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Prospect of biomass to bioenergy in India: An overview

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ABSTRACT

Energy is the most essential commodity for a rising nation like India. India's population has grown beyond 1.4 billion, driving a rapid rise in energy consumption. To meet this demand, India must explore all available energy sources, including bioenergy. Bioenergy is a renewable energy created from materials that were once alive, known as "biomass." This article examines the current energy situation in India and different biomass conversion technologies that can convert it into bioenergy.

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1. Introduction

India is considered a developing nation, yet it is now in the transitional phase of becoming a developed nation. The country of India's rapidly growing population is one of the factors that is working against its progress toward becoming a developed nation. According to the numbers provided by World Meter, the current population of India is 1.4 billion people (as of September 2022) [1]. The projected trend of India's population is shown in Fig. 1, which indicates that the country's total population would eventually exceed 1.7 billion people in 2060′s. Food, basic health care, and sources of energy are the primary requirements of a massive population [2]. In India, both rural and urban areas relied heavily on direct and indirect solar energy-based resources like biomass as their primary source of energy in previous decades [3–11]. The phrase "biomass energy" refers to the use of renewable resources such as plant and animal waste, agricultural leftovers, and wood fuels [12,13].

The primary energy demand that is now being met in India is satisfied by coal and oil. The statistics of primary energy demand are shown in Fig. 2, which demonstrates that the need for biomass and other renewable sources has declined. The primary energy usage in 2021 is estimated to be 9763 terawatt-hours (TWh), the majority of which is comprised of coal and oil; this consumption is expected to grow in the years to come [10,14]. The consumption of primary energy in India is shown in Fig. 3 (source: our world data), and the country's dependence on fossil fuels like oil and coal continues to grow. There is a very real possibility that one day there may be a scarcity of fossil fuels, which include coal, oil, and other similar resources [15]. A developing country like India has to discover an alternative to fossil fuels in order to help it become a developed nation. This would allow India to overcome the challenge of meeting the growing demand for energy despite limited resources [16].

Biomass has been used for centuries as a fuel source and is one of the most important sources of energy for countries like India. India is the third largest producer of biomass energy in the world after China and the United States [17]. In recent years, biomass energy has gained increased attention due to its potential to reduce greenhouse gas emissions and to provide renewable energy [18]. Bioenergy is the answer to the impending problem of an inadequate supply of energy [19]. Bioenergy is a kind of renewable energy that is generated from biomass, which refers to materials that were biologically alive not too long ago [20]. Biomass is defined as material that was once present in the environment. Bioenergy may be converted into a variety of useful forms, including fuel for vehicles, heat, and power. Fig. 4 illustrates the trend of growth in the amount of power generated by bioenergy and demonstrates the potential of bioenergy (source: IRENA).

The current study examines the potential applications of bioenergy and biomass in India. The first part of the paper will provide an overview of the topic. In the second part, the biomass, its sources, and its categorization are discussed. In the third part, the various methods of converting biomass are discussed.

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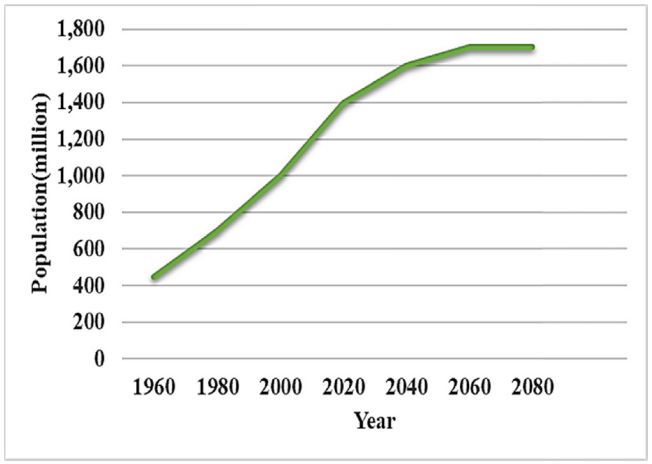

Fig. 1. Forecasted India population [21].

2. Types of biomass resources available in India

Any organic matter, such as wood, cereals, seaweed, or animal waste, that may be converted into usable energy is referred to as "biomass." After the sun, biomass is most likely the oldest source of energy that we have. Burning wood has been a common method for humans to heat their houses and cook their meals for thousands of years [24,25]. Important sources of biomass include municipal solid waste, animal residue, forest residue, farm residue, industrial waste, and agricultural residue, other important sources include sewage [26–29]. Waste from agriculture was produced at a rate of 400 million tonnes per year in India, whereas waste from municipal solid waste was produced at a rate of 150 million tonnes per year, and waste from municipal liquid waste was produced at a rate of 1460 million tonnes per year in India [29,30].

It is possible to generate useful amounts of energy from waste material, including municipal solid waste, liquid waste, and agricultural waste. Waste management is another one of India's bur-

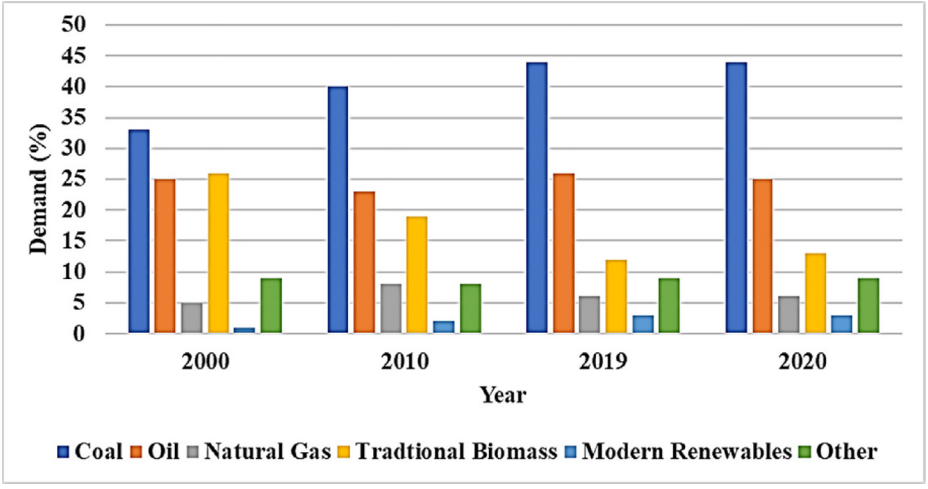

Fig. 2. Primary energy demand in India [22].

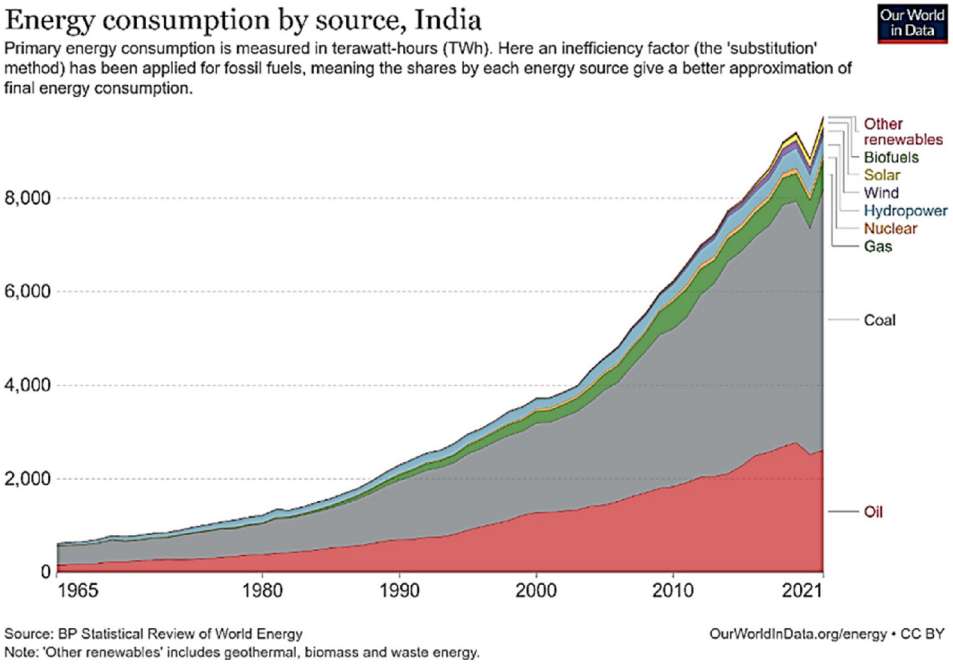

Fig. 3. Primary Energy Consumption, India [14].

densome problems since it is such a difficult task to administer. The vast majority of garbage is disposed of in ways that contribute to pollution, such as by dumping liquid waste in rivers, which in turn pollutes those rivers [31].

2.1. Classification of biomass

As illustrated in Fig. 5, biomass may be generally classified into three categories: that which is derived from crops, that which is derived from natural vegetables, and that which is derived from organic waste and residues. Organic waste and residues may be further categorized as floating plant waste, animal waste, forest residue, agricultural residue, municipal waste (solid and liquid), and industrial waste [32,33].

Several farmers burn agricultural residues, causing air pollution in many countries. Agriculture waste needs immediate attention. Historically, biomass and agricultural waste were burned or organically transformed into organic fertilizer. Agricultural waste bio-

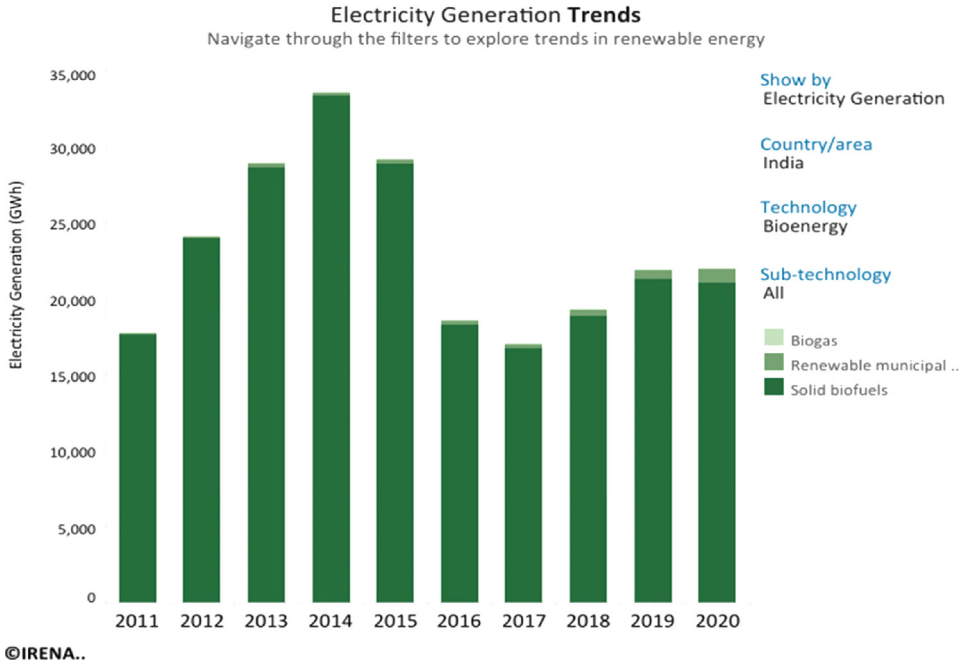

Fig. 4. Electricity Generation Trends in India [23].

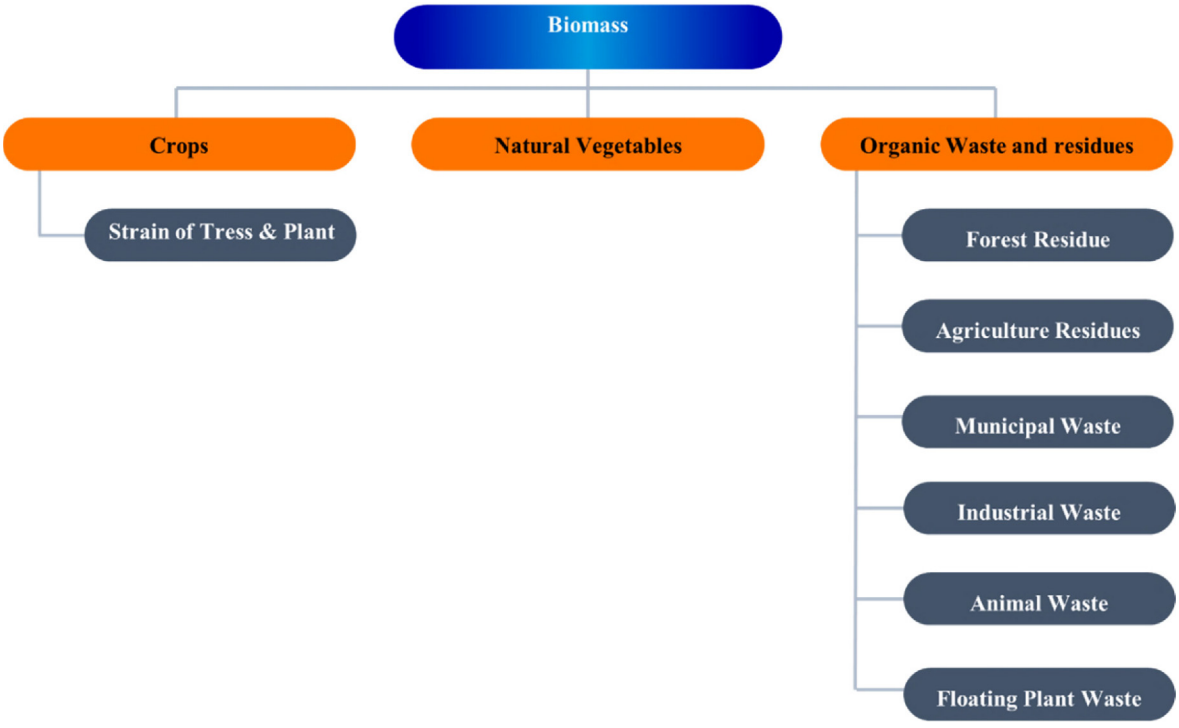

Fig. 5. Classification of biomass [36].

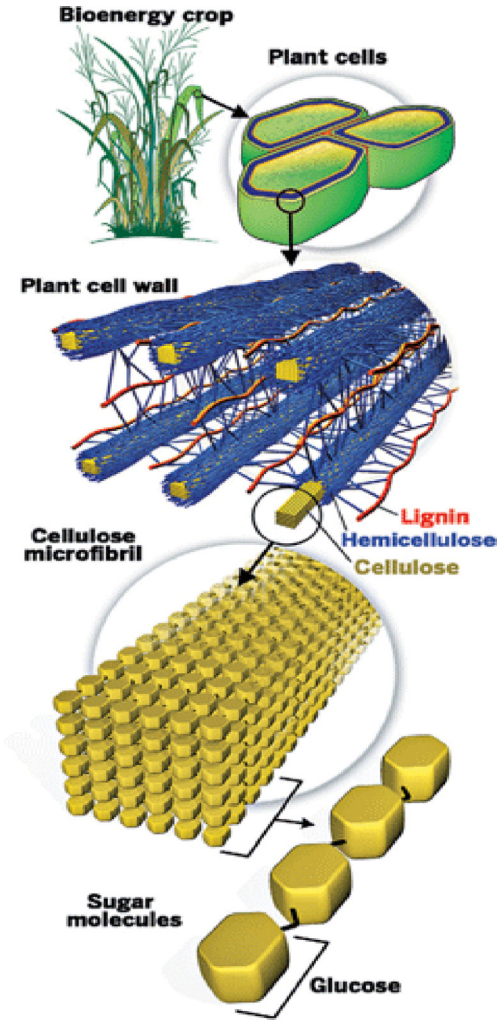

Fig. 6. Lignocellulose biomass structure [39].

mass is currently utilized to create energy since it can be easily converted. Since biomass is plentiful worldwide, we must employ alternative energy to meet our energy demands. Using agricultural waste effectively may turn it to electricity [34,35].

2.2. Biomass chemical characterization

There is a huge variety of different components that make up biomass. For instance, leftovers derived from plants are mostly made up of cellulose, hemicellulose, and lignin in different proportions, but cow dung is rich in proteins and grains are primarily made up of starch [13–16]. Naturally, diverse chemical structures will give rise to distinct variations in chemical characteristics. Fig. 6 shows the lignocellulose biomass structure which consists of cellulose, hemicellulose, and lignin [38,39].

The cell walls of vascular plants consist of macromolecular substances:

- Cellulose (50 % of dry wood weight)
- Hemicellulose (20 %)
- Lignin (30 %)

Cellulose is a linear polymer that is a complex carbohydrate, also known as a polysaccharide. It has a high molecular weight and may include up to 10,000 monomeric units of D-glucose that are bound together by β-1,4 glycosidic linkages [40]. Hemicelluloses are a kind of non-cellulosic polysaccharide that mostly have β-1,4 glycosidic links in their structure [41].

In the realm of plant life, lignin has the distinction of being the second-most prevalent and significant organic component [42]. Lignin is a heterogeneous aromatic polymers that are always generated in the presence of carbohydrates during the process of plant cell wall biosynthesis [43]. This process involves the random dehydrogenative polymerization of three major precursors [44]. Lignin is a family of complex organic polymers that comprise essential structural components in the support tissues of vascular plants and certain algae. Cellulose, hemicellulose, and lignin have very important applications in biomedical, chemical, and many other industries. Lignin can be used for the production of biofuel [45].

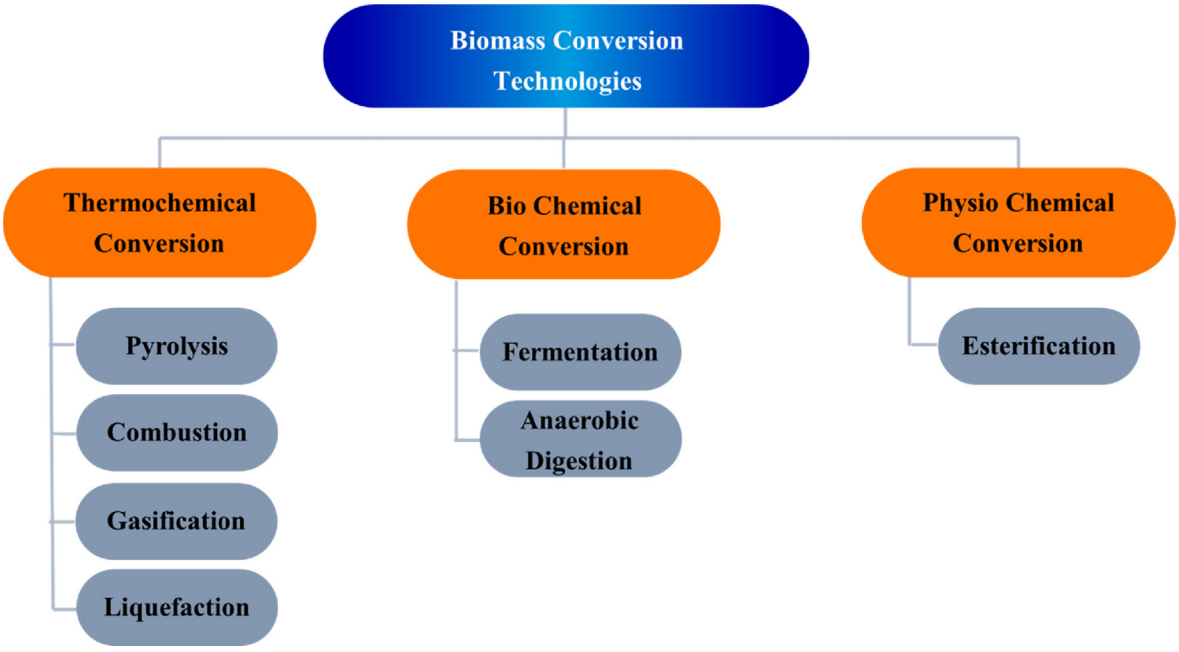

Fig. 7. Biomass Conversion Technologies [49–51].

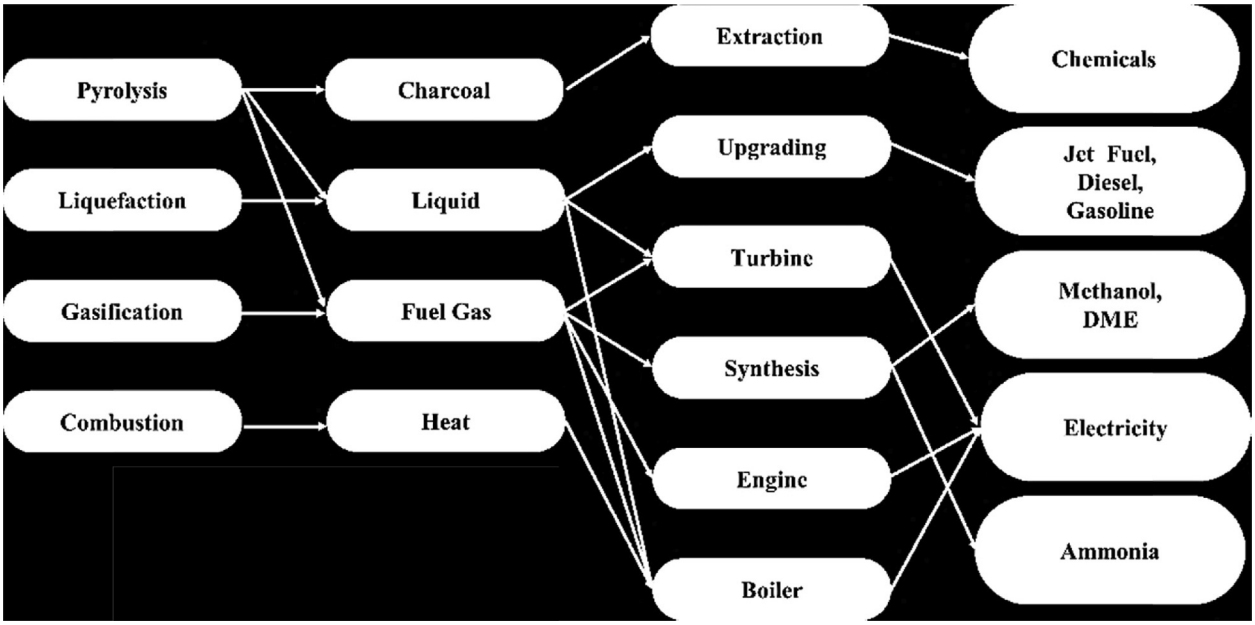

Fig. 8. Thermochemical conversion techniques and their end product [53].

3. Technologies for biomass conversion

The method of transforming biomass into usable forms of energy is referred to as "biomass conversion technology" [46]. The technologies that are used to convert biomass may be divided up into three primary groups, which are referred to as thermochemical conversion, biochemical conversion, and physiochemical conversion, respectively, as shown in Fig. 7. Combustion, pyrolysis, gasification, and liquefaction are the four subcategories that fall under the umbrella of thermochemical conversion [38]. The process of biochemical conversion may be broken down into two categories: fermentation and anaerobic digestion, which can be used in energy harvesting [47]. Esterification and transesterification are two categories that may be used to describe physiochemical conversion [48].

3.1. Thermo chemical conversion

Heat and various chemical reactions are used in the production of energy in the process known as thermochemical conversion. The most widely used technique in thermo chemical conversion is combustion in which end product is heat and electricity [52]. The majority of thermochemical conversions of biomass were carried out either with or without the use of catalysts, despite the fact that the use of catalysts has unique impacts on the end-products [53]. Fig. 8 shows the biomass thermochemical conversion techniques and their end product obtained. End product of thermochemical conversion are chemical, jet fuel, diesel, gasoline, methanol, DME, electricity and ammonia [28].

3.1.1. Gasification

Biomass gasification is an endothermic thermochemical conversion of solid biomass fuel utilising air, steam, or CO_2 to generate combustible gases such as H_2, CH_4, CO, and CO_2 [54]. The procedure is performed at temperatures ranging from 800 to 1300 ℃ [37]. In today's world, the adaptability of gasification technology, in conjunction with the wide variety of applications for the syngas that is generated, makes it possible to integrate biomass gasification with a variety of industrial processes as well as power production systems [55–58].

3.1.2. Pyrolysis

The de-polymerization of organic materials with the use of heat, either in the presence of nitrogen or in the absence of oxygen, is what is referred to as pyrolysis. Pyrolysis is an exothermic reaction with heat needs that vary between 207 and 434 kJ/kg [59]. In order to produce vapors and a carbon rich residue, a variety of biomass materials, including those derived from wood and agricultural products, were heated in an inert environment [60]. Fragments of cellulose, hemicellulose, and lignin polymers made up the vapors that were being released. These vapors may be condensed into an organic liquid that is free flowing and is referred to as the bio-oil [61,62].

3.1.3. Combustion

During the process, the biomass feedstock is transformed to CO2 and water, along with a lesser amount of other species [63]. The exact makeup of these other species is determined by the process parameters as well as the content of the biomass [64]. The energy content of the feedstock is a significant factor in determining how efficiently biomass can be burned [65]. The quantity of thermal energy that is produced throughout the process is dependent on the conversion efficiency of the reaction as well as the amount of energy that is contained in the feedstock [66–68].

3.1.4. Liquefaction

The conversion of biomass into liquid form is known as liquefaction, and it takes place in water at temperatures ranging from 280 to 370 °C. and under high pressure (10–25 MPa) [59]. In addition to these by-products, the process results in the production of a liquid bio granulate that is analogous to crude oil, as well as various gaseous, aqueous, and solid by-products [35–38]

3.2. Bio chemical conversion

Conversion of biomass that has been subjected to biological pre-treatments is referred to as biochemical biomass conversion technologies [64]. By selecting a variety of microbes or enzymes, the purpose of these pre-treatments was to convert the biomass into a variety of products and intermediates [72]. Fuels and chemicals including biogas, hydrogen, ethanol, butanol, acetone, and a

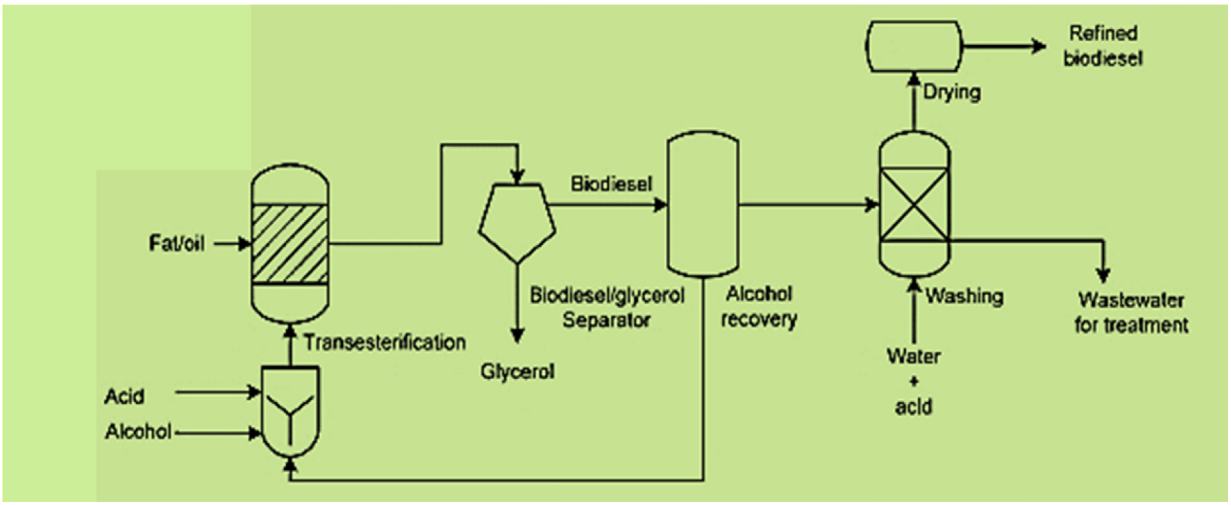

Fig. 9. Biodiesel transesterification flowchart [82].

broad variety of organic acids may be obtained via the method, which serves as a platform for their production [73].

3.2.1. Anaerobic digestion

The process of anaerobic digestionis one of the most environmentally friendly and cost-efficient technologies for treating lignocelluloses and other types of waste to recover energy in the form of biofuels [74]. This procedure not only reduces the overall quantity of waste, but it also converts the waste that is produced into bioenergy [75]. Additionally, the process results in the production of digestates, which may be used as fertilizer for agricultural applications due to the high nutritional content of the digestates [76].

3.2.2. Fermentation

Under anaerobic circumstances, microorganisms, mostly yeasts, transform simple sugars (hexoses and pentose) into ethanol and carbon dioxide (CO2) during the fermentation process of organic materials [48]. This process involves a number of metabolic processes [77].

3.3. Physio chemical conversion

The generation of high-density biofuels is accomplished by the use of physicochemical methods that are applied to biomass. To be more precise, the methods of esterification and/or transesterification are used in the manufacturing of biodiesel from a variety of different kinds of vegetable oil and animal fats [78,79]. A chemical process known as transesterification is responsible for the transformation of triglycerides, also known as fats, that are present in oils, also known as feed stocks, into biodiesel that may be utilised. Because of its much reduced viscosity, biodiesel that has been created via the process of transesterification may successfully replace diesel fuel made from petroleum in diesel engines as shown in Fig. 9 [80,81].

4. Potential of biomass to bioenergy in India

Biomass is an important renewable energy source, which has the potential to provide a significant contribution to the global energy mix. India has abundant biomass resources, which can be used for producing energy. Biomass is an organic material obtained from plants, animals, or other biological sources and can be used as a source of renewable energy [83]. The conversion of biomass to energy is known as biomass to bioenergy (B2B) conversion [84].

In India, biomass is one of the most commonly used energy sources, and is used both as a direct energy source and as a feedstock for energy production. It is estimated that about 80 % of the total rural energy demand in India is met by biomass. Biomass is mainly used as fuelwood and agricultural residues for cooking, heating, lighting, and also for generating electricity [85]. The major sources of biomass in India include crop residues, agro-industrial wastes, animal wastes, wood residues, forestry residues, and municipal wastes [86].

For country like India, the use of biomass for energy production has several advantages, as it's a renewable resource and is relatively abundant and widely available. Biomass is also considered to be carbon–neutral, as it does not produce additional carbon dioxide when used for energy. It is also relatively inexpensive compared to other energy sources, and can be used to generate electricity and heat. Despite the advantages of biomass to bioenergy conversion, there are several limitations to its use [70]. The use of biomass as an energy source is limited by the availability of suitable feedstock. It is also difficult to store, transport, and process biomass. In addition, the conversion of biomass to energy requires specialized equipment, which can be expensive [43].

Despite the limitations of biomass to bioenergy conversion, it is expected to play an important role in meeting India's energy needs. The government of India has set a target of generating 10 % of the total energy from renewable sources by 2022. It is expected that biomass to bioenergy conversion will be an important part of achieving this target [69,71]. In addition, the development of advanced technologies such as gasification and pyrolysis has made biomass to bioenergy conversion more efficient and cost-effective. These technologies have the potential to increase the efficiency of energy production from biomass and reduce the costs associated with energy production [87].

Biomass to bioenergy conversion has the potential to play an important role in meeting India's energy needs. The use of biomass as an energy source has several advantages, such as being renewable and carbon–neutral. However, there are several limitations to its use, including the availability of suitable feedstock and the cost of specialized equipment. Despite these limitations, it is expected that biomass to bioenergy conversion will play an important role in meeting India's energy needs in the future [88].

5. Conclusion

This review paper provides an overview of the potential of biomass to energy in India. Biomass resources are abundant and

diverse, ranging from agricultural residues to energy crops. Their chemical composition can vary, which affects the type of conversion technology that is suitable for their conversion into energy. Technologies such as thermo-chemical, biochemical and physio-chemical conversions are used to convert biomass into energy. The major finding includes:

- Municipal solid waste, municipal liquid waste, and agricultural waste may all be utilised as feedstock for the generation of bioenergy, which will alleviate several issues in India, including the country's energy crisis as well as the pollution problem that has arisen as a result of the energy crisis.
- The generation of bioenergy from a variety of sources of biomass, such as waste from floating plants, has not yet reached its full potential.
- The generation of energy is the primary focus of research on various techniques for converting biomass. There was a need to discover other methods as well.

In conclusion, biomass offers a great potential to provide energy security in India. The appropriate use of biomass resources, combined with the development of efficient conversion technologies, can enable India to reduce its dependence on fossil fuels, meet its energy needs and achieve sustainable development. Therefore, further research and development is needed to fully utilize the potential of biomass resources to generate energy in India.

Researchers will have a better understanding of the potential field in India and the ways in which population growth may impact energy requirements in India after reading this article. Biomass has the potential to provide an efficient solution to India's energy and other challenges. There is a need for additional people to pursue research in this area.

CRediT authorship contribution statement

Kunal Chauhan: Conceptualization, Software, Writing – original draft. **Varun Pratap Singh:** Supervision, Writing – review & editing.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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