Chapter 19

Application of nanotechnology for the sustainable development of algal biofuel industries

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19.1 Introduction

Modernization has made today's life easier in many areas, however it has also paved the way for increasing consumption of energy at an alarming level (Mathimani, Kumar, Chandrasekar, Uma, & Prabaharan, 2017). In every aspect, the use of energy in all areas has grown rapidly, resulting in the exhaustion of hydrocarbon fuel resources and increases in environmental pollution (Adeniyi, Azimov, & Burluka, 2018; Hosseini & Wahid, 2016; Yoro & Sekoai, 2016). These dynamic forces have led to an exploration for the improvement of policies and practices to enhance production and uses of renewable energy sources (Pragya, Pandey, & Sahoo, 2013). Biofuels are categorized as primary and secondary biofuels. Primary biofuels are produced from plants, animal waste, and crops like corn starch, soybean, and canola seeds, etc. The further extension of biofuel production triggered a debate about food versus fuel (Munasinghe & Khanal, 2010; Ramanavicius, Kausaite, & Ramanaviciene, 2008). Meanwhile secondary biofuels are produced from biomass from various feedstocks that do not compete with the food chain directly. However, second-generation biofuel production is limited due to the application of expensive technologies used during the substrate pretreatment process.

Among all the other alternative renewable energy resources, converting algal biomass into biofuel has been a golden key and potentially known source

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of energy to meet the global demand for clean energy (Chen, Lin, Huang, & Chang, 2014; Isahak, Hisham, Yarmo, & Yun Hin, 2012; Lee & Lavoie, 2013). Biofuels, which are produced from biomass, provide a greater and most promising sustainable energy source (Anitha, Kamarudin, & Kofli, 2016; Nanda, Yuan, Qin, Poirier, & Chunbao, 2014; Nomanbhay, Hussein, & Ong, 2018). Ultimately the use of algal biomass as an alternative to fossil fuels is considered to be carbon-neutral, where the generated CO_2 output is generally offset by CO_2 fixation through photosynthesis during biomass growth.

Biofuels, such as biodiesel, bioethanol, biogas, and biohydrogen are produced from algae and have received attention from researchers around the globe for their fast growth rate, renewable, nontoxic, nonedible, cheap, and environmentally friendly properties (Kaparaju, Serrano, Thomsen, Kongjan, & Angelidaki, 2009; Santoro, Arbizzani, Erable, & Ieropoulos, 2017; Sewsynker-Sukai and Gueguim Kana, 2017).

19.2 Global view of biofuel

Currently, coal, oil, natural gas, and other renewable sources provide most of the global energy supply. The energy produced from renewable sources accounts only for 10% of the total global need, which clearly indicates that the world is dependent on fossil fuels. However, many countries in such as Norway, New Zealand, Brazil, Colombia, Canada, and Italy are using renewable energy for electricity production. Global biofuel production has increased in recent years. In 2016, 30.8 million m^3 of biofuels were produced, which is about 7.5% greater than in 2015. It is estimated that biofuel production will increase 4.5% annually and reach 50 million m^3 of biofuel by 2025. European Union nations are expected to remain the main producers and consumers of biofuel at 10.7 Mm^3, equivalent to 34.7% of global biofuel production in 2016 (Marcos, Cristie, Rafael, Mario, & Aldara da, 2018). The European nations aim to increase their usage of renewable biofuel energy by about 20% in the coming years. Biofuel options like bioethanol and biomethane are the best alternative for scientists and stakeholders as a probable candidate to intensify the renewable energy market (Cesaro & Belgiorno, 2015; Taherzadeh & Karimi, 2008). Bioethanol is also forecast as a substitute fuel to address the unrelenting energy burden and environmental damage (Azhar et al., 2017). This implies the use of biomass consistency as a principle of green technology. In this scenario, green technology combined with nanotechnology has boundless potential to supply diverse industrial sectors with high energy production as part of a sustainable energy development process (Shafiei, Karimi, Zilouei, & Taherzadeh, 2014).

19.3 Nanotechnology solutions

Nanotechnology is defined as a technology for the invention, synthesis, application, and replacement of materials at the nanometer size. Nanomaterials

have sizes in the range of 1−100 nm.Nanotechnology is applied by engineers, biotechnologists, and chemists in different industries such as drug delivery, food industry, bioremediation, cosmetics, and cosmetics coating (Engelmann, Aldrovandi, Guilherme, & Filho, 2013; Lopez-Serrano, Olivas, Landaluze, & Camara, 2014). The physiochemical properties of nanomaterials could be a promising solution for biofuel production. The application of nanotechnology also extends to the purification and refinement of biofuels, which ultimately reduces the cost and time required (Harun, Singh, Forde, & Danquah, 2010; Milano et al., 2016). Nanotechnology could enhance the effects of metabolic engineering of the reaction and has gained momentum over the years in diverse biofuel production applications (Sekoai et al., 2018; Show, Lee, Tay, Lin, & Chang, 2012; Tyagi, Rawtani, Khatri, & Tharmavaram, 2018). Different nanomaterials, such as carbon nanotubes, and magnetic and metal oxide nanoparticles are advantageous in the progressing of an indispensable part of sustainable bioenergy production (Rai et al., 2016).

19.4 Nanotechnology in biofuel productions

Biofuels are usually produced by a transesterification reaction between alcohols (mainly methanol) and oils/fats from animals or plants in the presence of a catalyst. Limitations of first- and second-generation biofuels included the use of sophisticated instruments and low return on investment, leading to the foundation of the third generation of biofuel. When compared with all other renewable sources for the production of biofuel, algae gained importance due to their renowned characteristics. The advantage of using algae as feedstock has multifold advantages including low cost, low area requirement, and utilization of a high level of CO_2 in the atmosphere, making algae a good choice for the production of biofuel (Liu et al., 2017). The oil content of algae is more than 30 times that of the earlier generation of biofuels. They can grow in all types of water with growth rates 20−30 times faster than with oil- and food-yielding crops. The biofuels-producing algae are completely sulfur-free and the residual algae can also be used as fertilizer and feed for fish (Ullah et al., 2015). However, some challenges such as consistent selection, production and cultivation of algae on a large scale, harvesting of algae, and biofuel extraction and production from lipids remain to be addressed. Nanotechnology provides many potential solutions to the issues facing the commercialization of algal biofuels by adopting novel techniques in progression of algal culture and enhanced methods for harvesting, extraction, and separation of biofuels.

19.4.1 Process of converting biomass into biofuel

Both microalgae and microalgae are used as potential sources for the production of third-generation biofuels (Scott et al., 2010). Bioethanol is also an

alternate to fossil fuels and is produced by transesterification of lipids attained from algae to form methyl esters of long-chain fatty acids (Demirbas & Demirbas, 2011). Algae usually require light for energy production and carbon dioxide for biomass generation. In earlier studies, it was found that 1.8 kg of carbon dioxide is consumed for 1 kg of algal biomass production under ambient temperature and pH conditions (Abdel-Raouf, Al-Homaidan, & Ibraheem, 2012; Arnold, 2013). Some algae have about 66% lipids, commonly called triglycerides. Biomass to fuel conversion usually follows three steps like extraction, transesterification, and producing value-added chemicals. In addition to biofuels, algal biomass can be converted to any form of renewable energy centered on the choice of technology, properties of the feedstock, end product, economic constraints, and environmental standards (Brennan & Owende, 2010). After lipid extraction, the biomass can be chemically converted into biofuel via a transesterification reaction (Johnson & Wen, 2009). Bioethanol, methane, and hydrogen are produced by biochemical alteration of algal biomass using an anaerobic fermentation process, and other valuable commodities as shown in Fig. 19.1 (Daroch, Geng, & Wang, 2013; Suganya, Varman, Masjuki, & Renganathan, 2016). Another approach is thermochemical conversion to yield biofuels by the thermal decomposition of organic biomass compounds. In order to accelerate biofuel production, nonedible materials such as lignocellulosic materials are used as feedstock by various microbes which are abundant, renewable, and low cost (Balan, 2014; Kuhad & Singh, 1993).

19.4.2 Nanocatalyst in biofuel production

Catalyst plays a dynamic role in converting lipids and alcohol into biofuel and triglycerides. The catalyst used in the transesterification process of biofuel production can be homogeneous or heterogeneous. The unrelenting need

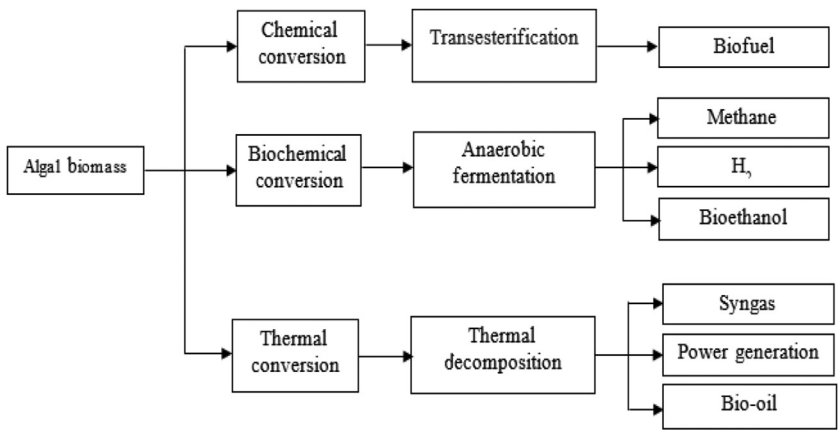


FIGURE 19.1 Production of valuable commodity from algal biomass.

for catalyst improvement in the biofuel production process leads to nanocatalysis. The nanocatalysts hold the potential to achieve higher product quality and yields, leading to the development of more efficient, economic, and stable biofuel (Gardy et al., 2018). The nanoparticles can be coupled with either homogeneous or heterogeneous catalyst which could open up a new dimension in converting algal lipid into biofuels. Nanocrystalline CaO (97.633 m^2/g) has 1.54 times greater specific area as compared with commercial calcium oxide (74.64 m^2/g). Badnore, Jadhav, Pinjari, and Pandit (2018) stated that at a similar operating condition due to the high surface area nanocrystalline CaO has an 18.81% higher conversion of oil into biofuel than commercially available CaO catalyst. The higher conversion rate is achieved by nanocatalyst as there is additional surface to react with the reactants. In adition to the higher conversion rate, the nanocatalyst reduces the reaction time, influencing the conversion of oil to biofuel.

Chen, Liu, He, and Liang (2018), experimented with magnetic nanoparticle Fe_3O_4/ZnMg (Al) O for its effect in biodiesel production using microalgae. The catalyst exhibited a good surface area to volume ratio with excellent magnetic responsivity which favored 94% biodiesel production and the conversion rate was more than 82% even after seven cycles.

The major advantage of using magnetic nanoparticle-based catalyst is that it can be reused and easily separated from reaction media, leading to more economical, industrial-scale biodiesel production (Gardy et al., 2018). Carbon-based nanocatalysts such as carbon nanotubes, carbon nanofibers, and biochar also hold great potential for biodiesel production using a wide range of feedstocks (Guan et al., 2017; Mahto et al., 2016; Yahya, Ngadi, Jusoh, & Halim, 2016). The application of a nanotechnology catalyst ensures the economic viability by recovery and reusability in the biodiesel production and conversion efficiency, as documented in several studies (Bet-Moushoul et al., 2016; Chiang et al., 2015).

19.4.3 Application of nanomaterials in the purification process/ harvesting process

Isolation and purification are the last step in the biofuel production process. The translation of biomass feedstock into biofuel and other value-added products is a highly complicated, challenging, and expensive process. The most important bottleneck in converting microalgae into biofuel depends on the culture media, pH, cell dispersity, and concentration, which play a significant role in the conversion process (Leite & Hallenbeck, 2013; Wang, Stiles, Guo, & Liu, 2015; Farooq et al., 2013). Initially, algal biomass is broken into protein, lipid, and carbohydrate as the main components in the extraction process. Several further techniques like gasification, pyrolysis, anaerobic digestion, and transesterification are adapted to convert the components into biofuel, hydrogen, methane, syngas, etc. (Gavrilescu & Chisti, 2005).

The dosage of magnetic nanoparticles, particle size, implementation conditions, and cell types are essential factors in the microalgae harvesting process (Seo et al., 2014).

A new group of separation techniques is being developed using magnetic nanoparticles along with the existing technologies like chromatography, ultrafiltration, precipitation, and so on. Nowadays, a single nanoparticle or hybrid with other compounds shows high accessibility in the harvesting procedure. Most commonly, bare iron-oxide (Fe_3O_4) and yttrium iron-oxide ($Y_3Fe_5O_{12}$) nanoparticles are used in harvesting efficiency. Fe_3O_4 nanoparticles possess high surface area, magnetism, and biocompatibility. The external magnetic field covers the negatively charged algae, leading to electrostatic flocculation which results in greater than 95% efficiency (Hu, Wang, Wang, Liu, & Guo, 2013; Yang et al., 2018). The recyclability of nanoparticles reduces the cost of algae harvesting. The relevant process has certain limitations, however, and tremendous efforts have been made for the effective use of nanotechnology for the long-term consistency of algae-based products for their marketability.

19.5 Crude glycerol production

In general, during the transesterification process, one part of vegetable oil/animal fat/algal lipids reacts with three parts of alcohol (methanol) in the presence of a catalyst under a sequential reaction that yields three parts of alcohol and one part of glycerol. The products consist of 9 kg biodiesel and 1 kg of crude glycerol as by-product. The resultant by-product crude glycerol consists of a mixture of compounds including glycerol, with catalyst salts, ash, unreacted mono/di/triglycerides, and water, all left over from the reaction process (Fountoulakis & Manios, 2009). The impurities in crude glycerol are the major drawback in biodiesel production as it cannot be easily disposed of and treated economically (Anuar & Zuhairi, 2016; Monteiro, Ambrozin, Liao, & Ferreira, 2008). Therefore it becomes mandatory to utilize the crude glycerol effectively to confirm the sustainability of worldwide production of biodiesel.

19.5.1 Application of crude glycerol

The increasing production of biofuel has led to surplus production of crude glycerol as a by-product. The disposal of crude glycerol causes various environmental issues due to the impurities present in it. Glycerol exemplifies an excellent carbon source and is used for numerous bioconversion processes and production of industrially important products. Through the biotechnological process, many prokaryotic and eukaryotic organisms can assimilate glycerol as the sole carbon source and produce ethanol, butanol, citric acid, succinic acid, etc. as high-value products (Amaral, Ferreira, Fontes, & Coelho, 2009; Johnson & Taconi, 2007). Utilization of crude glycerol into any form of

renewable energy or for the production of other value-added products which provides additional income to the biofuel producers avoids the legal sanctions of disposal and also benefits the environment in an eco-friendly manner. Crude glycerol is admitted as a renewable waste substrate with abundant applications which in turn helps to establish more biofuel industries.

19.6 Conclusion

Biofuel is considered to be a fuel of the future and nanotechnology has an interesting contribution in its production. The application of nanomaterials in biofuel production from algae helps to overcome various difficulties in the treatment process and in achieving high efficiency. The conversion of biomass into biofuels results in encouraging renewable and clean energy production methods. The combination of nanotechnology and algal biorefinery concepts in all aspects provides a substantial solution in reducing the time and cost of processing and production of biofuel from algae. Nanomaterials also play a great role in reducing pollution globally by providing cheap and clean energy.

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