.

KEY WORDS: Algae, biofuel, energy, microalgae, biomass

INTRODUCTION

The height of human prosperity can be attributed to the discovery and utilization of fossil fuels. The planet earth has an abundant quantity of oil, the reserves of which are increasing to date (Cheney & Hawkes, 2007). However, the existing trust in the oil era is declining (Heinberg, 2005); the gases may also be peaking soon (Darley, 2004) and it will be marking the end of the hydrocarbon age or the fossil fuel age (Goodstein, 2005). The fossil fuel depletion scenario may be attributed to the supply chain disconnection due to the oil embargo in 1970s and paradigm shift toward energy efficient cars, electricity and gas heating in the past centuries (Toth & Rogner, 2006). The fossil fuels have their adverse effects on nature. So, environmentalists advise to minimize the use of fossil fuels. They correlate this with peak emission of CO_2, which is constantly increasing. This significant greenhouse gas-mediated climate change is affecting the health of people throughout the world directly and indirectly. The existing global economy requires fossil hydrocarbons and other renewable energy resources to providing the energy requirements of the world towards lighting, heating and transportation and other basic needs. The countries move towards improving their gross domestic product so their demands for energy resources will increase continuously. With our increasing population and expanding economy, there is a need to create new and expanding resources of fuel production.

Mankind has been using coal since many decades, yet it was taken as regular fuel after the invention of steam engine. Steam engines were replaced by diesel and electric engines by the middle of the 20th century. There are huge reserves of coal in various parts of the world. China and America are the largest coal producers and consumers (Lin & Liu, 2010; Tao & Li, 2007). The coal utilization would continue to increase due to decline and depletions of oil and gas in the future (Mohr & Evans, 2009). But, coal is also subject to peak, decline and depletion (Patzek & Croft, 2010). Conventional oil and gas reserves may deplete in the second half of this century, yet it is not the final end of oil and gas (Lynch, 1999, Nick et.al., 2010, Renato, 2011). The fossil fuels account for about 86% of the global primary energy demand which is rising gradually. At present, oil, gas, coal, renewable and alternative energy resources have a major share in the global energy mix. While solar, wind, geothermal, biomass, tidal and nuclear power accounts for minor fragments in the global energy mix (Maggio & Cacciola, 2012).

A grand energy transition (GET) is underway from solid to gas phase fuels (Robert, 2009). Gas phase fuels (Hydrogen, methane and water gas etc.) can directly be ignited to run internal combustion engines (Edward, 2010). Reviews on solar (Solangi et.al. 2011), wind (Herbert et. al. 2007), hydrogen (Moriarty & Damon, 2009), Bioenergy (Faaij, 2006), artificial photosynthesis (Pearce, 2002), fission and fusion (Duffey, 2005) show that natural and artificial resources other than fossil fuels can meet world energy demand. Energy harvested from other renewable sources such as ocean tidal and wave power sources is also on constant rise. Transition from fossil fuels to sustainable and renewable energy resources requires major investment and innovatory technologies. An energy mix consisting of fossil fuels, hydrogen, bio-fuels, and renewable energy sources seems to be a good initiative.

A SHIFT TOWARDS BIOFUEL TECHNOLOGY

The most promising sustainable alternatives are almost exclusively categorized under the term 'biofuels'. This term describes a diverse range of technologies that generate fuel with at least one component based on a biological system. The major technologies presently employed for biofuels begin with terrestrial plants and culminate with ethanol, whether this is corn starch to sugar to ethanol, or sugarcane sugars to ethanol. To a lesser degree, oils from terrestrial plants – for example, soy and palm – are used to produce biodiesel. These strategies are functional at the small scale; however, as their use has increased, it is evident that they are not sustainable, owing to the enormous amount of agricultural land that would be required to supplant a significant fraction of petroleum using this strategy (Fargione et.al. 2008, Searchinger et. al. 2008). But these strategies are insufficient to accommodate the global demand for liquid fuels.

BENEFITS OF MICROALGAL BIOFUEL PRODUCTION

Algal species grow in a wide range of aquatic environments, from freshwater to saline. Algae can produce biomass very rapidly, with some species doubling in as few as 6 h, and many exhibiting two doublings per day (Sheehan et.al 1998, Huesemann et.al. 2009). All algae have the capacity to produce energy-rich oils, and a number of microalgal species have been found to naturally accumulate high oil levels in total dry biomass (Rodolfi et.al. 2009). The microalgal species (like diatoms, green algae, golden brown, prymnesiophytes, eustigmatophytes and cyanobacteria) are being investigated as potential biofuel crops.

Microalgae have additional advantages over terrestrial plants. Since they are single-celled organisms that duplicate by division, high-throughput technologies can be used to rapidly evolve strains. This can reduce processes that take years in crop plants, down to a few months in algae. They can be grown on land that would not be used for traditional agricultural, and are very efficient at removing nutrients from water. Thus, not only would production of algae biofuels minimize land use compared with biofuels produced from terrestrial plants but, in the process of culturing these microalgae, waste streams can be remediated.

Algae production strains also have the potential to be bioengineered, allowing improvement of specific traits (Rosenberg et.al 2008, Zaslavskaia et.al. 2001) and production of valuable co-products, which may allow algal biofuels to compete economically with petroleum. These characteristics make algae a platform with a high potential to produce cost-competitive biofuels. The high growth rates, reasonable growth densities and high oil contents have all been cited as reasons to invest significant capital to turn algae into biofuels.

CHALLENGES TOWARD BIOFUEL PRODECUTION

The major challenges towards using microalgae for biofuel production include strain isolation, nutrient sourcing and utilization, production management, harvesting, coproduct development, fuel extraction, refining and residual biomass utilization.

IMPROVEMENT IN EFFICIENCY OF BIOFUEL

There are significant challenges for engineers to either design photobioreactors (PBRs) that are cheap enough for large-scale deployment, and to develop species that grow efficiently in low-cost open systems (Borowitzka 1999). PBRs have advantages over open systems in that they can more easily maintain axenic cultures, and can maintain more controlled growth environments, which may lead to increases in productivity. The existing strategies for extracting oil from algae are relatively expensive, either in terms of equipment needed or energy required to extract the crude algal oil and the pure fuel production. The harvesting and extracting oil from algae still needs improvements to make it economically more efficient.

AVAILABILITY OF LAND FOR INDUSTIAL LEVEL PRODUCTION

Away from the marine water, and to meet the local needs of biofuel, the significant area of land should be allocated to establish algal biofuel production units at industrial level.

Water and nutritional requirements algae grown in open ponds have water requirements per unit area similar to that of cotton or wheat, but less than that of corn, to replenish the water lost in evaporation. Although many alkaline reserves are available, water will remain a central issue for algae biofuels production and will need to be considered carefully as the industry expands.

Algae require nutrients, light, water and a carbon source, most often CO2, for efficient growth. The major nutrients required by most algae include phosphorous, nitrogen, iron and sulfur. Often, the nutrient requirement necessary for algal growth is ignored, since algae are very efficient at sequestering these nutrients when present in their environment (Marchetti 2009, Ruiz-Marin et.al. 2009). Micro- and macro-nutrient supplements, or fertilizer, account for significant costs in the current terrestrial agriculture industry. Algae, similar to plants, require sources of phosphorus, nitrogen and potassium and the optimal growth of many algal species also requires chelated iron and sulfur.

CROP PROTECTION

Algae biofuel production projects are considering both open and closed systems. These options have significantly different challenges. Much like terrestrial monocultures, large algal monocultures will be invaded by pests and pathogens, and therefore, crop protectionis a major challenge to algal pond sustainability. Identifying strains resistant to pathogens, along with many other strategies, will need to be employed. Another solution to minimize contamination is to use microalgae that can grow under extreme conditions, which are not suitable for most of the potential contaminants. Microalgae have developed morphological, behavioral and chemical mechanisms for defending themselves from pathogens and predators. Chemical defense is widely present in the ‘algae group’ against bacteria, fungus, protozoans, aquatic invertebrates, other algae and even viruses (Kulik 1995, Thyrhaug et.al. 2003, Bhadury & Wright 2004). The majority of antibiotic extracts studied so far have been from marine macro- and micro-algae (Bhadury & Wright 2004, Pesando 1990, Gupta & Shrivastava 1965); however, they are also present in many freshwater species (Gupta & Shrivastava 1965, Chu et.al. 2004, Santoyo et.al. 2009).

BIOPROSPECTING AND BIOENGINEERING

To move a species into an applied pipeline after initial species identification, significant physiological, biochemical and genetic characterization must occur. This characterization includes establishing optimal growth conditions (i.e., temperature, nutrient levels, salinity and pH), growth characterization (i.e., rate of growth and final culture density), and analysis of metabolite accumulation (i.e., lipid composition and accumulation). In parallel, functional genomics (genomics, proteomics and metabolomics) can provide insight into metabolic pathways present in these species and provide a foundation for future metabolic engineering.

Artificial selection of desired traits in agricultural plants has probably been occurring since the dawn of agriculture. The two traditional strategies have been identification of traits of interest from the naturally occurring diversity of the crop species, and selectively combining these traits through interbreeding. Directed and successful breeding of some species of microalgae is possible, but little is known about the sexual lifecycle of the vast majority of species. This is partly owing to the enormous diversity in the algae groups, from the diploid diatoms to the haploid chlorophyceae. There is potential to improve algae for biofuels by developing the tools for selective breeding and using these to move traits that have an impact on biofuels between closely related species, or to improve specific strains of one species. These breeding strategies have an advantage, in that polygenic traits can be moved between strains; however, currently mutagenesis and molecular genetics are at the forefront of algal strain improvement. The bioprospecting and bioengineering are being investigated to improve the economics of algal biofuels.

IMPROVEMENT IN HARVESTED BIOFUEL MOLECULES

Algae can be harnessed to produce a number of molecules that can be used for fuels. Although harvesting endogenous lipids, or even improved lipids through bioengineering is the most likely strategy for biofuel production, algae can produce a number of other potential fuel molecules. In addition to hydrogen, algae produce hexose sugars, which can be fermented to produce ethanol, butanol and potentially longer chain hydrocarbons. Algae have the potential to produce a number of secondary metabolites that have characteristics much closer to existing petroleum fuels. The most promising of these are the terpenes, which offer a potential new fuel source outside of fatty acids that is compatible with our existing fuel framework.

CONCLUSION

Algae have the potential to produce a number of secondary metabolites that have characteristics much closer to existing petroleum fuels. The most promising of these are the terpenes, which offer a potential new fuel source outside of fatty acids that is compatible with our existing fuel framework. For an economic process development in comparison to others, a cost-effective and energy efficient harvesting methods are required with low energy input. Producing low-cost microalgal biofuels requires better biomass harvesting methods, high biomass production with high oil productivity through genetic modification, which will be the future of algal biology.

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