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Strategies for selection of thermo-chemical processes for the valorisation of biomass

Rawel Singh [a, b], Bhavya B. Krishna [a, b], Garima Mishra [a, b], Jitendra Kumar [a], Thallada Bhaskar [a, b, *]

[a] Thermo-catalytic Processes Area(TPA), Bio-Fuels Division (BFD), CSIR-Indian Institute of Petroleum (IIP), Dehradun 248005, India
[b] Academy of Scientific and Innovative Research (AcSIR), New Delhi, India

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ABSTRACT

Research on biomass conversion has been gaining a lot of interest as biomass is renewable and sustainable in nature. Products from biomass can be obtained by different methods amongst which thermo-chemical route has a very high potential. Biomass is generally available in a localised manner in varying quantities and qualities throughout the year and hence, region specific technologies have to be developed considering the end user requirement. Pyrolysis is a very versatile technique with the above considerations. The process parameters can be tweaked to necessity to produce more bio-oil or bio-char. Thermogravimetric analysis is essential for understanding the decomposition behaviour of the feedstock before the lab scale pyrolysis is carried out. Pyrolysis using several regional feedstocks has been carried out under nitrogen and hydrogen atmosphere and different biomass feedstocks were also liquefied using sub/supercritical solvents. This review aims to provide a comparison of the results obtained using various processes. This helps in the decentralised processing of biomass (dry biomass using pyrolysis and wet biomass by hydrothermal liquefaction) to produce bio-crude which can be upgraded to produce fuels/chemicals/petrochemical feedstocks in an environmental friendly manner.

1. Introduction

Fossil resources derived fuels have played the most important role in the rapid technological progresses over the past few centuries. It is estimated that more than 85% of the world's energy requirements are obtained from conventional fuels [1]. Energy scenarios project that world's annual energy consumption will increase steeply from current value of 500 to 1000–1500 Exa Joules per annum by 2050 [2–4]. Use of fuels derived from fossil resources leads to global warming due to high levels of CO_2 emission in atmosphere. Renewable, sustainable and environment friendly alternate resources are required to address these issues. Solar radiation, winds, tides and biomass are renewable resources and while first three resources can be used to obtain energy, biomass can be used to produce energy, chemicals and materials [5]. Need for a secure source of transportation fuels and chemicals make it essential to explore bio-fuels/bio-based hydrocarbons as alternatives to hydrocarbons derived from fossil resources [6]. The transition from the current fossil-based to bio-based carbon economy is expected to evolve continuously in the coming decades and a continuous changeover to more complex bio-renewable feedstocks like agricultural residues, industrial wastes, green plants, wood, or algae will occur [7].

2. Types of biomass feedstocks

Biomass is a plant matter of recent (no geologic) origin or material derived there from and can be used to produce various useful chemicals and fuels [8,9]. Biomass contains variety of plant species with varying morphology and chemical composition. Low hydrogen to carbon ratio and high oxygen to carbon ratio in biomass suggests that biomass can be utilised for the production of fuels as well as functional chemicals [7]. Depending on the nature of biomass used different biomass generation are shown in Fig. 1.

First-generation bio-fuels are derived from edible feedstock from the agricultural sector such as corn, wheat, sugarcane, and oilseeds. First generation biofuels have limitation of food versus fuel issue. **Second-generation bio-fuels** are non-edible and

* Corresponding author. Thermo-catalytic Processes Area(TPA), Bio-Fuels Division (BFD), CSIR-Indian Institute of Petroleum (IIP), Dehradun 248005, India.
E-mail addresses: tbhaskar@iip.res.in, thalladab@yahoo.com (T. Bhaskar).

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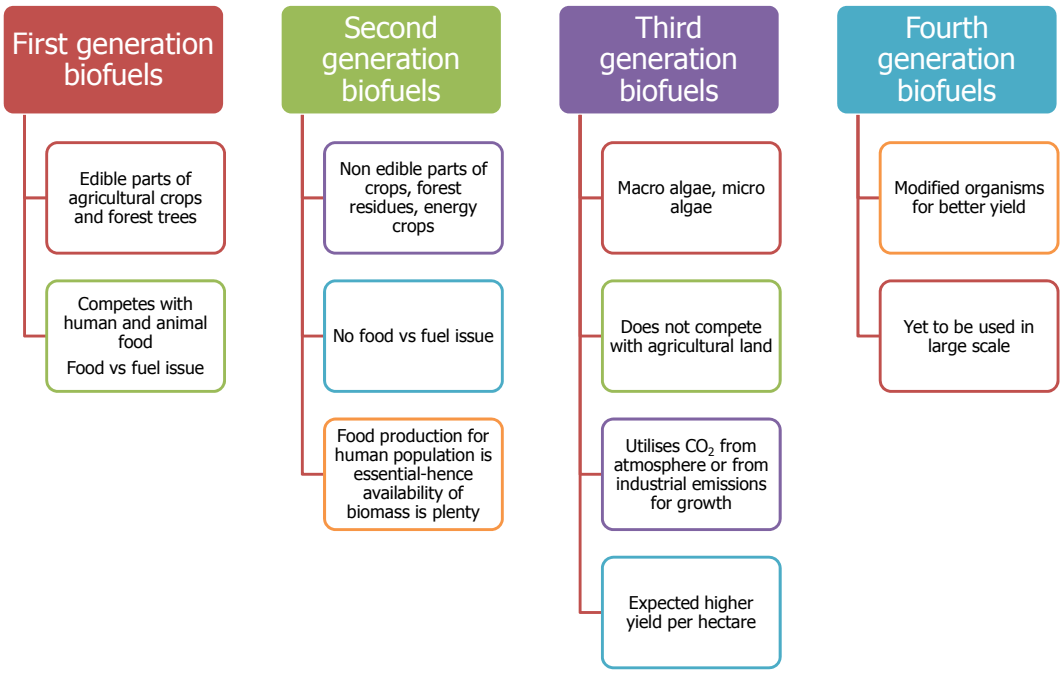

Fig. 1. Different biofuel generations depending on biomass type.

comprise of raw materials derived from lignocellulosic biomass and crop waste residues from various agricultural and forestry processes [10,11]. **Lignocellulosic biomass** has three major components: cellulose, hemicellulose and lignin. The agricultural residues can be classified as field and seed crop, fruit and nut crop, vegetable crop and nursery crop [12]. The residues generated from the forest products industry can be divided into two categories: (1) logging residues-generated from logging operations, e.g., from final fellings and (2) industrial by-products- generated by the forest industries during processing of timber, plywood, particleboard, pulpwood, etc. [13,14]. Energy crops are specifically grown to produce some form of energy. Energy crops are generally divided into two types: herbaceous and woody. Herbaceous energy crops are mostly types of grasses, which are harvested like hay. Perennial grasses, such as switchgrass, miscanthus, bluestem, elephant grass, and wheatgrass could all potentially be grown as energy crops [15]. **Third generation** bio-fuels are based on algal matter (micro- and macro algae) and cyanobacteria, which yield carbohydrates, proteins, vegetable oils (lipids), and, subsequently, biodiesel and hydrogen gas, are gaining considerable interest. The term algae can refer to microalgae, cyanobacteria (the so called “blue-green algae”), and macro algae (or seaweed). The differences between microalgae and macro algae are shown in Fig. 2.

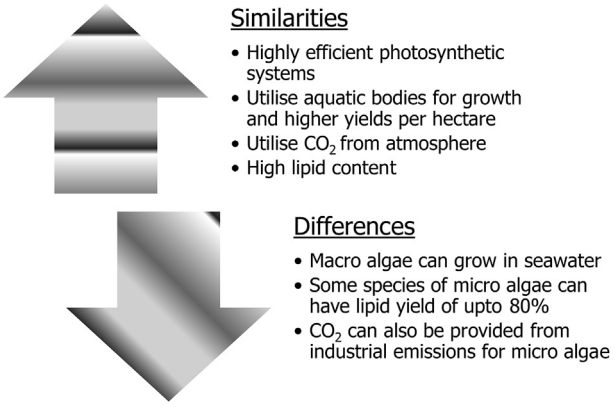

Fig. 2. Comparison of microalgae and macro algae.

3. Thermochemical conversion of biomass

There are several methods of conversion of biomass viz: mechanical, chemical, biochemical and thermochemical. Mechanical processes only perform a size reduction of feedstock. Chemical processes carry out a change in the chemical structure of the molecule by reacting with other substances. These processes include the wide class of chemical reactions where a change in the molecular formula occurs [16]. Bio-chemical processes occur at lower temperatures and most common types of biochemical processes are fermentation and anaerobic digestion. The fermentation uses microorganisms and/or enzymes to convert a fermentable substrate into recoverable products (usually alcohols or organic acids) [17]. Anaerobic digestion involves the bacterial breakdown of biodegradable organic material in the absence of oxygen over a temperature range from about 30 to 65 °C. The main end product of these processes is biogas (a gas mixture made of methane, CO_2 and other impurities) [16,18]. An overview of thermochemical and biochemical processes during biorefinery is shown in Fig. 3.

Thermochemicals processes are carried out in the presence of heat and can also use catalyst. Thermo-chemical methods utilize the entire biomass without any pre-treatment steps to produce value added hydrocarbons. In comparison to the biochemical processes, thermochemical processes occur faster in the range of few seconds, minutes or hours when the former takes time in the range of days to complete. The other advantages of thermochemical methods of conversion are that they are not feedstock specific and can also process moisture-rich/aquatic feedstocks. The micro-organisms are feed specific and even the slightest of change could lead to its non-functionality. This poses a major risk in the commercialisation of the process at an