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Production of Biofuels from Agricultural Waste

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Agricultural waste represents a largely untapped resource that could be utilized for the production of biofuels through various conversion pathways. As the global demand for renewable and sustainable energy grows, biofuels offer solutions to mitigate climate change impacts while improving waste management. This review analyzes using agricultural residues and by-products as feedstocks for biofuel production through biological, thermochemical and chemical conversion processes. The different types of lignocellulosic biomass available from agricultural activities are discussed, along with their compositions. While agricultural waste has advantages like wide availability and low cost, challenges relating to heterogeneous composition, pre-existing contamination and seasonal availability must be addressed. Fermentation, anaerobic digestion, pyrolysis and gasification are examined as established routes for converting agricultural waste into liquid biofuels and biogas. Pretreatment methods, enzyme production pathways and synthesis of fuels like ethanol, butanol and diesel substitutes are outlined. Environmental benefits of biofuels from waste, including greenhouse gas mitigation and recycling of soil nutrients, are evaluated against fossil fuel

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alternatives. Case studies on operational plants and feasibility studies provide insights into technical and economic viability at scale. Challenges regarding feedstock logistics, conversion efficiency, commercial scale-up and sustainability assessment are identified for future research focus. In conclusion, the review finds that agricultural waste is a promising renewable resource for biofuel production when integrated with appropriate thermochemical, biochemical or anaerobic digestion technologies. While the field is advancing, further improvements in areas such as feedstock supply, pretreatment technologies, and demonstration of sustainability will be critical to realize the full potential of this emerging bioeconomy sector. The review recommends steps to accelerate commercialization and policy frameworks to incentivize waste-to-energy solutions.

Keywords: Agricultural waste; lignocellulosic biomass; fermentation; anaerobic digestion; pyrolysis; gasification; sustainability; biofuels.

1. INTRODUCTION

In the last few decades, biofuels have gotten a lot of attention as low-carbon, renewable options to fossil fuels like gasoline, diesel, and jet fuel. With more people owning cars and flying around the world, the demand for transportation energy is steadily rising [1]. Still, the transportation industry is very dependent on oil, which makes greenhouse gas emissions and the rise in global temperature worse [2,3]. This has made people look for biofuels that are sustainable and have low emissions that can be used in cars instead of petroleum goods. When it comes to environment and energy security, biofuels are much better than fossil fuels in a number of important ways. Unlike oil supplies, which can only be used up, these fuels can be made over and over again from biomass feedstocks that can be grown and replaced. The closed carbon cycle is created when they are burned because the amount of carbon dioxide released is the same as or less than the CO2 taken in during plant growth [4,5]. Because of this, biofuels are better for the environment than fossil fuels, which release "new" carbon that was put away millions of years ago. Making biofuels also helps the country become less reliant on oil imports and improves energy security. By replacing oil with biofuels, harmful pollutants like particulate matter, carbon monoxide, unburned hydrocarbons, and sulfur dioxide are reduced, which is good for both the environment and general health [6]. Some studies show that biofuels could help cut down on up to 30% of greenhouse gas emissions from transportation by 2050, provided that technology gets better and more of them are used [7]. As part of the Paris Agreement's goals, this could make a big difference in the world's efforts to stop climate change.

First-generation biofuels made from food crops like corn, sugarcane, and vegetable oils got a lot of government support. But now it is clear that we need next-generation biofuels made from lignocellulosic feedstocks that aren't edible [8]. This is because using food and feed crops to make fuel causes problems with food prices, competition for farmland, and changes in land use that make it harder to save greenhouse gases [9]. Lignocellulosic feedstocks are good options because they don't threaten food security, can be grown on poor land, and lower greenhouse gas emissions more through cellulosic ethanol or other advanced biofuels. However, the marketing of advanced biofuels has been slow because of many technical and economic problems [10], even though research and development have made a lot of progress. One of these problems is that lignocellulosic material has a complicated and uneven structure that makes it harder and more expensive to break down than simple sugars, starches, and oils in food crops. The current methods for getting feedstock and changing biochemicals and thermochemical also need to be improved in order to reach economies of scale and lower the high costs of production compared to regular petroleum fuels. Corn, wheat, rice, sugarcane, oilseeds, and other crops generate over 1 billion tons of farm waste annually, according to [11]. About 30 to 50% of field wastes can be removed without harming soil or crop production. This depends on the crop and the area. Lifecycle assessments (LCAs) show that about 500 million tons of corn stover and 150 million tons of wheat straw could be found in a way that is good for the environment in the US and Europe, respectively.

In the same way, animal manure is a common waste product—every year, cattle produce over 64 billion tons [12]. Some things that hurt the environment when they are not handled properly are chicken litter, cow/pig manure slurry, and poultry litter [13]. Because it is high in carbohydrates, fats, and proteins, manure has a lot of energy. This means that it can be turned into biofuels through anaerobic processing or other methods. Along with residues and manure, wastes from processing fruits and vegetables, such as bagasse, rice husks, nutshells, city solid waste, and algal residues, are also great sources of feedstock [14]. Each year, these wastes add up to several hundred million tons around the world. This gives waste-based biorefineries a chance to make bioenergy and bioproducts with extra value [15]. Using agricultural waste to make biofuel has many benefits over growing crops specifically for energy. Residues are lignocellulosic materials that don't need farmland or other inputs to grow, so using them keeps food and fuel from competing with each other. As trash, they don't cost much or anything at all, which is good for the economy [16,17]. Because they are spread out and only happen during certain times of the year, they need decentralized, small-scale technology uses that work well in rural areas and developing economies.

At the same time, planning how to gather, pre-treat, and convert waste effectively requires planning how to move things around. There are also limits to the steady supply of residues throughout the year because of changes in crop yield and weather effects [18]. However, using them for advanced biofuels could have big benefits, like increasing incomes in rural areas, lowering the cost of managing waste, lowering greenhouse gas emissions by diverting garbage from landfills, and making use of materials that aren't being used enough right now.

Agricultural waste is a huge, underused renewable resource that could help biofuel development in the long term if it is combined with the right tools for conversion. To reach this capacity, it is important to solve problems related to the supply of feedstock, logistics, the efficiency of conversion, and the ability to make money on a large scale. The parts that follow will talk about the biological and thermochemical ways that agricultural waste can be turned into biofuels. These will be followed by case studies, effects on the environment, and directions for future research.

1.1 Scope

This review addresses the merits and cons of using agricultural waste biomass to make biofuels sustainably. Globally produced agricultural waste will be included. Waste from cultivating cereals, sugarcane, oilseeds, and fibers is included. Agricultural waste and animal dung from large animal feed producers will also be examined. The literature will examine waste stream biomass, compositional variability, and predicted levels. It will examine thermochemical, biochemical, and chemical strategies to convert lignocellulosic crop waste into liquid biofuels and biogas. Biochemical processes like anaerobic digestion and fermentation will be emphasized. Thermal processes, including pyrolysis, gasification, and biomass synthesis gas fuels, will be discussed.

It will examine demonstration and commercial-scale biofuel facilities worldwide that use various agricultural wastes. Techno-economic factors will include feedstock handling and preprocessing, fuel conversion, energy balances, fuel costs, and earnings. It will also examine how residue removal influences soil carbon and nitrogen dynamics and how much greenhouse gas emissions are conserved compared to fossil fuels. The review aims to improve information on agricultural waste biomass qualities and conversion technology best practices. It will identify the key technological, economic, and environmental barriers to large-scale integrated biorefinery utilization. Biofuel growth policy assistance, sustainable feedstock production, and waste management will also be discussed. Finally, the study will identify the most significant research areas to maximize agricultural waste's potential for carbon-negative biofuels. These include overcoming feedstock shortages, improving energy efficiency, generating autonomous models, and demonstrating process longevity. This website is for bioenergy and farm waste-based bioeconomy enthusiasts.

1.2 Objectives

(1) Provide a thorough analysis of agricultural waste resources and bioconversion technologies for producing biofuels from these residues. This includes evaluation of waste types, quantities, characteristics, as well as thermochemical, biochemical and chemical conversion processes.
(2) Critically assess the technical, economic and environmental aspects of bioconversion pathways based on case studies and literature and identify key challenges for large-scale implementation.
(3) Synthesize knowledge on agricultural waste biofuels to outline critical research gaps and recommendations, with the aim of realizing

their potential for sustainable bioenergy production.

2. LITERATURE REVIEW

2.1 Agricultural Waste as a Feedstock for Biofuel Production

A lot of different kinds of waste are made every year by agricultural operations. There are three main types of these wastes: lignocellulosic biomass, food residues, and animal manure [19,20]. Things like straw, wood, energy crops, and pulping waste are all examples of lignocellulosic biomass. Xue et al. [21] say that cereal straws from wheat, rice, and corn, bagasse from sugarcane, orchard pruning and nut shells, and corn cobs and stover are some of the most important crop leftovers. Over 300 million tons of sugarcane bagasse are made every year around the world [22], making it one of the most common waste materials.

There is also a lot of trash from animal farming. At concentrated animal feeding operations, a lot of garbage comes from the manure of cattle, chickens, and pigs [21]. Over 1 billion tons of manure are thought to be made every year in the US alone from raising animals [23]. A lot of agricultural garbage is made up of agro-industrial waste from making food and paper, like rice husk, corn fiber, fruit pomace, and sugarcane trash [24]. These residues are the leftovers from different conventional and organic processes used in the food and biomass processing businesses [25].

2.2 Composition and Characteristics of Agricultural Waste

Agricultural residues can have very different makes-ups based on the type of crop or animal source [26]. Lignocellulosic materials found in most leftovers are lignin, hemicellulose, and cellulose, along with different amounts of ash, proteins, and extractives (Ali et al., 2019). 30–50% of the dry matter in residues is cellulose, which makes rigid microfibrils that are linked to other polymers. There are no clear shapes in hemicellulose (20–30%), which connects cellulose to lignin (10–25%). Lignin is a complicated protein that makes plant cell walls stiff [7].

The moisture content is a key property that can change. It can be anywhere from 10 to 60%, based on the type of waste and the time of year. It is harder to collect, move, and store things that are wet, and the energy density goes down [27]. Ash content (2–20%) and macro and micronutrients present are two other types of variety [28]. Lignocellulosics can be used as feedstocks for processes like anaerobic digestion and thermal/chemical methods to make fuels and value-added products because they have high carbon and oxygen content and low sulfur content [29]. However, different types of trash also cause problems.

2.3 Advantages and Challenges of Agricultural Waste

Utilizing large amounts of agricultural waste has many advantages over growing straight food and energy crops. Remains are leftovers that have low or no production costs and don't cause problems with food versus fuel [30]. Additionally, their use helps with waste management objectives by avoiding problems with open burning or dumping [31]. Crop residues that are collected and removed help the soil's nutrient cycle and organic matter replenishment [30]. Waste materials can be turned into useful energy [32]. Hence can improve the economic viability of combined biomass supply and conversion systems.

Table 1. Composition and characteristics of agricultural waste

Component	Percentage Range	Description
Cellulose	30-50%	Rigid microfibrils, linked to other polymers
Hemicellulose	20-30%	No clear shapes, connects cellulose to lignin
Lignin	10-25%	Complicated protein, makes plant cell walls stiff
Moisture Content	10-60%	Varies based on waste type and season, affects handling and energy density
Ash Content	2-20%	Inorganic residue remaining after combustion
Macro and Micronutrients	-	Varies in composition
Carbon and Oxygen	High	Suitable for processes like anaerobic digestion and thermal/chemical methods
Sulfur	Low	Suitable for processes like anaerobic digestion and thermal/chemical methods

Source: [27].

Moreover, life cycle studies show that when handled in a way that doesn't harm the environment, waste biomass-based biofuels save more greenhouse gases than fossil fuels. Diverse composition, seasonal changes, decentralized generation, and the lack of standardized supply systems are still problems [33]. Distribution of small-scale garbage generators and changes in waste quality and quantity make collection and transport more difficult. Supplies are still very expensive because of this [34]. According to [28], the sustainable removal rates and soil fertility/carbon effects also need to be carefully studied and managed. Unfortunately, farm waste can be useful as long-lasting and inexpensive feedstock's if these problems can be fixed.

The biomass resources in agricultural waste are plentiful and not being used to their full potential. If they are grown sustainably as biofuel feedstocks, they could have technical and economic benefits. Composition varies but usually includes lignin, hemicellulose, and cellulose, which can be converted in different ways. To fully utilize this potential on a commercial level, it will be necessary to solve problems related to decentralized supply, seasonal changes, and unknown impacts.

2.4 Biological Pathways for Bioconversion of Agricultural Waste

2.4.1 Fermentation processes

Pretreatment methods: Pretreatment is needed to break down tough material by changing its structure so that enzymes can break it down and ferment it better [35]. Some common pretreatments are chemical (alkalis, organic liquids), physicochemical (steam explosion, ammonia fiber expansion), biological (microbes and enzymes), and physical (milling and irradiation). Before the process, lignin-carbohydrate complexes and crystallinity are broken up, which makes more surface area and pores available [36]. Soaking in an alkaline solution helps get rid of lignin and hemicelluloses, and using high-pressure and high-temperature water in a steam explosion breaks up the structure of plant cell walls [37]. The choice relies on things like the type and makeup of the biomass, the end products that are wanted, and the available technologies [38].

Enzymatic hydrolysis: Pretreatment makes cellulose and hemicellulose more easily broken down by enzymes like cellulase and xylanase cocktails. These groups of enzymes work together to split glycosidic bonds in carbohydrate chains into single sugars [37]. Endoglucanases, exoglucanases, and β-glucosidases are enzymes that are often used to break down cellulose efficiently [38]. Variables like pH, temperature, substrate loading, and enzyme dosage can be used to improve the process and increase sugar outputs [32].

Fermentation of sugars to biofuels: Biomass hydrolysis produces monomeric sugars that are used as fermentation substrates by microbes to turn them into energy products that are wanted. Some methanogens, like Saccharomyces cerevisiae, use hexoses to make ethanol, while more advanced forms also use pentoses [39]. During prep, crops like sorghum naturally make extracts that can be fermented. Bacteria and fungi that have been genetically modified can turn mixed sugars into butanol, isopropanol, and other alcohols [40]. To get high product titers, yields, and productivities at a low cost, process factors like inoculum size, nutrient supplementation, and product inhibition controls are fine-tuned.

2.4.2 Anaerobic digestion

Process overview: Anaerobic digestion (AD) is a biological process that uses bacteria and archaea when there is no oxygen present [41]. It can be found naturally in many places and is also used in industry to stabilize waste and make green energy [42]. The AD process has four main steps: exoenzymes break down complex organics, sugars and amino acids are acidogenesis, volatile fatty acids are acetogenesis, and CO2 and H2 are used to make methane [41]. For the best process stability, system design can be either wet or dry, depending on the type of trash [42].

Biogas production: Biomass amounts are reduced by anaerobic digestion, which creates biogas that are high in methane (CH4) and carbon dioxide (CO2). It is possible to burn biogas to make heat and electricity directly (Chen et al., 2008). Newer types can also be used instead of natural gas in some situations (Ahring, 2003). In addition to the type of feed, temperature (mesophilic 35°C or thermophilic 55°C), holding time, the carbon to nitrogen ratio, pH, and nutrients all affect the activity of microbes and the amount of methane they produce [42]. Digesting farm waste along with animal waste increases biogas potential in a way that works well with each other.

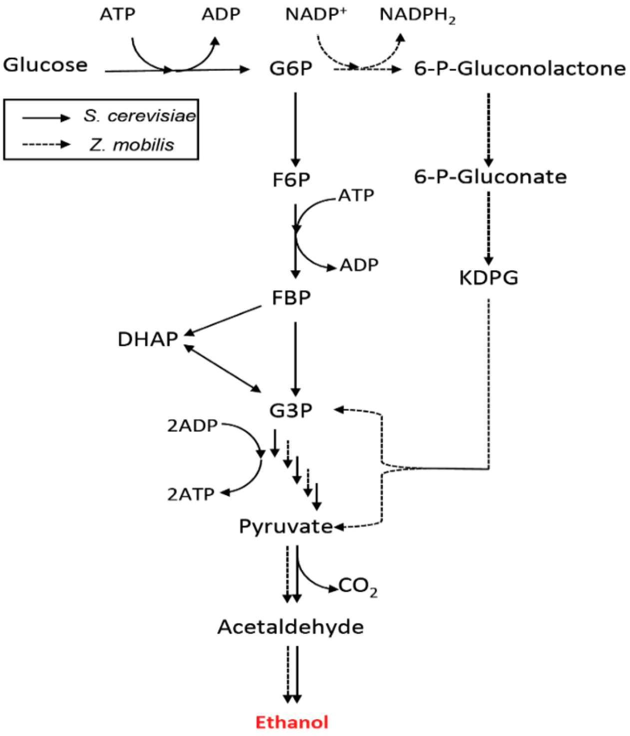

Fig. 1. Ethanol fermentation pathways in S. cerevisiae (solid line, EMP glycolysis pathway) and Z. mobilis (dashed line, ED glycolysis pathway). While the EMP pathway produces two ATPs per glucose molecule, the ED pathway produces only one ATP molecule per glucose molecule. KDPG, 2-keto-3-deoxy-6-phosphogluconate; G6P, glucose 6-phosphate; F6P, fructose 6-phosphate; FBP, fructose 1,6-diphophate; DHAP, dihydroxyacetone phosphate; G3P, glyceraldehyde 3-phosphate
Source [43]

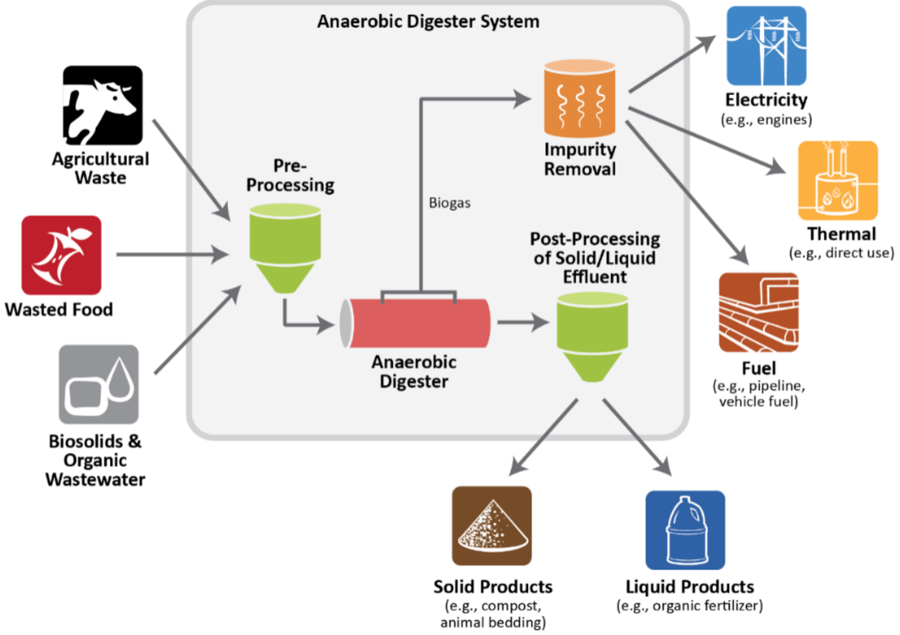

Fig. 2. Anaerobic digestion
Source: Anaerobic digestion. (n.d.)

Factors affecting biogas yield: The production of biogas relies on the properties of the biomass itself, such as its structure, the amount of carbon and nitrogen it contains, and how quickly it breaks down [41]. Temperature, mixing, loading rate, and solids content are some of the operational factors that affect microbial groups and conversion rates [42]. Pathogens, ammonia, heavy metals, sulfide, and organic acids are some of the toxic chemicals that come from industrial and farm trash that stop methane producers from working if they are not stopped [42]. To get the most biogas out of farm waste, it is important to do good pretreatment and process optimization. Fermentation and anaerobic digestion are both well-known biological ways to turn lignocellulosic waste biomass into biofuels, power, and products with extra value. For them to be used on a big scale, they need to be combined with the best pretreatment, hydrolysis, and fermentation methods.

2.5 Chemical and Thermochemical Conversion Pathways

Pyrolysis: Thermochemical conversion technology called pyrolysis breaks down biomass into solid, liquid, and gaseous parts without air [44]. Based on the time and temperature of stay, it is split into slow, fast, and flash pyrolysis [6]. Slow pyrolysis (400–550°C) makes more solids like ash, while fast pyrolysis (400–650°C) makes the most liquid bio-oil [44]. Fast pyrolysis is a good way to go because it makes bio-oil that can be used instead of chemicals and fossil fuels (75%). Oxygenated hydrocarbons, water, organic acids, aldehydes, ketones, phenolics, and biomass-derived sugars make bio-oil a thick, dark brown liquid [11]. Pyrolysis bio-oil's chemical and physical properties depend on feedstock and heating settings [8].

Due to its high-water content (20–30%), corrosive components, low heating value, and thermal instability, bio-oil cannot immediately replace petroleum fuels [16]. So, numerous upgrading procedures are applied to make bio-oil better and more stable for end goods. Catalytic and thermal cracking are two ways to improve things by getting rid of oxygen, increasing energy density, and reforming parts [44]. Emulsification, catalytic reforming, hydrotreating, and liquid liquefaction are some other methods [8]. The bio-oils that have been upgraded and refined have qualities that make them a good replacement for regular fuel oils. Some improved pyrolysis oils can even be processed along with other oils in oil plants that are already in use, such as FCC units [16]. Overall, fast pyrolysis along with the right upgrading routes is a good way to turn farm waste into liquid fuels and bio-products with high value.

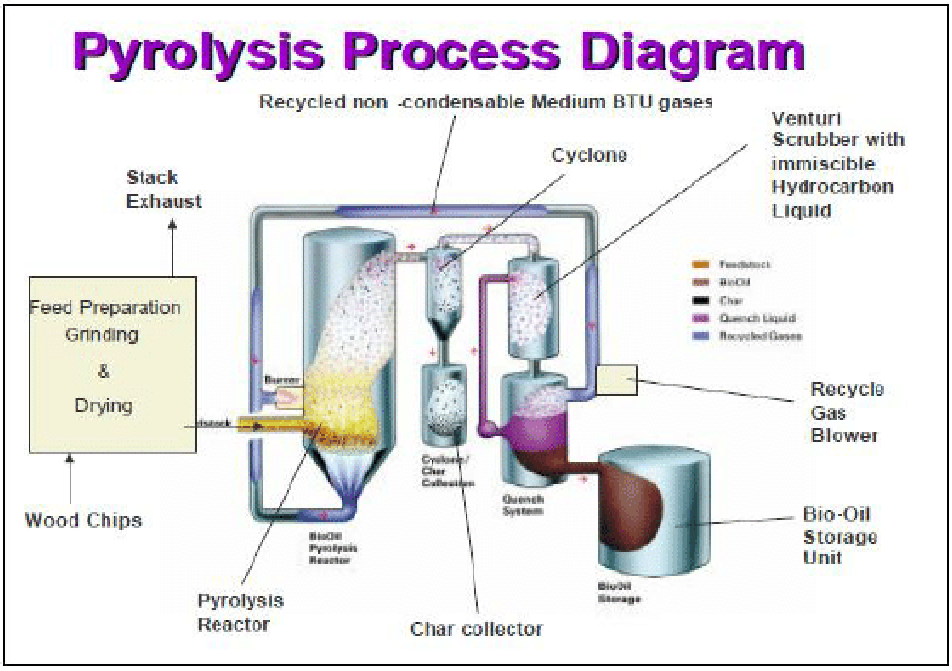

Fig. 3. Pyrolysis process
Source: Popoola, et al. [15]

Gasification: A controlled amount of air, oxygen, and steam is used to partially oxidize or steam reform wood at high temperatures (800–1500°C) in gasification. This creates syngas, which is a mixture of CO, H2, CO2, and CH4 (Arregi et al., 2018). Gasification is better than burning because it gives you more fuel options and uses less energy because the product gas is cleaned up and used [35]. After pollutants are taken out, the syngas stream has a high heating value and can be burned directly for heat and power purposes [16]. Nevertheless, syngas is also a key step in the production of liquid fuels for vehicles through catalytic processes like Fischer-Tropsch synthesis.

Syngas from wood gasification goes through catalytic conversion reactions in the Fischer-Tropsch (FT) process to make different types of liquid hydrocarbons [39]. Chemicals that are based on iron or cobalt are used to turn gases into liquids that boil in the range of diesel to gasoline [12]. FT makes drop-in green liquid fuels that are better than bio-oils made through pyrolysis. To protect catalysts and get the most production out of syngas before FT, it needs to be cleaned of any impurities [15]. Gasification and FT synthesis can turn farm garbage into green liquid fuels thermochemically. Farm biomass may be converted into fuels and products via pyrolysis and gasification. Better improvements and multi-product biorefineries could make waste biomass more cost-effective, technologically feasible, and durable.

2.6 Biofuel Production from Agricultural Waste Is Good for The Environment

Greenhouse gas emission reduction: Research shows that agricultural waste-based transportation fuels emit less GHG than fossil fuels. Greff et al. [25] found that integrated biorefining of residual biomass reduces emissions by approximately 80%. Photosynthesis absorbs airborne carbon instead of fossil carbon that has been concealed for a long period [21]. Anaerobic digestion of garbage to make biogas also stops the release of methane, a greenhouse gas that is highly harmful to the environment. Together, waste-to-fuel routes and renewable energy can get very close to having no greenhouse gas emissions [16].

Waste management and resource recovery: Making biofuels from food waste helps cut down on the amount of farm waste and the pollution that comes from burning it, which is bad for the environment and people's health [43]. It makes something useful out of cheap, easily accessible materials that would otherwise break down and release pollution [26]. This helps reach goals for sustainable waste management and offers green options to fossil fuels [19]. Biorefining also gets minerals that are stuck n waste and puts them back on farmland [31].

Soil nutrient recycling: When lignocellulosic leftovers are harvested strategically, the nutrients are left in the ash and the extra carbon is taken away for biofuels [38]. This increases the amount of organic matter in the soil and keeps phosphorus, potassium, and other macronutrients cycling, which is important for keeping the soil fertile and increasing crop output over time [42]. Co-digestion with animal manure improves the power to change the soil even more [25] So, collecting residues in a sustainable way and managing nutrients help carbon-negative farming.

Comparison with fossil fuels and feedstocks: Biofuels see cost competitiveness compared to petroleum at oil prices above $60-80/barrel currently [45]. But their primary benefit lies in delivering large GHG cuts hard to achieve through emissions offsets in transportation [18]. They also replace ozone-depleting SF6 in electric utilities with renewable biogas having zero global warming potential [41]. As waste feedstocks, their cultivation has minimal land use change impacts versus direct food/energy crops [25].

Overall, biochemical and thermochemical routes harnessing agricultural residues constitute more environment-friendly fuel alternatives.

Table 2. Comparison of biofuels from agricultural waste and fossil fuels

Fossil Fuels (e.g. gasoline, diesel)	Biofuels from agricultural waste
Source	Long buried fossil carbon reserves
GHG emissions	Higher emissions; Extraction releases sequestered carbon
Cost competitiveness	Mature and subsidized industry
Feedstock	Finite resources, geopolitical supply risks

Table 3. Differences between biofuels from agricultural waste and other biofuel feedstocks

Biofuels from agricultural waste	Other biofuel feedstocks (e.g. energy crops)
Feedstock source	Locally available waste biomass
Waste management	Reduces waste volumes and pollution; Boosts beneficial waste reuse
Soil impacts	Recycles nutrients and improves soil organic matter when sustainably harvested
Land use change	Negligible indirect land use impacts
Food security	Avoids competition for arable land and food resources
Overall sustainability	Reduces environmental impact of agriculture if best practices followed

3. CASE STUDIES AND INDUSTRIAL APPLICATIONS

3.1 Successful Implementations and Commercial Projects

Europe's biogas plants: More than 16,000 agricultural biogas plants make heat and energy from manure and crop waste in places like Germany, Italy, and Sweden [33]. The biggest is a 35 MW plant that breaks down chicken litter and wheat straw together. Decentralized energy helps rural areas grow and improve. Since 2007, Ensyn Renewables in Canada has been using its patented Rapid Thermal Processing technology to turn logging waste into green gasoline and diesel blendstocks in a commercial-scale fast pyrolysis plant. Gives off 15 million gallons of clean energy and electricity every year [25]. REG Synthetic Fuel, US: In Ralston, Iowa, a 30 million gallon/year biofuel plant gasifies corn stover and wheat straw and then uses Fischer-Tropsch synthesis on the gas. Since 2014, more than 160 million gallons of gasoline, diesel, and jet fuel made from biomass have been made (Tanger et al., 2013). SEKAB E-Technology, Sweden: Since 2012, the Pitea biorefinery has shown that it can make cellulosic ethanol from forest waste on a commercial basis. Lignin leftovers are changed into furanic chemicals used in plastics and resins by enzyme breakdown [39].

3.2 Techno-economic Analysis and Feasibility Studies

A techno-economic analysis and feasibility study was done to see if a planned 20 million gallon per year biorefinery in Kansas, USA could turn agricultural waste (corn stover) into ethanol [42].

Food and transportation: The biorefinery would get 150,000 tons of corn stover every year from places within 75 miles. A mass and energy balance showed that a densified loose load collection system would be able to gather 33% of the stover. It lowers the amount of nutrients taken away and the damage to the land. It would cost $52 per ton to store and send the dried and ground stover all year long [41].

Pretreatment and Hydrolysis: In order to obtain the most sugar, two stages of weak acid pretreatment and enzymatic hydrolysis were chosen [22]. This turns 72% of the cellulose into glucose and 57% of the hemicellulose into xylose. The cost to build the plant is $46 million, and the cost to run it is $0.11/gallon of ethanol [46].

Fermentation and Distillation: Genetically modified yeast is used to separate sugars and digest glucose and xylose at the same time [47]. During fermentation, 95% of the glucose and 73% of the xylose are turned into ethanol. The 190-proof ethanol is cleaned up even more by distillation, which costs $0.07/gallon and costs $25 million to set up. The techno-economic study shows that the proposed 20 MGY stover-to-ethanol project is technically and financially possible. With helpful policies in place, the plant has a good chance of being put into use and making money [45].

3.3 Challenges and Lessons Learned

Getting economies of scale is hard because of things like a complicated supply chain, changing garbage quality, gaps in infrastructure, and changes that happen with the seasons [25]. Process optimization using factors such as temperature profiles, catalyst formulation, and the addition of bioproduct routes leads to higher efficiency and the ability to make money [36]. Learning from decades of test operations helps make plant designs and operations more likely to work.

Long-term plans need to include things like limits on how much residue can be removed, the soil's carbon balance, and releases that happen further down the line [48]. Using sustainability measures to show results boosts trust among investors and the public [49,50]. Overall, even though there are some problems, strategic development based on pilot projects can help make the technical and economic promise of agricultural waste resources a reality. Key are careful management of the supply chain and environmentally friendly practices.

3.4 Challenges and Future Research Directions

One of the biggest problems is making sure that commercial-scale biorefineries have a steady source of different types of feedstocks, like crop residues, all year long. Seasonality changes the costs, needs for storage, and logistics preparation. If they are not used correctly, integrated biomass production systems may fight for arable land and water resources, but they can help keep supplies stable. To cut down on costs, more research needs to be done on advanced feedstock logistics models that find the best collection routes, pre-harvest evaluation, densification methods, and central depots.

Technically, it is still possible to get a lot more sugar out of different types of lignocellulosic leftovers after they have been pretreated and broken down by enzymes. It's possible to make bioprocessing more efficient by using cell-free enzymatic systems or custom thermophiles, ionic liquids, and greener catalysts [51]. To see if the idea can work in the real world on a large scale, we also need bigger test and demonstration sites. Different conversion routes should be used to make drop-in fuels, chemicals, and other high-value by-products from platforms other than ethanol.

In order to be truly sustainable, life cycle analyses need to look at a lot of factors, such as the effects on greenhouse gases, the balance of energy and water use, and the indirect use of land across true supply sheds. It's just as important to study the quality of the soil, how crop yield changes, and how carbon moves around after a harvest. Policies need to think about the fact that there are still data gaps about the best times, amounts, and effects of collecting data in the long run. Models of community and stakeholder involvement will also help people accept new technologies in their own communities. To encourage the building of unique business facilities and to grow this important industry, we need laws, incentives, and public-private partnerships that work together. In general, agricultural waste biorefineries have a huge amount of long-term promise because they can solve problems by learning new things, coming up with new ideas, and demonstrating them on bigger and bigger scales over time. To fully enjoy the benefits of this exciting area of the bioeconomy, we will need to take a comprehensive, diverse approach that includes technical, economic, and environmental factors.

4. CONCLUSION

In conclusion, agricultural waste biomass holds significant promise as a renewable resource for biofuel and bioproduct production through diverse thermochemical and biochemical conversion routes. Case studies and feasibility analyses demonstrate the technical and economic viability of converting various agricultural residues into fuels, power and value-added chemicals at both pilot and commercial scales. When sustainably implemented, waste-to-energy pathways offer clear environmental advantages over fossil fuels by substantially reducing greenhouse gas emissions while supporting improved waste management.

Looking ahead, further research and development is recommended to optimize feedstock logistics and supply chains handling dispersed volumes of heterogeneous residues. Advanced pretreatment technologies are also needed to maximize sugar yields and conversion efficiencies from different lignocellulosic materials. Future biorefineries should evaluate integrated multi-output platforms beyond ethanol to diversify revenues through coproduction of fuels, chemicals and materials. Comprehensive life cycle assessments and monitoring of soil carbon impacts post residue collection remain essential to refine best management practices and sustainability policies. Demonstration of emerging thermochemical and hybrid conversion routes at larger scales can help validate new process configurations.

Collaboration among industry, national laboratories and universities through public-private partnerships will be key to address challenges and progressively refine technologies. Supportive policy frameworks incentivizing first-of-kind commercial facilities in regions with ample residues can facilitate early adoption. With continued scaling of innovative solutions within a holistic multidisciplinary framework encompassing technical, economic and social dimensions, agricultural waste biorefining holds tremendous future potential to establish a sustainable low-carbon bioeconomy worldwide. Overall, residues from agro-industrial systems show promising long-term potential as environmentally strategic feedstocks for the production of renewable biofuels and biochemicals through continually advancing waste-to-value platforms.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Callegari A, Bolognesi S, Cecconet D, Capodaglio AG. Production technologies, current role, and future prospects of biofuels feedstocks: A state-of-the-art review. Critical Reviews in Environmental Science and Technology. 2020 Feb 16;50(4):384-436.
2. Rose PK. Bioconversion of agricultural residue into biofuel and high-value biochemicals: Recent advancement. InZero waste biorefinery. Singapore: Springer Nature Singapore. 2022 Jan 12;233-268.
3. Pattanaik L, Pattnaik F, Saxena DK, Naik SN. Biofuels from agricultural wastes. InSecond and third generation of feedstocks. Elsevier. 2019 Jan 1;103-142
4. Long SP, Karp A, Buckeridge MS, Davis SC, Jaiswal D, Moore PH, Moose SP, Murphy DJ, Onwona-Agyeman S, Vonshak A. Feedstocks for biofuels and bioenergy. Bioenergy & Sustainability: bridging the gaps. 2015;302-47.
5. Robertson GP, Dale VH, Doering OC, Hamburg SP, Melillo JM, Wander MM, Parton WJ, Adler PR, Barney JN, Cruse RM, Duke CS. Sustainable biofuels redux. Science. 2008 Oct 3;322(5898):49-50.
6. Solomon BD. Biofuels and sustainability. Annals of the New York Academy of Sciences. 2010 Jan;1185(1):119-34.
7. Sawatdeenarunat C, Surendra KC, Takara D, Oechsner H, Khanal SK. Anaerobic digestion of lignocellulosic biomass: challenges and opportunities. Bioresource technology. 2015 Feb 1;178:178-86.
8. Kumar G, Shobana S, Chen WH, Bach QV, Kim SH, Atabani AE, Chang JS. A review of thermochemical conversion of microalgal biomass for biofuels: chemistry and processes. Green Chemistry. 2017;19(1):44-67.
9. Ziolkowska JR. Biofuels technologies: An overview of feedstocks, processes, and technologies. Biofuels for a more sustainable future. 2020 Jan 1;1-9.
10. Panpatte DG, Jhala YK. Agricultural waste: a suitable source for biofuel production. Prospects of renewable bioprocessing in future energy systems. 2019;337-55.
11. Machado H, Cristino AF, Orišková S, Galhano dos Santos R. Bio-oil: the next-generation source of chemicals. Reactions. 2022 Jan 28;3(1):118-37.
12. Dieterich V, Buttler A, Hanel A, Spliethoff H, Fendt S. Power-to-liquid via synthesis of methanol, DME or Fischer–Tropsch-fuels: a review. Energy & Environmental Science. 2020;13(10):3207-52.
13. Ge S, Yek PN, Cheng YW, Xia C, Mahari WA, Liew RK, Peng W, Yuan TQ, Tabatabaei M, Aghbashlo M, Sonne C. Progress in microwave pyrolysis conversion of agricultural waste to value-added biofuels: A batch to continuous approach. Renewable and Sustainable Energy Reviews. 2021 Jan 1;135:110148.
14. Popoola LT, Adeoye BK, Grema AS, Yusuff AS, Adeyi AA. Process economic analysis of bio-oil, production from wood residue using pyrolysis in south-western Nigeria. Journal of Applied Chemical Science International. 2015 Jan 17;2(1): 12-23.
15. Arregi A, Amutio M, Lopez G, Bilbao J, Olazar M. Evaluation of thermochemical routes for hydrogen production from biomass: A review. Energy conversion and management. 2018 Jun 1;165:696-719.
16. Demirbas A. Biofuels securing the planet’s future energy needs. Energy conversion and management. 2009 Sep 1;50(9):2239-49.
17. Javourez U, O’donohue M, Hamelin L. Waste-to-nutrition: a review of current and emerging conversion pathways. Biotechnology Advances. 2021 Dec 1;53:107857.
18. Dixon S, Tran A, Schrier MS, Dong J, Deth RC, Castejon A, Trivedi MS. Metformin-induced oxidative stress inhibits LNCaP

prostate cancer cell survival. Molecular Biology Reports. 2024 Dec;51(1):729..

19. Koutinas AA, Wang RH, Webb C. The biochemurgist–bioconversion of agricultural raw materials for chemical production. Biofuels, Bioproducts and Biorefining: Innovation for a sustainable economy. 2007 Sep;1(1):24-38.
20. Saini JK, Saini R, Tewari L. Lignocellulosic agriculture wastes as biomass feedstocks for second-generation bioethanol production: concepts and recent developments. 3 Biotech. 2015 Aug;5:337-53.
21. Xue L, Zhang P, Shu H, Wang R, Zhang S. Agricultural waste. Water Environment Research. 2016 Oct;88(10):1334-69.
22. Makinde P. F. and Anjorin S. A. Performance evaluation of single slope and double slope solar stills integrated with a solar pond in a tropical humid climate. Journal of Scientific and Engineering Research. 2018;5(12):187-196
23. Pattanaik L, Pattnaik F, Saxena DK, Naik SN. Biofuels from agricultural wastes. InSecond and third generation of feedstocks. Elsevier. 2019 Jan 1; 103-142
24. Dixon S, Deth R, Dong J, Tran A, Schrier M, Trivedi M. Metformin Induced Oxidative Stress Alters Transsulfuration Pathway and Inhibits Prostate Cancer Cell Growth. The FASEB Journal. 2021 May;35..
25. Nwokocha GC, Adhikari P, Iqbal A, Elkholy H, Doerrler WT, Larkin JC, Grove A. Transcription factor PecS mediates Agrobacterium fabrum fitness and survival. Journal of Bacteriology. 2023,25;205(7):e00478-22.
26. Olaitan MO, Ujowundu CO, Nzebude CP, Ujowundu FN, Ugwu AO, Azuoma FC, Nwokocha GC. Organic wastes of Citrus sinensis Peels-a source of eco-friendly and sustainable bioactive compounds for promoting health. Asian Journal of Biochemistry, Genetics and Molecular Biology. 2024 Feb 8;16(2):21-31.
27. Dixon S, O'connor AT, Brooks-Noreiga C, Clark MA, Levy A, Castejon AM. Role of renin angiotensin system inhibitors and metformin in Glioblastoma Therapy: a review. Cancer Chemotherapy and Pharmacology. 2024 Jun 25:1-23.
28. Ayele B, Getachew D, Oginni O, Bekele BB. Determinants of birth registration and certification in Southwest Ethiopia: Implication for a new strategy to achieve Sustainable Development Goals (SDGs); 2024.
29. Duque-Acevedo M, Belmonte-Ureña LJ, Cortés-García FJ, Camacho-Ferre F. Agricultural waste: Review of the evolution, approaches and perspectives on alternative uses. Global Ecology and Conservation. 2020 Jun 1;22:e00902.
30. Gontard N, Sonesson U, Birkved M, Majone M, Bolzonella D, Celli A, Angellier-Coussy H, Jang GW, Verniquet A, Broeze J, Schaer B. A research challenge vision regarding management of agricultural waste in a circular bio-based economy. Critical reviews in environmental science and technology. 2018 Mar 19;48(6):614-54.
31. Nwokocha GC. The Influence of Fieldtrip as a Practical Skill Acquisition Technique in Biology Education. Asian Journal of Education and Social Studies. 2024 May 23;50(6):269-79.
32. Parekh S, Vinci VA, Strobel RJ. Improvement of microbial strains and fermentation processes. Applied microbiology and biotechnology. 2000 Sep;54:287-301.
33. Koul B, Yakoob M, Shah MP. Agricultural waste management strategies for environmental sustainability. Environmental Research. 2022 Apr 15;206:112285.
34. Makindea P. and Obikoya E. Implementation of solar system for electricity generation for rural farmers: A review. World Journal of Advanced Research and Reviews. 2024;22(03):458–471.
    Available:https://doi.org/10.30574/wjarr.2024.22.3.1705
35. Ojo A, Olanipekun PO. Refinements of generalised Hermite-Hadamard inequality. Bulletin des Sciences Mathématiques. 2023 Nov 1;188:103316.
36. Dixon S, Trivedi M, Deth RC, Dong J. Metformin Induced-Hydrogen Sulfide Modulates Prostate Cancer Redox Status Promoting Antiproliferative Effects..
37. Makinde P. F. and Adisa A.F. Performance Test of Grain Cleaner in Conjunction with Maize Sheller. Journal of Scientific and Engineering Research, 2024;11(2):140-150
38. Habib AR, Akpan EE, Ghosh B, Dutta IK. Techniques to detect fake profiles on social media using the new age algorithms-A Survey. In2024 IEEE 14th

Annual Computing and Communication Workshop and Conference (CCWC) 2024 Jan 8 (pp. 0329-0335). IEEE.
DOI: 10.1109/CCWC60891.2024.10427620

39. Okere oo, kokogho e. Determinants of customer satisfaction with mobile banking applications: Evidence from University Students. 2023:2.
40. Snehesh AS, Mukunda HS, Mahapatra S, Dasappa S. Fischer-Tropsch route for the conversion of biomass to liquid fuels-Technical and economic analysis. Energy. 2017 Jul 1;130:182-91.
41. Ojo A, Olanipekun P. Examining Students' Concept Images in Mathematics: The Case of Undergraduate Calculus. Voice of the Publisher. 2023 Nov 30;9(04):242-56.
42. Tunde Aborode A, Badri R, Ottoho E, Fakorede S, Etinosa P, Mangdow M, Oginni O, Nwaogelenya Opia F, Adenike Adebiyi A, Williams T, Adelakun I. Effects of migration on Sudanese women and children: a public health concern. Medicine, Conflict and Survival. 2024 May 4;1-9.
43. Dixon S, Tran A, Schrier M, Trivedi M. Nucleic acid biomarker technology for cancer immunotherapy. InEngineering Technologies and Clinical Translation 2022 Jan 1 (pp. 331-356). Academic Press..
44. Ojo A, Oginni OG, Akinrinola OE, Oginni RI. Impact of Cognitive-Behavioral Intervention on Alleviating Depression and Anxiety in Mathematics: Enhancing Students' Learning Experience and Academic Performance. Voice of the Publisher. 2023 Dec 14;9(04):257-71.
45. Akpan E. Fake Profile Detection on social media using Generative Adversarial Networks (GANs).
46. Iqbal A, Nwokocha G, Tiwari V, Barphagha IK, Grove A, Ham JH, Doerrler WT. A membrane protein of the rice pathogen Burkholderia glumae is required for oxalic acid secretion and quorum sensing. Molecular Plant Pathology. 2023,24(11): 1400-13
47. Optimum Oil Yield from Egyptian jatropha Seeds Using Screw Press, International Journal of Mechanical & Mechatronics Engineering, IJMME-IJNES. 2017; 17(1).
48. Experimental Study on the Effect of Preheated Egyptian Jatropha Oil and Biodiesel on the Performance and Emissions of a Diesel Engine, International J. of Mechanical & Mechatronics Engineering IJMME. 2020;20(1):59-69.
49. Nwokocha GC. Evaluation of Iodine and Goitrogens in Selected Vegetables from Owerri Imo State in Nigeria. Asian Journal of Biochemistry, Genetics and Molecular Biology. 2024 May 23;16(6):81-8. Available:https://doi.org/10.9734/ajbgmb/2024/v16i6385
50. Tijani MO, Ojo A, Akinsola O. Some Refinement of Holder's and Its Reverse Inequality. Advances in Pure Mathematics. 2023 Aug 31;13(9):597-609
51. Balat M, Balat M, Kırtay E, Balat H. Main routes for the thermo-conversion of biomass into fuels and chemicals. Part 1: Pyrolysis systems. Energy conversion and Management. 2009 Dec 1;50(12): 3147-57.

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