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Review

Availability of Biomass and Potential of Nanotechnologies for Bioenergy Production in Jordan

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Abstract: Jordan's energy situation is in a critical state of dependency, with the country relying heavily on imports to satisfy its ever-increasing energy requirements. Renewable energy is a more competitive and consistent source of energy that can supply a large proportion of a country's energy demand. It is environmentally friendly and minimizes atmospheric pollutant emissions. Thus, bioenergy has the potential to be a crucial alternative energy source in Jordan. Biomass is the principal source of bioenergy; it accounts for approximately 13% of the primary energy demand and is anticipated to supply half of the total primary energy demand by 2050. Nanotechnology has emerged as an important scientific research area with numerous applications, including biofuels. This review summarizes the application of nanoparticles to improve the properties and processes of biofuels. It presents the availability and viability of nanotechnology-supported bioenergy production in Jordan. Jordan generates up to 5.8 million tons of biomass each year and has access to abundant nonedible plant resources (such as Jojoba, Handal, and Jatropha). The theoretical energy potential of waste and residue available in Jordan was also assessed; it was discovered that the 1.28 million tons of dry crop residues (vegetables, fruits, and farming crops) could generate 6.8 PJ of energy per year and that biogas could be generated at a rate of 817 MCM/year

Keywords: bioenergy; biomass; nanotechnology; biofuels; biodiesel; biogas

Citation: Al-Bawwat, A.K.; Cano, A.; Gomaa, M.R.; Jurado, F. Availability of Biomass and Potential of Nanotechnologies for Bioenergy Production in Jordan. *Processes* **2023**, *11*, 992. https://doi.org/10.3390/pr11040992

Academic Editors: Davide Dionisi and Miguel Ladero Galán

Received: 31 January 2023
Revised: 9 March 2023
Accepted: 21 March 2023
Published: 24 March 2023

1. Introduction

Energy requirements have increased dramatically due to the increasing global population [1,2]. Furthermore, electricity consumption is rapidly growing due to increased industrialization [3,4]; solar, wind, and biomass-derived energy may be the optimal solution to meet these requirements [5–7]. Renewable energy (RE) can safeguard the environment by reducing pollutive emissions [8,9] and greenhouse gases (GHGs) that contribute to global warming [10], especially since the use of RE is critical in reducing GHG reduction and minimizing the impact of climate change [11,12]. Between 2008 and 2017, global fossil CO_2 emissions increased at a rate of 1.5% per year, which has clearly contributed to the issue of global warming [13].

Biomass is plentiful on Earth and is regarded as one of the most common sources of sustainable energy generation [14]. Biomass is the world's fourth-largest energy source, contributing approximately 35% of the primary energy demand in both developing and developed countries [15]. Various physical, thermal, and biological processes can be used to convert biomass into different kinds of biofuels or energy [16].

Bioenergy possesses all of the necessary characteristics to overcome the obstacles associated with the increased use of fossil fuels while simultaneously reducing GHG emissions [17,18]. Jiang et al. [19] showed that bioenergy is a dispatchable and carbon-neutral fuel source. Bioenergy can be produced from a wide range of raw materials in various forms [20]. The utilization and techniques used to produce bioenergy vary by country [21]. Developed countries use bioenergy to generate electricity or liquid energy, such as biodiesel or bioethanol. For example, Europe generates bioelectricity from biomass. In contrast, bioenergy is used for cooking and heating homes in developing countries [22]. The expected tariff for biomass and biogas energy are 13.0 c€/kWh and 9.0 c€/kWh, respectively [1]. Nanotechnology has been revealed to be a prospective tool in the effort to degrade biomass feedstocks in the development of second-generation biofuels [8].

Biodiesel is considered to be an excellent alternative to conventional fuel because it is a sustainable resource and is environmentally friendly, reducing CO_2 emissions (although it does not reduce NO_X emissions) [23–25]. Biodiesel is potentially better than conventional fuels and can be produced via the transesterification of lipids, waste vegetable oil, and frying oil. Biodiesel has been widely and extensively introduced worldwide due to the sharply increasing price and rapid depletion of fossil fuels and exhibits desirable properties such as biodegradability, a high flash point, non-toxicity, and its nature as a renewable source. The demand for biodiesel is constantly increasing because of the contamination, increased price, and limited lifetime of fossil fuels [26].

Jordan is considered to be a semi-desert and steppe area [27], especially in southern and eastern lands [28], known as the Jordanian steppe or Badia [27]. Jordan's natural resources are limited, as illustrated in Figure 1 [29]. Jordan's energy situation is critical; as a result, Jordan primarily relies on fossil fuel imports to meet its energy needs. Energy is regarded as the most significant impediment to the growth of Jordan's industrial sectors; bioenergy may help to solve this critical issue. Jordan's policy debate is now focused on energy security. Authorities and the general public are both aware of the need to develop strategies for achieving long-term energy security, diversifying energy and import sources, and increasing the share of domestic sources [30]. Historical developments have shaped Jordan's energy market, and reviewing them could assist in better comprehending the strategies and options that are currently being considered to meet the country's growth. Jordan's reliance on fossil fuels was reinforced in the 1990s energy needs. Until 2002, Jordan relied almost entirely on Iraq to import low-cost crude oil and its derivatives [31]. Iraq supplied crude oil to Jordan for about one-third of its market value under Saddam Hussein and also permitted Jordan to compensate in consumer goods [32]. Jordan also met its energy demands by importing power from Syria and Egypt [33]. With the 2003 Iraq War and the demise of Saddam Hussein's regime, Jordan might no longer rely on Iraq to meet its oil needs and began importing oil at market prices, primarily from Saudi Arabia. Following the steady rise in global oil prices, the energy bill began to rise. To reduce expenses, Jordan has begun importing liquefied natural gas from Egypt via the Arab Pipeline, which went into effect in 2003 [30].

All of these events prompted the government to create the first National Energy Efficiency Strategy (2005–2020). The strategy was first published in 2005, and it was then revised in 2007 to become the Master Energy Sector Strategy (2007–2020) [34]. The strategy and master plan were divided into three major chapters, (1) natural gas, electricity, and oil; (2) the sectors of sustainable energy and energy conservation; (3) the sector of alternative and local energy. In 2012, the "Renewable Energy and Energy Efficiency Law" was enacted [33]. For the period 2015–2025, a second National Energy Sector Strategy was developed, followed by another for the period (2020–2030). Both of these strategies, in general, place a strong emphasis on energy security and share the main goals of the 2007–2020 document [30].

Jordan's energy sector has been restructured in several significant ways. First and foremost, the crude oil and petroleum derivatives markets have been gradually restructured and liberalized. Three firms were granted a license in 2013 and began operations in 2016. Redefining strategies for a more renewable energy sector is high on Jordan's political agenda and authorities have been considering alternatives, but progress has been slow thus far. To guarantee the transition to a renewable energy sector, both energy supply and demand must be reflected synergistically. When it comes to energy supply, the primary concern should be on enhancing energy efficiency and optimizing energy consumption management, beginning with transportation, the sector of water, and households. In terms of energy supply, it needs to focus on diversification and import reduction, in addition to a greater reliance on domestic energy sources [30].

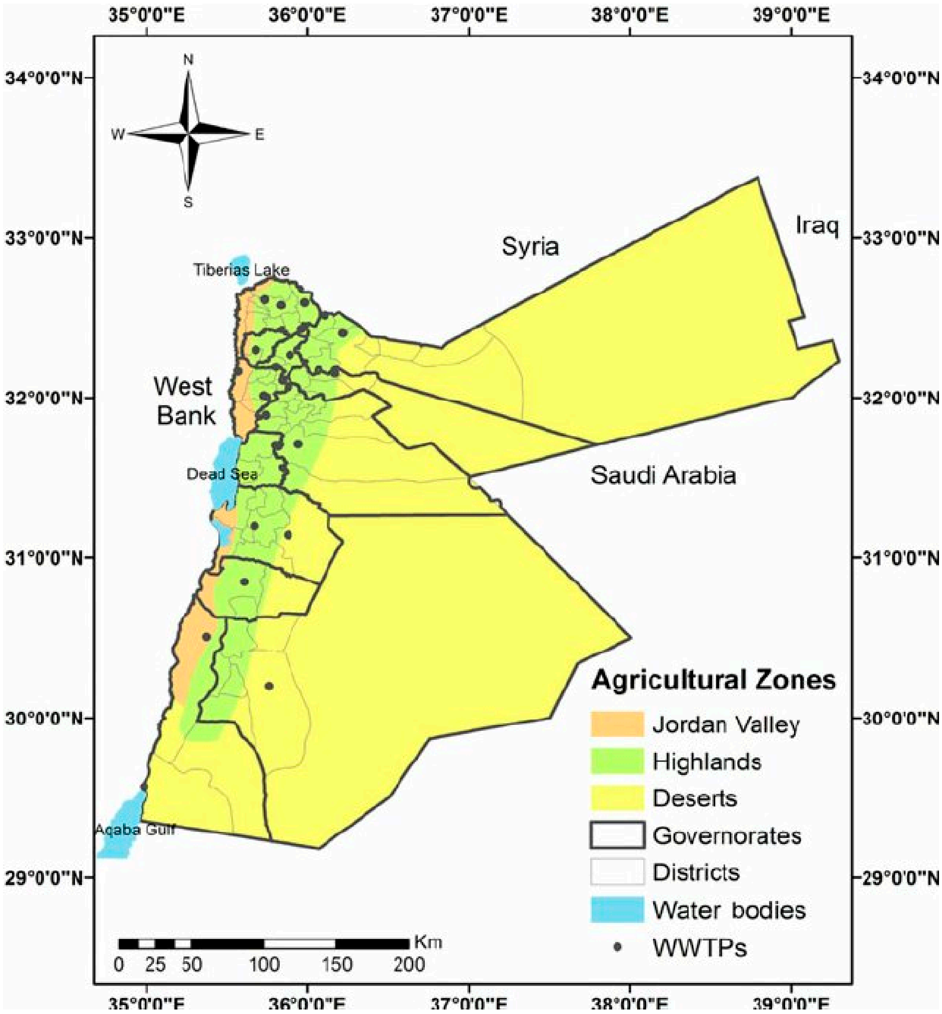

Figure 1. Map of the Jordanian desert, Badia, and agricultural zones.

This would necessitate resolving existing stakeholder conflicts by adopting a more participatory reform approach, which might enhance energy sector governance by increasing consensus on reforms and strategies.

Jordan generates a massive amount of solid waste each year, with 28 million tons of waste generated per year between 2014 and 2019, with the number still rising [35]. If used properly, such waste could be extremely valuable for Jordan. Instead of being disposed of in landfills or burned, solid waste can be collected, recycled, and subsequently converted into energy [36]. Employing these resources for energy production and/or biofuel generation is critical from both an economic and environmental standpoint [37].

Despite the opportunity for Jordan to utilize energy resources derived from biomass, there has been little research into bioenergy and its applications. Al-hamamre et al. [37] researched Jordan's biomass situation and any prospective energy sources; municipal solid waste (MSW), agricultural waste, and animal manure were all considered as sources of biomass sources. Al-hamamre et al. [36] described Jordan's diverse biomass resources and proposed efforts to exploit such biomass feedstocks as sustainable energy projects.

However, Jordan has shown no interest in its biomass resources, and more studies and assessments are required to estimate the annual availability of biomass.

The use of bioenergy in Jordan may significantly increase its net annual power generation and be an excellent alternative fuel. This would conserve fossil fuels, reduce GHGs, and would have positive social impacts [13].

This work aims to (i) determine the state of bioenergy in Jordan and (ii) assess the economic, technical, and environmental factors associated with employing bioenergy from agricultural residue, nonedible plants, and animal manure in Jordan by integrating this process with nanotechnology. To achieve this, many studies involving bioenergy projects from both inside and outside Jordan were collected. At the moment, there is no literature regarding the popular perception of bioenergy nanotechnology in Jordan and little literature regarding the popular perception of bioenergy; hence, this review was supplemented with additional studies from around the world, as these could provide further insights [8]. Here, the authors reviewed the range, scope, and comprehensiveness of the literature on bioenergy regarding the use of nanotechnologies in the production of biofuels and the possibility of using them in biofuels production in Jordan. There is currently a lack of a comprehensive understanding of the various types of additives that can be used to help in promoting clean bioenergy efficiency. The dosages, applications, and impacts of each additive, in particular, must be discussed. As a result, summarizing the impact of various additives on biofuels production has become an essential research topic in recent years

2. Nanoparticle: Preparation, Synthesis, and Characterization

Nanomaterials are well-known for their distinct properties. Physical and mechanical characteristics such as reactivity, resilience, elasticity, durability, and a high level of electrical and thermal conductivity [38]. The properties of nanoparticles are heavily influenced by their size, morphology, and structure. Various research initiatives for developing various nanoparticles from environmentally friendly materials have been undertaken over the last decade [39]. Enzymes are employed to hydrolyze biofuels and to generate biofuel from fat and oil. To improve the properties of bio-oil, new research on the use of aluminum oxide nanoparticles has been conducted [40]. Various synthesis methods have been created to track the structure, size, and morphology of nanoparticles [41]. Nanoparticles can be employed as appealing carriers to immobilize catalysts, enabling them to be recovered from liquid processes through filtering or centrifugation [42].

2.1. Nanoparticles-Synthesis

Nanoparticles are classified according to their source, chemical characteristics, synthetic path, structure, size, composition, and implementation [43]. Nanoparticle production/preparation can generally be performed from the bottom up or from the top down. The bottom-up method, as the name implies, involves the formation of the nanoparticles by single molecules or atoms of nanoparticles [44].

2.2. Nanoparticles-Characterizations

Chemical properties, size, and structure all have an impact on the properties of the NPs that emerge from them. Using microscopic methods, including tunneling microscopy, electron micro-scanning, and electron transmission, nanoparticles are typically classified by size, structure, and surface load [45].

Light scattering techniques are mainly used to determine the NPs size. The most commonly used technique for determining the size of particles in colloidal suspensions is a dynamic light scattering [46]. Absorption, distribution of energy, spectroscopy, and diffraction are all possible with X-ray techniques. These methods frequently provide information on substrate structures and surfaces, crystallographic structure, or basic composition. X-ray absorption is used in nanoparticles to recognize untreated electronic states, chemical properties, and the conditions of bonding [47].

NPs tracking technology is among the most widely used methods for tracking particulate matter with sizes ranging from 15 to 1250 nm, with a lesser detection limit determined by the refractive index of the NPs [48]. Quantifying NPs is another important step in comprehending their behavior, origin, and presence under various conditions [49].

3. Plant-Based Nanoparticles

Metallic nanoparticles, including silver, and their numerous components, have become commonplace in everyday life [50]. Since these 100-nanometer-diameter NPs now play a significant role in our everyday lives, there are also concerns about the possible danger to humans and the environment [51]. Natural NPs must be distinguished as they are form or synthesized in the environment without human involvement [52].

3.1. Natural Sources (Plant-Based) of Inorganic Nanoparticles

On Earth, there have been numerous discoveries of inorganic nanoparticles derived from natural sources. These particles are also regular and, most of the time, ordinary. Volcanic powder mist generates a wide range of miniaturized polydispersion sizes as well as nanoparticles. These NPS range in size from (50–250 nm) and are mostly composed of silicate and iron composites [53]. These NPs circulate in the air on purpose, and exposure to pulmonary circumstances cannot occur until they solidify [54]. Even so, these inorganic substances have prompted counterparts to produce several related particles based on distilled NPs such as Fe_3O_4 and MnO_2 [55].

3.2. Metallic Nanoparticles-Synthesized Based on Plants

Metals have long been regarded as a symbol of strength, as well as some metals, such as gold and silver, remain popular today [56]. Gold is used to heal wounds and ulcers. In actuality, colloidal silver NPs have served as wound-wrapping materials, tooth bonds, and filtration systems [57].

Long-term silver NPs synthesis employed both physical and chemical methods. Moreover, progress has revealed the essential importance of biological processes [58]. Gold nanoparticles are used in a variety of applications. By connecting the electron to the surface of the molecule, the Au (3+) ion is reduced to the Au atom, whereas the Au clumps and integrates to form gold NPs [59]. Zinc oxide (ZnO)-NPs are even more intriguing due to their other characteristics. Researchers are concerned about zinc oxides-NP due to their widespread use in biomedical, electronics, and optics systems [60]. ZnO-NP has powerful anti-inflammatory and wound-healing properties [61].

4. Bioenergy Production and Blending with Nanotechnologies

Bioenergy has all of the characteristics required to meet the difficulties associated with the increasing use of carbon fuels whereas massively minimizing GHG emissions [17]. The methods and technologies used to generate bioenergy differ by country [21]. Figure 2 shows the main types of bioenergy [36].

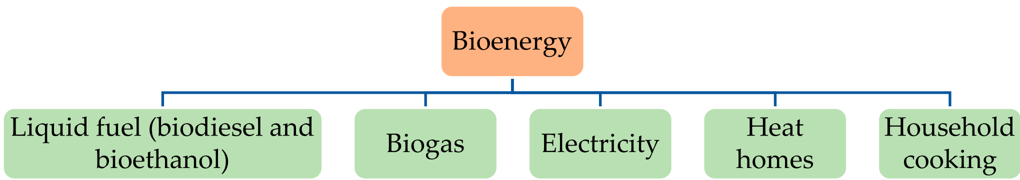

Figure 2. Mainly types of bioenergy.

4.1. Biofuels Production Utilizaing Nanotechnologies

The term "biofuel" is used to describe liquid or vaporous fuels derived from biomass, lipids, and sugars through transesterification and fermentation processes. Biofuels are commonly produced through the biochemical and thermochemical processing of biomass resources [62]. Biomass is viewed as a promising feedstock for biofuel production [63] as it is naturally widely distributed, abundant, and clean; it is the most commonly used component in the production of sustainable energy [36]. Biofuels with low carbon footprints and economic benefits have emerged as potential candidates for the replacement of fossil-based energy [62]. During pyrolysis, the biomass is converted to biofuel and other components at high temperatures in the presence of the inert gas atmosphere [63]. Global biofuel production reached 127.7 billion liters in 2014 and supplied approximately 4% of the fuel used for global transportation in 2016, accounting for approximately 23% of global CO_2 emissions. Biofuels currently account for <1% of global energy consumption and support approximately 3% of the transportation sector [8]. Bidir et al. [62] found that the use of nanoparticles (NPs) in the biofuel industry could be a useful tool in developing intelligent and process-efficient strategies for the creation of biofuel products, reducing the cost of biofuel production. Furthermore, this could reduce the amount of solvents and catalysts used in biofuel production. Because of their outstanding physiochemical properties, NPs have important applications in the production of biofuels. Several NPs with unique properties, such as titanium dioxide, zinc oxide, and tin oxide, have been employed to produce biofuels [64]. Moreover, because of their large surface volume fraction, small-scale immobilizing characteristics, quantum characteristics, and magnetic NPs are widely used in the production of biofuels [65]. Nanocatalysts are an environmentally friendly and sustainable biofuel production method that provides improved catalytic conversion, enhanced selectivity, cost-effective processes, and more pleasant working conditions [66]. Table 1 describes the various feedstock and NPs used in biofuel production.

Table 1. Various feedstocks and nanocatalysts for biofuel production.

Feedstock	Nano-Catalyst	Biodiesel Yield	Refs.
Olive oil	Zno	94.8%	[67]
Olive oil	TiO_2	91.2%	[68]
Silybum eburneum seed oil	MgO, Al_2O_3-CaO, TiO_2	91.0%	[69]
Moringa oleifera seeds oil	MgO	93.7%	[70]
Microalgae oil	Fe_3O_4/ZnMg(Al)O	94.0%	[71]
Jatropha curcas oil	CaO-$A_{l2}O_3$	82.3%	[72]
Waste frying sunflower oil	Magnetic $CaO/ZnFe_2O_4$ hollow microspheres	98.0%	[73]
Soybean oil	a-MoO_3	96.9%	[74]
Neem oil	$Ni_xZn_{1-x}Fe_2O_4$	93.0%	[75]

Bioethanol Production Utilizaing Nanotechnologies

Ethanol is a low-cost, oxygenated fuel produced from various biomasses such as corn, sugar beet, and sugarcane via alcoholic fermentation in the presence of high oxygen content (34 wt%) [62]. Hashmi et al. [72] showed that bioethanol is a robust biofuel that accounts for more than 90% of total usage. It is produced through the enzymatic conversion of starch-containing organic material into sugar via fermentation before being converted to ethanol. Bioethanol production in the world was 110 billion liters in 2018 and is predicted to reach 140 billion liters by 2022 [76]. Furthermore, the market for bioethanol fuel has grown at an annual compound growth rate of 7.6% between 2016 and 2022 [77]. Even though ethanol is produced globally, The United States and Brazil are the leading producers of ethanol, accounting for about 84% of world production in 2020 [78]. Weber et al. [79] found that bioethanol is among the most widely used commercial biofuels. Sweet potato (*Ipomoea batatas*) has already been suggested as a potential raw resource for bioethanol production, as shown in Figures 3 and 4. It yields more starch per unit area of land than other grains. The total sugar and moisture content in potatoes (cream peel and cream pulp) has been reported to be 26.93 ± 0.86% and 68.16 ± 0.38%, respectively. While higher distilled beverage production rates would be the most profitable, higher ethanol production scenarios are considered to be economically unfeasible based on research on the following scenarios: 80% bioethanol production, 60% bioethanol, and 20% distilled beverage production. The best scenario for bioethanol and distilled beverage production is 80%, which has a net present value (NPV) of USD 1,078,500, an internal rate of return (IRR) of 51%, and a lowered payback of 1.06 years. Utilizing NPs in the production process of bioethanol could enhance the efficiency of the entire system by improving handling capacity, enzymatic hydrolysis, and degree of reaction during fermentation. The reusability of catalysts is an essential concern in the ethanol production process as it directly impacts production costs [62]. Kim et al. [80] found that the use of methyl-functionalized silica NPs during the syngas fermentation process produces 166.1% bioethanol. Kim and Lee [81] also found that the use of functionalized cobalt-ferrite silica ($CoFe_2O_4$@SiO_2-CH_3) NPs increased ethanol production of acetic acid, ethanol, and biomass by 59.6%, 213.5%, and 227.6%, respectively, when compared to a control. Weber et al. [79] found that the optimal conditions used *Saccharomyces Cerevisiae* Angel thermal tolerance alcohol yeast, with Stargen 002 as the hydrolysis enzyme. To reduce viscosity, the Pectinex Ultra AFP pectinase enzyme was used. However, this enzyme could not be used in the beverage production process due to the limited amount of methanol that could be used in the presence of pectinase. In addition, potentially hazardous side effects (such as headache, vomiting, dizziness, and nausea) could make this an undesirable compound in beverage products. The total sugar content in sweet potato waste is assumed to be 30%. Based on theoretical calculations, 180 g of glucose could produce 92 g of ethanol. Kim et al. [80] resulted that the use of methyl-functionalized silica NPs increased the dissolved concentrations of H_2, CO_2, and CO by 156.1%, 200.2%, and 272.9%, respectively. The addition of 0.3 wt% methyl-functionalized silica NPS to the fermentation of syngas by *C. ljungdahlii* resulted in significant increases in the production of acetic acid, biomass, and ethanol levels by 29.1%, 34.5%, and 166.1%, respectively. Bioethanol was produced from Sesbania aculeate biomass using cellulase immobilized on magnetic NPs [82]. Similarly, for the production of bioethanol, Aspergillus fumigates-associated cellulase was immobilized on manganese oxide (MnO)-NPs [83]. Given the numerous advantages of nanoparticle-mediated enzyme catalysis, viz. enhancing simple sugar production in addition to bioethanol yield [84]. Cellulase immobilized on gold nanoparticles (A-NPs) demonstrated saccharification ability, and bioethanol production from alkali-pre-treated aquatic weeds followed [85]. In the presence of nickel nanoparticles (NiO-NPs), there was also an increase in bioethanol production from potato peel waste. Thus, the potential for using nanoparticles to improve biofuel production from starch-based agricultural residues such as potato peel waste is highlighted. The use of nano-biocatalysts in the simultaneous fermentation and saccharification of potato peel waste significantly increased bioethanol production (>65%) [86]. However, the production kinetics of tomato waste bioethanol in the existence of nano-biocatalyst has not been clarified.

4.2. Biodiesel Production and Blending with Nanotechnologies

Biodiesel is produced by transesterification, a simple procedure that converts fats and oils into their corresponding esters. In general, three types of catalysts are used in the transesterification reaction: homogeneous catalysts, heterogeneous catalysts, and biocatalysts. NaOH, KOH, or H_2SO_4 are used as homogeneous catalysts in biodiesel manufacturing [26]. Biodiesel can be used in the operation of standard diesel engines. No sulfur, polycyclic aromatic hydrocarbons, or crude oil residues were reported in the biodiesel products. While the cost of conventional diesel is lower than the cost of biodiesel produced from superior, refined edible oils, the actual cost of the oil is nearly four times less than the stated value because feedstock costs account for around 75–80% of the operational costs of producing biodiesel. Thus, the use of nonedible oil as a feedstock could be commercially viable [87]. However, pure biodiesel likely cannot be used for the operation of diesel engines due to issues such as the lower cetane number, lower calorific value, and higher density compared to conventional diesel; hence, the use of biofuel-diesel blends is preferred. Biodiesel can be mixed with alcohol (ethanol and methanol) for use in direct injection (DI) or compression ignition (CI) diesel engines. Tse et al. [88] found that the addition of ethanol to the mixture improves the HHR and the cylinder pressure, as well as a reduction in the amount of NO_x emissions. Further research carried out by Atmanli et al. [89] assessed the performance of a DI diesel engine at full operational load when fed with a mixed fuel blend composed of butanol, diesel, and biodiesel. Using a sprinkle mixing technique, the optimal canola-hazelnut-cottonseed oils (CHC) and sunflower corn–soybean oil (SCS) blends have already been assessed on a vol.% basis; compared to pure diesel fuels, CO levels are increased by 41.57%, and 26.89%, respectively. Nanotechnology has been the subject of significant interest in the production of biodiesel using NPs-based catalysts. It has also prompted innovations and investigations into the competency and consistency of nanocatalysts, economic stability, and the ability to obtain higher-quality products. Numerous catalysts have been used by researchers in the advancement of biodiesel, such as nanocatalysts, homogeneous/heterogeneous catalytic acids, and basic uniform/heterogeneous catalyst biocatalysts [90]. The transesterification process using heterogeneous base catalysts has been observed to be economical in mild conditions due to its reusability, widespread availability, easier separation from the product, and longer lifespan [91,92]. Base-catalyzed transesterification is more widely used in industrial output than acid-catalyzed transesterification due to the high yield of fatty acid methyl esters in a short reaction time [93]. Srinivasa Rao and Anand [94] showed that the presence of water and NPs significantly affected the performance of biodiesel in CI engines. They found that untreated biodiesel had lower BTE and greater emission levels than 100% diesel fuel. The addition of water and NPs significantly improved the effectiveness and release quality of the test engine. However, carbon-based sulfonated catalysts (CBSCs) have recently attracted the attention of the scientific community. CBSCs are effective heterogeneous catalysts for a wide range of acid-catalyzed reactions. *Ziziphus Mauritania* can be used to obtain cheap hydrothermal carbon catalysts (HTCCs) [26]. Vellaiyan et al. [95] found that the combination of carbon nanotubes (CNTs) and soybean biodiesel could be fed into a diesel engine to achieve the maximum brake mean effective pressure (BMEP), while fuels with added CNT NPs showed a 4.5% decrease in brake-specific fuel consumption (BSFC). The exhaust gas temperature (EGT) was found to be 3.7–4.9% less in base fuels containing CNT NPs compared to neat base fuels. However, the integration of CNT NPs into base fuels fundamentally enhances the combustion, performance, and discharge levels regardless of engine load conditions. Yuvarajan et al. [96] operated a vertical AC SC-4S diesel engine with a mixture of diesel, neat mustard oil methyl ester (MOME), and an emulsion of MOME that contained TiO_2 NPs and found that the smock discharge from the exhaust as well as CO, HC, and NO_x emissions were reduced. Örs et al. [97] also used a diesel engine with a blend of diesel, butanol, and cooking oil-waste-derived biodiesel in the presence of TiO_2 NPs and found that the operating performance of the diesel engine was enhanced, the BSFC declined, and the ignition improved (lower emissions). Radhakrishnan et al. [98] found that NPs should be added before starting the transesterification process after using alumina NPs in the combustion process of cashew nutshell biodiesel in an unmodified diesel engine. The emissions of CO, HC, NOx, and released smoke for BD100% (biodiesel without the addition of alumina NPs) and for B100-A (biodiesel with the addition of alumina NPs) were reduced in comparison to conventional diesel fuel as described in Table 2. The BTE was also reduced by 1.1% and 2.3%, respectively compared to conventional diesel fuels, while the BSFC increased by 3.8% and 5.1% for B100-A and B100, respectively. Xie and Ma [99] observed that the conversion efficiency of olive oil to biodiesel was around 94.8% when processed for 8 h at 150 °C when ZnO nanorod catalysts were used. In addition, Bidir et al. [62] found that the inclusion of NPs to diesel-biodiesel ethanol mixtures significantly increased their BTE while decreasing their BSFC. Furthermore, harmful emissions such as HC, CO, and PM were considerably lowered. However, NO_x emissions could rise by up to 55%. Nevertheless, the use of NPs in diesel-biodiesel-ethanol or biodiesel-diesel blends in the operation of CI engines could allow the engines to run efficiently, resulting in improved performances and effectively regulated emissions.

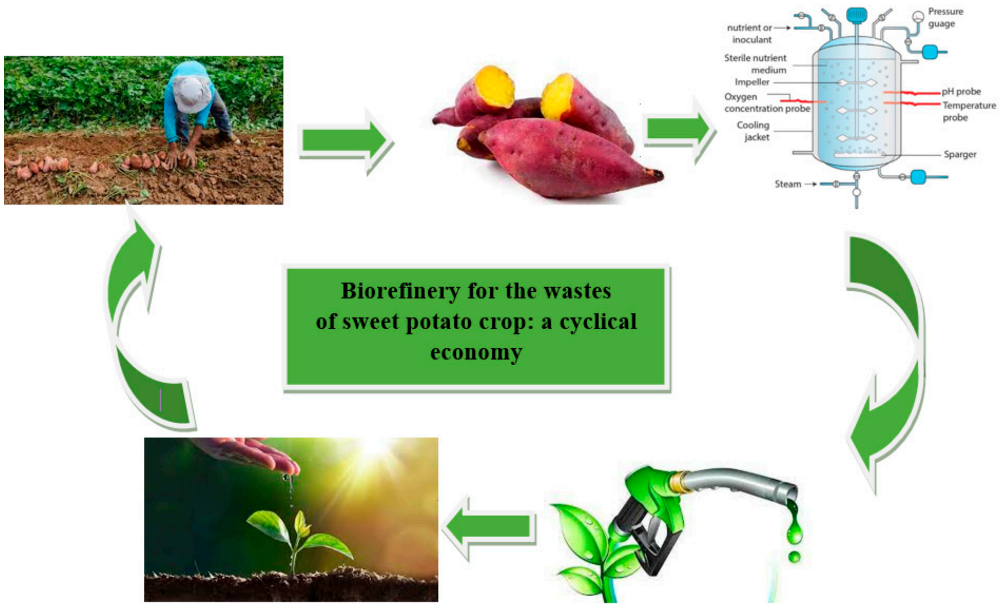

Figure 3. A circular bio-economy concept of a biorefinery for sweet potato crop waste.

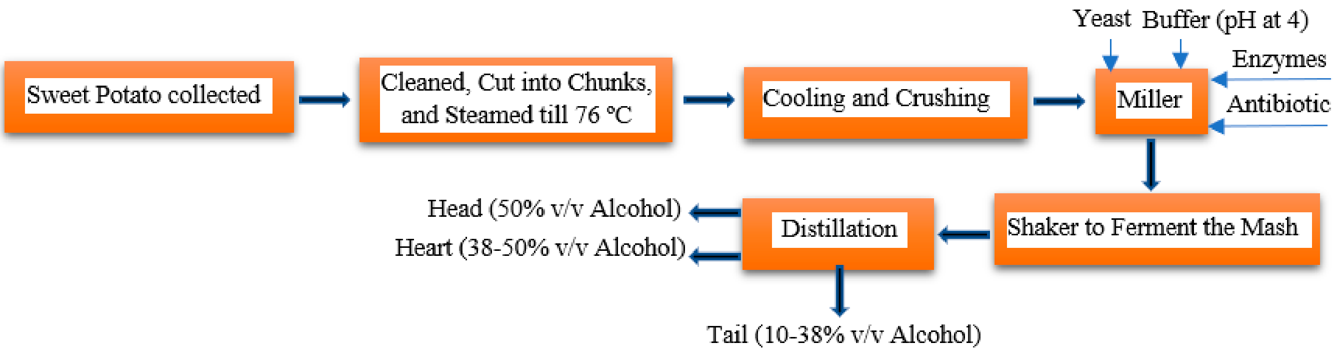

Figure 4. Scheme for the synthesis of bioethanol from sweet potato waste.

Table 2. Combustion emissions reduction of cashew nutshell biodiesel in comparison with conventional diesel fuel [98].

	Combustion Emissions			
Biodiesel	**CO**	**HC**	**NO_x**	**Released Smoke**
BD 100%	5.3%	7.4%	10.23%	16.1%
BD 100-A	8.8%	10.1%	12.4%	18.4%

4.2.1. Biodiesel Production from Waste Tomatoes by Using Nanoparticles

Tomato agriculture is widely prevalent in Jordan. These crops are either consumed locally or exported abroad [100]. Nearly 160 million tons of tomatoes are produced worldwide [101], of which one-third of the world's tomato production is used in the industrial production of juice, ketchup, paste, and salsa [102]. In the tomato process industry, such as in the production of juices, sauces, and pastes, nearly 33–40% of the raw tomato cultivations are wasted, resulting in millions of tons of unwanted byproducts, usually in the form of seeds (60 wt% waste) [100], with a fraction of nearly 60% [102] and peels (72 wt% waste) [101]. Such wastage leads to environmental problems, such as their conventional disposal in landfills or as livestock feed [102]. Tomato seeds contain about 24–25% oil [100] and have a dry basis of 20–40% [102]. Tomato seed oils have the following physicochemical characteristics: a refractive index (25 °C), a saponification index (mg KOH/g), an acid value (mg KOH/g), and an iodine value (g I_2/100 g) of 1.467, 192, 2.3, and 123, respectively. The soybean seed oil has a refractive index (25 °C), a saponification index (mg KOH/g), an acid value (mg KOH/g), a relative density (25 °C), and iodine value (g I_2/100 g) of 1.471, 189.2, 0.341, 0.923, and 128.4, respectively [100]. Tomato seeds have a high amount of unsaturated fatty acids, especially linoleic acid, and are thus considered to be a suitable source of oil. Around 0.20 million tons of oil are being extracted globally [102]. However, it cannot be used directly because of its high acidity [101]. Nevertheless, the extraction of these oils could potentially be cost-effective. The steps to extract oil from tomato seeds involve collecting, drying, crushing, and the Soxhlet extraction of the oils at a specific temperature range (60–80 °C) [100]. Tomato seed oil is considered to be a cheap, nonedible source of biodiesel production via transesterification processes as illustrated in Figure 5. The physical characteristics of tomato seed oil biodiesel (TSOB) have been obtained based on the ASTM D975 standard as follows: it has a kinematic viscosity at 40 °C of 5 cSt as calculated via standard test method (STM) D445; a density of 883 kg/m^3 at 15 °C (STM D4025); a closed cup flashpoint of 12 °C (STM D2500); a sulfur content of 172 ppm (STM D4294); a cetane index of 47.7 (STM D976); a total acid number (TAN) of 0.74 mg/KOH (STM D974), and a lower calorific value of 36,666 J/g (STM E711-87). Karami et al. [101] found that, under standard test conditions (STC), the best performance and the most efficient mixture was the B10 blend (10% biodiesel, 90% diesel) when operating an engine with an indicated work (W_i) between 910 and 960 J at full load. The greatest average peak cylinder pressure (CP) was also associated with B10 and varies between 65 and 69 MPa.

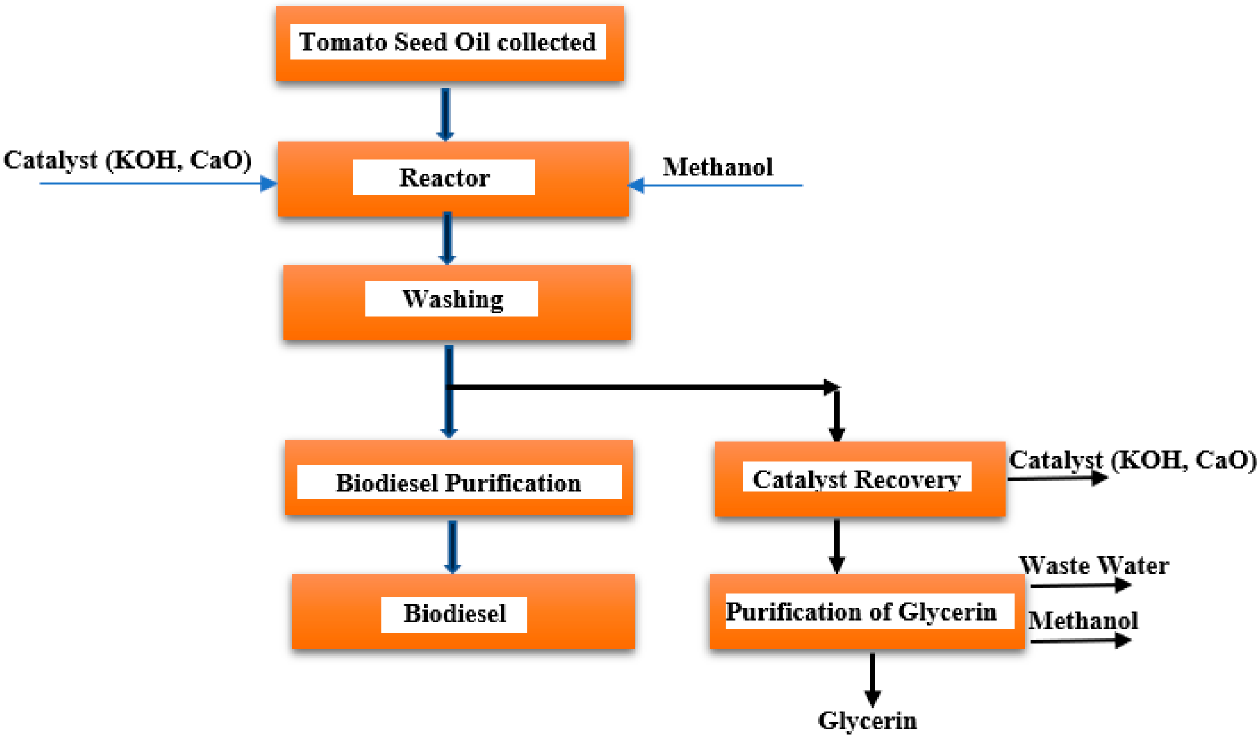

Figure 5. Scheme of the synthesis of biodiesel from tomato seed oil.

The enzyme-catalyzed transesterification process is regarded as a novel method of producing biodiesel, is considered to be green technology, and has recently received a significant amount of attention worldwide. This technology introduces the lipase process, in which enzymes catalyze the transesterifications of oil and fat (lipids). Thus, it does not have the common disadvantage of traditional chemically driven transesterification processes, does not need the pretreatment processes that are necessary for FFA-rich oils, and the reaction is not hampered by the moisture content of the raw oil. However, this technology is not widely used in the production of biodiesel as the enzymes are prohibitively expensive and have longer reaction times [102].

Sarno and Iuliano [102] reported on snowman-like Fe_3O_4/Au NPs as a new magnetic lipase biocatalyst; these NPs have a uniform size and can be obtained from small NP of Au (<2 nm) that could be grown on larger quasi-spherical Fe_3O_4 NPs (nearly 8 nm). It exhibits a significant amount of catalytic activity and is very stable. Fe_3O_4/Au NPs can be used directly to bond to the lipase, and the immobilized lipase has been reported to result in the 97% hydrolysis of olive oil triglycerides. Thermomyces lanuginosus (TL) lipase directly linked to citric acid (CA)-modified Fe_3O_4/Au NPs could be used to produce biodiesel from tomato waste, as shown in Figure 6. The lipase can readily bind to the surface of NPs, eliminating the need for reagents or complex procedures. Lipase products obtained from TL have many applications in industry, such as in fine chemicals or biodiesel production. Utilizing lipase anchored on snowman-like Fe_3O_4/Au NPs to catalyze the oil transesterification process results in a greater degree of activity than pure magnetite (Fe_3O_4). The biodiesel products obtained from tomato seed oil contain oleic acid methyl esters, linoleic acid methyl esters, and palmitic acid methyl esters, which comprise around 94% of the oil. Specifically, fatty acid methyl esters (FAMEs) comprise 97.2 ± 0.26% of the oil, with linoleic methyl esters concentrations of up to 4.3 ± 0.22% [102].

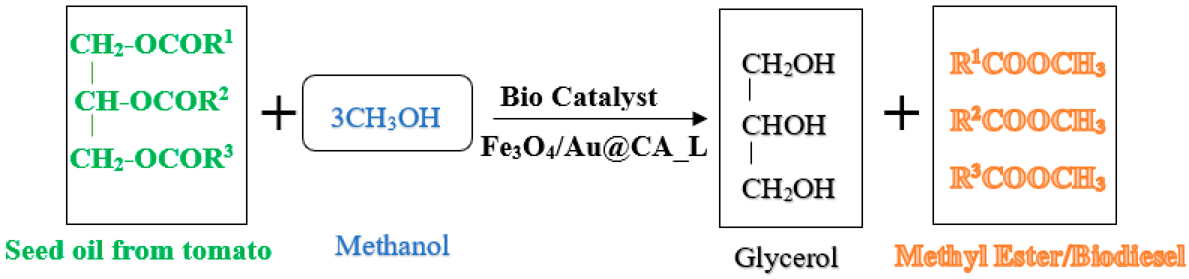

Figure 6. Transesterification reaction in tomato seed oils.

4.2.2. Biodiesel Nano-Additives' Effects in Internal Combustion Engines

The scientific community has devised several novel methods for reducing harmful gas emission levels from internal combustion engines. One approach is to use nano-additives in biofuel as a catalyst or ignition promoters [94]. Recently, researchers confirmed that nano-additive melded fuels outperform renewable fuels in terms of thermal brake performance [103]. Numerous nanocatalysts with high biodiesel production effectiveness have been demonstrated, including zeolites, hydrotalcite, and single metal oxides, hydrotalcite [104]. Compression Ignition (CI) engines have been tested with biofuel emulsion-fueled NPs. They discovered that nano-additive blended biofuel emulsions outperformed clean fuels in terms of brake thermal efficiency, decreased peak cylinder pressure, decreased release time, and decreased combustion speed [105]. Emulsions containing nano-additives exhibit significantly improved emission properties. For blended nano-additives for sustainable biofuel, the combined effects of reduced unburned hydrocarbons and CO emissions have been noted [106]. As a dispersion agent, oxide nanoparticles are widely used in diesel and biofuel blends [107]. Tables 3 and 4 show the effects of various biodiesel with NPs on performance characteristics and emissions.

Table 3. The effects of different nanoparticles on engine emissions.

			Combustion Emissions at Full Load				
Biodiesel	**NPs**	**Blend**	**CO (% by Volume)**	**NOx (ppm)**	**Hydrocarbon (ppm)**	**Smoke Opacity (%)**	**Reference**
Grape seeds oil	CeO_2, Al_2O_3	B30 + 20 ppm CeO_2	0.17	1580	-	-	[108]
Jatropha oil	CeO_2, Al_2O_3	B30 + 30 ppm Al_2O_3 + 30 ppm CeO_2	0.02	1208	12	25.6	[109]
Mahua indica oil	SiO_2	B20 + 120 ppm SiO_2	0.44	980	102	52.0	[110]
Watermelon seeds oil	CeO_2	B20 + 20 ppm CeO_2	0.15	1600	60	-	[111]
Aloe Vera	CeO_2	B30 + 20 ppm CeO_2	0.052	820	54	-	[112]
Sapindus seed oil	CeO_2	B30 + CeO_2	0.053	1050	77	-	[113]
Waste cooking oil	Al_2O_3 + Multi-Walled Carbon nanotubes	B20 + 50 ppm Al_2O_3 + 50 ppm Multi-Walled Carbon nanotubes	332 (ppm)	954	-	31.2	[114]
Hemp seed oil	TiO_2	B30 + 75 ppm TiO_2	0.057	257.37	40.29	0.706	[115]

Table 3. *Cont.*

B20 (20% biodiesel, 80% diesel), B30 (30% biodiesel, 70% diesel).

Table 4. The effects of different nanoparticles on engine performance characteristics.

			Engine Performance Characteristics at Full Load		
Biodiesel	**NPs**	**Blend**	**BTE (%)**	**BSFC (kg/kWh)**	**Reference**
Grape seeds oil	CeO_2, Al_2O_3	B30 + 20 ppm Al_2O_3/B30 + 20 ppm CeO_2	24.5	0.24	[108]
Jatropha oil	CeO_2, Al_2O_3	B30 + 30 ppm Al_2O_3 + 30 ppm CeO_2	31.0	0.29	[109]
Mahua indica oil	SiO_2	B20 + 120 ppm SiO_2	25.8	0.34	[110]
Watermelon seeds oil	CeO_2	B20 + 20 ppm CeO_2	33.0	0.20	[111]
Algae oil	CeO_2	B30 + 100 ppm CeO_2	35.3	0.25	[116]
Aloe Vera oil	CeO_2	B30 + 20 ppm CeO_2	40.0	0.25	[112]
Sapindus seed oil	CeO_2	B30 + CeO_2	38.0	0.25	[113]
Waste cooking oil	Al_2O_3 + Multi-Walled Carbon nanotubes	B20 + 50 ppm Al_2O_3 + 50 ppm Multi-Walled Carbon nanotubes	30.65	-	[114]
Hemp seed oil	TiO_2	B30 + 75 ppm TiO_2	27.94	1.08	[115]

B20 (20% Biodiesel, 80% diesel), B30 (30% Biodiesel, 70% diesel).

4.3. Biofuel Cells by Using Nanotechnologies

A fuel cell (FC) is an electrochemical device used to generate electricity with high efficiency through direct chemical conversion [117]. FC technology is widely recognized as a clean, sustainable energy source due to its long lifespan and environmentally friendly emissions [118]. Hydrogen FCs can be used in a multitude of applications, such as in industry, electricity and heat generation, and transportation [119], which traditionally contribute around two-thirds of global CO_2 emissions [13]. There are numerous advantages to using fuel cells, such as their small size compared to other energy conversion devices, the low noise levels of the process, and their low environmental impact [117]. Rezk et al. [120] reported that proton exchange membrane fuel cells (PEMFCs) were the most common, commercially available FC that can operate under various loads, ranging from a few hundred to several thousand kWs. PEMFC technology is the most advanced FC system on the market [100]. Lee et al. [121] found that the most significant obstacles to the adoption of FCs were institutional and political considerations; in addition, the price of the device itself and the fuel cell infrastructure necessary to operate it are significant.

Dhimish et al. [122] noted that hydrogen PEMFCs also faced significant functionality and degradation challenges.

Biofuel cells (BFCs) are devices that use the metabolic reactions of microorganisms as they degrade organic contaminants to transform the chemical energy of available organic matter into electricity [13]. BFCs, such as traditional FC devices, utilize catalysts at two oppositely charged electrodes to detach hydrogen atoms from their electrons before combining the remaining hydrogen ions with oxygen to form water at the cathode. The free electrons are then siphoned off and used to perform work [123]. The main advantages of BFCs are that it operates at mild operating conditions (e.g., pH 5–8 and 25–37 °C) as well as their extended longevity. In BFCs, enzymes, whole living cells, or organelles are used as anodes or cathodes to produce electricity from biomass [13]. Zhao et al. [124] reported that the main challenge regarding the commercial applications of microbial fuel cells (MFCs) is the lower electron transfer efficiency between the microbes and the anodes. This can be improved by enhancing the surface properties of the electrode and streamlining the immobilization process. Enzymes or microorganisms are used as biocatalysts on either one or both sides of BFCs in the form of bioelectrodes [125]. Enzymatic biofuel cells (EBFCs) are a type of FC in which enzymes act as catalysts [124]. Yahiro was the first to propose the concept of EBFCs in 1964 [119]. A key component of EBFCs is the collection of electrons produced by the bio-electrocatalytic reaction between the redox enzymes and the substrates on the surface of the electrode [125]. The study of EBFCs has received much attention recently and is widely regarded as an excellent device for efficient power transformation. Energy conversion is accomplished by using naturally occurring enzymes as bio-electrocatalysts to catalyze fuel oxidation, resulting in a potential difference between the two bioelectrodes in the cells [126]. In EBFCs, redox enzymes are used to catalyze the oxidation of the fuel and the reduction of the oxidant at the bio-anode and bio-cathode, respectively. BFCs can use many types of organic matter, such as bodily fluids and wastewater [125]. Rahimnejad et al. [127] reported that, because the surface of the biocatalyst does not always have electrochemically active proteins, mediators are badly needed as secondary fuels to move electrons to the anode side of the biocatalyst. Flimban et al. [128] found that the mediator passes through the cell membrane of MFC and is then reduced by capturing the electrons produced by the electron transport chain. Electrons are subsequently transported and deposited on the anode by the reduced mediator. Following electrons release, the mediator reverts to its original oxidized state and can continue the process. However, Mishra et al. [13] concluded that due to their limited life span and reduced power density, promoting the use of BFCs is extremely difficult. Xiao [126] showed that future efforts could be directed toward resolving the EBFC's limited power density and lifetime.

Glucose is an excellent potential fuel as it is plentiful, sustainable, easily stored and transported, non-toxic, cheap, and has a reasonably high power density [129,130]. FCs can be used to convert energy in glucose to electrical energy [131]. EBFCs could be adapted to produce electricity through glucose oxidation processes [128]. Redox enzymes can extract electricity from biofuels while maintaining high catalytic activities despite operating in mild conditions [132,133]. Li et al. [125] concluded that a cascade of hybrid and organic oxidation catalysts such as enzymes, glucose oxidase (GOx), and 2,2,6,6-tetramethyl-1-piperidine N-oxyl (TEMPO) could be used to electrochemically oxidize glucose content. TEMPO can mediate electron flow between the redox center of GOx and the surface of the electrode. A cascade of organic and enzymatic catalysts can work together to catalyze the $4e^-$ oxidation of glucose, significantly improving catalytic efficiency. The hybrid enzymatic and organic cascade (HEOC) system for EBFCs has already been proven by Li et al. [125] by building glucose/air EBFCs comprised of a HEOC anode and an air-breathing Pt cathode.

Many characteristics of nanomaterials such as their considerable surface area, high catalytic activity, durability, efficient storage capacity, and high adsorption capacity can improve the stability, performance, and efficiency of BFCs. The use of nanomaterials within BFCs can enhance their efficiency and facilitate the direct transmission of electrons from the enzymes to the electrodes, improving the power output of BFCs [13]. Palaniappan [134] found that common nanomaterials can be used as catalytic agents to increase the rate of the anaerobic reaction, enhancing the yield of the process by reducing the effect of the inhibitory compounds and improving electron transport. Osman et al. [135] found that incorporating nanomaterials within the structure of bioelectrode can solve the problem of low electron transfer efficiency between the active enzymes and the surface of the electrode, which is the main limitation of using EBFCs. Several different nanomaterials are used in the present day, such as metallic NPs, inorganic nanomaterials, and carbon-based nanomaterials (CBNs). A wide range of CBNs can be used in BFCs and have been shown to significantly improve their performance [13]. Mishra et al. [13] noted that the use of metallic NPs dramatically increased the cost of BFCs but also significantly enhanced their power density. Inorganic nanomaterials are commonly employed to improve the functionality of membrane material. As biocatalysts are comprised of large molecules, they cannot easily transfer electrons to the BFC electrodes since the electron center of biocatalysts is deeply embedded within their macromolecular structure. Table 5 briefly summarizes the aspects of BFC nanotechnology.

Table 5. Summary of biofuel cells nanotechnology.

NPs	Advantages of Use
Glucose Oxidase (GOx). 2,2,6,6-tetramethyl-1-piperidine N-oxyl (TEMPO). Metallic nanoparticles. Inorganic nanomaterials. Carbon-based nanomaterials (CBNs).	Catalyzes the 4e$^-$ oxidation of glucose. Enhances BFC efficiency. Facilitates the direct transmission of electrons from the enzyme to the electrode. Improves the power output of BFCs. Increases the rate of the anaerobic reaction. Enhances the yield of the process by reducing the effect of inhibitory compounds. Solves the problem of low electron transfer efficiency from the active enzymes to the surface of the electrode. Significantly enhances power density. Enhances the functionality of the membrane material.

4.4. Biogas Production by Using Nanotechnologies

Agricultural waste is a significant source to produce biogas production; additionally, biogas is primarily produced from raw crops, fruits and vegetables, grasses, and industrial waste, in nature, these types of bioenergy are both safe and environmentally friendly. During the biogas production process, biomass is converted into energy through the use of anaerobic digestion [136,137]. Significant advantages and stages have been achieved in biogas production, CO_2 emission reduction, simple processing technologies, product biodegradability, harvesting methods, and compositions [138]. Trace elements are essential additives for guaranteeing a stable anaerobic digestion process and have the potential to boost biogas production [139]. The use of additives in AD not only boosts biogas production but also decreases air pollution during the manufacturing process. The digestion of various feedstocks differs significantly depending on whether the additives are the same or different [140]. The fate of nanomaterials in landfills is determined by the properties of landfill leachate, which varies depending on the composition of solid waste and landfill design. It is also affected by the age of the landfill and environmental factors such as precipitation rate and temperature change [141,142]. It is therefore crucial to examine the fate of nanomaterials in landfills to assess their effects on waste stabilization, biogas production, and the potential discharge of nanomaterials into groundwater systems via landfill leachate [143]. With the rapid advancement of nanotechnology over the last decade, nanoparticles are now commonly used in commercially available products. Because of their distinct physicochemical properties, NPs are considered ideal for use in manufacturing industries [144]. Among the numerous nanomaterials, nano-ZnO has received much attention due to its widespread use in industrial and medical uses [143]. ZnO NPs are widely used in consumer products such as sunscreen, anti-bacterial coatings, and a variety of medical and industrial applications [145]. The release of such compounds into the environment is unavoidable as commercial and industrial applications expand [146]. NPs have the potential to inhibit the digestion processes of sludge [143]. No previous research has outlined the achievement of nanomaterials in the production of biogas and waste contaminants removal from wastewater. NPs are efficient in eliminating contaminants such as H_2S and CO_2 from biogas [147]. In recent years, summarizing the impact of various additives on anaerobic digester performance has become an important research topic to understand the effect of various additives on biogas production efficiency. Table 6 briefly summarizes the aspects of biogas nanotechnologies.

Table 6. Summary of biogas nanotechnologies.

NPs	Advantages of Use	Ref.
ZnO	➢ Biogas production was reduced by 43% and 74% in the existence of 120 and 240 mg/L ZnO-NP, respectively; ➢ The addition of 1 mg ZnO/g total suspended solids did not affect methane production (TSS).	[148]
ZnO	➢ In simulated landfill bioreactors, both with and without the inclusion of ZnO-NP, stabilization of waste was quicker; ➢ The existence of ZnO-NP in the waste resulted in a 15% reduction in biogas production.	[149]
$TiO_2 + Al_2O_3 + SiO_2$	➢ TiO_2, Al_2O_3, and SiO_2 nanoparticles concentrations of up to 150 mg/g TSS had no negative effect on the anaerobic digestion of waste-activated sludge; ➢ The addition of 1 mg ZnO/g total suspended solids did not affect methane production (TSS).	[150]
TiO_2 + ZnO + Ag	The presence of coated nanomaterials in leachate had no impact on biological processes, specifically the five-day biochemical oxygen demand and methane production processes.	[151]
Ag	Biogas production was reduced by 43% and 74% in the existence of 120 and 240 mg/L ZnO-NP, respectively.	[152]
CeO_2 + ZnO	➢ CeO_2 and ZnO NPs inhibited biogas production to varying degrees, with ZnO NPs at g/L concentration reducing biogas by 65.3%; ➢ CeO_2-NP at a low concentration of 10 mg/L increased biogas production by 11%.	[143]
Metal, metal nutrient, Fe_2O_3	Metal nutrient-NPs, Metal-NPs, and iron oxide (Fe_2O_3)-NPs are more appropriate for increasing biogas and methane (CH_4) production than metal oxide NPs (Al_2O_3, ZnO, and CuO).	[147]
Co	Various concentrations of Co-NPs (0.06–6 mg/L) increased CH_4 yield by 7–15%.	[153]
ZVI, Fe_2O_3	When compared to the control, the use of ZVI-NPs (10 mg/g) and Fe_2O_3-NPs (100 mg/g) and increased methanogenic archaea activity and increased biogas yield by 120% and 117%, respectively.	[154]
ZVI, Fe3O4	The use of ZVI-NPs at a concentration of 20 mg/L and Fe_3O_4 magnetic NPs at a concentration of 20 mg/L increased biogas production by 45% and 66%, respectively.	[155]
Nanographene	The best nanographene concentrations (120 and 30 mg/L) increased the production of CH_4 production by 51.4% and 7.0%, respectively.	[156]

5. Potential Biomass Supply in Jordan

Jordan has a wide variety of biomass feedstocks that can be used to produce biofuels. Between 2014 and 2019, the average annual residue from vegetables, fruits, crop farming, animal residue, and MSW in Jordan was reported to be 227, 940, 117, 10910, and 16,094 kilotons per year, respectively. These sources have a total waste energy potential of 124,567 TJ/year, and a potential biogas yield of 817 MCM/year, as described in Table 7. Jordan also has a wide variety of nonedible plants, as illustrated in Table 8.

Table 7. Biomass residues in Jordan between 2014 and 2019 (available data).

Type	Average Quantity (Dry Waste) [35] (Kiloton/Year)	Waste Energy Possibilities (TJ)	Average Biogas Yield (MCM)
Vegetable residue	227	340	22
Fruits residue	940	5981	137
Farming crops residue	117	520	8
Animal residue	10,910	11,2968	499
MSW	16,094	4758	151
Total	28,188	12,4567	817

Table 8. Nonedible plants in Jordan.

Type	Average Seeds Quantity (ton/ha)	Average Oil Quantity (ton/year)	Location
Jojoba [87]	5000	1811.8	Eastern Badia
Citrullus Colocynths (Handal)	-	-	Eastern Badia, Wadi Rum, Wadi Araba, Al-Ghours, Aqaba
Jatropha	5	1.3–2.5	Desert

6. Potential Bioenergy Supply in Jordan

Jordan primarily relies on imports to meet the country's ever-increasing energy demands [22,157]. Jordan's electricity demands have dramatically increased, as illustrated in Figure 7, and are expected to reach 82.4 TWh by 2050 [10]. Figure 8 shows that bioenergy can be a highly beneficial, clean technology that could solve the energy issues in Jordan [36]. Jordan aims to increase the contribution of RE to 11% by 2025 [158].

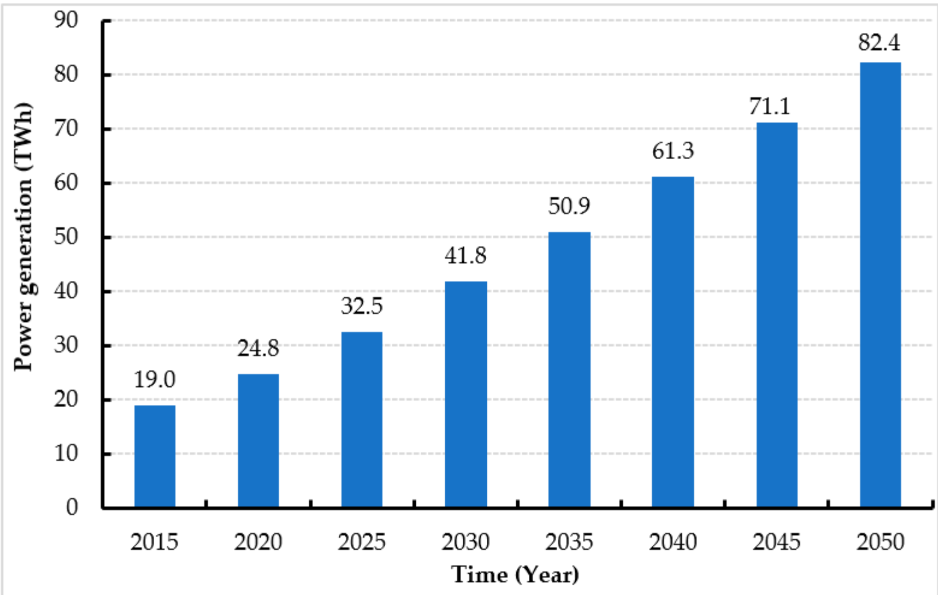

Figure 7. Jordan's electricity requirements between 2015 and 2050.

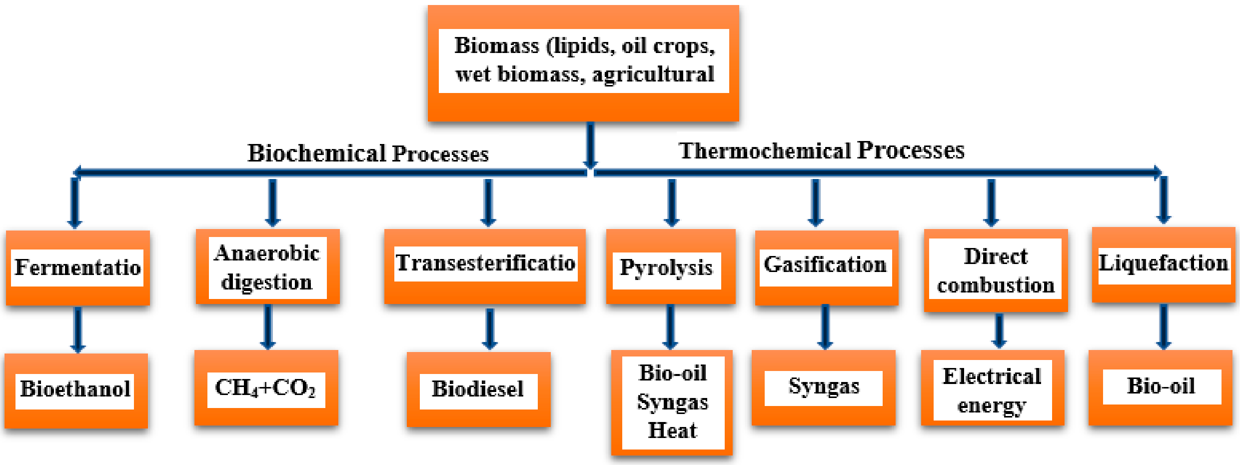

Figure 8. General bioenergy production scheme.

6.1. Potential Bioenergy from Crop Residues in Jordan

6.1.1. Biofuel from Corn Leaf Waste in Jordan

There are many large corn farms in Jordan Valley, located in the western area of Jordan. Thus, there is a large amount of corn waste in the form of stalks, leaves, husks, and cobs. Amer et al. [63] concluded that many feedstocks could be used to produce biofuels, such as straws, rice husks, corn leaves and stovers, and wheat straws. However, in terms of dry basis, corn leaf waste in Jordan has a chemical content as described in Table 9. It has slightly higher C, N, and S contents compared to average corn leaf wastes from China, Pakistan, and Brazil (C: 36.6–47.0; N: 0.17–2.0, S: 0.05–0.63), but falls within the average values of calorific and ash content. The yield components of the corn leaf waste sample are described in Table 10.

Table 9. Chemical analysis of Jordan's corn leaf waste [63].

Analysis							
C	H	N	S	O	Ash	Calorific Value	Atomic H/C Ratio
(wt% daf)	(wt% daf)	(wt% daf)	(wt% daf)	(wt% daf)	(wt% db)	(MJ/kg)	(-)
47.7 ± 0.5	6.4 ± 0.4	2.9 ± 0.1	0.9 ± 0.0	42.1 ± 0.8	9.7 ± 0.2	17.9 ± 0.3	1.59 ± 0.07

Table 10. Components of Jordan's corn leaf waste sample [63].

Components					
Ethanol Extract	Hexane Extract	Water Extract	Cellulose	Hemicellulose	Lignin
(wt%)	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)
13.2 ± 0	8.9 ± 0.1	7.3 ± 0	32.1 ± 0.5	18.1 ± 0.3	11.9 ± 0.4

Amer et al. [63] found that the biomass feedstock of corn leaf waste could be pyrolyzed to produce biofuel using the following methodology. First, the waste should be dried at 105 °C in the presence of constant flowing N_2 for 3 h. It should then be pyrolyzed in four stages at 300 °C, 350 °C, 400 °C, and 450 °C as illustrated in Figure 9. The retort should be kept at the fourth stage to ensure that no further oil is spilled. The oil product obtained from each stage should be analyzed and characterized separately. Biofuel content can then be measured as described previously, where the percentage weight of oxygen (O) content is equal to the total percentage weight of C, H, S, and N. Corn leaf waste in Jordan has a high H/C ratio, volatile matter, oxygen, and calorific value. Biomass that contains more volatile matter (more C-O) and lower ash contents generally result in greater biofuel yields. In addition, the calorific value of biofuel is less than that of conventional fossil fuels due to the high O content, low C and H contents, and relatively low C:O+H ratio compared to fossil fuels. Furthermore, the bond energy content in C-C is greater than the bond energy content in C=O and C-H. Pyrolysis at 450 °C was found to yield more oil from corn leaf waste. As the pyrolysis temperature increased, the mass flux and specific heat of the products increased while the water content decreased as moisture was removed. Corn leaf waste biofuels contain a significant amount of carbon and oxygen, which decreases as the pyrolysis temperature increases. However, it also contains a high proportion of conventional diesel (57–73%), which can be used in space heating.

6.1.2. Biodiesel from Jojoba in Jordan

In Jordan, Jojoba is considered to be a suitable resource for biodiesel production because 40–50% of the total dry weight of its seeds is comprised of oil. Jojoba is traditionally grown in semi-arid areas, where it can acclimate to temperatures from 0 to 54 °C and <100 mm/year of rainfall. Jojoba can be grown on land that is unsuitable for most other food crops. Jojoba plants are evergreen and can survive for 150–200 years. Jojoba plants produce fruit every three years depending on the watering rate and take around 10–12 years to reach full maturity. One hectare of fully mature Jojoba plants can produce 2.0–3.5 tons of seeds and can reach production rates of around 5000 tons/ha after 12 years. Jojoba farms in eastern Badia, Jordan occupy an area of 1000 hectares with around 1666 trees/ha; each mature tree can produce 2.5 kg of seeds with an oil content of 50%, which would allow farmers to obtain nearly 1811.78 tons of oil per year. The methodology for obtaining biodiesel from Jojoba seeds is illustrated in Figure 10. This process is assumed to have an oil generation rate of 1750.62 t/h, with a capital expenditure (CAPEX) and an annual operating expenditure (OPEX) of USD 12,701.36 and USD2, 352.38, respectively. The drip irrigation framework is the most expensive part of the system and accounts for approximately 45.83% of the CAPEX and 25.79% of the OPEX. Biodiesels derived from Jojoba oils can be either used in diesel engines by combining them with conventional diesel at a specific ratio or in furnaces. Glycerol is the most common byproduct of biodiesel; this can be converted to solketal via a two-stage acetalization process. Glycerol reacted with acetone. The biodiesel cost of this project could be reported as USD 1.19/L if the glycerol byproducts are sold. However, this cost reduces to USD 0.70/L when accounting for solketal generated from glycerol byproducts [87].

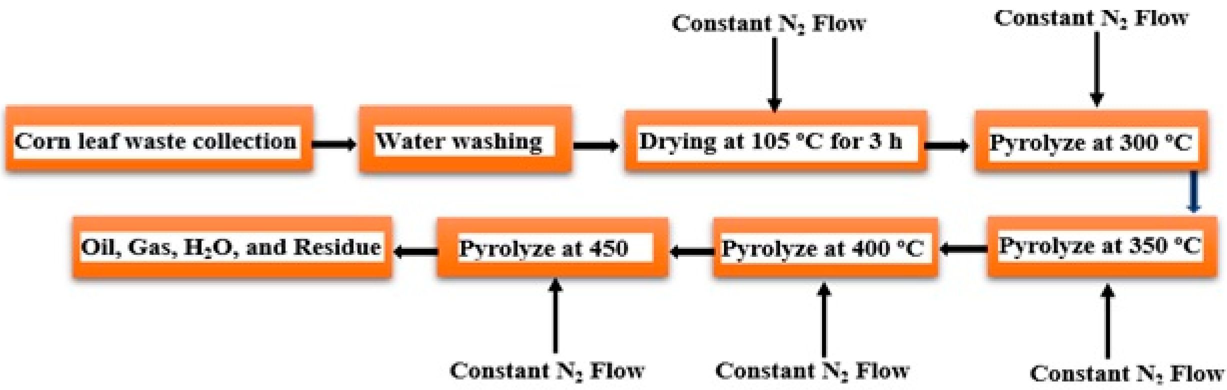

Figure 9. Scheme describing the synthesis of biofuel from corn leaf waste.

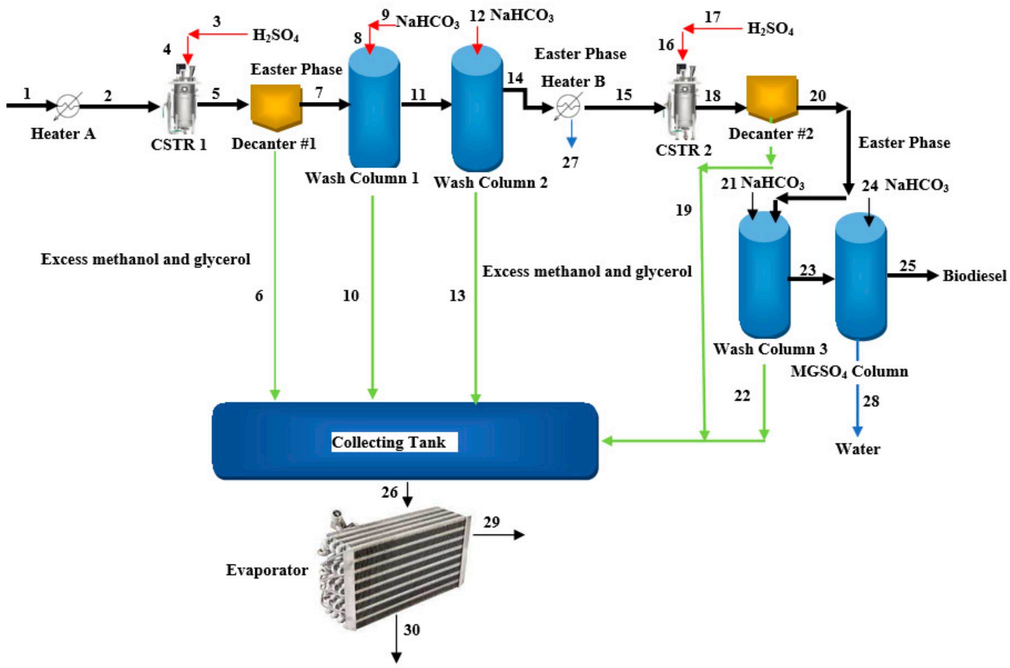

Figure 10. Process flow diagram for the synthesis of biodiesel from Jojoba seed oil.

6.1.3. Biodiesel from *Citrullus colocynthis* in Jordan

There have been few studies on *Citrullus colocynthis* (Handal) as a nonedible source of biomass [159]. *C. colocynthis* (L.) Schrad is a vegetable plant that is usually farmed and cultivated and is geographically distributed across the deserts of Asia, the Middle East, Asia, Southern Europe, and North Africa [160]. Handal is a poisonous, crawling plant found in deserts that is closely related to watermelons and is classified as a member of the Cucurbitaceous family [159]. It can survive in hyper-arid desert environments with annual precipitation rates of 50 mm/y and an annual temperature range of 14.8–27.8 °C [161]. Handal can be grown and cultivated in sandy soils, especially during the rainy season, and produces fruit in the winter. Handal seed oil is comprised of 50 wt% of golden yellow-brown oil [162].

De Melo et al. [163] concluded that to determine the composition of Handal seed oil, Handal plants were gathered from various locations throughout Jordan, and the seeds from 20 kg of Handal were removed and cleaned. The seeds were dried for three days at room temperature before being ground with an electric blender. Al-Hwaiti et al. [164] found that the primary fatty acids found in Jordanian Handal seed oils were linoleic acid (74.8 ± 0.1%), palmitic acid (8.35 ± 0.03%), stearic acid (5.36 ± 0.06%), and oleic acid (9.04 ± 0.09%). Minor amounts of ω-3- and hydroxy-polyunsaturated fatty acids (<1%) were also observed. Biodiesel can be produced from Handal seed oils as described in Figure 11.

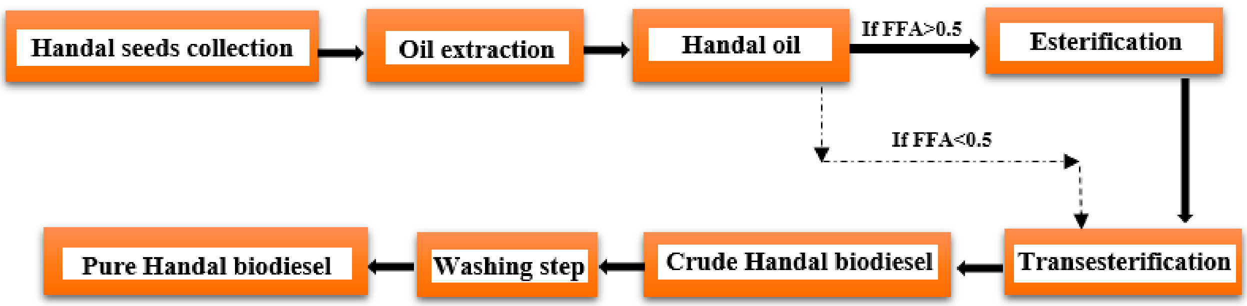

Figure 11. Process flow diagram for the synthesis of biodiesel from Handal seed oil.

The amount of acid value (*AC*) in an obtained oil sample can be calculated via the following equation:

$$AC = \frac{56.1 \times KOHvolume\ used(mL) \times N(KOH)}{Sample\ weight(g)} \quad (1)$$

where 56.1 is the molecular weight of potassium hydroxide (*KOH*; g/mole), and *N* is the molarity of *KOH* (mole/L) [163].

Esterification should be performed prior to treatment with methanol and a sulfuric acid (H_2SO_4) catalyst to reduce the FFA content. The FFA content after esterification must be less than 0.5% for biodiesel production [163]. Esterification is also the most commonly used process for reducing the viscosity of various vegetable oils [165].

The optimal method for the transesterification of Handal oil requires the addition of methanol and sodium methoxide can be calculated via the following equations:

$$Methanol = \frac{0.217}{Unreacted\ Triglycerides(g)} \quad (2)$$

$$Sodium\ Methoxide = \frac{0.25 + 0.19 \times \%FFA}{100 \times Unreacted\ Triglycerides(g)} \quad (3)$$

The crude biodiesel obtained is then washed and purified by filling the separator funnel with hot distilled water and gently shaking to mix the distilled water and crude biodiesel; the resultant layers are allowed to settle for one day. After repeated washings, the bottom aqueous layer is removed. This process was repeated three to four times until pure water was obtained. The washed biodiesel samples are then dried at 110 °C for 2 h to remove excess water and methanol [165].

The handle seed oil has the same density as pre-standard vegetable oil fuels and is compatible with combustion engines. The kinematic viscosity of Handal oil is greater than that of carbon diesel fuel but less than heavy oil fuels. The higher heating value (HHV) of Handal biodiesel (39.60 MJ/kg) is marginally lower than the tolerance level of fossil diesel (42.2 MJ/kg). The engine performance of a B20 blend (20% biodiesel obtained from Handal seed oil and 80% diesel obtained from fossil fuels) was markedly higher than that of pure diesel in terms of torque, brake power, and performance. The performance of Handal biodiesel blends with respect to brake power, torque engine speed, and thermal engine speed was fairly similar to pure fossil diesel. This suggests that Handal seed oils can be effectively blended with biodiesel for use in internal combustion (IC) engines. The percentage of biodiesel in blends also considerably enhanced brake thermal efficiency (BTE). Engine performance assessments showed that the B100 blends (100% Handal biodiesel) could be effectively used in internal combustion engines without impacting engine efficiency. This would help preserve both the environment and natural resources for future use [165].

6.1.4. Biodiesel from Jatropha in Jordan

Jatropha curcas is a tall bush or small tree from the Euphorbiaceae family that grows up to 5–7 m tall [166]. The origins of the Jatropha tree are unknown, but it may have originated in Mexico or Central America. It was first introduced to Africa and Asia before expanding to the rest of the world. This drought-tolerant species grows in arid and semi-arid environments, preferring well-drained soils with excellent aeration, and can adapt to peripheral soils with low nutritional value. It grows fairly quickly, starts producing seeds after 12 months, reaches peak productive capacity after five years, and can produce seeds for up to 50 years [167] is a promising, commercially viable nonedible vegetable oil. The decorticated seed of Jatropha contains 43–59% oil [168] and 30–40% [169], depending on the variety. The plant is critical for tackling climate change issues since a mature plant or tree can absorb 18 lbs of CO_2 annually [170]. Becker et al. [171] found that one hectare of J. curcas can absorb up to 25 tons of atmospheric CO_2 every year for around 20 years.

The oil of *J. curcas* contains approximately 47.3% crude fat, 24.6% crude protein, and 5.54% moisture [172]. Like most other nonedible oils, J. curcas contains a high concentration of FFAs. Oils obtained from the Jatropha plant contain saturated fatty acids such as stearic acid (7.0%) and palmitic acid (14.2%), as well as unsaturated fatty acids such as linoleic acid (32.8%) and oleic acid (44.7%) [173].

The cost of producing biodiesel is dependent on the size and type of seeds used (Table 11) [174]. Hence, Jatropha seeds appear to be a viable option for biodiesel production, as shown in Figure 12.

Table 11. Jatropha oil biodiesel production cost comparison with other oils [174].

Biomass Resources	Country	Productivity/Hectare (ton)	Rate/Barrel (USD)
Jatropha Oil	India	3.0	43
Palm Oil	Malaysia	5.0	46
Rapeseeds Oil	Europe	1.0	78

Recently, many researchers have investigated the pyrolysis of available vegetable oils from nonedible plants and their cakes, including *J. curcas* [175]. Telfah [176] concludes that Jatropha oil has a high FFA content of around 15%. Hence, a two-step pretreatment process is used to reduce the FFA content to less than 1%. The first step is a pre-esterification step conducted in methanol in the presence of a 1.0% (w/w) sulfuric acid (H_2SO_4) catalyst at a 0.6 (w/w) methanol to oil ratio at 50 °C for 1 h. The second step transesterifies the layer of Jatropha oil obtained using a 0.24 (w/w) methanol to oil ratio in the presence of an alkaline catalyst of 1.4% (w/w) sodium hydroxide (NaOH) at 50 °C for 2 h to produce Jatropha biodiesel with a yield of around 90%. When processed using 12 wt% methanol and 1.0 wt% H_2SO_4 for 2 h at a temperature of 70 °C, the acid value of the obtained Jatropha oil can be diminished from 14 mg KOH/g oil to less than 1 mg KOH/g oil. The FFA content was reduced by 97% after reacting with 4 wt% solid acid and molar methanol to FFA ratio of 20:1 for 2 h at 90 °C. Phospholipids are eliminated during the pre-esterification process, eliminating the need for a separate degumming operation. A 98% biodiesel yield was generated by transesterification when using a 1.3% KOH catalyst and molar methanol to oil ratio of 6:1 at 64 °C for 20 min. Qudah et al. [174] describe another two-step process. A homogeneous acid-catalyzed pre-esterification reaction was performed at a constant temperature of 60 °C. A 100 mL round-bottomed flask was filled with 25 g of Jatropha oil and treated with concentrated H_2SO_4 (1.2% w/w acid to oil ratio) and dried methanol (25% w/w methanol to oil ratio); the mixture was refluxed 60 °C for 3 h. After washing the mixture to remove residual methanol and sulfuric acid, the products were dried with anhydrous Na_2SO_4. In the transesterification step, a KOH catalyst was used in a homogeneous base-catalyzed transesterification for 3 h at 60 °C. A 250 mL round-bottomed flask was filled with 40 g of pre-esterified Jatropha oil and heated to the appropriate temperature; the mixture was then treated with methanol (6:1 methanol to oil ratio) and KOH (1.2% w/w KOH to methanol ratio). The mixture was refluxed for 3 h while being continuously stirred. The products were then washed with distilled water and dried with anhydrous Na_2SO_4. This two-step process reduced the acid value of the raw Jatropha oil obtained to 0.30 mg KOH/g oil.

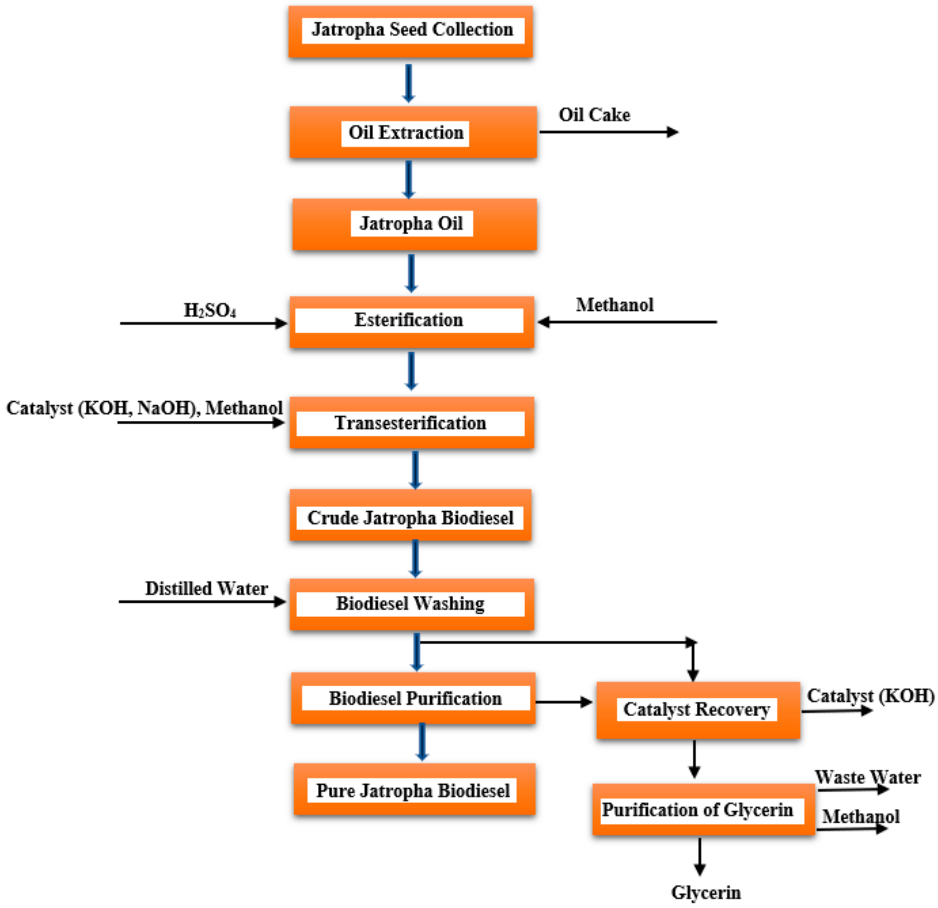

Figure 12. Process flow diagram for the synthesis of biodiesel from Jatropha seed oils.

Qudah et al. [174] found that dolomite is a natural rock found in Jordan that contains 66% Ca, 28% Mg, and 6% Fe that can be used as a catalyst in the transesterification process. The dolomite should be crushed, finely ground, and exposed to a series of thermal treatments under flowing oxygen or ambient air before use. Two procedures that employed a dolomite catalyst were tested, and both involved treatments at 800 °C for 2 h. In the first procedure, 10 g of ground Jatropha seeds were blended with 4.0 g of dolomite catalyst, 100 mL of chloroform, and 75 mL of methanol in a 250 mL volume round-bottomed flask. The mixture was refluxed for 10 h, filtered to separate the Jatropha powder, and evaporated using a rotary evaporator to remove the solvent from the filtrate. In the second procedure, 10 g of ground Jatropha seeds were blended with nearly 100 mL chloroform in a 250 mL round-bottomed flask. After filtration, the liquid phase was transferred into a 250 mL flask and blended with 4.0 g of dolomite catalyst and 75 mL of methanol. The mixture was constantly agitated for 2 h at 60 °C and subsequently refluxed for 10 h before being evaporated with a rotary evaporator to remove the solvent under reduced pressure. To optimize the transesterification process (>96% conversion rate) of Jatropha seed oils at 60 °C and 6:1 methanol to oil ratios, the dolomite should be thermally activated at 800 °C for at least 30 min. This heightened activity is correlated with the creation of CaO but not MgO, which forms when heated to 600 °C. The minimum mass ratio of catalyst to oil required to achieve such an ideal biodiesel yield is 1:50 (2%); It is important to note that the catalyst cannot be recycled and can only accomplish a 2% transesterification rate if reused. Nevertheless, activated dolomite can be considered to be a less expensive alternative to the more commonly used KOH catalyst.

The viscosity of *J. curcas* oil/diesel fuel blends at ratios of 50:50 and 40:60 is similar to that of pure diesel fuel at the temperature of 328–333 K and ~318 K, respectively, while a mixture of *J. curcas* oil/diesel fuel at a ratio of 30:70 has a viscosity similar to diesel fuel at the temperature of 308–313 K [177].

6.2. Potential Yield of Biogases in Jordan

Figure 13 shows that biogas technology has grown in popularity over the last few decades [178]. Biogas can be used as a replacement for natural gas (NG) in stoves. It can also be used to produce electricity by feeding an internal combustion engine that is directly connected to an electrical generator. The extra heat from the combustion engine can heat an entire room (space heating) as well as heat the anaerobic digester [36]. However, these applications have not yet been widely adopted in developing countries [178]. Al-hamamre et al. [31] concluded that Jordan is theoretically capable of producing approximately 706.9 MCM of biogas per year even without taking the availability of energy into account; this is equivalent to around 388.1 MCM of NG per year or 2.57 MCM of barrel oil per year. Al-hamamre et al. [37] reported that the total amount of biogas that Jordan could theoretically generate is around 428.19 MCM/year and that it can also generate around 235.5 MCM of methane (CH_4) per year. This amount would account for 29.2% of Egypt's total NG imports in 2011 (Table 12). Al-hamamre et al. [36] also found that if Jordanian biogas was used for electricity generation, this would generate approximately 917.41 GWh_e of power per year, which would be 17% more than the total amount of power imported from Syria and Egypt (784.3 GWh_e), assuming a conversion efficiency (biogas to electricity) of 27.5%.

As a sustainable source of energy, biogas can play a key role in maintaining the balance between long-term advancement, economic strength, and the preservation of the environment in Asia [179]. Recently, the anaerobic digestion of agricultural and industrial waste has emerged as one of the most appealing sustainable energy solutions. The most popular digester designs are fixed domes (Chinese type) and floating covers (Indian type) [178]. However, Surendra et al. [180] found that these two types of digests are difficult to adopt in developing countries; they do not provide temperature control, have prohibitively expensive installation costs for farmers, and require specialized skills. The biogas produced from biological waste is mostly a natural process. Hence, a majority of the project's costs involve the collection of waste and the construction of the biogas plant [158]. Al-hamamre et al. [37] found that the total annual power that Jordan might theoretically generate from CH_4 was around 698.1 GWh_e, which is equivalent to around 5.09% of energy consumption in 2011 and 39.65% of the power imported from Egypt and Syria. Abu Qdais et al. [181] also calculated that if all potential biomass in Jordan was used to generate energy in 2012, about 53.35% of the primary energy consumption could be replaced by NG or could replace about 66.23% of the total amount of NG imported from Egypt. They found that 28.34% of this biogas could be generated from animal waste and that 62.18% of this amount could be derived from sheep and goat waste, with poultry residues contributing the remaining 32.29%. Biogas production from dung could be used as a substitute for conventional fossil fuels in the generation of electricity and would thus contribute to the reduction of GHG emissions and other pollutants [178]. Al-hamamre et al. [36] found that the use of anaerobic digestion to produce biogas would be an alternative to traditional waste disposal methods in Jordan (such as landfilling or incineration), which emits toxic gases such as CO_2 and carbon monoxide (CO). Jafar and Awad [178] reported that the most common applications for biogas were limited to lighting and cooking in developing countries. Utilizing biogas in rural areas would cut down on firewood consumption, prevent deforestation, and boost soil productivity; hence, biogas could contribute significantly to sustainable development. Milbrandt and Overend [182] concluded that the amount of biogas produced is primarily dependent on the digester volume. The main components of biogas are CH_4 (50–70%) and CO_2 (30–50%), with the rest being trace gases (hydrogen and nitrogen) [36]. Wang Ris [183] found that a pretreatment process was necessary to enhance CH_4 production via anaerobic digestion. Al-hamamre et al. [36] concluded that when co-digesting agricultural waste with cattle manure, the yield of biogas products increased by 0.62 L/kg volatile solid (VS). About 85.62 GWh_e of electricity could be obtained if the MSW in the Akaider landfill was used, saving approximately 92.86–194.8 × 10^3 t/year of CO_2. Furthermore, nearly 538.2 GWh_e of electricity can be obtained by using the MSW in the Al-Ghabawi landfill with CO_2-equivalent savings of 582–1220 × 10^3 t/year. Each ton of MSW used to produce electricity can reduce CO_2 emissions by around 725–1520 kg. If the entire supply of MSW was used to obtain electricity, this number could reach 1005 × 10^3–2108 × 10^3 kg. Malkawi et al. [158] found that in the absence of "fuel costs", operational expenses tended to be less than that of traditional power plants. However, due to socioeconomic and institutional barriers, the prospective growth of the Asian biogas industry is relatively poor [179]. Aggarangsi et al. [184] found that biogas digesters significantly decrease environmental pollution.

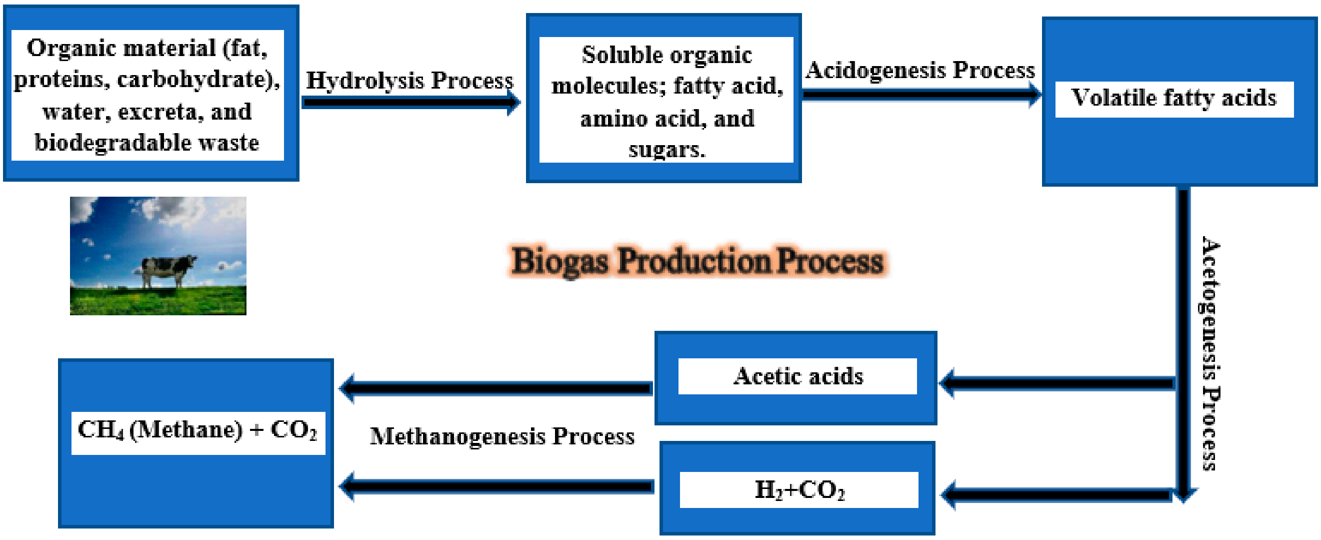

Figure 13. Scheme describing the production of biogas.

Table 12. Jordan's biogas and electricity yield potential [37].

Biomass Resources	BG Yield * TJ/year	Electricity GWh_e/year
Animal Manure	600.5	45.9
Agricultural Residue	644.5	49.2
Sludge and Wastes	1224.2	93.5
Total	2469.2	188.6

* BG Yield: considering availability energy factor of 12.5.

A summary of Jordanian bioenergy research and how it compares to global bioenergy technology is presented in Tables 13 and 14.

Table 13. Summary of Jordan's bioenergy.

Biomass Resources	Bioenergy	Process	Applicability	Conclusion	Findings	Strength	Shortcoming
Corn leaf waste	Biofuel	Pyrolyss (300–450 °C)	Applicable	Feasible	450 °C was found to yield more oil from corn leaf waste.	Chemical analysis is well considered.	Economic analysis is not considered Nanotechnologies are not considered.
Jojoba oil	Biodiesel	Esterification and transesterification	Applicable	Feasible (CAPEX USD 12,701.36, OPEX USD 2352.38)	1. The biodiesel cost of this project could be reported as USD1.19/L if the glycerol byproducts are sold. 2. The biodiesel cost reduces to USD0.70/L when accounting for solketal generated from glycerol byproducts.	Economic analysis is considered.	1. Chemical analysis is not considered 2. Nanotechnologies are not considered.
Citrullus Colocynts (Handal) seeds oil	Biodiesel	Esterification and transesterification	Applicable	Feasible	1. Handal seed oils can be effectively blended with biodiesel for use in IC engines. 2. The percentage of biodiesel in blends also considerably enhanced brake thermal efficiency. 3. B100 blends (100% Handal biodiesel) could be effectively used in internal combustion engines without impacting engine efficiency.	1. A chemical and physical analysis is well considered. 2. IC engine combustion performance is well technically covered.	1. Economic analysis is not considered. 2. Nanotechnologies are not considered.
Jatropha	Biodiesel	Esterification and transesterification	Applicable	Feasible	1. The viscosity of J. curcas oil/diesel fuel blends at ratios of 50:50 and 40:60 is similar to that of pure diesel fuel, at the temperature of 328–333 K and ~318 K, respectively. 2. Mixture of J. curcas oil/diesel fuel at a ratio of 30:70 has a viscosity similar to diesel fuel at the temperature of 308–313 K. 3. To optimize the transesterification process (>96% conversion rate) of Jatropha seed oils at 60 °C and 6:1 methanol to oil ratios, the dolomite should be thermally activated at 800 °C for at least 30 min. Activated dolomite can be considered to be a less expensive alternative to the more commonly used KOH catalyst.	1. Biodiesel production processes in general are well considered. 2. Production cost comparison between Jatropha oil with other biomass feedstock oils is considered. 3. Using a new natural catalyst (dolomite), compare it with the KOH catalyst.	1. Economic analysis not considered. 2. Chemical analysis not well covered. 3. Physical analysis not considered.
MSW and animal manure	Biogas	Anaerobic digestion	Applicable	Feasible	1. Total amount of biogas that could potentially be created is around 817 MCM/year. 2. Total amount of power that might be theoretically acquired from CH4 yield per year is 961 GWhe.	Different biomass resources are considered (MSW, animal manure) with suitable technical and economic analysis.	1. The latest biogas technologies are not considered. 2. Jordan's biogas challenges and solutions are not well covered.

Table 14. Jordan's bioenergy in comparisons with global bioenergy.

Biomass Resources	Country	Bioenergy	Process	LCC	Techno-Economy
Corn leaf waste	Jordan [63]	Biofuel	Pyrolysis (300–450 °C).	-	450 °C was found to yield more oil from corn leaf waste.
Cornleaf-waste	Canada [185]	Biofuel	Pyrolysis (200–430 °C).	-	At 550 °C, a biochar yield of 10% to 12% is achievable.
Jojoba oil	Jordan [87]	Biodiesel	Esterification: It is used in the production line of biodiesel to reduce the fatty acid concentration to less than 1.0 wt% before getting a transesterification reaction. Transesterification: Using KOH 1.0 w/w as a catalyst. Methanol to oil ratio (1:3.3). The reaction temperature is 65 °C.	CAPEX USD 12,701.36. OPEX USD 2352.38.	The biodiesel cost reduces to USD 0.70/L when accounting for solketal generated from glycerol byproducts.
Jojoba oil	Egypt [186]	Biodiesel	Transesterification: Using KOH 0.5 wt% as a catalyst. Methanol to oil ratio (3:18:1) by step 1:1. Reaction time (0.5 h to 3.0 h) by step 0.5 h.	-	1. The ideal situation for producing biodiesel from Jojoba oil: Using a KOH base catalyst containing 0.5% wt of the extracted oil. 2. The ratio of methanol to oil (6 to 1). The reaction temperature is 60 ± 1 °C. 3. Reaction time is 2 h. 4. Blending intensity is 600 rpm.
Jojoba oil	India [187]	Biodiesel	Transesterification: No catalyst. Methanol to oil ratio (30:1). The reaction temperature is 278 °C. The reaction pressure is 123 bars. Reaction time 23 min.	-	At optimal conditions, the supercritical methanol transesterification method creates the most biodiesel (95.67%).
Citrullus Colocynths (Handal) seeds oil	Jordan [165]	Biodiesel	Esterification: The catalyst is sulfuric acid (H_2SO_4), and the reactant is methanol (CH_3OH). The FFA content after esterification must be less than 0.5% for biodiesel production. Transesterification: The optimal method for the transesterification of Handal oil requires the addition of methanol equivalent to 0.217 × (unreacted triglycerides in grams) as well as sodium methoxide equal to [0.25 + 0.19 × (%FFA)]/[100 × unreacted triglycerides in grams]. The crude biodiesel obtained is then washed and purified with hot water.	-	1. Handal seed oils can be effectively blended with biodiesel for use in IC engines. The percentage of biodiesel in blends also considerably enhanced brake thermal efficiency. 2. B100 blends (100% Handal biodiesel) could be effectively used in internal combustion engines without impacting engine efficiency.
Jatropha seeds oil	Jordan [176]	Biodiesel	Esterification: Using methanol in the presence of a 1.0% (w/w) sulfuric acid (H2SO4) catalyst at a 0.6 (w/w) methanol to oil ratio at 50 °C for 1 h Transesterification: using a 0.24 (w/w) methanol to oil ratio in the presence of an alkaline catalyst of 1.4% (w/w) sodium hydroxide (NaOH) at 50 °C for 2 h to produce Jatropha biodiesel with a yield of around 90%.	USD 43 per barrel	A 98% biodiesel yield was generated by transesterification when using a 1.3% KOH catalyst and molar methanol to oil ratio of 6:1 at 64 °C for 20 min.
Jatropha seeds oil	Jordan [174]	Biodiesel	Esterification and transesterification using KOH as a catalyst. Esterification and transesterification using dolomite as a catalyst.	-	Activated dolomite can be considered to be a less expensive alternative to the more commonly used KOH catalyst.
Jatropha seeds oil	India [188]	Biodiesel	In the transesterification reactor, Jatropha seeds oil is combined with alcohol (Methanol) and a catalyst mixture (KOH, NaOH). The reactor is maintained at reaction temperature for a set period of time while being vigorously agitated. Following the reaction, the biodiesel and glycerol mixture is transferred to the glycerol sedimentation tanks. Crude Jatropha biodiesel is gathered and washed with water to obtain pure biodiesel.	-	1. Biodiesel produces more torque, power, and brake thermal efficiency at different load conditions than petroleum diesel. 2. The biodiesel mixture B20 (20% biodiesel and 80% petrol-diesel) outperformed the petrol-diesel and other mixes.

Table 14. *Cont.*

Biomass Resources	Country	Bioenergy	Process	LCC	Techno-Economy
Jatropha seeds oil	Egypt [189]	Biodiesel	Transesterification: Using NaOH 1.0 wt% as a catalyst. Methanol to oil ratio (6:1). Reaction time 1.0 h. Reaction Temperature 338 K. Yield 93.0%.	-	1. The characteristics of the biodiesel produced are comparable to those of diesel fuel. 2. Glycerol with a purity of 85% was generated and assessed as a useful byproduct of the procedures. 3. FFAs and sodium phosphate salts with commercial processes are also manufactured and assessed.
Jatropha seeds oil	India [190]	Biodiesel	Esterification: It is conducted in the presence of a sulfuric acid catalyst (H_2SO_4) and NaOH. Transesterification: Using KOH 0.55 wt% as a catalyst. Methanol to oil ratio (5.41:1). Reaction time 1.0 h. Reaction Temperature 333 K. Yield 93.0%.	-	The maximum biodiesel yield with two steps of esterification and transesterification was 93% (v/v), which was higher than that with one-step (transesterification) at 80.5%.
MSW, animal manure	Jordan [36,37,181,191]	Biogas	Anaerobic digestion (Landfill)	Feasible	1. The total amount of biogas that could potentially be created is around 817 MCM/year. 2. Total amount of power that might be theoretically acquired from CH4 yield per year is 961 GWhe.

Table 15. Possibility of bioenergy production and blending with nanotechnology from some biomass resources in Jordan.

Biomass Resources	Biofuel	NPs			
		Type	Current Situation	Applicability in Jordan	Advantages of Use
Tomato waste	Biodiesel	Snowman-like Fe_3O_4/Au	Not applied	Applicable	Enhance the conversion efficiency.
General	Biodiesel	Carbon-Based Sulfonated Catalysts (CBSCs)	Not applied	Applicable	Significantly improved the engine's effectiveness and release qualities.
Soybean	Biodiesel	Carbon Nano Tube (CNT)	Not applied	Applicable	4.5% decrease in BSFC. Enhances the combustion, performance, and discharge levels regardless of engine load conditions.
Mustard oil	Biodiesel	TiO_2	Not applied	Applicable	1. The smock discharge from the exhaust, CO, and HC are reduced. 2. NOx emissions have significantly reduced.
Cooking oil waste	Biodiesel	TiO_2	Not applied	Applicable	1. The performance of the diesel engine was enhanced. 2. BSFC declined. 3. Low released emissions.
Cashew nutshell	Biodiesel	Alumina nanoparticles	Not applied	Not Applicable	The engine emissions of CO, HC, NOx, and released smoke have been reduced by 8.8%, 10.1%, 12.4%, and 18.4%.
Olive oil	Biodiesel	ZnO nanorods	Not applied	Applicable	Enhance the conversion efficiency.

Table 15. *Cont.*

Biomass Resources	Biofuel	NPs			
		Type	Current Situation	Applicability in Jordan	Advantages of Use
Sweet potato	Bioethanol	Methyl-functionalized silica, Cobalt-ferrite silica, nano-biocatalyst	Not applied	Applicable	1. Enhance the whole system's efficiency. 2. Improving handling ability. 3. Improving the enzymatic hydrolysis. 4. Improving the reaction degree. 5. Increasing bioethanol production (>65%).
Animal manure, Agricultural residue, Sludge, and wastes	Biogas	Metal-NPs, metal nutrients, Co, ZVI, Fe_2O_3, Fe_3O_4, Nanographene	Not applied	Applicable	Increasing biogas and methane (CH_4) production.

7. Potential Bioenergy Production and Blending with Nanotechnologies Discussion

A systematic investigation was carried out to weigh the pros and cons of employing bioenergy in Jordan through the use of nanotechnologies to obtain alternative fuels or in the generation of power from both a technological and an environmental standpoint.

In Al-Rossaifa, the volume of liquid waste was reported to be 770 m^3 in 2011, which is capable of generating 5.9 MWh_e of electricity. By utilizing the MSW in the Akaider landfill, approximately 85.62 GWh_e of electricity can be obtained, with CO_2-equivalent savings ranging between 92.86 and 194.8 $\times 10^3$ t/year. Furthermore, using MSW from the Al-Ghabawi landfill would generate around 538.2 GWh_e of electricity, with CO_2-equivalent savings ranging between 582 and 1220 $\times 10^3$ t/year. In addition, the total amount of power that might be theoretically acquired from CH_4 yield per year is 961 GWh_e, which is approximately equal to 5.1% of the total electricity consumption in 2019. Biofuels can also be produced from corn leaf wastes via pyrolysis. Corn leaf biofuel contains a high proportion of conventional diesel (57–73%), allowing it to be used in space heating. Biodiesel can be obtained from Jojoba with an estimated production rate of about 1750.6 t/year and costs around USD 1.19/L, assuming that any glycerol byproducts are sold. However, this price reduces to USD 0.70/L once solketal products, which can be produced from glycerol, are accounted for. Nonedible plant sources of biomass that are available in Jordan include Jojoba, Handal, and Jatropha.

The potential amount of electricity that can be obtained from the biogas products of various biomass feedstocks can be calculated through the following equation:

$$P_e = \frac{f_{CH_4} \times H_{vCH4} \times B_{igas} \times \eta_e}{3.6 \times 10^6} \tag{4}$$

where P_e is the annual potential generation of electricity (GWh_e/year), B_{igas} is the overall annual production of biogas (m^3/year), f_{CH4} is the CH_4 gas fraction in the obtained mixture of biogas, η_e is the efficiency of the electricity generation system (%), and H_{vCH4} is the CH_4 gas heating value (39 MJ/m^3) [37].

Two projects were initiated in Jordan between 2007 and 2015). The first project involved the use of MSW with a power capacity of 20–30 MW, which had an investment volume of USD 30–40 million. The second project was an agricultural initiative to produce bioethanol and biogas, with an initial investment of USD 50–100 million. At the Al-Ghabawi landfill, two waste-to-energy plants transform disposable waste into power via incineration, which has a 6 MW LFG recovery. Another pilot project of LFG recovery is operated by JBC and is located at the old dumpsite at the Ruseifah MSW [36]. The plant at Al-Ruseifah produced nearly 7.6 MCM of biogas in 2011, generating around 8005 MWh_e of electricity [37].

The computational and experimental results presented in this paper indicate that bioenergy produced by such projects (biodiesel, bioethanol, biogas, and biomass) could have a positive impact in a wide variety of fields, such as significant net annual electricity generation, energy security as an alternative fuel source, and the reduction of GHGs emissions. Other valuable products can also be obtained, such as alkyd resins, glycerol, and solketal. Thus, not only would bioenergy projects preserve conventional fossil fuel resources and reduce CO_2 emissions, but new jobs and income opportunities would also be created for locals. Hence, these projects could be viable and feasible in Jordan.

In addition, employing NP technology in biofuel production would be viable and feasible in Jordan as it would lower the cost of biofuel production as well as reduce the number of solvents and catalysts required for the production of biofuels. Thus, employing nanotechnology in current and future bioenergy projects in Jordan could have vital technological, financial, social, and ecological impacts, as is the case in many developed countries. Table 15 briefly summarizes the aspects and possibilities of bioenergy production and blending by using nanotechnology in Jordan.

There are numerous challenges to employing biomass resources in Jordan. First, biomass from animal waste and leftovers is currently underutilized. Jordan has many livestock farms that are becoming increasingly localized within municipalities, with smaller and smaller distances between them. Furthermore, the use of biomass in Jordanian industry, agriculture, and livestock breeding is limited and insufficient. There have been a few instances of small-scale biomass usage, but it is limited to thermal uses (heat) rather than power production. To overcome this obstacle, funds must be raised for pilot plant facilities to transform organic biomass into power on the foundation of well-developed economic models. Furthermore, the lack of a clear strategy, planning, and regulations regarding the deployment of biomass energy projects may hamper the development of an integrated and effective biomass resource management sector in Jordan. However, biomass resources are distributed geographically, making their cultivation and collection complicated. Such distribution is a major impediment to the deployment of biomass-based power plants in Jordan, leading to high manual labor requirements as well as increased assembly, transportation, and storage costs. Furthermore, Jordan lacks a well-equipped biomass laboratory, which has resulted in a lack of research and progress with regard to the development of new biomass products that have higher energy contents, are easier to handle and transport, and are based on a mixture of various solid biomass sources [36,37].

Finally, if the Jordan government wants to pursue strategies to promote bioenergy usage as an energy solution, it must look for ways to compensate for the price disadvantage of bioenergy production compared to petroleum-based fuels. This can be performed via primary commodity assistance programs for bioenergy yields as well as financial incentives for investment. In addition to investment laws, a critical component of the implementation of a long-term plan to boost bioenergy applications for alternative fuels and energy production is the establishment of trading platforms that may provide affordable assistance to power generators for the use of carbon fuel substitutes and decreased GHG emissions. Financial incentives for cooperative farm owner organizations with regards to the regulation and organization of the gathering of distributed biomass feedstock such as MSW, lipids, energy crops, nonedible natural crops, and agricultural byproducts should also be encouraged; this can be accomplished by collecting feedstocks in abandoned open spaces at Jordan governorates for use as alternative fuels, electricity generation purposes, as well as other medical and synthetic products. This would contribute significantly to ensuring a dependable supply of feedstock at a fair price.

8. Conclusions

Our findings show that biomass residues have the potential to contribute greatly to the energy mix. Between 2014 and 2019, approximately 1284, 10910, and 16,094 kilotons of agricultural residue, animal manure, and MSW were available as biomass resources each year, respectively. Jordan also has access to excellent biomass resources in the form of nonedible plants such as Jojoba, Handal, and Jatropha. Thus, Jordan has the potential to generate a significant amount of bioenergy in the future, derived primarily from agricultural residues and animal manure. The total amount of biogas that could potentially be created is around 817 MCM/year. The total theoretical power obtained from CH_4 is approximately 961 GWh/year, which was equivalent to around 5.1% of the energy demand in 2019. By utilizing the MSW in Akaider and Al-Ghabawi landfills, approximately 85.62 GWh_e and 538.2 GWh_e of electricity could be obtained, respectively. Some feasible bioenergy projects have been presented in Jordan, such as biodiesel produced from nonedible Jojoba plants, biofuel from corn leaf wastes through pyrolysis processes, and biogas production. Finally, the biomass produced could be used to power local household biogas systems. Jordan's biomass resources can be transformed into various types of usable bioenergy such as biofuels, electricity, as well as other byproducts (alkyd resin, solketal, and glycerol). This paper illustrates the use of various nanoparticles to improve fuel properties and quantity. Thus, our findings show that the following:

1. Nanoparticles can boost overall performance in biofuel production in range of (82.3–98.0%);
2. To fulfill the next energy requirements, nanoparticles have the potential to significantly improve the quality and quantity of biofuel production in range of (11.0–166.1%);

3. Nanoparticles have enhanced the emissions, efficiency, and combustion characteristics of IC engines; BSFC (0.20–1.08 kg/kWh) and BTE (24.5–40%), CO (0.02–0.44% by volume), NO_x (257.37–1600 ppm), hydrocarbon (12–102 ppm), and smoke opacity (0.706–52%);
4. Nanotechnologies employed in conjunction with bioenergy production could contribute significantly to Jordan's energy mix. This would have a significant positive socioeconomic and environmental impact, as well as contribute to Jordan's energy independence and environmental protection;
5. Jordan's bioenergy/biomass savings and revenue would allow for further investments into health, education, and social assets that would improve long-term local security, livelihood, and productivity;
6. In the future, nanoparticle technologies will have large-scale applications in biofuel production and the fuel sector, overcoming numerous technological and commercial obstacles.

Finally, in addition to aid from the central government, local governments/communities can be given the responsibility to execute such projects and should implement appropriate practices and policies, such as aimed education programs or coordinated promotional campaigns, to accomplish a sustainable and environmentally friendly energy future.

Author Contributions: All authors contributed to the study conception and design. All authors are equal in material preparation, data collection and analysis. The first draft of the manuscript was written by (A.K.A.-B.) and all authors commented on previous versions of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Data Availability Statement: All data are available in the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

ABEI	Acetone-Butanol-Ethanol-Isopropanol
AD	Anaerobic Digestion
Au	Gold
BD	Bio Diesel
BFCS	Biofuel Cells
BG	Biogas
BMEP	Brake Mean Effective Pressure
BSFC	Brake-Specific Fuel Consumption
BTE	Brake thermal efficiency
CA	Citric Acid
CAPEX	Capital Expenditure
CBNs	Carbon-Based Nanomaterials
CBSCs	Carbon-Based Sulfonated Catalysts
CaO	Calcium Oxide
CH_4	Methane
CHC	Canola Hazelnut Cottonseed
CI	Compression Ignition
CNT	Carbon Nano Tube
CO	Carbone Monoxide
CO_2	Carbone Dioxide
CP	Cylinder Pressure
cSt	Centistokes
DI	Direct Injection
Db	Dry Basis
EBFCs	Enzymatic Biofuel Cells

EGT	Exhaust Gas Temperature
FAME	Fatty Acid Methyl Ester
FC	Fuel Cell
Fe	Iron
FFA	Free Fatty Acid
GHGs	Greenhouse Gases
GOx	Glucose Oxidase
Ha	Hectare
HC	Hydro Carbone
HEOC	Hybrid Enzymatic and Organic Cascade
HHR	Heat Release Rate
HTCC	Hydrothermal Carbon Catalyst
H_2SO_4	Sulfuric Acid
I_2	Iodine
IRR	Internal Rate of Return
KOH	Potassium Hydroxide
LFG	Landfill Gas
MCM	Million Cubic Meter
MFCs	Microbial Fuel Cells
MgO	Magnesium Oxide
Ml	Milliliter
MOME	Mustard Oil Methyl Ester
MSW	Municipal Solid Waste
Na_2SO_4	Sodium Sulfate
NaOH	Sodium Hydroxide
Nm	Nano Meter
NOx	Nitrogen Oxides
NPs	Nano Particles
NPV	Net Present Value
OPEX	Operating Expenditure
PM	Particle Matter
PMEFCs	Proton Exchange Membrane Fuel Cells
Pt	Platinum
RE	Renewable Energy
SCS	Sunflower Corn–Soybean
STC	Standard Test Conditions
TEMPO	2,2,6,6-tetramethyl-1-piperidine N-oxyl
TL	Thermomyces Lanuginosus
tph	Ton per Hour
VS	Volatile Solid
Wi	Indicated Work
wt%	Percentage Weight
WWTPs	Wastewater Treatment Plants

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