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Microalgae biomass: A multi-product biorefinery solution for sustainable energy, environmental remediation, and industrial symbiosis

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ABSTRACT

The rapid expansion of industrialization and the depletion of non-renewable fossil fuel have urged the search for alternative and sustainable renewable resources to fulfil the escalating energy demand while reducing water pollution and greenhouse gas emissions. Microalgae have emerged as a promising and sustainable solution, capable of not only treating wastewater but also yielding valuable products. This study aimed to explore the primary applications of microalgae, including wastewater treatment and CO_2 sequestration, while assessing the viability of utilizing the resultant microalgae biomass (MB) across diverse sectors such as liquid and gaseous biofuels, bioplastics, animal and aquatic feed, nutraceuticals and pharmaceuticals, biofertilizers, and cosmetics production. Additionally, the study discusses the importance of assessing the environmental impacts of these applications through life cycle assessment (LCA) studies and elaborate the concept of a multi-products biorefinery system. To address the contemporary challenges of the bio-economy in simultaneously producing multiple high-value products, the biorefinery complexity index (BCI) was estimated to be 37, highlighting the need for further research to establish the practicability of a multi-products biorefinery system.

Abbreviations: AC, Acidification; AD, Abiotic depletion; ARA, Arachidonic acid; BCI, Biorefinery complexity index; C/N, Carbon to nitrogen ratio; CGF, Chlorella growth factor; COD, Chemical oxygen demand; DF, Dark fermentation; DHA, Docosahexaenoic acid; ED, Energy demand; EPA, Eicosapentaenoic acid; EU, Eutrophication; FD, Fossil depletion; FDA, Food and drug administration; FSSC, Food Safety System Certification; GHG, Greenhouse gases; GMO, Genetically modified organisms; GMP, Good manufacturing practice; GRAS, Generally recognized as safe; Gt_{CO2}, Gigatonnes of carbon dioxide; GWP, Global warming potential; HACCP, Hazard Analysis Critical Control Points; HRT, Hydraulic retention time; HT, Human toxicity; HY, Hydrogen Yield; IR, Ionizing radiation; ISO, International Organization for Standardization; LCA, Life cycle assessment; LCFAs, Long chain fatty acids; LU, Land use; MB, Microalgae biomass; MY, Methane Yield; NAXA, Natural Algae Association; OD, Ozone layer depletion; PA, Polyaminde; PBAT, Polybutylene adipate terephthalate; PBR, photo bioreactors; PBS, Polybutylene succinate; PCL, Polycaprolactone;; PCO, Photochemical oxidation; PE, Polyethylene; PET, Polyethylene terephthalate; PF, Photo fermentation; PHA, Polyhydroxyalkanoates; PLA, Polylactic acid; PMF, Particulate matter formation; POME, Palm oil mill effluent; PP, Polypropylene; PTT, Polytrimethylene terephthalate; PUFAs, polyunsaturated fatty acids; T, Temperature; TE, Terrestrial ecotoxicity; TGFA, Triglyceride fatty acids; TRL, Technology readiness level; TS, Total solids; TVS, Total volatile solids; US $, United states dollar; UV, Ultraviolet; VFAs, Volatile fatty acids; VS, Volatile solids; WD, Water depletion.

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