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Review article

Possibility of utilizing agriculture biomass as a renewable and sustainable future energy source

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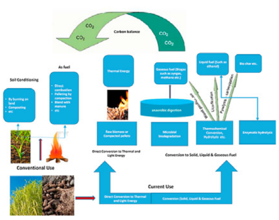
G R A P H I C A L A B S T R A C T



A R T I C L E I N F O

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A B S T R A C T

Issues related to depletion of conventional fuel resources and environmental concerns have become the driving force to explore an environment friendly, renewable, economical and sustainable alternate energy source. Huge quantities of agriculture biomass are being produced globally which can be transformed to biofuels by utilizing various procedures. However, issues such as environmental damages and competing uses of agriculture biomass need to be investigated factually considering the short as well as long-term acuity considering its effect on the soil and conversion to biofuels. This review provides an insight into the potential of various biomass as an energy source. Presently available conversion techniques to convert biomass to energy in various phases are discussed. The review also addresses the technical, socio-economic and environmental concerns and limitations with the appropriate control measures. Present study revealed that by the year 2020 most of the developed countries including the USA, Canada, China and Poland are switching to, renewable energy including agriculture biomass. Techno-economic analysis performed shows the feasibility of utilizing agriculture biomass as a competitive energy source. The information provided will help stakeholders, energy managers and decision makers working in the sustainable and renewable energy sectors to consider agriculture biomass for energy production at a larger scale.

1. Introduction

Fossil fuel reserves are non-renewable and finite. Several researchers report clear indications of depleting fossil fuel resources. According to estimates, the global recoverable oil reserves are diminishing at a rate of 4 billion tonnes per annum. Even if it is assumed that the depletion of these reserves continue at the present rate, it is projected that all of these reserves will be exhausted by 2060. More reserves may be discovered before this time, which will extend the deadline somewhat. However, the threat still exists. Therefore, it is essential to find other alternative resources of energy in order to continue our pace of living. Those are the renewable and sustainable sources of energy.

The use of fossil fuels has inherent issues related to ecological impacts. The burning of fossil fuels produces about 21.3 billion tonnes of carbon dioxide (CO_2) along with other greenhouse gases (GHG) per year. It is reported that natural processes can only eradicate 50% of that

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amount. Therefore, there is an overall rise of 10.65 billion tonnes of CO_2 per annum in the atmosphere [1]. Consequently, there is a need to explore renewable, sustainable and environment friendly energy resources. Agriculture products have a great benefit of consuming the increasing atmospheric CO_2 level by biological sequestration of CO_2 [2]. Biomass could be one of the renewable energy sources that can be transformed into energy directly or indirectly [3].

Biofuels are an environmentally safe alternative fuel which can be used in various diesel engines and generally without any engine alteration. At present, a growing interest is observed in the use of agriculture products for biodiesel preparation as it gives lesser emissions and is renewable as compared to the traditional diesel fuel [4]. In Sweden, Denmark and Poland, renewable energy is meeting more than 50% of the energy demand. Poland is planning to produce this renewable energy from biomass, particularly from agriculture biomass, by the year 2020 [5]. There, increasing demand of renewable energy mainly comes from a strong acceptance of biomass for production of biofuels for transport and electricity generation. Poland is planning to have at least 80% of the total energy be produced from renewable sources, including biomass. More than 75% of biomass energy will be produced from agriculture biomass [5]. It is reported that the biomass based energy option will share more than 50% of the net energy demand in most of the developed countries by the year 2050 [6]. Agriculture biomass could be utilised for the production of biofuels and enhance the future energy security without jeopardizing food availability.

As the information related to biomass utilization as a renewable and sustainable source is scattered and often repetitive, it is necessary to inventory such information in an organized way. Studies in the past have tried to depict this information. However, specific information related to the latest biofuel production methods is not sufficient [3, 4, 8]. The main objective of the current review is: to present a systematic overview on the research which has been done in the past concerning the idea of agriculture biomass utilization as a renewable and justifiable energy option, to analyse and evaluate the current state of the information, and to point out the potential future research directions. The study presents the current scenario of the global attainments especially in countries leading in the achievement of future targets. The approach of presenting this review starts with summarizing the information in three categories: the availability and utilization of biomass as fuel material, issues of concern with control measures adopted globally, and available technologies for conversion to biofuels feasibly and viably with the identification of the most promising pre-treatment, processes/technologies. A techno-economic examination based on information available in the literature is presented here for biofuel production utilizing agriculture biomass. The literature covers the information from the first quarter of the 18^{th} century to the latest research until 2021. This study will provide understanding about the current situation and future trends in an international context. The information will be helpful for decision makers, facilitators and managers for technical policies.

2. Biomass availability and utilization

Utilization of agriculture biomass as a source of energy is mentioned in literature dating back to 1830, which mentioned the production of biofuel in Ethiopia using the *Euphorbia abyssinica* plant [9]. During 1834, the first US patent for alcohol as a lamp fuel derived from biomass was awarded to S. Casey. Biomass is generated in huge quantities globally, including corn straw, wheat straw, rice straw and sugarcane bagasse. Sarkar et al. (2012) collected the information about the global availability of these agriculture wastes and found the highest production to be of wheat straw, as shown in Table 1 [1]. Asia is generating highest quantity of wheat and rice straw while USA is the leading generator of corn straw and sugarcane bagasse [10]. Research during the past 30 years in Mexico shows the highest number of research projects and publications in the country, which reveals the highest average potential of 3203 PJ per annum [11].

Table 1. Major agricultural wastes available globally [1].

Agricultural wastes	Quantity (million tons)
Wheat straw	354.34
Rice straw	731.3
Corn stover	128.02
Sugarcane bagasse	180.73

Lignocellulose materials, present in agriculture biomass in abundant amounts, are the key component in biofuel production. The typical composition of major agriculture biomass in weight percentage of dry matter basis compiled by Ali and colleagues is presented in Table 2 [12].

It is reported that, in Europe, about 950 million tonnes of biomass is produced annually and it can be used to produce 300 million tonnes of oil equivalent fuel. This means that biomass has the potential to provide about 65% of the total consumption of oil in Europe [21].

3. Biomass as fuel material

Agriculture biomass is a possible precursor material to produce sustainable energy. The energy content of biomass depends on the type of crop species. For example, rice straw has an energy content of about 3015 kcal/kg (12.614 MJ/kg) and hay contains about 3738 kcal/kg (15.639 MJ/kg) [22]. The approximate fuel values of agriculture biomass generated in the USA and at global level is estimated by Lal (2005), presented in the following Table 3 [23].

Agriculture biomass is popular in most of the developing countries due to economic factors and ease of availability [20]. As depicted in Figure 1, the biomass consumption varies greatly: 47% for Asia to 1% for Oceania [24]. It is reported that there is a considerable difference in biomass energy used among developed and developing countries, which is estimated to be 4% and 22% respectively. This scenario is mainly due to the limitations imposed in developed countries for the protection of the environment [25].

Although, agriculture biomass is bulky and has a relatively low calorific value, it has been used in various countries in Asia and Africa as a prime fuel source. However, it is still behind the consumption of wood being used for cooking and heating [25].

The potential of agriculture biomass as an source of energy has been investigated in many countries such as India, China, Denmark, Poland and Nigeria [5, 26, 27, 28, 29]. Although biomass is a viable option as an economical and accessible source of energy, further economic and environmental factors need to be investigated in order to compare it to the available competing sources with a tangible and comprehensive approach in the long-term [26, 28, 29].

Table 2. Composition of major agriculture biomass.

Crop waste types	Cellulose %	Hemicellulose %	Lignin %	Reference
Rice straw	39.04	20.91	5.71	[13]
Rice hull	33.47	21.03	18.80	[14]
Wheat straw	43.2	34.1	22.0	[15]
Soya hull	56.4	12.5	18.0	[15]
Maize (corn straw)	42.6	21.3	8.2	[1]
Sugar cane (Bagasse)	65.0 (total carbohydrates)		18.4	[1]
Sorghum straw	32	24	13	[10]
Barley straw	40	30	15	[10]
Coconut husk	24.7	12.26	40.10	[16]
Rapeseed straw	32	16	18	[17]
Soybean straw	35	17	21	[18]
Sunflower straw	32	18	22	[19]
Peanut shell	40.5	14.7	26.4	[20]

Table 3. Estimated energy values of agriculture biomass in USA and in whole world [23].

Parameter	USA	Global Average
Total agriculture biomass (10^6 Mg/year)	488	3758
Oil equivalent (10^6 barrels)	976	7560

4. Agriculture biomass as fuel in various forms

Agriculture biomass can be utilized as an energy source in various forms, depending on its physical and chemical properties in addition to its availability. Following are the general uses of agriculture biomass in its various forms:

4.1. As a directly combustible fuel

Worldwide more than 30% of the household energy is derived from agriculture biomass for heating, cooking and lighting [30]. Any processed or raw biomass produced during agricultural activities is suitable for heat and power production at a commercial scale [3].

According to Minister Gospodarki of Poland (2010), about 25–28 million tonnes of straw was produced annually. Among that, about 4.9 million tons of rape straw and cereal was used to produce energy. About 1.5 billion m^3 of biogas can be produced utilizing combustion processes [30]. It is reported that, in China, about 37% of the agriculture biomass is being used as a direct combustible fuel for heating and cooking in addition to other household usage [31]. Badarinath et al. (2009), reported that more than 2500 Tg of agriculture biomass is used in Asia as fuel material [32]. Pakistan, Bangladesh, India, and other Asian countries are generating huge amounts of rice straw, and most of it is used as fuel for heating and cooking [33]. In China, more than 190 million residents benefited from cooking stoves utilizing agriculture biomass as fuel [30].

4.2. As a gaseous fuel

Biogas, produced from agriculture biomass, is stored and transported for domestic use in order to cope with the requirement of energy for heating, cooking and lighting [7]. A study revealed that every year more than 3 Tg of methane (CH_4) gas is used as fuel gas in Asia alone [34]. Germany hosts about 50% of the bio-methane production plants based on agriculture biomass as a precursor material [35]. According to the report published by EU Commission, there is a desire to increase the share of agriculture biomass, manure and slurry as feedstock and improve the efficiency of biogas and bio-methane production plants [36]. Straw could be used for energy production as a precursor material for production of biogas. It is estimated that, in Poland, about 1.5 billion m^3 of biogas can be produce from biomass utilizing gasification processes [37].

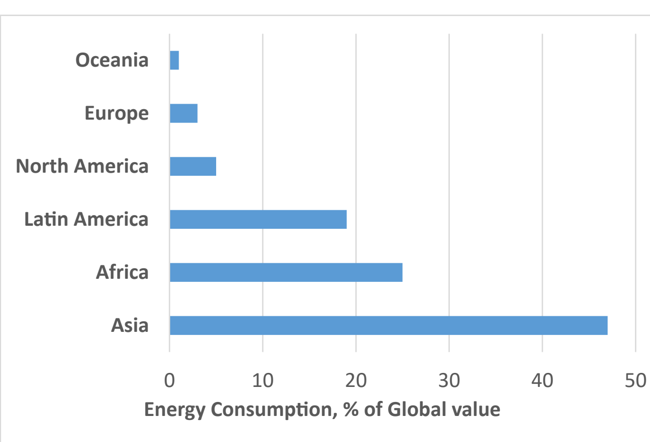

Figure 1. The share of global biomass energy consumption.

4.3. As liquid fuel

Agriculture biomass is can be utilized for producing ethanol. However, there are various other methods to utilize agriculture biomass that need to be explored and their feasibility needs to be evaluated. The main ingredient of agriculture biomass is cellulose and hemicellulose, which can be converted to bio-ethanol. Wheat straw contains more than 80% cellulose and hemicellulose material, which is a good source of fuel and can be transformed into xylose and glucose, and later into bio-ethanol [38]. Research conducted in the past revealed that agriculture biomass is a feasible source for substituting conventional fuels when it is transformed to bio-ethanol, which can be used in automobiles as fuel. Study conducted elsewhere by Acharya et al. (2019) reported the improvement in the oxidation stability of mineral diesel while utilizing mahua and jatropha biodiesel blend of 20% and 30%, respectively [39]. Poland is a leading country that is taking steps towards the utilization of agriculture-based ethanol additives in petrol. Krasowicz reported that by the year 2020, about 2.5 million tonnes of biomass will be utilized to produce bioethanol in Poland [40].

Canada has a prominent status in bio-ethanol production and has the capability of producing 5336M liter of bio-ethanol from agriculture biomass annually [41]. The augmented use of agriculture biomass to produce biofuel is reflecting a major change in policies and related environmental priorities, which will bring significant revolution in the fuel market. Globally, the production of ethanol estimated in 2001 was more than 30 GL (Giga Liters) [42], while it increased to more than 94 GL in the year 2015. The main contributors of ethanol production are the USA and Brazil, having a share in about 85% of the world's ethanol production [12].

4.4. As fuel pellets

Sometimes dry leaves, tree bark and tree pruning, produced from agriculture land are utilized to manufacture fuel pellets. Bechis (2017) prepared these fuel pellets and demonstrated the use of these pellets for cooking food. They reported that about 1.4 kg of fuel pellets are required, which is corresponding to 0.20 kg/day per capita [29]. The fuel pellet market is growing significantly with time, and it has been reported that more than 720 metric tonnes of fuel pellets are being produced annually. An increase of 13% in the use of fuel pellets in industrial boilers has been observed [43]. Studies reported that the pellets produced from logging residue provide a higher thermal value which may be used in conventional boilers to generate power [44].

In a study conducted by Pradhan et al. (2018), fuel pellets were fabricated from garden biomass without using any binder with comparable quality. Appropriateness of pellets to be used for household cooking was confirmed by combustion test. A prototype study for palletization was also conducted and confirmed the feasibility of fuel pellets [45]. Recently, study on torrefied and untorrefied pellets of wheat straws and cotton waste was conducted in which various mixing ratios at 300 °C and a residence time of 30 min were used. Results show that the torrefied pellets having higher CW to WS ratio provide a higher carbon content (41.5%–64.84%) and energy value (18.3 MJ/Kg to 28.5 MJ/Kg) owing to higher devolatilization rate of hemicelluloses in CW. In addition to that, the torrefaction index and energy yield demonstrated higher values, of 1.379 and 91.67%, respectively as compared to untorrefied pellets, which shows promising application of torrefication in fuel pellets production [46].

4.5. For generating electric power

Production of electric power from biomass is a viable option in developing countries [47]. Use of biomass to generate electricity has also been reported in Europe and North America. The European Union is running various power plants for electricity generation utilizing agriculture biomass. A 38 MW electric power plant constructed in Cambridgeshire, UK uses straw as fuel [44]. Study conducted in Pakistan reported that about 162 MW of electricity can be generated from agriculture biomass produced from wheat and rice straw [7]. Study conducted in Spain to evaluate the possibility of generating electricity from forestry and agriculture biomass shows the potential of generating about 118 PJ annually [48].

In a study conducted by Gospodarki (2010) in Poland, it is reported that the structure of biomass utilization will change within 20–25 years. Most of the biomass will be devoted to produce electricity and biofuels instead of heat production [3]. Table 4 provides the significant changes in the structure of biomass utilization from year 2006–2030 in percentage of total renewable energy.

5. Issues of concern and control measures

Investigations in the past revealed that forest and agriculture residues are one of the potential sources of generating energy. The positive side is that their use is not shadowing food production and has limited impact on it [49]. However, there are still concerns to address before agriculture biomass can be utilized as an energy source.

5.1. Problems involved in using agriculture biomass for biofuel production

There are issues related to the benefits and detriments in utilizing agriculture biomass for biofuel production. The energy production via gasification process is an ecologically and economically suitable solution, which may provide sustainable global development. The environmental impacts of gasification process may become more tolerable when a decarbon dioxide technology is utilized [50]. However, there are still concerns about utilizing agriculture biomass for energy production due to the available subsidized market for fossil fuels, which will undoubtedly diminish with time.

5.1.1. Security of energy supply

Global conventional fuel reserves are limited and are going to be consumed in the near future. The decline in fossil fuel availability will in turn increase fuel bills and affect the economic situations of countries, especially those already suffering from energy deficiency. Therefore, the availability of biofuel from agriculture biomass would be the attractive option to ease the reliance on diminishing traditional fuels [51].

During 2009, the Defense Logistics Agency conferred with several contractors to get jet fuel HRJ-5 which is a renewable biofuel. The cost of fuel came around $66 to $149 per gallon [52]. During the last decade, the US Navy and Air Force have used a number of aircrafts and ships demonstrating the use of biodiesel and bio-jet fuel as a preemptive fuel. During 2011, the US Navy obtained 450,000 gallons of bio-diesel and jet fuel having cost more than $12 million. The bio-fuel utilized had a cost of around $26.75/gallon, which is about 10 times more costly than conventional diesel fuel [53]. Furthermore, the Thunderbolt II flew the first flight of an aircraft powered merely by a biomass-based jet fuel mixture [54].

Table 4. Present and expected variation in the biomass utilization during 25 years [3].

Options for biomass utilization	2006	2010	2020	2030
Electricity	3.8	6.3	14.9	16.1
Heat	94.0	83.3	71.4	72.3
Biofuels	2.2	10.4	15.7	11.6

All the values are in percentage out of total 100%.

5.1.2. Greenhouse gas (GHG) emissions

It is a common conception that burning of biomass will increase the GHGs emission and contribute to global warming. Contrarily, agriculture biomass may actually play an important role in plummeting the overall GHG emissions. It is true that the processes for the production of biofuels from biomass generate GHGs. Yet, while utilizing biofuels, lower emissions are given off as compared to conventional fossil fuels and in turn there are reduced overall emissions [51]. Rathore et al. (2016) estimated the energy and GHG saving while producing and consuming biofuels in developing countries. They reported that not only biofuels give less emission, but during the cultivation of crops, the uptake of carbon by these plants significantly reduces the overall GHG concentration in the atmosphere. Estimated GHG saving obtained by utilizing biomass to produce biofuel is presented in Table 5 [51]. Reddy et al. (2008) also pointed out the significantly lower emissions from biomass cultivation and biofuel use as compared to fuels derived from crude oil. He reported that utilizing biodiesel (B 20) which has about 20% diesel, reduced the emission of carbon monoxide by up to 20%, un-burnt hydrocarbons by 30%, and aerosol particles by 25%. Furthermore, the utilization of 10% blends with ethanol can decrease emissions of GHG in the range of 12%–19% as compared to fossil fuels. Similarly, combustion of 85% ethanol will reduce the NOx emissions by up to 10% as compared to mineral fuel [47]. Information in the literature shows that the transformation of carbon dioxide into bio-fuels and other products by biochemical processes can reduce GHG concentration significantly [52].

5.1.3. Cheaper energy imports

As a raw material, biomass is available in almost all countries from which they can generate their own fuel and thus ease their reliance on conventional fuels [47]. Agriculture biomass driven fuels could potentially cut the encumbrance of expenditure of importing fuel, especially for countries having limited energy sources [27]. Recently, China and India prepared to increase production of bio-fuel at least two fold within the next 15 years. The objective will be achieved by the reorientation of agricultural research to reduce the cost of production without compromising food and fodder security. This involves improvement in the energy value by selecting proper feedstock crop species, and exploring new crop species, along with optimized management of biofuel production steps [47]. Recent studies provided the option of utilizing energy crops coupled with phytoremediation as a dual benefit [55].

5.2. Risk and control measures

5.2.1. Food vs fuel issue

Conventional biofuels are generally produced from biomass obtained from food crops. At present, first-generation biofuels seems to be unjustifiable due to the impending pressure it may place on food products [56]. However, second-generation biofuels are solely produced from

Table 5. Summary of estimated GHG saving based on various biomass utilized to produce biofuels [51].

Biomass	*GHG saving (%)
Reed canary grass	84
Switch grass	114
Hybrid poplar	117
Corn soybean	38–41
Switch grass & Corn stover	70
Jatropha	72
Rapeseed	56
Grass	54–75
Bagasse	Slight
Potato peels	65–69

*Based on CO_2 equivalent.

non-food biomass, including agriculture biomass, which could subside the issue of food security [57]. Second-generation bio refineries may require to shape centered on sustainable products utilizing new and established environment friendly chemical technologies, including bioprocessing comprising Fisher Tropsch, pyrolysis, and established catalytic processes which will support it in making complex molecules and other constituents on which an impending sustainable society can be established [58]. Cultivation of this biomass utilizes land and water, which could coincide with the available resources for food crops. However, most of the crops needed for biofuel production can be grown on arid and even infertile land that does not have much potential agricultural value [59]. Presently, some plants such as jatropha are utilized that can be cultivated on barren land and require less water [60]. It is reported that the fragmentation and depolymerization via lignin valorization help in the production of biofuels and other chemicals. These strategies may result in the production of biofuels which may originate from non food based materials [61]. Nevertheless, it is necessary to integrate catalyst design, and reactor and process operation to increase the efficiency of various processes being used for the production of biofuels in a biofuel production plant [56].

Kumar et al. (2020) provided a comprehensive review on potential application of algal biomass, a non-food source, for the production of biofuels and bio-based products. Study shows great potential of utilizing the non-food based algal biomass for fuel production [62].

5.2.2. Reduced soil quality

Biomass, such as crop residues, aid with water retention in the soil, minimize loss through evaporation, and in turn improve the soil quality. Consuming the biomass for fuel production may hamper this and impart a negative impact on the soil quality. Farmers can circumvent this situation by leaving behind some portion of the biomass on the cultivation land. However, crops used for the production of biofuels can be cultivated on marginal land, inducing minimal effects on soil quality. Damage to the biodiversity is a serious issue and is among the critical issues related to the domination of monoculture [63]. However, it can be handled by exploiting efficient administration procedures. By using the second-generation biofuel precursor materials such as native grasses as a diverse plantation, biodiversity can be sustained [51].

5.2.3. Economic sustainability

The most critical barrier to instigating an agriculture biomass based fuel is the lack of financial support [64]. However, various countries are implementing policies to encourage the use of biomass based fuel usage. Examples are the legal acts of the European Commission for promoting biofuel usage as well as the biodiesel policy considering the energy shortage and environmental concerns by the Malaysian government [65]. Johari et al. (2015) reported that the shortage of subsidies is a major obstacle in adopting the option [66]. Therefore, the use of agriculture biomass certainly needs financial incentives, including tax credits and subsidies on the production as well as on the use, to make it feasible and competitive with the conventional fuels [51].

5.2.4. Need for technological improvements

There are several possibilities to augment the benefits of the utilization of biofuels produced from agriculture biomass. Improvements can be done in the growth, yield and collection of biomass by utilizing state of the art technologies, equipment and efficient agriculture management. Furthermore, biomass production efficiency can be improved by reducing the agriculture input, such as water, fertilizer and agrochemicals. A study done by Kim and Dale (2004) demonstrated the improvement in the eco-efficiency of related crops while using corn stover and winter cover crops [41]. Improvement in the efficiency of up to 75.15% in the biodiesel production for rice bran oil was reported by Ihoeghian and Usman (2018) while using heterogeneous catalyst to combat the thermodynamic inefficiencies [67].

5.3. Environmental concerns due to inefficient use of agriculture biomass

Burning of agriculture biomass in the field is a traditional practice to improve the fertility of the soil and reduce pest invasion once plantation is done [68]. Researchers reported that the purpose of burning the rice straw in China was to acquire a seedbed for improved workability of soil, reduce the obstructions for new seedlings and eliminate the growth of undesirable plants, which can pave the route for diseases and pests before the next harvest [68]. Burning of agriculture biomass has damaging effects on the environment and it boosts the build-up of atmospheric methane, which is about 60 times more efficient in absorbing the reflected infrared radiation than carbon dioxide [26]. At present, the production of methane from agriculture biomass is about 10% of the overall methane emissions from the combustion of fossil fuels [26].

6. Technologies for conversion to biofuels

Popular available biomass conversion technologies are defined in terms of the use of resources, reduced environmental impacts, climate change and economic feasibility [69]. Various thermochemical transformation procedures to thermally transform biomass into products include gasification, pyrolysis, and combustion. These products could be used to generate energy and produce fuels and chemicals utilizing chemical and/or biological methods [70]. The conversion of biomass is carried out mostly through combustion, gasification, pyrolysis, fermentation and chemical processes called transesterification [71].

During the processes of gasification and pyrolysis, energy is provided to breakdown the raw material for conversion to syngas, which is a mixture of hydrogen, carbon monoxide, biological oil and char. Further improvement in the process efficiency can be done by enhancing thermodynamic and heat transfer capabilities of the reactor [72]. Studies in the past investigated the pre-treatment of agriculture biomass in order to generate methane utilizing an anaerobic fermentation process. Possibilities of enhancing the lignocellulose materials' utilization efficiency were found for the biogas production. However, the studies recommended more in depth experimental investigations to evaluate the influence of various physiochemical factors, which may affect the process during pre-treatment.

6.1. Direct combustion as a fuel

Agriculture biomass is directly combustible in the presence of air, and produces heat and light. It is reported that more than 96% of the global energy is generated via direct combustion of biomass [70]. Energy produced from the direct combustion of biomass is mainly used in domestic cooking and heating [71]. A study conducted in Pakistan to evaluate the potential of rice husk as a precursor material in power production, it was revealed that there is a possibility to produce about 1,328 GWh of electricity if only 70% of the rice husk is utilized. The estimated cost of this electricity was reported as 47.36 cents/kWh, while the usual cost of electricity is 55.22 cents/kWh when generated by coal [73].

6.2. Gasification process

Gasification was found to be a robust process, which converts biomass into a combustible gaseous mixture mainly containing hydrogen, carbon monoxide, carbon dioxide and methane [78]. Gasification agents, including air, oxygen, steam or a blend of these gases, provide syngas having good flammable characteristics [74]. Hydrogen fuel produced by gasification process produces water (H_2O) and energy during combustion and does not contribute to the emission of GHGs [75].

Zhang et al. (2014) utilized two gasification processes to convert agriculture biomass to fuel; in the first one, atmospheric oxidation process was used to produce biogas chemically and crop straw was transformed to fuel gas with lower calorific value. In the second one, fuel gas with medium calorific value was produced when carbonization pyrolysis gasification process converted the biomass into charcoal and straw tar [76].

6.3. Pyrolysis

It is a thermal decomposition process in which bio-oil can be produced at an elevated temperature [77]. Further processing of bio-oil provides petrol, gasoline, kerosene oil and diesel. Such fuels have a high content of oxygenates, including alcohols, ethers and aldehydes [31]. Another product of pyrolysis process is bio-char, which is a solid residue with a high content of carbon along with light hydrocarbon gases [70].

In a study conducted by Bian et al. (2016), pyrolysis was applied on various agriculture biomasses, including maize straw, wheat straw, rice husk and rice straw. The procedure was carried out at 400 °C (isothermal pyrolysis). The results reflect that rice straw bio char has great potential to be used as a soil modifier for an acidic and nutrient deficient soil. Highest yield of bio char (43.8%) was achieved when rice straw was used [77]. In addition, pyrolysis can produce biochar during biofuel production which has multifunctional value and has emerging applications in various biofuel production processes [78].

6.4. Hydrothermal liquefaction

Hydrothermal liquefaction is an excellent option to convert lignocellulose material to fuel because the process does not require drying of material and produces good quality fuel. Hydrothermal liquefaction of wet biomass has been discussed in detail by some researchers and showed that the process seems to be a promising route to obtain bio-oil with properties similar to pyrolysis oil. However, the economy of the process is a concern due to the significant energy consumption in high pressure processes [79]. In a study conducted by Singh et al. (2015), hydrothermal liquefaction (280 °C for 15 min) under catalytic (KOH, K2CO3) and non-catalytic conditions was applied on various biomass, including forest pinewood, wheat straw, deodar biomass and sugarcane bagasse. Results obtained revealed that the process yields high conversion under thermal and catalytic conditions when agriculture biomass is used as compared to forest biomass. Among the tested materials, the highest conversion (>95%) was achieved when sugarcane bagasse was used [80].

6.5. Enzymatic hydrolysis

Significant quantities of rice straw is produced during harvesting of rice, which is one of the most promising bio resources to produce bioethanol. Studies show that enzyme hydrolysis step is the foremost economical as well as technical bottleneck in the agriculture biomass-to-ethanol bioconversion method. Álvarez et al. (2016) used various group of enzymatic blends with enzyme loading ranges between 20 to 25% of the total solid which led to a wide range of conclusions. Generally, glucose yields were between 60% and 95% and they were achieved with diverse pre-treatments and various wood-biomass species [81]. In a study conducted by Belal (2013), enzymatic hydrolysis process was applied to rice straw that separates cellulose material from lignin. Delignification process was carried out after pre-treatment to separate cellulose from lignin, and later yeast converted them into bioethanol utilizing enzymes and glucose. The process was found to be an economical, reliable and safe. It was achieved by fermentation of rice straw while keeping optimum conditions. In fact, lignocellulose wastes valuable enzymes to convert material and produce bioethanol by the reduction of sugars [82]. Another research that evaluated the feasibility of converting biomass into biofuel by enzymatic hydrolysis showed encouraging results. Steam explosion method was employed in a reactor designed specifically for this study [83].

6.6. Anaerobic digestion process

In anaerobic digestion process, microorganisms decompose biomass in an oxygen deficient environment [84]. Studies reported the feasibility of this process, technically as well as economically, which reduces the dependency on costly chemicals, special enzymes and expensive equipment [84]. Biogas production was demonstrated at a pilot scale digester utilizing agriculture crop residues. It was found that digestion was stable below 11 °C. Maximum net energy was produced at 30 °C, while keeping a loading rate of 3.3 kg VS/m^3 day. The process was found to be cost economical and produced an optimal quantity of methane [85].

The main obstacle in anaerobic digestion of agriculture biomass is the non-biodegradability of lignocellulose material having low concentration of nitrogen. Enhancement of digestibility of agriculture biomass is possible by pre-treatment of biomass, including exposure to electron beam radiation, crushing to increase surface area, thermal treatment, and treatment with enzymes. Therefore, it should be co-digested with other materials in order to make the process technically and economically feasible by utilizing microorganisms instead of expensive chemicals, biological enzymes or mechanical equipment [86].

In order to establish guidelines for co-digestion of agriculture biomass along with dairy waste, researchers reported that production of methane gas can be improved by including chopped field agriculture biomass in dairy manure. The optimum non-lignin C/N ratio of these input mixtures ranged from 25 to 32. This research also evaluated the C/N ratios for various other available agricultural residues [87]. Another study conducted by Zhang et al. (2013) to produce biogas from crop residue blended with goat manure revealed that the mixture is a suitable precursor material for anaerobic digestion as it contains a higher nitrogen content and shows better fermentation stability [88]. Recently, biochar was used successfully as an additive in the anaerobic digestion of biomass for improved conversion into bioenergy. Researchers pointed out the potential of the integrated process, which is found to be economically more feasible and demonstrated environment sustainability [89].

6.7. Transesterification

Vegetable and agro-oils can be converted to biodiesel utilizing transesterification process [71]. Rathore et al. (2016) reported that the biodiesel fuel, due to its ester content, is comparable to conventional diesel fuel; however, it has marginally lower power and torque. From an environmental and economical point of view, biodiesel has potential for use in the future, as it has lower emission of sulfur and acceptable values of flash point and lubricity along with better biodegradability [51].

6.8. Current technological development

In order to improve the yield and quality of biofuels, extensive work on technological improvement has been done and significant advancements are reported [88]. Research on indirect liquification process demonstrated the feasibility of two stage liquification, including thermochemical gasification followed by Fischer-Tropsch (F-T) process. This process is utilized for producing high biogenic biofuels from waste materials and shows potential to obtain high quality biofuel from agriculture biomass [90]. Single and multistage hydrolysis-fermentation processes were developed to produce ethanol from lignocellulose biomass, which do not require pretreatment or external enzyme addition, and demonstrate promising results in terms of process efficiency [91]. Gabra et al. (2019) evaluated four strains of biofuel-producing bacillus species and produced bio-hydrogen with high efficiency and economic feasibility.

They reported the ethanol production to be up to 1.55 g/L and bio-hydrogen up to 2450 ml/L from sugarcane molasses along with other chemicals. Researchers recommended interlinking the biofuel technology with bio-fertilizer production utilizing N_2-fixing bacterial biomass [92].

At present, fast pyrolysis is being utilized as an emerging technology, demonstrating higher efficiency of biofuel production with lower production time, low capital involvement and higher efficiency as compared to slow pyrolysis. However, reactor design is an important factor for achieving high performance of the technology [93]. Up-to-date work on technological improvements for upgrading the biofuel is in progress and improvements in the extraction and better calorific values are reported [94]. Literature shows that direct liquification of biomass is a promising technology to convert the biomass into biofuels, including hydrolysis, fermentation and thermodynamic liquification processes that can be utilized to upgrade the biofuels and enhance the economic value of biofuels.

7. Use of high energy crops

It is found that some plants have better performance as charge fuel for boilers and are classified as high-energy crops [23]. These plants provide a significantly higher amount of energy as compared to normally used plants. Examples of these plants include willows from the genus Virginia fanpetals *Sida hermaphrodita* Rusby, *Salix viminalis* var. *Gigantea,* Jerusalem artichoke *Helianthus tuberosus* L., Japanese rose *Rosa muli flora*, common locust *Robinia pseudoacacia* L. and poplars *Populus* L. These species also comprise the various grasses such as genus *Andropogon gerardi, various species of Miscanthus* and *Spartina pectinata*. A study in Poland demonstrated the ease of harvesting these along with high yields, which provides economic benefits and potential for future adoption of such species [95].

8. Techno-economic perspective of agriculture biomass for biofuel production

The techno-economic evaluation of agriculture biomass for conversion to biofuels is primarily based on the technical traits and the viability of the thermo-chemical procedures utilised for the production of biofuels from agriculture biomass as presented in Figure 2. The agriculture biomass produced in the fields is initially characterized to determine the chemical and physical properties, including lignin, cellulose content, hemicellulose content, ash content, elemental analysis, calorific value, etc. Later, an economic examination is conducted by quantifying the energy consumption as input to the process, and the energy that can be acquired from the produced biofuels. If evaluation shows economic viability and the process is found to be cost economical then the agriculture biomass can be used for converting to biofuel utilizing thermo-chemical methods. If not, then the agriculture biomass can be utilised as a fertilizer after composting, soil conditioner, feed for animals, soil stabilizer to decrease erosion of soil or construction material having required properties [12]. Baum et al. (2013) conducted a techno-economic evaluation on production of biodiesel from non-edible crops, and reported that by going to this option, a large number of employment opportunities will be available, especially in the rural regions. Furthermore, the cost for conversion could be abridged further if renewable solar energy is used for numerous unit processes and operations. This will also result in an effective reduction in the carbon footprint and the saving of significant amounts of energy being consumed [3].

Study conducted by Saeed et al. (2015) estimated the cost of bio-ethanol and biogas production and found it to be \$ 0.45/m^3 and \$ 1.8/m^3 respectively. They also calculated the cost of electricity produced from agriculture biomass utilizing gasification technique and it was found to be ¢ 8, while the cost of biofuel produced by pyrolysis technique utilizing rice straw as raw material was found to be ¢ 6/kg [31].

According to Saeed et al. (2015), replacing one litre of gasoline and diesel with bio oil or bio alcohol will decrease the production of CO_2 by 2.68 and 2.31 kg, respectively. A study elsewhere carried out a techno-economic analysis on the production of bioethanol exploiting four lingo-cellulosic dregs, namely coffee cut-stems, sugarcane bagasse, rice husk, and fruit bunches. In the analysis, factors such as cost of material, utilities, equipment, manpower and other operational charges were considered. Results obtained revealed the suitability of producing bio-ethanol utilizing the studied material.

Manganaro and Lawal (2012), conducted a techno-economic analysis on thermochemical transformation of biomass to transportation fuel. They recommended the fast pyrolysis process and pointed out that the net price of biofuel extracted from biomass depends on its market price and increases with the capacity of the plant. The study recommends modifying procedures of biomass collection and transportation [96].

A techno-economic comparative study was conducted at the University of Iowa, comparing two plants converting biofuel from biomass utilizing gasification process. In the study, they considered capital and operational costs. The transportation fuel was produced utilizing Fischer-Tropsch process and electrical energy as the coproduct. The conversion plants used corn stover (2,200 tons per day). The first plant used fluidized bed operating at 870 °C, oxic-condition with a non-slagging system, while the other plant used entrained flow at 1300 °C, oxic-condition and

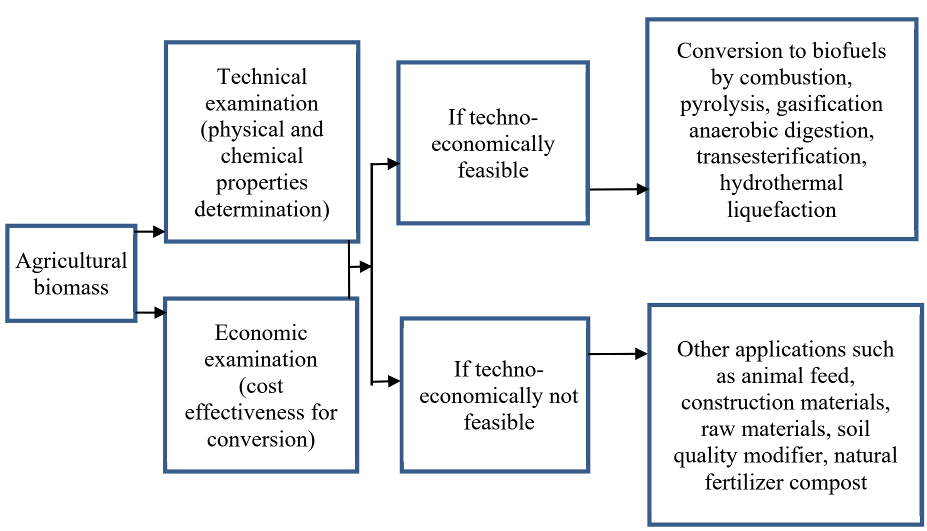

Figure 2. Flow chart of techno- economic analysis of biofuels production from agriculture biomass.

a slagging system. Both plants utilized Fischer-Tropsch process, hydro processing to naphtha and distillate aqueous fractions. A 10% internal rate of return along with current value of zero were used while considering a 20-year discounted cash flow return rate. The fuel product value was calculated as $4.30 and $4.80 for each gallon of gasoline equivalent produced respectively. They reported efficient yield at high temperatures. The most influencing factors were the capital and material cost affecting the product [97].

The most significant existing challenges for biofuel production using agriculture biomass that were pointed out in a previous study are the environmental aspects, economical factors, social consequences, sustainable management and soil fertility [98]. Agriculture biomass utilization may upset the soil fertility, carbon footprint, and sustainable food production; however, it provides a way to reinforce future energy security. There is a need to conduct a detailed and object oriented evaluation of the impact of various biomass harvest rates on soil content in order to utilize agriculture biomass as a precursor material for the production of biofuel. Failure to do this may cause perturbation in the environment and negatively impact the sustainable management of soil productiveness and energy security [99].

9. Discussion

The area of renewable and sustainable energy is in the zenith of an enthusiastic and exciting period of research and development. Various researchers have investigated the option from different approaches and the resulting information is extensive and scattered that necessitates the need to inventory the past work in an organized form. Present work is an attempt to provide a systematic and readily available collection of information on biomass utilization as a renewable and sustainable energy source. The information is presented in a methodical way to avoid any overlapping and present the information in chronological order. A detailed picture of the present status along with the issues that remain obscure are pointed out to facilitate the researchers in aligning the direction of their future research.

Present study shows that the use of biomass utilization for production of biofuel is dated from the early 18th century in the USA and Africa. Most of the work during the last half century on biomass utilization has been done in Sweden, Denmark and Poland. However, generation of huge amounts of biomass and need of energy almost all over the world forced researchers everywhere to drive energy from biomass. At present, Europe is emerging as a leader in adopting the renewable energy option at an accelerating rate. Biomass could be burned directly to get energy or can be used as solid, liquid and gaseous fuels. Studies revealed that the key components that help to improve the yield are the percentage of lignocellulose material, types of source plants, such as high-energy crops (e.g. Virginia fanpetals Sida hermaphrodita Rusby, various species of Miscanthus and Spartina pectinate) and method of production. Literature shows that the present day researchers are having concerns about the GHG emission control, lower yield of biofuels, and competing market price of fossil fuels. Some of these problems can be circumvented by considering the feedstock as a disposable waste in most of the agriculture countries. Biomass at present could be considered as a supplement source of energy, especially for countries importing fuel to fulfil their requirements. In the current scenario, the limited subsidies are a major obstacle in adopting biomass-based fuel. In order to promote the agriculture biomass based fuel at present day, financial subsidies and governmental support is necessary.

Recent data shows that the European Union (EU) targeted share of 20% renewable energy and climate energy package for electrification, transport and heating is not achieved [100]. The Czech Republic, for example, did not reach to its targets. However, they may succeed in reducing their energy consumptions and GHG emissions. Similarly, biomass is one of the basic priorities of the Energy Policy of Slovakia to increase renewable energy share in the country. However, its achievement is at risk due to improper implementation of policies [101]. The study shows a growing role in the use of agriculture biomass. Another study was conducted by Simionescu et al. (2020) about the achievement of renewable energy targets in EU; 28 countries reported the need of more attention to the policies in which funding opportunities would be dependent on the achievements of renewable energy targets [102].

Some researchers pointed out the food versus fuel issue, which diminishes the popularity of biofuels derived from food crops based biomass. However, second-generation biofuels are solely produced from non-food biomass, including agriculture biomass, which could subside the issue of food security.

Improvements can be done in the growth, yield, and collection of biomass by utilizing state of the art technologies, modification in production methods and equipment, along with efficient agriculture management. Furthermore, biomass production efficiency can be improved by reducing agriculture input, such as water, fertilizer and agrochemicals. Improvement in the eco-efficiency of some crops was demonstrated while using corn stover and winter cover crops [41]. Therefore, there are possibilities to use advanced technological tools to improve the benefits of using biofuels significantly. The most important is to reduce the cost of biofuel and improve its quality comparable to fossil fuel in addition to reducing the emissions by technological improvements in conversion of biomass to biofuel. Present study shows a number of technologies being used, including gasification process, pyrolysis, direct and indirect liquification, transesterification and biological anaerobic digestion process. However, research on indirect liquification process demonstrated the feasibility of two stage liquification, including thermochemical gasification followed by Fischer-Tropsch (F-T) process. The process was utilized for producing high biogenic biofuels from waste materials and showed potential to obtain high quality biofuel from agriculture biomass. Up-to-date work on technological improvements for upgrading the biofuel is in progress, and improvements in the extraction and better calorific values are reported [94]. Information available in the literature also shows that direct liquification is a promising technology to convert the biomass into biofuels, including hydrolysis fermentation and thermodynamic liquification processes, and can be utilized to upgrade the biofuels and enhance the economic value of biofuels.

This study may recommend that biomass based energy is the best option for rural areas, which does not only offer development in those areas but also provides benefits, such as sustainability, decline in GHGs emissions, improvement in social structure and local development, in addition to other trivial benefits. The growing market of biofuels will enhance the economic situation of rural areas by providing more jobs and utilization of waste material.

This study also presented the techno-economic perspective of biomass utilization for biofuel production, which shows the feasibility of utilizing agriculture biomass as a competitive energy source. In the following section, conclusions and a summary of the main findings of the study will be stated, along with future research avenues.

10. Summary, conclusions and future prospects

Utilization of agriculture biomass as an alternate energy source seems to be a viable option, which is demonstrated by various countries including the USA, Canada, China and Poland. The prime use of agriculture biomass is in biofuels production, which could be processed to any phase of biofuels utilizing various thermo-chemical, biochemical and other chemical conversion procedures. In addition, it provides a sustainable source of fuel, which will probably replace the depleting fossil fuel resources, and minimize GHG and solid waste.

As there is a global diversity in the agriculture biomass production, which generally depends on the local topographical and climatic conditions, countries may explore their agriculture biomass and come up with the optimum solution to convert biomass to biofuels utilizing the most economical and realistic route. In addition to that, the concomitant technical challenges and a viable market drift required to be deliberated in order to use the agriculture biomass as a feasible major biofuel production precursor. The techno-economic evaluation done in the past showed that agriculture biomass is a potential candidate for energy production. However, a detailed comparative investigation is required to rank it with other viable renewable sources of energy, including solar, geothermal, wind and tidal energy.

In order to utilize agriculture biomass efficiently and economically to produce energy, clear guidelines need to be developed. It is expected that energy production using agriculture biomass may offer new opportunities and prospects to the farmers so they can modify agricultural activity, such as growing energy efficient plants. Although there is a gap in the biomass energy market, and an inadequately organized system and lack of subsidies for energy crops, significant economic benefits are expected from this option. Incongruities in the classification of agriculture biomass, which is anticipated to be a potential source of biomass for production of energy, is one of the obstacles. The scarcity of knowledge about the requirement of equipment, their efficiencies and their potential thermal conversion are some of the possible obstacles in using agriculture biomass in the near future. Present study results in the following findings:

- Review shows a growing shift from oil and gas to renewable biomass energy.
- Concerns about environmental forfeits of contending uses evaluated with short and long-term perception and mitigation measures showing long-term feasibility.
- Utilization of renewable biomass for energy production will provide overall reduction in emission.
- Europe is the leader in adopting renewable energy options at an accelerated rate, although still behind the schedule in achieving targets.
- Available conversion technologies are discussed, among which the most common are gasification, pyrolysis, and combustion.
- Techno-economic analysis shows the feasibility of utilizing biomass as a renewable energy source.
- A major shift in policies and their implementation is needed.

Study shows the GHG emissions associated with the production and use of biomass-based ethanol were found to be lower than the emissions from coal for electricity generation [103]. Therefore, future prospects for the research in agriculture biomass energy production are development of more efficient processes, including gasification. In the future, it is expected that the use of biomass for electricity generation will have far greater potential than the production from conventional mineral fuels [104]. As the use of biofuels has an increasing trend in the transportation sector, it may emerge as a key policy strategy which will substitute conventional fuels in the near future. Review shows the need of research on the development of a better biofuel economy braced by supportive policies which involve influential governmental backing focusing on major disruptions, such as modifications in environmental doctrines of countries, technological revolutions and advancements, higher cost of oil, and preservation of climate. Finally, bioenergy production from agriculture biomass has enormous socio-economic benefits, in addition to environmental benefits. Production of bioenergy from agriculture biomass can provide employment to the public and complete value chain, as well as raise the income of farmers and improve the local economy.

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Author contribution statement

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