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# Latest development in microalgae-biofuel production with nano-additives

Microalgae have been experimented as a potential feedstock for biofuel generation in current era owing to its' rich energy content, inflated growth rate, inexpensive culture approaches, the notable capacity of CO2 fixation, and O2 addition to the environment. Currently, research is ongoing towards the advancement of microalgal-biofuel technologies. The nano-additive application has been appeared as a prominent innovation to meet this phenomenon. The main objective of this study was to delineate the synergistic impact of microalgal biofuel integrated with nano-additive applications. Numerous nano-additives such as nano-fibres, nano-particles, nano-tubes, nano-sheets, nano-droplets, and other nano-structures' applications have been reviewed in this study to facilitate microalgae growth to biofuel utilization. The present paper was intended to comprehensively review the nano-particles preparing techniques for microalgae cultivation and harvesting, biofuel extraction, and application of microalgae-biofuel nano-particles blends. Prospects of solid nano-additives and nano-fluid applications in the future on microalgae production, microalgae biomass conversion to biofuels as well as enhancement of biofuel combustion for revolutionary advancement in biofuel technology have been demonstrated elaborately by this review. This study also highlighted the potential biofuels from microalgae, numerous technologies, and conversion processes. Along with that, the study recounted suitability of potential microalgae candidates with an integrated design generating value-added co-products besides biofuel production. Nano-additive applications at different stages from microalgae culture to end-product utilization presented strong possibility in mercantile approach as well as positive impact on the environment along with valuable co-products generation into the near future. Biofuel has caught substantial attention worldwide nowadays as an alternative fuel due to its capability to adapt with gasoline for a maximum 85% blend without any engine modification. Subsequently, the suitability of various candidates for biofuel is being continuously quested by the researchers and environmentalists. In this recent era, one of the most sophisticated technologies, nano-technology integration with bioenergy application by the nano-energy sector has brought a revolutionary impact on biofuel conversion processes and enhancement of engine performances. Nano-technology is defined as designing a device or material in nano-scale (10–9 m). To accelerate the biofuel yield and improve the efficiency of biofuel utilization in petrol and diesel, nano-technology has been initiated via nano-additives such as nano-magnets, nano-crystals, nano-fibres, nano-droplets, and others. The perspectives of nano-additives on microalgae cultivation to microalgal-biofuel implementation.

On this eve of the quest for suitable biomass for biofuel, the concept of microalgae cultivation appeared to the spotlight for biofuel manufacturing due to several positive perspectives such as (i) they do not clash with human or animal food chains, (ii) very rich with carbohydrate, protein, and oil content, (iii) can grow in aqueous media such as wastewater, freshwater, saline water, and assimilate nutrients from brackish water, salt water, or highly polluted water, (iv) demand low water, (v) sustain capability to grow whole year naturally with sunlight presence, (vi) can be cultivated in the waste dump area, sea, ponds, rivers, industrial, and municipal waste drainage, wet bare lands especially in cold regions, (vii) develop sustainable O2 generation system, and (viii) diminish CO2 by up taking it for photosynthesis respiration. In addition, microalgae contain very short harvesting life cycle

and yield nascent biomass that drives higher productivity of the desired biofuel. Interestingly, microalgae carry a prodigious amount of carbohydrates, protein and lipid, the sole components of biofuel conversion. Nano-technology applications have been implemented to biofuel industries, since the existing controversial approaches of traditional microalgae culture-biofuel production contain a number of limitations such as inconsistent industrial-scale microalgae production, high microalgae production and harvesting cost, energy consumption for biofuel production from microalgae, and the increase of greenhouse gas intensity in environmental. Nano-technology applications can be entailed in different stages from microalgae cultivation to microalgae-biofuel application in fuel engines due to durability, recyclability, adsorption efficiency, catalytic performance, stability, crystallinity, economical advantage, high storage capacity, excellent biofuel yield, and environment-friendly characteristics. According to the previous studies, nano-technology application enhanced microalgae cultivation, the maximum yield of numerous microalgae biofuels as well as microalgae-biofuel implications in petrol and diesel engines. Various nano-materials, e.g., nano-fibres, nano-particles, nano-tubes, nano-sheets, and other nano-structures, have been investigated as effective nano-catalysts in direct and indirect approaches in biofuel (e.g., bioethanol, biodiesel, biomethane, and others) yield enhancement. For instance, magnetic nano-particles were used as a carrier for enzyme immobilization for bioethanol and biodiesel generation effectively. Owing to high coercivity and powerful paramagnetic characteristics, magnetic nano-particles were also preferred for methanogenesis to produce biomethane.

To authors' best knowledge, no review study has been performed on numerous biofuel productions from microalgae integrated with the nano-additive application so far. The closest review with this study was conducted on the bioenergy production from lignocellulosic biomass (agricultural residues), industrial waste (sludge) as well as algae (microalgae and macroalgae) with the nano-scale optimization which has merely emphasized on the mechanism of nano-particles, biomass characteristics, and nano-particle application on biomass growth. Compared with that, the current review contextualized the numerous biofuel productions from pure microalgae and optimization with nano-additive application on biomass growth to end-product application. Therefore, the major objectives of this review work are (i) to determine the array of the techniques and methods associated with nano-particles incorporation with microalgae culture as well as microalgal biofuel, (ii) to demonstrate divergent nano-additive applications on microalgae cultivation, biomass conversion to biofuels, and biofuel combustion, (iii) to identify the potential sources of microalgae, especially the carbohydrate, protein, and lipid-enriched microalgae types for biofuel production and determine the possible microalgae biofuels, biomass conversion technologies, and processes to biofuels, and (iv) to assess the future prospects of the process development planning along with integrated design of some other value-added products besides biofuel. Numerous biofuels, e.g., bioethanol, biodiesel, bio-oil, biomethane, bio-hydrogen, and others, have been extracted from microalgae. Nano-particles' incorporation with microalgae cultivation (e.g., cell suspension, cell separation, and cell harvesting), biofuel conversion technologies, and biofuel application have amplified the overall yield in every stage. According to the previous studies, a very small amount of colloidal hydrous iron(III) oxide particles boosted almost 100% microalgae cell suspension; magnetic particles incorporated with aluminum sulfate were very effective for cell separation from the mixed culture of Anabaena and Aphanizomenon microalgae species; silver nano-particles application on Chlamydomonas reinhardtii and Cyanothece 51142 microalgae harvesting increased 30% higher biomass productivity; and calcium-oxide nano-particles escalated the large-scale biodiesel conversion yield up to 91% via catalytic transesterification. This study summarized the overall microalgae cultivation integrated with nano-particles until biofuel production.