SHORT FEATURE

Microalgae-based Biofuels: *Potential & Challenges*

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POPULATION growth and the expansion of industries have led to an increase in global energy demand. The current energy supply of the world is primarily dependent on fossil fuels derived from petroleum resources. But the global fossil fuel reserves are also depleting rapidly, thereby necessitating the development of alternative fuels and sources of energy.

Biofuels derived from biological materials are a potential alternative to fossil fuels since they can be used with the existing engine infrastructure. Biofuels can be primarily categorised into first-, second- and third-generation biofuels depending on the biological feedstock used to produce them. First-generation biofuels are associated with the controversy of "food versus fuel" since they are derived from food crops. Although second-generation biofuels overcame this issue by the use of energy crops as feedstock, their applicability is also limited due to the requirement of energy-intensive processing steps, longer regeneration cycles and lower energy/oil yield of the feedstock.

Third-generation biofuel, or microalgae-based biofuel, has the potential to overcome the issues inherent in the first and second generations. Microalgae have significantly higher growth rates compared to terrestrial plants (up to 10 times higher), and their oil content can reach up to 70% in dry weight. In addition to oil (lipids) which can be employed to produce biodiesel, microalgae accumulate other organic compounds such as carbohydrates which can be converted into other forms of biofuel including bioethanol and biogas.

Moreover, unlike first- and second-generation feedstock, microalgae can be grown in non-arable land which cannot be utilised for agricultural purposes. Microalgae can also be cultivated using seawater or wastewater, instead of freshwater. Therefore, microalgae can be considered as a promising feedstock for biofuel production.

However, although microalgae-based biofuels are viewed as more sustainable and environment-friendly than fossil fuels, some major issues prevent their large-scale production. The foremost challenge is the economic infeasibility of biofuel production from microalgae. Microalgae-based biofuel production involves the major steps of biomass production (cultivation), harvesting, drying, pre-treatment, product extraction and conversion. The high capital and operating costs involved in these processes is a major bottleneck in the commercialisation of microalgae-based biofuels.

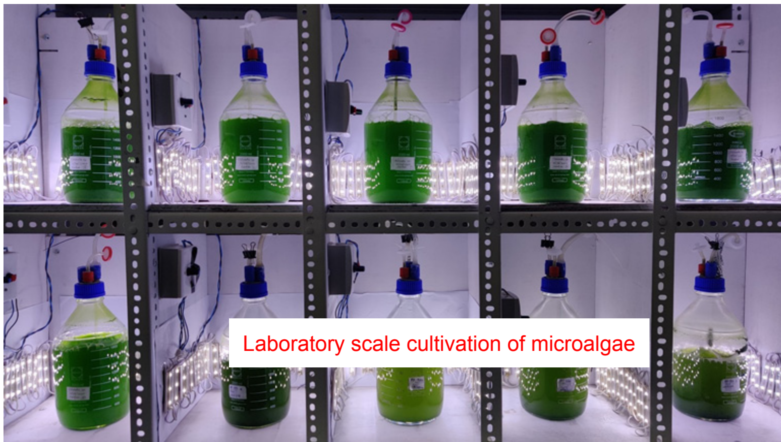
In contrast to other energy crops, microalgae require more sophisticated cultivation systems to produce high quantities of biomass. These cultivation systems include open and closed bioreactor systems. Closed bioreactors are less susceptible to contamination with unwanted organisms, and allow more efficient control over operating parameters. Thus, closed systems exhibit higher biomass growth rates and increased accumulation of target metabolites. However, these systems entail high capital and operational costs.

Open systems are cheaper in terms of fabrication and operation, but do not allow much control over the culture parameters and are easily contaminated with unwanted organisms. Hence, to realise economically feasible microalgae cultivation, there is a pressing need for the development of novel and cost-effective growth systems that allow significant control over culture parameters.

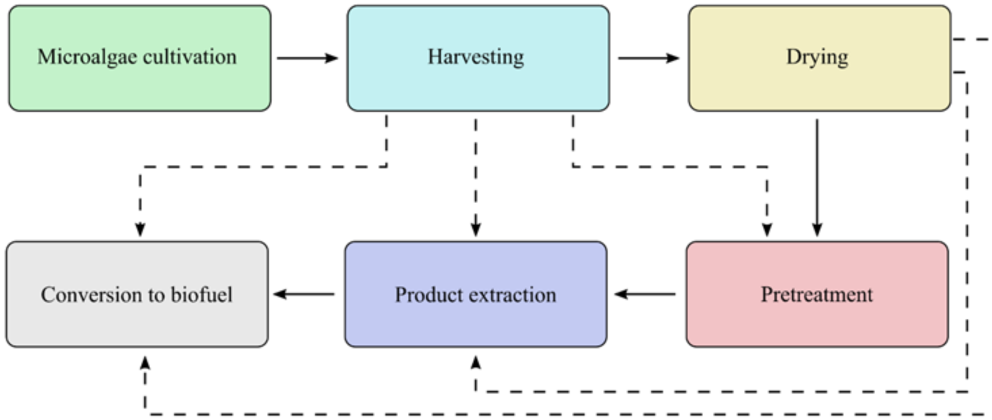
Another challenge involved in the cultivation of microalgae is the requirement of copious quantities of water. This is a major concern in the cultivation of freshwater microalgae species. For instance, approximately 148 trillion litres of water will be consumed to produce the quantity of microalgal biodiesel required to replace 5% of the global petroleum diesel demand. Thus, a scenario where microalgae-based biofuel can completely replace petroleum-based fuel is not realisable with the rising water scarcity. This issue could be alleviated by employing marine microalgae capable of growth in seawater, or microalgae that can grow in industrial or domestic wastewaters.

However, wastewater may contain inhibitory substances and predatory species that may limit the biomass and oil yields. Pretreatment of wastewater to remedy these undesired characteristics may result in additional costs that could challenge the economic viability of the production process. Moreover, marine microalgae require cultivation systems and downstream processing equipment to be fabricated with materials that are resistant to corrosion by seawater, thus increasing capital costs.

The economic feasibility of cultivation is significantly affected by the external nutrient requirement of microalgae. For instance, the production of 1 MT of microalgal biomass consumes approximately 23.05 kg and 5.21 kg of nitrogen and phosphorus respectively. Thus, the cultivation of microalgae to produce biofuels can place considerable stress on the global nutrient deposits, particularly phosphorus since it is a non-renewable resource. The most potent solution to this issue is the utilisation of waste streams for microalgae



Laboratory scale cultivation of microalgae



Production process of microalgae-based biofuels

cultivation since this allows the recycling and reuse of nutrients. However, all the issues related to wastewater-based cultivation are applicable here, including the presence of pathogens, susceptibility to contamination and limitations in biomass valorization.

In addition to upstream processing (i.e. cultivation) of microalgal biomass, downstream processing to produce biofuel can present several challenges as well. For instance, it has been estimated that the harvesting process of microalgae can account for 20-30% of the total production cost. Microalgae generally achieve biomass concentrations of 0.5-1 g/L in open ponds and 5-10 g/L in closed photobioreactors. This is considerably low compared to other types of microorganisms such as yeast and bacteria. Hence, due to the lower biomass concentration of microalgae cultures, 100-2000 L of water needs to be processed to obtain 1 kg of microalgae biomass. Although centrifugation can be employed for efficient separation of biomass from the growth media, it is highly energy-intensive and is only a feasible option during the cultivation of microalgae to produce high-value products (pharmaceutical, nutraceuticals, etc.).

The most promising approaches for low-cost harvesting of microalgae for biofuel production would be based on gravity settling, auto-flocculation and chemically/biologically induced flocculation. Further research and development are needed to make these harvesting technologies more feasible and economical.

Drying is another critical step in the downstream processing that enhances the extraction efficiency of lipids and other metabolites. However, inefficient drying processes can contribute to nearly 75% of the total operating cost in biofuel production. Even if efficient drying steps are used, the capital and operating costs of industrial dryers would be relatively high. Therefore, the development of cost-effective and energy-efficient drying systems is of paramount importance. Alternatively, this issue could be addressed by the development of efficient wet processing technologies to achieve high product yields, so that the drying step can be eliminated.

In some cases, the production of microalgae-based biofuel requires pretreatment of biomass. This involves cell disruption techniques to facilitate the release of lipids and carbohydrates from microalgal cells to make them available for subsequent transesterification or fermentation. On a large scale, this can be a bottleneck for the production of biofuels since pretreatment techniques are often cost-intensive. Hence, researchers need to develop more economical methods of biomass pretreatment or develop biofuel production processes that bypass the requirement of pretreatment.

Extraction of target metabolites and their conversion into biofuel also involves costly processing steps. Extraction processes, in particular, require different types of solvents and sophisticated equipment. This can significantly increase the cost of biodiesel and bioethanol production. Although some conversion techniques such as anaerobic digestion and thermochemical conversion do not require pretreatment or extraction, they still require advanced infrastructure. Anaerobic digestion requires careful monitoring of operating parameters whereas thermochemical conversions are highly energy-intensive due to the high pressures and temperatures required during processing.

The net energy ratio (i.e. the ratio between the total output energy and the total input energy) is an important factor that should be considered when selecting processing routes for microalgal biomass. In microalgae-based biofuels, the output energy implies the energy obtained by the combustion of a unit mass of fuel, whereas the input energy is the total energy consumption during all the processing steps involved in producing the same amount of fuel. Thus, a net energy ratio that is greater than 1 is desired in the production of any fuel. However, a major concern in the production of microalgae-based fuel is that the employed processing technologies generally result in a lower net energy ratio as compared to petroleum fuels. Therefore, it is vital to focus on reducing the energy intensity in producing microalgal biofuels.

Considering all these issues, it can be said that there is a long road ahead prior to the commercialisation of microalgae-based biofuels. In this context, researchers and scientists have a major role to play in reducing the costs and sustainability issues associated with the production of microalgal biofuel. Therefore, if these major challenges could be addressed, microalgae-based biofuels could undoubtedly be introduced to the market as a sustainable alternative to fossil fuels.

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