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Review

Alternative Fuels for Agriculture Sustainability: Carbon Footprint and Economic Feasibility

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Abstract: Agriculture is the foremost source of food for humans. Fossil fuels are typically used to operate farm machines, contributing to carbon emissions and accelerating climate change. It is possible to mitigate environmental damage by promoting renewable or alternative fuels, namely biofuels, solar energy, biomass, wind, geothermal, small-scale hydro, and wave power. Biofuels are considered as low carbon-emitting alternatives to conventional fuels. The use of biofuels promotes reduced emissions of greenhouse gases and reduces the related detrimental impact of transport. As an alternative to fossil fuels, renewable fuels seem to present a promising scenario. However, if low carbon products are promoted, analysis of each particular product's GHG emissions and carbon footprint (CF) is needed. Nowadays, CF is considered as the prime indicator of environmental impact, and its calculation is in utmost demand. Agriculture significantly benefits from the use of renewable resources. The carbon footprint measurement has the potential to assess and compare carbon emissions generated by agricultural products and to identify points for improving environmental performance. Several studies have compared alternative fuels with conventional fuels, and it has been proven that using alternative fuels can significantly reduce traditional fuel consumption. Bioenergy includes a number of socio- economic, technical as well as environmental benefits that helps in achieving the UN sustainable development goals (SDG). The aim to end malnutrition and hunger (SDG 2) requires a sustainable system for food production as well as resilient agriculture practices to improve agricultural productivity. The revenues from bioenergy projects can provide food and a better diet for small farming communities, thereby improving their quality of life. The present review aims to provide a comprehensive outlook of the role of alternative or biofuels in the agriculture sector, in terms of economic feasibility and carbon footprint, for sustainable development. This review also discusses the various generations of biofuels in attaining carbon neutrality, biofuel's impact on the environment, applications in agriculture, and limitations.

Keywords: alternative fuels; sustainable agriculture; biofuels; carbon neutrality; carbon footprinting

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1. Introduction

Every country's socio-economic growth is correlated with its energy expenditure. Humans have developed a multitude of approaches to produce energy because they assess its utility, starting with the exploitation of timber and progressing to current synthetic fuels [1]. Notwithstanding the awareness and need for energy, mankind has devised several technologies to amplify energy. As an umbrella term, it covers all forms of energy, including renewable (biomass, hydro, solar, geothermal, wind, and tidal) and non-renewable (nuclear, coal, and petroleum). For centuries, mankind has used fossil fuels derived from carbon sources. They contribute significantly to climate and environmental imbalances due to their high carbon emanation [2]. Apparently, the world's recoverable oil reserves are decreasing by four billion tonnes per year. According to projections, if these reserves continue to deplete at the current rate, they will all run out by 2060 [3]. The discovery of new reserves is possible during this period, extending the deadline. Nevertheless, the threat remains [3]. We must find alternative energy sources to sustain the pace of living, and urgently explore environmentally friendly, renewable, and sustainable energy resources.

Renewable energy is progressively more widely acknowledged as a vital element of mitigating climate change [4,5]. Almost all agricultural equipment and tractors use non-renewable energy sources like fossil fuels to generate power, leading to greenhouse gas emissions and global warming [6,7]. Significant research has previously been conducted to lessen our reliance on petroleum-based products. Many alternatives, including biopyrolysis and biogas, have been studied.

The concept of sustainability in the agricultural sector is focused on striking a balance between increasing productivity, fostering economic growth, and minimizing negative environmental repercussions [8]. Sustainable agricultural methods are set up to make the most of the current soil energy flows, nutrients, beneficial soil organisms, water cycles, and insect control mechanisms. Environmental harm can be prevented or reduced by using existing processes and flows [9]. These methods also attempt to generate nutrient-rich food free of contaminants that might harm human health. Producers can satisfy their demands in their surroundings, operations, and communities by utilizing various agricultural tactics [10]. According to Lichtfouse et al. (2009), the main objectives of sustainable agriculture are:

- Making farm income more profitable;
- Maintaining a sustainable environment, such as:
  (a) Improving and protecting soil quality;
  (b) Reducing dependence on non-renewable resources, such as artificial fertilizers, fuel, and pesticides;
  (c) Achieving a minimal impact on water quality, safety, wildlife, and other environmental resources.
- Strengthening farming communities and families [11]

Global warming is one of the most pressing issues today. A large portion of anthropogenic GHG emissions comes from the energy sector [12]. In the period 1951 to 2010, global mean surface warming may have increased by between 0.5 and 1.3 °C due to anthropogenic GHG emissions, according to the IPCC (Intergovernmental Panel on Climate Change) [13]. Despite its later development in countries other than Brazil and the USA, bio ethanol production has grown rapidly. Approximately 3.45 million tonnes of ethanol were consumed in 2017 [14].

Human pressure on the environment is quantified and compared through the assessment of the "footprint" of a product or activity. A footprint serves as an indicator of human pressure on the environment, thus helping us to understand environmental changes and impacts due to this pressure [15]. A product's carbon footprint (CFP) measures the total GHG emissions caused by an activity or accumulated over its lifecycle [16]. Life cycle assessments are based on the simple climate change impact category and expressed as CO_2 equivalents [17].

It has been decades since the automotive industry began using biofuels. Rudolph Diesel, for example, test-fired his first engine using peanut oil after pulverized coal was found inappropriate [18]. Until the 1940s, biofuels, especially bioethanol blends such as Agrol, Discol, and Monopolin [18], were commonly used as transport fuels in North America, Europe, and other regions. Only Brazil began producing ethanol at a large scale, under the National Ethanol Program 'Proálcool', during the 1970s oil crisis [19]. In the late 1990s, with the rise of crude oil prices and energy security concerns, the USA and other European nations implemented policies that supported industries producing domestic biofuels [20]. Climate change mitigation policies and strategies to reduce GHG emissions from the transport sector have further increased the interest in biofuels over the past decades. Among them are the Renewable Fuel Standard (RFS) in the USA [21] and the Renewable Energy Directive (RED) in Europe [22].

Increasing economic growth and a rapidly growing population have led to a substantial increase in energy demand. The energy sector is diversifying from renewable to non-renewable energy to meet the energy demands of the huge population. A significant portion of global heat production comes from coal and natural gas, while crude oil alone contributes 92% to the global transport sector. Coal also plays a significant role in electricity generation. In 2020, India was the fifth most populous country and the second largest economy in the world [23]. According to different studies and projections, by 2040/2042 India will require approximately 1930 Mtoe (Million tonnes of oil equivalent) of primary energy compared to around 880 Mtoe in 2020 [24]. The coal industry in India supplied 44% of primary energy demand in 2020; oil and gas provided 31%, which was mostly imported.

Diesel engines can run on biofuels without modifying them, making them a safe alternative fuel. There is a rising demand for the employment of agricultural products to prepare biodiesel, as it emits fewer emissions and, therefore, is more sustainable than conventional diesel fuel [4]. Similarly, agri-foods can significantly reduce atmospheric CO_2 levels through CO_2 bio-sequestration [25]. These fuels tend to be more environmentally friendly when their resources are more sustainable.

Nevertheless, there are still a few technological and financial obstacles to their use. One of the essential measures of sustainable development is currently thought to be energy usage. This review aims to highlight alternatives to fossil fuels and their generation methods that are presently being used to reduce the carbon footprint in the agriculture industry. The limitations of large-scale production and commercialization of these fuels have also been discussed, in addition to their practical applications in today's world.

2. Conventional Fuels and Challenges

Our dependence on fossil fuels began in the 18th century with the invention of the steam engine. There is no uncertainty that fossil fuels are depleting, but they are one of the planet's most vital sources. This mystery regarding the amount of fossil fuels led people to believe there was a great supply of fossil fuels, and that the use of fossil fuels could be near infinite. Increasing environmental damages, including acid rain, global warming, and air pollution, are the most severe consequences of the excessive use of fossil fuels.

Since fossil fuels are not distributed equally throughout the world, their use is not only an environmental and economic crisis, but also social, as the Middle East alone holds over 50% of the world's oil [26]. All these environmental, economic, and political agendas have demanded reconsideration of our current usage of energy. In contrast, while renewable energy production is booming, non-renewable energy consumption has also increased—because of the growing population globally and the rapid growth of the economy worldwide—which could lead to a global slowdown in carbon emissions reduction [27].

Worldwide, a crucial role has played by coal in the development of the revolutionized industry. Coal produces steel, cement, or thermal power plants for electricity generation [28]. In India, thermal power generation contributes most to electric power production. Natural gas, diesel, and coal are the fuels that have been used in large thermal power plants. Approximately 41% of the world's electricity is generated by coal-fired plants [29].

3. Alternative Fuels

A fundamental supporter of advancements among the developed nations is energy. The instability of conventional fuels and their limited reservoirs threatens the development procedures in every sector [30]. Both the developed and developing nations are seeking a permanent solution in alternative fuel sources. Finding a sustainable fuel for future services is becoming of utmost importance. Alternative fuels, or biofuels, such as biodiesel, bioethanol, biomethane, and biobutanol, have the potential to replace conventional fuels [31–33].

Alternative fuels include emulsified or homogenized liquid fuels, gas turbine heavy fuels, slurry, and coal that has been pulverized into powders, all of which could be replaced by conventional sources of energy [5]. Alternative fuels are used in blended form with conventional fuels, though the usage of conventional fuel is ongoing. The permanent replacements are entirely different from traditional fuels in their properties, origin, and in the procedure of their formation.

The climate change caused by the excessive use of fossil fuels for thousands of years has developed an upsurge for their replacement to mitigate its detrimental effects. Biofuels emerged as a new alternative. This imperishable fuel is derived from abundant organic sources and biomass. Biofuels production varies depending on the raw material types, level of efficiency, volume production, the situation across the surroundings, and the user's requirement. A wide variety of organic waste, such as residues obtained from farming, includes stubble, by-products of blubber animals, and brans. Developing biofuels using clean and sustainable technologies is an area of research that could be explored fully [34,35]. Biomass is produced by using photosynthetic vegetable matter. Microorganisms, crops, and lignocellulosic crops can produce biomass for various transportation fuels [36,37]. Biofuels can be classified up to the fourth generation [38] based on source occurrence and production processes, as shown in (Figure 1).

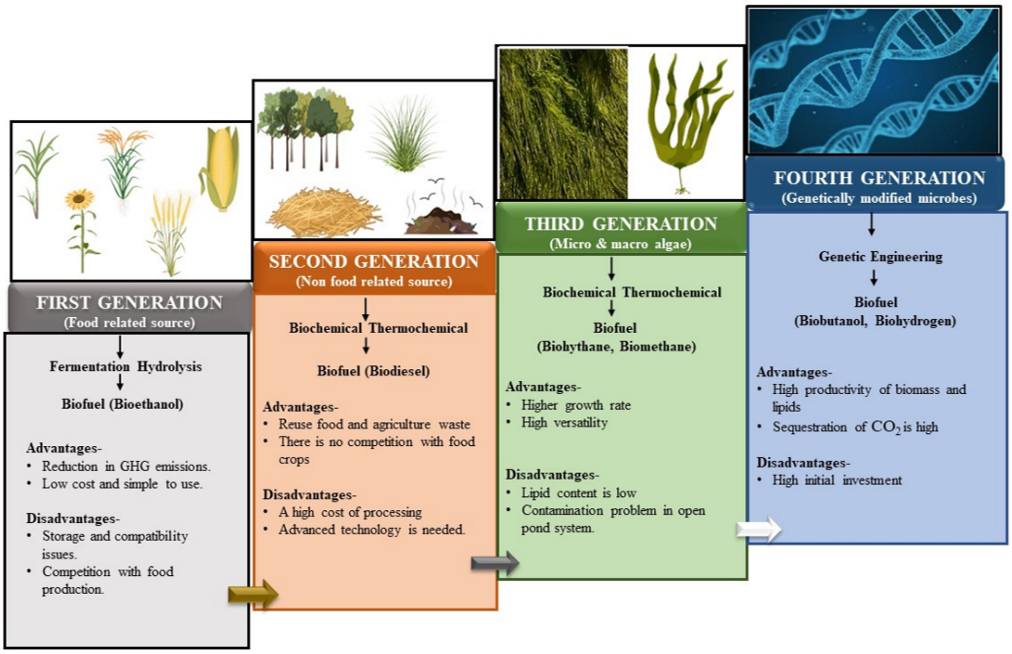

Figure 1. A schematic representation of the evolution of biofuels production.

3.1. First-Generation Biofuels

Fuels that are produced from vegetable oils, starch, and animal oil fall into the category of first-generation biofuels [39]. The procedure of conversion for first-generation biofuels is highly complex. Biomass usually used in the production technology of first-generation biofuels is mainly derived from corn and sugarcane, which are very commonly used in the USA and Brazil [40]. Specifically, corn is used in biorefineries to produce biofuel or bioethanol. The corn grain is processed by hammers and used in biorefineries to perform different chemical reactions [41]. The traditional use of maize as a staple food grain for people and animals is widespread worldwide. When corn is utilised to make biofuels and electricity, it may result in food shortages and disputes regarding fuel versus food [42].

3.1.1. Biofuel Types According to First Generation

The standard first-generation biofuels come from various subsistence crops, including maize, wheat, soybean, sugar, beets, and corn. Based on the processes used in their production, conventional biofuels come in various forms.

(a) Bioalcohols: Through the alcohol fermentation of cellulose, glucose, carbohydrates, starches, and other sugars, enzymes and microbes help produce bioalcohol. Bioethanol, biomethanol, biopropanol, and biobutanol are the other examples of bioalcohols [43].
(b) Biodiesel: Diesel produced from long-chain fatty acid esters found in plants, animals, or crops is biodiesel. A methyl, ethyl, or propyl ester is formed by chemically combining lipids like animal fat (tallow), soybean oil, or other vegetable oils with alcohol [44].
(c) Green diesel: Hydrotreating the vegetable oil triglycerides with hydrogen is another potential biosource of energy. Sunflower, soybean, and palm oils are utilised as feedstock for manufacturing. Three immediate reactions are involved in the hydrotreating process, namely decarbonylation (DCO), hydrodeoxygenation (HDO), and decarboxylation (DCO_2) [45,46].
(d) Solid biofuels: Solid biofuel is the most functional and significant bioenergy carrier. Some commonly utilised biofuels include wood, leaves, sawdust, and animal manure [47].

3.1.2. Bioethanol

At the international level, fuel is extensively used in biofuel [48]. In the current situation, at the international level, a variety of vehicles (Bajaj and TVS) are currently using bioethanol, which is one of the most popular fuels worldwide [49]. In terms of production cost, however, the primary barrier to bioethanol production will be the cost of producing it, which could surpass the cost of fossil fuels. Using agricultural waste as a bioethanol source can significantly reduce this cost [50]. Bioethanol can be used in blended form—with gasoline—or alone.

First-generation fuel, bioethanol, can be used in the blended form (gasoline) or alone. In cold weather, bioethanol must be blended with small amounts of petrol, because pure ethanol has difficulty vaporizing, resulting in vehicles stalling [51]. A variety of waste can produce bioethanol, including algae waste, wheat straw, sugarcane bagasse, agricultural waste, rice straw, and vegetable [52].

The conversion process of bioethanol is mentioned in (Figure 2).

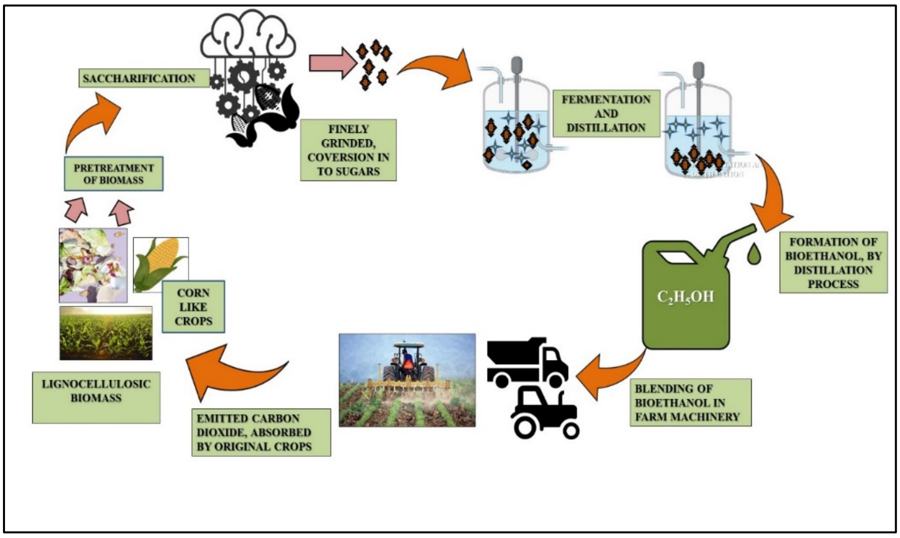

Figure 2. Production process of bioethanol and its blending with conventional fuels.

3.2. Second-Generation Biofuel

Cellulosic or carbohydrate biomass is used to produce biofuels. These carbohydrates are frequently derived from non-edible plant and agricultural materials [39]. Different chemical composition forms, such as cellulose, lignin, and polyose, make up cellulosic biomass (they have a lower density than grains such as corn or maize). Chemical pretreatment is required to dissolve the cellulose's lignin seal to facilitate the generation of these biofuels. Physical densification is required to enhance the energy density of the feedstock for cellulosic biomass to densify biomass [53–55]. To increase biomass density and decrease the size, physical densification techniques such as cutting, milling, grinding, and pelleting are used [56]. Pelleting is a standard method for reducing the biomass of non-edible crops [57], such as timber, leaves, and other forest debris.

3.2.1. Second-Generation Biofuel Is of the Following Types

The advanced second-generation biofuels come from various grass, trees, agricultural waste, and bushes. Numerous advanced biofuels exist based on the technologies used in their production, as provided in (Table 1).

(a) Ethanol cellulosic: This biofuel is produced by fermenting sugar sourced from cellulose and polyose, a lignocellulose compound.
(b) Algae-based biofuel: Algae can flourish in open and closed systems (like lakes, ponds, etc.). Algae has the advanced ability to be modified into a variety of biofuels, including biodiesel, biogas, and hydrogen [58]. The biomass concentration and extraction techniques include aggregation, centrifugation, purification, floatation, and flocculation [42].
(c) Alcohol: mixed alcohols or methanol are recovered from syngas via catalytic synthesis. By fermenting biomass with a specific type of microbe, syngas can also produce alcohol [59].

Table 1. Comprehensive overview of the technology used for the production of second-generation biofuels.

Generation	Biomass Type	Feedstocks Used	Production Technology	Process	Products	References
Second (Non-edible-based) Biofuels	Non-food biomass	Non-edible oil seeds, waste cooking oil.	Chemical	Acid pre-treatment	Alcohol, dimethylfuran	[60–64]
				Alkali pre-treatment		
				Organosolv pre-treatment ionic	Cellulosic ethanol, bio-SNG	
				liquids		
			Biochemical production	Enzymatic hydrolysis		
		Forest residues (Saw dust, thinned wood, stem, leaves, pulp waste)	Physical pre-treatment of feedstock	Milling	Biofuels such as biobutanol,	[63–65]
				Microwave		
				Mechanical extrusion	bioethanol, biodiesel, syngas	
				Pulse electric field		
			Thermochemical	Direct combustion	Biogas	
				Gasification		
				Liquification		
				Liquification	Liquid fuel	
		Ligno-cellulosic feedstock materials (agricultural residues): cereal straw, sugarcane bagasse, forest residues.	Hydrolysis	Fermentation	Ethanol, butanol	
			Pyrolysis	Refining	Bio-oil	
			Gasification	Condensation/ synthesis	Fischer–Tropsch liquids (FTL)	[63,65,66]
					DME	
					MeOH	
					Mixed alcohol	[63,64,67–69]
		Wet biomass	Hydro-thermal upgrading	Refining	Green diesel	[70]
	Food biomass	Vegetable oil	Transesterification	Refining	Biodiesel	[70]
		Sugars	Fermentation	Refining	Biodiesel	[70]
		Starch cereals	Hydrolysis		Bioethanol	

(d) Dimethylfuran: Despite its low carbon content, dimethylfuran is one of the most competitive oxygenated hydrocarbons for lowering engine emissions because it contains 17% of oxygen in gravimetric form [71]. Additionally, it can be used as a butanol and ethanol additive in diesel fuel [72].

(e) Natural gas produced synthetically (bio-SNG): Anaerobic digestion and some bacteria can produce biogas. Carbonic acid gas and mash gas combine to create this biogas. In addition to being used to refuel natural gas cylinders, biologically derived SNG is also employed in cars in the form of LNG and CNG [73].

3.2.2. Green or Biodiesel

Green or biodiesel are mono alkyl esters from sustainable resources of lipid such as inedible vegetables, lignocellulose biomass, and animal fats. Out of four generations of biodiesel, only two attained commercial status. The first-generation and second-generation biodiesel were derived from crops (sugarcane, corn, vegetable oil, and wheat) and energy or non-edible crops (lignocellulosic feedstock and waste oils), as shown in (Figure 3). To make biodiesel sustainable, it must be derived from products without interfering with the agri-food system [74]. Genetically modified organisms and algal biomass are now used to produce fourth and third generations of biodiesel.

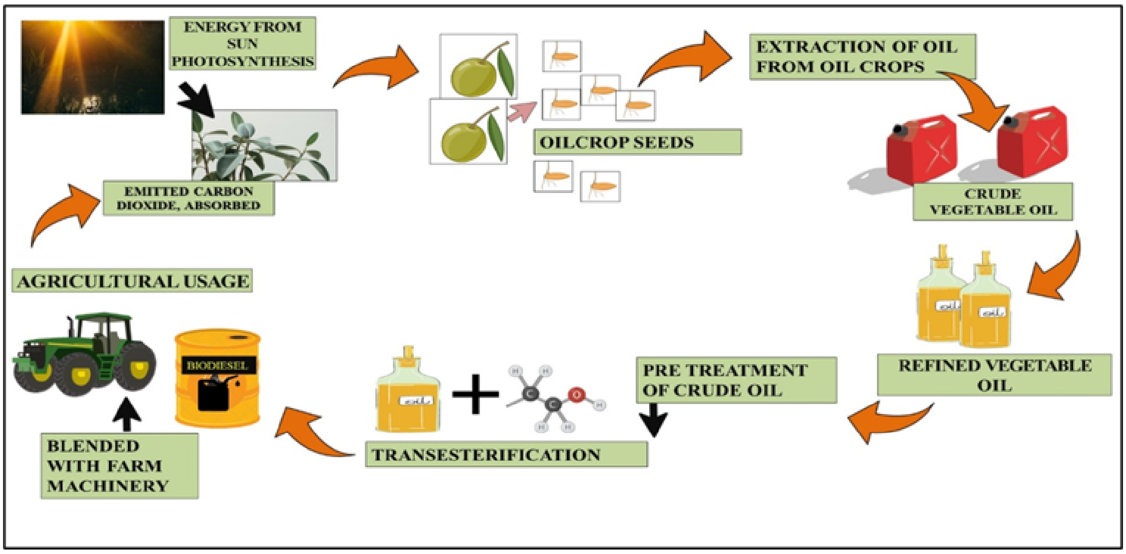

Figure 3. Production of biodiesel and its usage for agriculture purposes.

The major drawback of biodiesel is its high density and viscosity. To overcome this limitation, the biodiesel is mixed with conventional oil or diesel to escalate the fuel intake and cold start. Moreover, the lower the energy density, the higher the fuel consumption. Conversely, biodiesel offers impressive performance in traditional IC engines [75]. Using biodiesel in conventional machines reduces the emission of pollutants by approximately 78%. This reduction depends upon the two fuels' blending ratio and quality.

3.3. Third-Generation Biofuel

Oil derived from algae is formally recognized as 'algal fuel'. Liquid fossil fuels can be substituted with this option. Algae contain oil with high energy content, which makes it a good fuel source for this process. Biofuels' entrenched sugarcane sources are easily replaceable by the new algae-based fuel [76,77].

Those fuels and oils that are extracted from microscopic algae are known as seaweed fuel and seagrass oil. The operating cost and investment required to grow algae are higher than other biofuel crops, but microalgae are 10 to 100 times as effective as other crop types for producing fuel, oil, and food [78]. The growing of microalgae has been suggested by some researchers as a source of fuel, lipids, oils, and even food, by generating algae [79].

The low return on investment, technological advancements, and modern production methods of a third-generation biofuel makes it superior to first- and second-generation biofuels. Unprocessed materials used to produce this generation of biofuels include cyanobacteria, diatoms, and Euglena, which fall into the category of photosynthetic organisms. (Table 2) lists the microbes that are used to enhance biofuels efficiency in all the four generations used till now.

Table 2. Tabular representation of different feedstocks' composition, methods of production, challenges, and applications for the production of biofuels.

Biofuels Classification	Feedstock's	Production Process	Products	Microorganisms Used	Challenges	Applications	References
First-generation biofuels (based on edible food sources)	Vegetable oils (peanut oil), sugar crops and sweeteners, switch grass, starch crops	Transesterification	Bioethanol	*Escherichia coli, Zymomonas mobilis, Caldicellulosiruptor bescii, Trichoderma reesei*	Limitation in feed stock, issues in food chain security	Applicable for use in electricity generation, vehicle fuel.	[80–83]
			Biodiesel				
		Fermentation	Methanol				
			Biogas				
Second-generation biofuels (Based on non-edible food sources)	Waste of Wood Municipal Solid Waste Forest/agricultural residues of non- edible crop plants such as *Calotropis gigantia, Jatropha curcas*	Hydrogenation	Butanol Vegetable Oil Mixed alcohols Cellulosic ethanol Jet fuels Dimethyl-furan Alcohol	*Escherichia coli, Cryptococcus vishniaccii*	Efficiency is very low; feedstock production cost is comparatively high	Used in chemical industries, specially designed for CI engines	[84,85]
Third-generation biofuels (based on algae)	Autotrophic aquatic organism (algae)	Gasification	Biodiesel and green diesel (1.64 billion gallons) Ethanol (5.4 billion liters) Propanol Butanol	*Pseudomonas putida*		Used in transportation, in home as heating oil.	[38,86–89]
		Pyrolysis					
Fourth generation (biofuels based on microalgae)	Cyanophyceae, algae-based biomass, *Bacillus Escherichia coli*	Hydrolysis	Bio-butanol (15 million metric ton) Bio-hydrogen (1200 TJ) Synthetic biofuels Bio-methane (3.5 Mtoe)	*Clostridium acetobutylicum*		Usage in transportation fuel, as IC engine fuel.	[80,90–93]
		Fischer–Tropsch Fermentation					
		Hydrolysis					

3.3.1. Production of Biofuels Based on Algae

Biofuels such as biodiesel, bioethanol, biohydrogen, and biogas can be potentially produced with the aid of algae by the processes including biophytolysis, dark fermentation, and photo fermentation. Through acidogenesis, methanogenesis, acetogenesis, and hydrolysis, algae are able to produce biogas.

3.3.2. Biohythane

An upgraded and good product made by the mixture of biogas and biohydrogen (H_2 + CH_4), formally known as biohythane [94,95]. The mix of biogas and biohydrogen is produced by the process known as anaerobic fermentation, which implements their beneficial effects by minimizing disadvantages and environmental difficulties; This unique fuel is gaining more attention due to its positive roles and properties [96].

3.3.3. Biomethane

In more developed countries (primarily by North American oil and gas companies), biomethane advancement is becoming increasingly popular as it can mitigate greenhouse gas emissions, be used for carbon credit schemes, and provide ecological and commercial benefits to municipalities, small farmers, and counties. There are many uses for natural gas other than as fuel for compressed natural gas (CNG) vehicles, such as heating and electrical generation through the natural gas grid [96]. Recent decades have seen considerable progress in assessing and optimizing biomethane production systems involving upgrading and digestion. Methane is produced primarily by operating and optimizing anaerobic digestion [97]. Biomethane can be produced from industrial sludges and solid waste streams by developing techniques that maximize methane yield [98]. The biogas' primary components include carbon dioxide (60%) and methane (75%).

3.4. Fourth-Generation Biofuel

Fuels produced using the synthetic biology of the desired organism (algae) are termed fourth-generation biofuels. Macroalgae and cyanobacteria are the main suppliers of biomass for fourth-generation biofuel. Micro- and macroalgae are eukaryotic organisms belonging to the Protista kingdom, possessing membrane-bounded nuclei [99]. Microalgae used in the production process of biofuels are Chlorophyta and Pyrrophyta [100,101]. Cyanobacteria have great potential to produce biofuel due to their fast growing ability, genetic tractability, and fixation of carbon dioxide gas. These prokaryotes have membrane-entrapped organelles and belong to the Bacteria kingdom.

3.4.1. Biobutanol

A frequently considered substitute for current fuel is biobutanol, due to multiple properties such as low volatility, higher amount of energy content, and less absorptive nature [102]. Besides being a fuel alternative to gasoline, it can also serve as an industrial solvent because it does not require modifications [103]. The major obstacle to its widespread use is its cost of production, although biobutanol production seems to be highly useful. The cost of production can be reduced with lignocellulosic biomass [104]. Deposition of agricultural waste is higher in many agriculture-dependent countries; this waste can be productively converted to biofuel (biobutanol) through a simultaneous or sequential fermentation process. Biobutanol is produced by acetone, butanol, and ethanol fermentation, resulting from an anaerobic digestion reaction. The primary organism which is used for fermentation belongs to the Clostridium family [105].

3.4.2. Biohydrogen

Governments have ambitious as well as proclaimed plans for the economy based upon hydrogen, and the global hydrogen market is growing at 8% annually. Various renewable bioresources can be used to produce hydrogen sustainably. As substrates, for biohydrogen production agricultural residues, algal biomass and organic wastes can be used in both thermochemical and biological ways, as well as by reforming biogas. Recent progress has enhanced efficiency and reliability by optimizing online control processes, immobilization, fermentation conditions, inert membranes/materials on biofilms and by maintaining flocs as well as microbial biomass created by naturally formed granules [106].

4. Role of Alternative Fuels

4.1. In Sustainable Agriculture

Renewable energy sources such as solar power, geothermal energy, wind energy, and hydroelectric energy, which are cleaner than conventional fossil fuels and emit fewer pollutants, have been gaining popularity in recent decades. Biomass waste is an excellent candidate to fulfil energy needs; its use would escalate the amount of arable land used for biofuels production from approximately 1% today to around 2.5% in 2030 [107]. Energy crops are the crops that are primarily cultivated to obtain biofuels. These include microalgae, seaweeds, algae, and others. Nowadays, biofuels are viewed as an alternative to traditional fuels, as they limit the use of conventional fuels and reduce the carbon footprint.

Waste streams (wastewater and solid waste) are becoming increasingly attractive sources of biomass energy because of their potential to simultaneously reduce environmental impacts and provide energy security. With the aid of biotechnology, it is possible to convert corn starch and sugar into biobutanol and bioethanol, which can act as a substitute for gasoline [108]. The feedstock used for a first-generation fuel could be economic crops, while a second-generation fuel could be agricultural residues.

Microalgae-derived liquid biofuels, such as biodiesel, could replace petroleum-based fuels due to their high area and lipid contents [109]. Their energy yields are typically 7–31 times greater than palms, and up to 100 times greater than various oily plants [110]. Furthermore, microalgae can use wastewater for growing, converting the starch and nutrients in their biomass into liquid and gaseous fuels [108,111] Using microalgae as a fuel could result in a circular bioeconomy [111].

In addition to meeting user demand for green energy, renewable energy sources should help provide energy security. Due to this, farmers are strongly advised to use renewable sources. Numerous farms are located far from electrical networks and generate organic resources that can be used to create energy. These items include the waste that must be managed responsibly without endangering the environment. Compost substrates made from biowaste can be a great alternative to biomass as a material that provides heat for agricultural purposes. In hybrid systems, biomass could also be fermented to produce biogas that can be used for power generation and heat production (Figure 4). Other biofuels can be made from biomass and used to power combustion engines in agricultural vehicles and equipment.

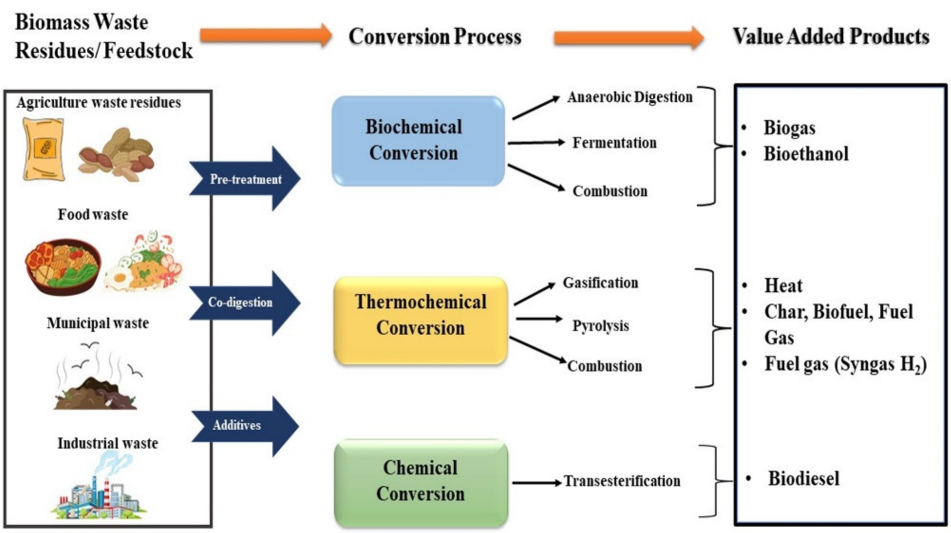

Figure 4. Pictorial illustration of the biomass conversion process to obtain enriched products.

The farming industry uses more sophisticated systems that convert solar energy into heat and power. Energy storage is a significant issue when using renewable energy sources in agricultural systems. Technologies of many kinds are being created. Nevertheless, with its size and complexity, this issue must be covered in detail in different works. To achieve technical efficiency, comprehensive implementation is needed, and local knowledge and capacity must be developed. Direct drilling, CTF (controlled traffic farming), precision agriculture, and minimal tillage are other agricultural techniques that might be employed to cut down on energy use [112].

4.2. In Reducing Carbon Footprint and Attaining Carbon Neutrality

With the growing concern about climate change in the 1960s, the concept of carbon footprint (CF) gained popularity. The term rapidly spread in the business, media, and political spheres because it drastically impacts the environment. While the concept of the carbon footprint has been around for decades, its precise definition is still debated. Environmental footprints are commonly used to represent water, land, and carbon footprints [113]. The carbon footprint of a product refers to its contribution to GHG emissions during its supply chain. Carbon footprints do not include emissions from land use change and industrial processes such as tractor manufacturing and diesel production.

Carbon footprint is defined as the total amount of carbon dioxide emitted over the use cycle of a product or activity in terms of mass units (kg, tonnes, etc.) [16]. It also includes other GHG emissions in terms of carbon dioxide equivalents [15,114]. CFs related to bioenergy are calculated as the sum of emissions in terms of CO_2 eq from soil management, N fertilizer production, and biofuel as well as biomass combustion in both scenarios. IPCC's tier 1 method is used to calculate all GHG emissions and CO_2 eq is calculated based on CH_4 and N_2O emissions from combustion [13]. Carbon footprints of biofuels can be calculated using Equation (1) [115]:

$$CF_{c,luc,mod,char} = \mu_{overall} + \alpha_{crop} + \alpha_{luc} + \alpha_{mod} + \alpha_{char} + \varepsilon \quad (1)$$

where *crop* (crop/feedstock), *mod* (modelling approach), *luc* (treatment of land-use change), and *char* (characterization model) are the carbon footprints determined in gCO_2 eq; α is the mean effect in each group; $\mu_{overall}$ indicates overall carbon footprint; and ε is the statistical model residual term. Four parameters (*crop*, *luc*, *mod*, and *char*) are assumed to be independently effective in this model [115].

A wide range of activities are responsible for producing carbon emissions globally, including transportation, industry, agriculture, electricity, and residential as well as commercial activities. Therefore, renewable energy sources could be used to lower CO_2 emissions and stimulate economic progress [116]. There was a recent record of 167 GW of renewable energy capacity installed worldwide in 2017 [117]. These included several renewable sources of energy, such as geothermal, hydropower, direct solar, modern biomass, wind, tide, and wave power.

However, current traditional energy resources impede the motivation to switch to renewable resources, particularly in developing countries, despite elevated growth. Therefore, climate change mitigation, social awareness about sustainability, and targets for CO_2 reduction are not sufficient to encourage people to shift to renewable energy. For economic growth and operations, the public and private sectors require significant amounts of energy [118].

The biogenic systems are usually perceived as more environmentally friendly than their fossil analogues [119]. The early view that biofuels were carbon neutral was supported by the fact that the carbon released during combustion was already sequestered from the atmosphere, as crops photosynthesis and grow, resulting in no carbon dioxide emissions. Taking into consideration all factors affecting the complete life processes (for example, agrochemicals, such as Nitrogen fertilizer, which are GHG-intensive to produce [120], changes in soil carbon stock (which may be beneficial or harmful, depending on the previous land use), iLUC (indirect land use change), and albedo effects) makes it evident that the impact of bioenergy is not neutral on climate change [121–123]. Therefore, bio-based systems that can actually help in mitigating negative environmental impacts must be supported.

As a result of using environmental system analysis tools (ESA), such as life cycle assessment (LCA), it has been demonstrated that biofuels often do not achieve the climate benefits they are expected to [124]. This can be attributed, in part, to indirect effects, such as iLUC [125]. The relative superiority of biofuel systems in terms of environment must be quantitatively analysed and comprehensively examined before robust conclusions can be drawn about their relative performance. It has been recognized that LCA can provide a decision-support tool for assessing the impacts of biofuel systems in a comprehensive manner along their supply chain (EU, 2009), in response to the need to assess systems comprehensively and along their entire supply chain. A life cycle assessment can reveal how biofuel systems affect climate change and, thus, help compare energy systems and identify those that meet policymakers' targets. For instance, the EU RED (European Union Renewable Energy Directive) was developed and implemented using LCA (EU, 2009) [126].

In comparison to conventional fuel, biofuels derived from grain-based feedstock emit very little carbon [127]. Despite utilizing less petroleum-intensive production techniques, current corn ethanol technologies still emit greenhouse gases at a rate similar to fossil fuels [119]. Biodiesel derived from soybeans, and ethanol derived from corn emit more GHG than fossil fuel derived from petroleum [128]. Furthermore, sugarcane ethanol may not be as effective as cellulosic ethanol in reducing greenhouse gas emissions [129]. Recent data indicates that cellulosic ethanol is the only ethanol that can significantly reduce greenhouse gas emissions [130]. Production from Jatropha can significantly reduce GHG emissions, compared to fossil diesel fuels, by up to 90%. The ethanol derived from straw has the lowest greenhouse gas emissions, no matter what method is used to calculate it [131].

Moreover, renewable energy investments surpassed fossil power generation capacity by roughly double in 2017, which amounted to approximately USD 241.6 billion [117]. In recent years, the cost of renewable energy technology has decreased significantly, thereby improving investment capacities. By reducing CO_2 footprint and energy efficiency by 90%, evolving innovative, carbon-free technologies can contribute to the UN's climate action goal of zero emissions by 2050 [118]. To achieve this, renewable energy needs to be strategically planned and supported by law. Prices have been lowered by auctions, and global tenders, especially recently, have reached record-high levels [132].

One of the most important and efficient carbon sequestration methods is using microalgae to capture and sequester carbon. Biocapturing carbon using microalgae results in a sustainable, environmentally friendly, and economically viable process. Despite their small size, microalgae are remarkably efficient at fixing carbon dioxide (10 to 50 times more than terrestrial flora) [133].

Biofuel-based agriculture also reduces the carbon footprint by utilizing alternative fuels instead of conventional fuels. Burning crop residue containing lignin can produce biofuel that reduces the overall carbon footprint of electricity generation. By substituting solar and biofuel-based machinery for diesel-based equipment, agricultural carbon footprints have been reduced by 8.1% and 3.9%, respectively, in cotton cultivation [134].

5. Global Status of Alternative Fuels

In any country, socio-economic growth runs parallel to energy consumption [135]. From 2005 to 2015, emission of CO_2 from crude oil and various industries rose by an average of 2.2% per year [136]. During these 10 years, China's emissions increased by 0.046 Gt Cyr-1 on average, while India's emissions increased by 0.015Gt Cyr-1. The EU 27 and the USA are, however, witnessing a decrease in CO_2 emissions. Globally, China, the USA, Europe, and India contributed 57% of CO_2 emissions till 2019, while the other countries contributed 43% [137]. According to Worldometer 2021 [138], 36.17% of the global population lives in Asia. Because of the sheer number of people in the region, the energy sector has been variegated into renewables and non-renewables to meet its energy needs. Overall, 80.2% of total energy consumed is generated by fossil fuels and 8.7% by other sources [139]. The use of fossil fuels is predicted to cease by 2060 [140]. The coal and natural gas sectors account for 85% of worldwide heat generation, while crude fuel solely accounts for 92% of worldwide transport. There will be an increase of 3.7 million barrels per day in liquid oil consumption by 2022, which will be higher than what it was in 2019 [139]. Meanwhile, fossil fuels are now being replaced more quickly with renewable energy. There are 36 billion tonnes of CO_2 emissions emitted each year, which are expensive and contribute to environmental pollution [141]. The IEA reports that in 2019, electricity generated by renewable as well as nuclear resources was more abundant than electricity generated by coal [139]. In this respect, rates of increase varied from 5.5% to 40% between Cyprus, China, Germany, the USA, Spain, and Canada [142].

Indonesia will surpass the US in geothermal power production by 2027, making it the second-largest producer globally [143] (Figure 5). A sugarcane-based ethanol program has been an integral part of Brazil's ethanol history since 1970. To promote biofuels, Brazil implemented numerous policies, such as the Renovabio program, which focused on reducing carbon emissions, systematically increasing the use of biofuels to reduce GHGs, and the withdrawal of sugarcane agro-ecological zoning, allowing sugarcane cultivation in the Amazon basin.

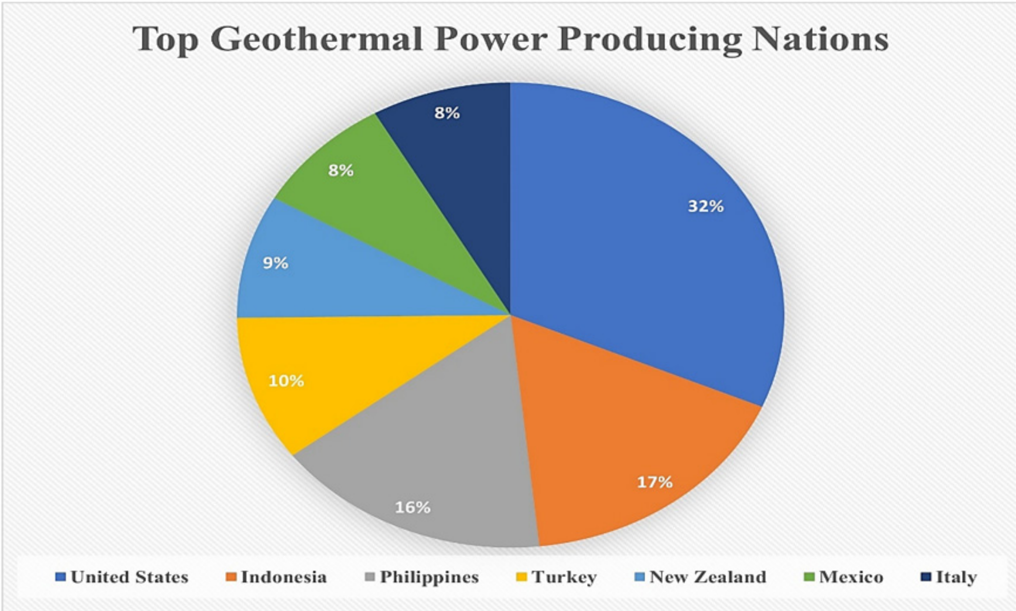

Figure 5. Pie chart depicting top geothermal power-producing nations globally. Source: Indonesia Investments Report—July 2022 Edition (https://www.indonesia-investments.com/news/todays-headlines/indonesia-has-become-world-s-2nd-largest-geothermal-energy-producer/item8775, accessed on 1 September 2022).

Among other things, Indonesia is a key producer of biodiesel and palm oil. Since 2006, Indonesia has been developing its biofuel industry through both government and private efforts. It is expected that the amount of biofuel produced will increase to 7.9 million metric tonnes between 2021 and 2030, a growth rate of 23.2%. Approximately 8.59 million kilolitres of biodiesel were produced in Indonesia in 2020. Biofuel production in Argentina is among the highest in the world [144]. In 2006, a mandatory amalgamation of biodiesel and bioethanol was implemented, which increases by 10% and 12%, respectively, in 2016. There were 61.6 petajoules of biofuel produced in 2020. In Bangladesh, biomass accounts for more than 3447 TWh of energy, an increase of three times over fossil fuel-based energy [145] (Table 3). However, Bangladesh lacks successful biofuel implementation due to a few factors [146]. According to Tauro and Garcia (2018), the solid biofuel potential of Mexico is approximately 2500 PJ/year, accounting for about 28% of prime energy demand [147]. Due to its biodiversity, waste biomass resource, and intensive agriculture, Mexico offers great potential for the production of biodiesel [148].

On the other side, with a GDP of USD 2.87 trillion and a population of about 1.38 billion people, India was the fifth most populous country in 2020 [23,149]. By 2050, it will have about 1.64 billion people, making it the second-largest economy globally [150,151]. Approximately, 730.87 MT of coal was produced in the country and 248.54 MT of coal was imported [152,153]. In terms of crude petroleum imports during 2019, India ranked third behind the USA and China [154,155]. As a result of declining domestic production over the past few years, India is dependent on imported crude petroleum. As a result of consuming 214.12 MT and producing 32.2 MT of crude petroleum in 2019–2020, the country's import dependence has increased to 85%. The import of oil in 2018–19 was estimated at USD 112 billion out of India's total imports of USD 631.29 billion. [156,157].

Table 3. List of leading countries producing biofuels globally (2021). Source: Statista Report, 2022 (https://www.statista.com/statistics/274168/biofuel-production-in-leading-countries-in-oil-equivalent/#:~:text=The%20United%20States%20was%20the,840%20and%20312%20petajoules%2C%20respectively, accessed on 1 September 2022).

Countries	Biofuel Produced (In Petajoules)
USA	1435.8
Brazil	839.5
Indonesia	311.9
China	142.7
Germany	121.2
France	107
Thailand	89.8
Argentina	85.6
Netherlands	84.6
Spain	71.9

Considering the associated positive environmental effects, India is committed to increasing its natural gas (NG) share in its power mix. This will help reduce GHG emissions. For road transportation in India, LPG and CNG are the most popular alternative biofuels. In December 2020, some novel areas in the Godavari and Krishna basin begun producing NG, which can increase domestic production of NG [158]. India's national green hydrogen mission launched in 2021, served as a catalyst for lowering the price of green hydrogen. This mission established a favourable policy encouraging the manufacture of key electrolysers in India and the use of green hydrogen in industries producing refined petroleum, ammonia, and steel. Thus, we will be able to reduce the price of electrolysers by creating demand for them. Moreover, since the cost of solar electricity in India is on the decline, the cost of energy will also decrease. Development and deployment of alternative fuels can lead to improved air quality index, energy security, and improved health in India.

6. Applications

Numerous energy resources, such as biomass, wind, biofuels, solar, organic wastes, hydraulic, as well as combined power and heat, offer a straightforward, environmentally friendly answer for preserving priceless non-renewable fossil resources. It is possible to use solar energy in a variety of ways. For example, renewable fuels, direct solar thermal, solar PV, and wind energy can all contribute to solving the world's energy issues and creating a sustainable environment for upcoming generations. A rice husk-based combined heat and power (CHP) electric generator was put into service by the Khadi Village and Industries Commission in Masudpur, Delhi [10]. Stirling (ST-5Model) combined heat and power engines operate at higher pressures and temperatures of five bars and 700 °C, respectively, with a highest water-cooling temperature of 60 °C at the exit. Stirling Dynamics Pvt. Ltd. (Bristol, UK) manufactures the CHP engine in Madras.

Scientists are increasingly using biological feedstocks to produce biofuels. A new technique for manufacturing sustainable, environmentally friendly biofuels is developing at the intersection of homogeneous and heterogeneous catalysis, using nanocatalysts [159,160]. Because of their solid state, they are modifiable, and their nanometric particle size allows them to be used for high-activity catalysis comparable to homogeneous catalysts, as well as for novel and special catalytic functions. Additionally, magnetic fields can be used to recover nanocatalysts created from active magnetic materials. A nanocatalyst can improve economic and energy efficiency. Nanocatalysts for cellulose hydrolysis, for instance, are stable, economical, very active, and selective. Additionally, nanocatalysts enable the reduction of chemical waste and the enhancement of feedstock utilization [161].

Pumping water using photovoltaic (PV) systems may prove to be the most affordable option for regions without existing power lines. Photovoltaic water pumps are incredibly dependable and require low maintenance when correctly designed and installed. The depth of the pumping, the amount of water needed, the cost of system acquisition and installation, and the local solar resource all affect the price and size of a PV water pumping system, although the cost of PV panels today makes most agricultural irrigation systems prohibitively expensive. These systems are particularly cost-efficient for minor irrigation systems, pond aeration, and remote animal water delivery.

Gasoline and ethanol can be mixed in a variety of ratios. For instance, E85 is a mixture of 15% gasoline and 85% ethanol produced by DOE-NREL paper. According to SARE, Stateline Farm in Shaftsbury is preparing to manufacture 100,000 gallons of biodiesel annually at its on-farm plant [10].

A mini-grid was recently set up in Ludhiana, Punjab, that uses a solar tress to provide electricity to farming machinery and light 24 h each day. A biodiesel plant can use virtually any raw material, including waste vegetable oil and animal fat. The process for producing clean and cheap hydrogen as an alternative fuel for industrial uses, called the SI (sulfur–iodine) thermochemical hydrogen cycle (IIT Delhi, New Delhi, India, 2021), was recently developed by IIT Delhi with the cooperation of ONGC [162].

An estimated 40–70% of methane can be found in biogas, which often undergoes further enhancement to generate natural gas (70–99% methane). Additionally, it can be further incorporated into the natural gas distribution system or used as a transportation fuel [163]. An inestimable amount of methane can be released from rice straw. It has also been testified that rice straw can generate biogas with around 50% methane. The methane produced from the biomass of sugarcane is estimated to be within the range of 0.266 to 0.314 m^3/kg [35].

7. Environmental Impact and Economic Feasibility

Burning excess crop residue is common practice in most of the developing nations, especially those in Asia. In terms of resources, different biomass sources are used for making biofuels. According to a study by NRC, ethanol derived from corn degrades water quality more quickly. Moreover, cellulosic ethanol appears to be less impactful on water than corn, which requires more fertilizer inputs to grow [164].

As a residue of the bioethanol process, the biorefinery generates more than 400 metric tonnes of lignin-rich solid a day. This mixture of lignin and sugars (unreacted) is burned for fuel but is almost economically worthless [165]. Between 2020 and 2025, the cellulosic ethanol market is expected to increase by USD 47.8 billion due to growing fuel demand. It has been recognized that LCB (lignocellulosic biomass) is the most abundant organic matter on earth and can be used as a renewable, cost-effective source of fuel [166]. Due to the burning of the lignin in the pilot plant, it releases toxic gases into the atmosphere, even though it contains nearly 50–60% moisture and a meagre calorific value.

Nevertheless, the aromatic properties of lignin make it a potential candidate for preparing valuable bio-based compounds such as phenolics, vanillin, aldehydes, etc., with respect to other petroleum-based products, thereby lowering greenhouse gas emissions and lowering the carbon footprint. A significant amount of bioethanol is produced as a renewable energy source. However, the major drawback is the pollution created in air, water, and land during its production [75].

Lack of financial support is the primary barrier to developing biomass-based fuels for agriculture. Despite this, many countries promote alternative fuel usage and carbon neutrality. Reports suggested that a shortage of subsidies limits renewable fuel adoption. In order to make agriculture biomass competitive and feasible, in comparison to conventional fuels, it certainly requires a financial encouragement of production and usage [1]. Baum et al. (2013) evaluated the techno-economics of producing second-generation biodiesel, finding that many new jobs would be created, particularly in rural areas. Using solar energy for numerous operations and processes could reduce the conversion cost. Reducing the carbon footprint will also result in substantial energy savings and a decrease in carbon emissions.

8. Shortcomings of Alternative Fuels

Numerous constraints presently hinder the widespread use of alternative fuels. Moreover, it is challenging for alternative fuels to satisfy cost-effective production prices because of the accessibility of conventional fossil fuels. The quality criterion is a significant issue with biofuels and waste fuels; more expansive use of the commercially available biofuels now on the market is restricted by factors such as decreased heating value, thermal stability, increased acidity, and others. However, research in this area has been carried out for some time, and the fuels that are created are always improving; therefore, their use in the future is not in doubt [167].

Conversely, despite a well-known manufacturing process, the compounds being evaluated (such as NH_3, H_2, and alcohol-based fuels) are mostly created for industrial purposes. This suggests that greater manufacturing costs are not an issue for such a purpose, but additional cost reduction is anticipated if they are intended to be used as fuel [5]. Furthermore, adapting current utilization technology is necessary to distribute new fuels. While alcohol-derived and green fuels might be used in current IC engines with minor changes, hydrogen and ammonia need the development of new technologies or substantial modifications.

Although much research is necessary to optimize the operational process and boost efficiency, fuel cells designed for hydrogen use can be extensively used for both fixed and portable applications [111]. The last barrier to the widespread use of alternative fuels is their production, which needs to move toward sustainable and clean solutions. This mainly entails the use of leftover industrial and agricultural biomass wastes to create high-grade, clean fuels in the case of biofuels. To become carbon neutral, synthetic fuel production must simultaneously migrate to new approaches that do not use conventional fuels as a feedstock.

Secondly, significant research efforts are being made to develop technologies that may be flexibly used commercially. This is crucial for carbon capture and electrolysis technologies, which generate the carbon dioxide and hydrogen that are necessary to produce alternative fuels. Combining these technologies with VRES would have several advantages, including lower production costs, increased grid stability, and fewer output interruptions.

9. Conclusions and Future Scope

With advances in technology, the demand for conventional fossil fuels has increased, which in turn causes the depletion of these fuels. Therefore, fossil fuels alone cannot satisfy the energy needs of a fast-growing society. To fulfil the requirement, alternatives, such as biofuels, are being found. Agriculture is one of the major sectors that is highly dependent on conventional fuels in numerous ways, such as in transportation, electricity, etc. Different generations of biofuels are being produced, namely first-, second-, third-, and fourth-generation biofuels, which are produced by edible, non-edible, macro- or microalgae, and genetically modified (GM) microbes, respectively. However, the first and second generations have their own limitations, including low rates of fuel production (corn produces an average of 350 gallons per acre), specific environmental conditions (sugarcane production occurs in specific areas), pathogenic disturbances (soyabean crop is prone to pest infections and will create food-chain imbalance). In second-generation biofuel production, the major shortcomings include the impossibility of using grasses in biodiesel production and the decreased engine life associated with unrefined vegetable oil use. Nevertheless, the development of third- and fourth-generation biofuels was useful in resolving these problems, as algae was found to be an efficient candidate to produce potential biofuels. The combustion of these algal-based biofuels does not emit carbon monoxide and carbon dioxide in the environment, providing immense benefit in the transport sector, and thereby reducing GHG emissions and the carbon footprint of the agriculture sector, in which transportation plays a key role.

In recent years, carbon footprinting has been regarded as a powerful and popular indicator for estimating the GHG intensity of any activity or organization. In this review, primary emphasis is laid on the agriculture sector, which is still developing in regard to the utilization of bioenergy as its principal source. Standard methodologies are required to address soil emissions, carbon sequestration, and emissions from farm equipment. As agricultural activities differ widely across the world, guidelines for selecting boundaries are essential. Additionally, uniform GHG estimation techniques are urgently needed. In addition, there are no specialized emission factors available for key agricultural inputs at the sector or region level. Various scenarios and changes in land use must be considered in the standard method. Agricultural carbon footprinting studies are increasing, but their comparison remains challenging due to varied differences. In spite of this, such studies provide a better understanding of how cultivation practices contribute to soil-borne greenhouse gas emissions, energy intensity, and carbon sequestration.

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