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Bio-oil as a potential source of petroleum range fuels

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ABSTRACT

Some efforts made to date in curbing greenhouse gases from the transportation sector have focused on the production of biofuels. Biomass derived oils have advantages that outweigh their flaws as fuels. Petroleum range hydrocarbons can be produced via secondary processing of bio-oils. Feedstock type and availability, catalyst choice and operating conditions have a significant influence on the potentials of biomass as a feedstock for petroleum Range hydrocarbons. Despite numerous works done, it is noted that more research is needed towards commercialising biomass conversion techniques with the view to producing petroleum range hydrocarbon and biomass like algae and palm oil have been seen to be very promising sources of biofuels.

1. Introduction

Energy has taken a pivotal point in the activities of man, knowingly and unknowingly. Fossil fuels continue to be a critical source of energy and materials for the petrochemical industry in the medium term. However, the finite, non-renewable nature and contributions to global warming has heightened the search for sustainable alternatives [1–3]. The increased greenhouse gas (GHG) emissions as a result of the extensive use of fossil fuels will need to be curbed before catastrophic damage is done [4–6], these greenhouse gases contribute significantly to global warming resulting in an adverse impact on the climate. Emerging from the climate deal that was struck at the Conference of Parties (COP 21), the average temperature rise was pegged at just over 1 °C, with Paris 2015 setting a 2 °C cap as the target by 2050 to limit damage to the ecosystem [4,6,7].

Asides, the problems of pollution, substantial uncertainties still exist on how long petroleum reserves will last, this coupled with volatile prices for crude oil which continuously affect economic development with the impact far reaching for non-oil producers [2,8] also calls for a rethink on the use of fossil fuels. Another major concern is the threat of unrest in majority of the crude oil producing regions. In order to make headway in combating the various challenges and threats posed by the reliance on fossil fuels, researchers have continued to look for potential alternatives that could serve as substitutes to fossil fuels. However, the fuels of choice should be environmentally friendly among other desirable properties. Biofuels are derived from materials that were once living and such fuels easily find themselves being a part of photosynthesis cycle making them renewable and potential substitutes to traditional fuels [8,9]. Biomass has significant potential to become more widely used as biofuel feedstock due to its numerous advantages with the resources widely distributed, abundant globally, and renewable in nature [1,7]. The transportation sector relies heavily on energy dense liquid fuels which unfortunately are responsible for releasing up to 25% of GHG's. While technologies such as gas to liquid and coal gasification have been promising in augmenting to the crude oil supplies, it is worth noting that these fuel sources also suffer the major drawback of being non-renewable, on the other hand a renewable material rich in carbon is biomass. Biomass oils present alternative feedstock that can contribute positively to the hydrocarbon pool required by the bulk of the transportation engines. This review focuses on highlighting the demerits of using fossil fuels and the roles biomass and its derived oils can play towards a cleaner fuel supply. The technologies of transforming the bio-oils to fuels have also been highlighted.

2. Biofuels and the modern fuel challenges

Biofuels have proven to have the potential to solve some of the modern challenges related to fossil fuel usage, with merits of lower emission profiles, renewability and sustainability in an era where the finite nature of fossil fuels resource might become a threat. The transition towards low-carbon energy systems is crucial if the effects of global warming and climate change are to be contained before they reach critical levels. The rise in average global temperature has primarily been attributed to increased GHG emitted through anthropogenic activities with the gases contributing to an undesirable phenomenon referred to as 'greenhouse effect [7]. The rate at which human economies and societies are emitting the GHG by far exceeds

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the capacity of the natural ecosystem to sequester the emissions. The economic growth and urbanisation of society has led to an increase in per capita consumption of energy, which has led to increased production and use resulting in an increase in emission profiles [4,7]. Sustainable energy provision will be vital if the goals ratified by member states towards the attainment of the Paris climate deal are to be realised [7].

Feedstock processing chains are an important factor to note as the drive towards low carbon economies and society intensifies with bioenergy production a key piece of the puzzle. Like in other continents, Africa has vast quantities of arable land that could be utilised for the production of feedstock for the bioenergy sector but the poor agricultural management systems in place for the bulk of the local communities has resulted in low yields and poor qualities [10,11]. In Asia the emergence of palm oil industry has also been blamed for loss of forest and biodiversity as the locals try and tap into the emerging market to produce palm oil for the biofuel industry [12]. Other issues associated with biofuel production has to do with the question of ethical concerns.

Nonetheless, there is a need for an urgent address to diversify the energy mix by increasing the content of renewable and environmentally friendly forms of energy. Bioenergy investments in developing countries have been lagging behind because of national priorities focusing on job creation, improving public and environmental health and poverty reduction as well as access to modern forms of energy [11]. The transportation sector which currently relies on fossil based fuels needs a shift in the fuel mix to include renewable and environmentally friendly sources [11].

Investments in low carbon fuel technology to cater for the transportation sector has resulted in established 1st generation biofuels which utilise traditional food crops derivative as feedstocks to produce ethanol (from starch and sugars) and biodiesel (from plant oil seeds) [13,14]. The current production routes have led to concerns on the ethical and sustainability profiles of the resulting biofuels through potential food versus fuel competition, land use change (clearing of traditional forest for agricultural land) with those in support pointing to economic development via poverty reduction, with marginalised communities benefitting through job creation and better market for farmers [14]. Next generation biofuel production is still in nascent stages of development with the systems looking to utilise lignocellulosic feedstock (agricultural and forest residue), energy crops (vegetative grasses and short rotation forest), non-edible oil seeds (e.g. jatropha) and algae [5,14].

The type of feedstock will depend on geological location and availability of resources [2,5]. In most developing countries the production of edible oils is not, sufficient enough to support biofuel production as well as feed the local community therefore use of non-edible oil is the best option [15]. However, considering waste management good practises, the utilisation of spent edible oil has become attractive economically and environmentally. Rapeseed and sunflower oils are mainly used in Europe, palm and coconut oils are mainly used in the tropics and soy bean oil is used in USA [14]. Policy makers have had to subsidise and offer incentives to allow for continued production and competitiveness with petroleum derived fuels due to the high operational costs [14].

Vegetable oils have proven to be valuable resource in the production of biofuels with both edible and non-edible oils having successful trials and implementation in the sector. Issues related to land use change, water utilisation and food vs. fuel debate continue to slow the growth of the sector as these factors are vital for the successful commercialisation of the sector on a large scale [16]. Social, economic and sustainability issues associated with 1st generation biofuels has shifted the balance of research to 2nd and 3rd generation biofuels [2,17].

3. Production of biomass oils

The production and extraction of plant oils is an important step in their utilisation in the daily livelihood of society. Different sources of biomass (plant) oils exist ranging from seeds, nuts, fruit, and lignocellulose material and to obtain the valuable product extraction is an important step. Extraction may be preceded or succeeded by a number of processes such as cleaning, drying, include, crushing, pressing, oil recovery and purification and based on the type of plant and extraction treatment processes, different yield and grades of oil may be obtained. Solvent extraction may also be used as a technique to extract oils from plant material where there is some level of difficulty in oil recovery. Once the oil is dissolved, the solvent is removed by distillation, and impurities such as water are removed, to leave pure vegetable oil. The oil extracted from plant material is useful as food, raw materials for cosmetic and drugs, however because of its potential as biofuel feedstock this use cannot be ignored and its application in this sector has been increasing.

Different techniques have been explored in the utilisation of biomass oils for the production of fuels. Plant oils such as palm, soya, sunflower, rapeseed oil have been used as feedstock in the production of 1st generation biofuels both from virgin and from used oil as the feedstock is part of the edible oil mix for human consumption [18,19]. This has created conflicts with some critics citing the rise in the commodity price for consumption by society has largely been because of their use as biofuel feedstock.

Perennial plants such as Jatropha have been explored as oil producing feedstock to support biofuel production [20]. The choice of feedstock production has been influenced by geographical location as well as supporting policies put in place by authorities [21], In South Africa for example, Jatropha plant was deemed invasive and banned from production as a biofuel feedstock [10]. Jatropha which is perennial crop though offer advantages in the sense that it is non-edible and can be grown on marginalised land but concerns over tillage and use of mechanical equipment on land have been raised [10,20].

Biomass derived oils come in different forms based on source, extraction technique and these include triglycerides based oils derived from oil bearing crops or seeds as well as pyrolytic or bio- oils obtained through the thermal degradation of biomass material in the absence of oxygen. The two type of oils mentioned above have shown potential to be useful as transportation and chemical feedstocks, however undesirable physicochemical properties makes them unsuitable for direct use. For triglycerides, which have about 9–13% oxygen content, a characteristic high viscosity as well as hydrolytic and oxidative instability based on the fatty acid profile present problems. Fig. 1 below show how biomass may be converted to biofuels to serve the different transportation systems. Biomass that is non cellulosic could be easily used as a source of natural oils, however as seen on the schematic, cellulosic biomass will usually have to undergo pyrolysis to produce pyrolytic oils [21,22] which can further undergo secondary treatment before desirable products such as biodiesel and bio gasoline are produced.

Bio-oils derived from pyrolysis are characterised by a high oxygen content, which may reach 40% weight content (typical for Lignocelulosic's bio-oils) lowering the energy content drastically as well as contributing to the acidic nature of the product. Pyrolytic products have a spectrum of hydrocarbons ranging from alcohols, aldehydes, ketones, carboxylic acids etc., which are highly, oxygenated products requiring upgrade to add value making them useful as transportation and chemical feedstock. Biomass fast pyrolysis has been explored by various research teams across the globe to yield bio-oil which are easier to transport (i.e. less bulky than the solid starting material) to places of effective usage [23].

In the quest for production of biomass oils, it has become imperative that life cycle analysis be done to ascertain the extent on ecosystem balance of the feedstock production systems. This is a critical area of concern for feedstocks which have high value in the