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A review on sustainable microalgae based biofuel and bioenergy production: Recent developments

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A B S T R A C T

Climate changes induced by anthropogenic greenhouse gas emissions (mainly carbon dioxide) is one of the major threats of the modern era. Primary causes are the high reliance on fossil fuels for power generation, transportation, manufacturing and the intensive land usage (deforestation). The current share of renewable biofuel production in the overall fuel demand has been found insufficient to replace fossil fuels. Microalgae can deliver a sustainable and complementary biofuel platform with some important advantages. This review aims to offer a state-of-the art review of algal biomass conversion methods into various biofuel products, including biodiesel, syngas, biogas, bioethanol. Emerging more sustainable biofuel/bioenergy production technologies are highlighted. Attention is also paid to sustainable cultivation methods, including wastewater treatment and bioremediation to capture CO_2 and fix nitrogen and phosphorus, produced from industrial, agricultural and municipal sources. Finally, a light is shed on the important role of algae metabolic engineering.

1. Introduction

The interference of anthropogenic activities in biogeochemical cycles and the extensive use of fossil fuels are the primary cause of the imminent global climate change. This scenario is expected to further deteriorate in the coming years, since the human population is expected to increase up to 9 billion by 2050 (Godfray et al., 2010). Goli et al. (2016) recently reported that around 87% of the global CO_2 emitted by anthropogenic activities result from the usage of fossil resources, with coal, oil and natural gas contributing 43, 36 and 20%, respectively. It has therefore become crucial to reduce the carbon emission by using sustainable energy resources on a global scale, but integrated at local scale. Over the last decade, biomass has drawn increasing attention in our society as a source of bioenergy and bioproducts. Various biomass sources including first, second, third and fourth generation feedstocks such as edible and non-edible energy crops, wood, agricultural residues and algae have been exploited so far for the development of bioenergy production methods.

1.1. Microalgae vs. plants

Microalgae derived biomass exhibits some important advantages over plant derived biomass (Naik et al., 2010; Lam and Lee, 2012; Rawat et al., 2013). Most importantly, microalgae do not depend on (fertile) land availability and in many cases they can be grown in wastewater or in seawater. Typically, the production of 1 kg of microalgae biomass requires 1.83 kg of CO_2 (Chisti, 2007). Compared to plants, microalgae have in general higher photosynthetic efficiencies. They convert *ca.* 3–8% of the solar energy during cellular metabolism against 0.5% typically for terrestrial crops. Microalgae can exhibit exceptional fast growth rates and can be produced more continuously as compared to plants. Microalgae derived biomass is typically enriched in lipids (*ca.* 4.5–7.5 ton ha^{-1} y^{-1}, Tsukahara and Sawayama, 2005) compared to soybean (0.4 ton ha^{-1} y^{-1}), rapeseed (0.7 ton ha^{-1} y^{-1} Chisti, 2007) and jatropha (4.1 ton ha^{-1} y^{-1}, Lam and Lee, 2011). Finally, they hardly contain the

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