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Assessment of diesel engine performance when fueled with biodiesel from algae and microalgae: An overview

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ABSTRACT

Biofuels derived from algae can have lower impact on the environment and the food supply than biofuels produced from crops. The strain selection, cultivation method, culture conditions and the chemical composition strongly influences the production costs but also the engine's performance and the exhaust gas emissions. The scope of this paper is to make a critical review about the impact of the use of biofuels produced from (micro) algae to power diesel engines. There is a huge disparity in the amount of papers published for algae culture, oil extraction, and biodiesel production compared to reporting performance on diesel engines. This paper presents an analysis of the papers published in this specific field. Generally, a reduction of torque and power output is reported. A wide range of blends up to B50 but also pure biodiesel has been tested. The blend showing results closest to diesel fuel appears to be B20. Several pollutants can be reduced if biofuels from different strains are used but an increase in NOx is generally reported, associated to higher temperatures in the combustion chamber. The use of emulsions instead of blends or neat biodiesel reveals a promising alternative with important reductions of CO_2 and NOx. However, the few reports for engine tests present some contradictions, or are lacking important information about the experiments. The assessment of biodiesel produced from algae or microalgae is a field hardly explored and until today some reference papers contain contradictory results or non-well studied behaviors as this survey demonstrates.

1. Introduction

Microalgae offer an attractive way of generating renewable and sustainable biofuels. An alternative to diesel fuel should be liquid, compatible with the engine, economically competitive, and available [1]. Biofuels derived from algae have lower environmental impact compared to biofuels produced from crops and do not compete with food supply [2–5]. Among many advantages, the production and use of biofuels from (micro) algae shows: a high CO_2 sequestration capability [2,6–9]; reduction of the use of freshwater [8–10] for its culture and/or land use [5,11–14], grows in residual wastewaters; it uses areas unsuitable for agricultural purposes; the cultures can be induced to produce a high concentration of feedstock; it can be harvested without the use of fertilizers and pesticides; it produces value-added co-products [15] and represents the only source of renewable fuels with capability for meeting the global demands of energy for transportation [3]. An important advantage of algae and microalgae for biofuels is that different fuels can be produced from it as is observed in Fig. 1. Through fermentation, ethanol can be produced; from anaerobic digestion, methane and hydrogen can be obtained; and bio-oil through pyrolysis [16–18]; fuel gas from gasification, and biodiesel from oil transesterification. The biofuel produced from algae is classified as a third generation biofuel [5,19,20]. The first generation biofuels should not exceed 6% of the final energy consumption in European transport by 2020, as opposed to the current 10% target in the existing legislation [21]. Therefore, compared to other feedstock, biofuels from algae could play an important role in the future.

Algae (macroalgae) are macroscopic photosynthetic organisms while microalgae are microscopic. Both can be found in marine and fresh water environments and also use CO_2 and nutrients for growth. They also can be found in a wide range of available strains. Microalgae are more advantageous because they are the fastest growing photosynthesizing organisms and can complete an entire growing cycle every few days [3].

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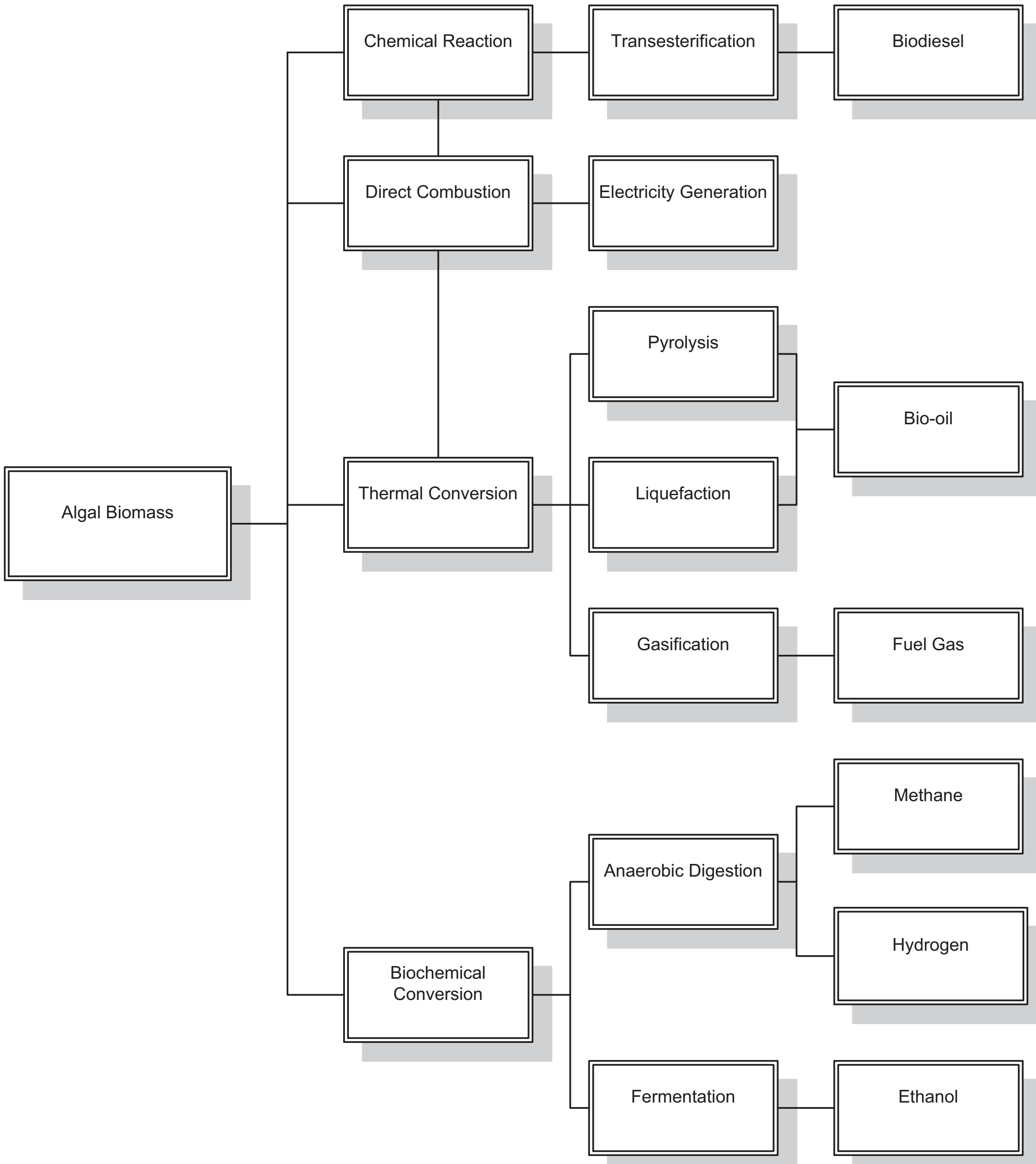

Fig. 1. Different energetic outputs for the algae biomass conversion. The figure contains a scheme that represents the full frame of fuels that can be from algae obtained.

Biodiesel produced from microalgae compared to rapeseed or soybean crops requires less land, around 100 times. Biodiesel from algae seems to be the only renewable biofuel that has the potential to completely displace petroleum-derived transport fuels without adversely affecting supply of food and other crop products. The land use for the production of biofuels, which depicts that all bioethanol and biodiesel crops are utilizing huge land area in comparison to algal biodiesel production [5,22]. One of the main consumers for both items is when soybean is used as feedstock.

The lipid content in algae and microalgae is between 8% and 40% of biomass [13] depending on the algae strain but it is also strongly influenced by culture conditions. This interval defines low lipid contain for some strains compared to first generation feedstock, but this can be enhanced by genetic engineering reaching higher lipid content and greater photosynthetic efficiency, but also through stressing culture conditions. In addition, strains rich in oil (up to 80%) of algae biomass are reported [3]. The unsaturation level in microalgae is normally high. This could affect biofuel stability, reduce storage time and negative influence the engine performance and exhaust emissions, but this is compensated by the advantages offered by this feedstock. Microalgae are very efficient solar energy converters, more than any other feedstock. A comparative evaluation of the fatty acid composition of microalgae with other feedstock is detailed in [23].

While microalgae are estimated to be capable of producing 10–20 times more biodiesel than rapeseed, they need 55–111 times more nitrogen fertilizer: 8–16 t/ha/year. Such quantities of nitrogen and phosphorus could damage the environment. Additionally, it could limit the economic viability of microalgae. Nitrogen and phosphorus found in algal waste, after the oils have been extracted, must therefore be recycled [3]. To reduce the impacts of algae cultivation to make it comparable to terrestrial crops, the use of water as a culture media instead of fresh water is an important issue.

Based on life-cycle assessment of algal biofuel, several studies shows a negative energy balance, especially when algae is cultivated