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Research Article

Biomass & Bioenergy; case studies Bioresources, chemical and biological processes, biomass products for sustainable, renewable energy and materials

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Abstract

Over the next two decades, the proportion of global energy demand attributed to fuel consumption will grow. The escalating costs of fossil fuels and apprehensions regarding the ecological repercussions of greenhouse gas emissions have rekindled the enthusiasm for the advancement of alternate energy sources. The Fukushima Daiichi incident was a pivotal moment in the demand for alternative energy sources. Renewable energy is currently seen as a preferable fuel source compared to nuclear power, primarily because it lacks the potential risks and tragedies associated with it. Since carbon dioxide is the primary constituent of greenhouse gases, there is a worldwide apprehension regarding mitigating carbon emissions. Various strategies can be implemented to decrease carbon emissions, including promoting the use of renewable energy and fostering technological advancements. Two primary methods can be employed to mitigate CO2 emissions and address the issue of climate change: substituting fossil fuels with renewable energy sources to the greatest extent feasible and improving energy efficiency. This article explores potential solutions to enhance renewable energy deployment and increase energy consumption efficiency. There is widespread international concern about the utilization of biomass waste as a primary resource for producing biofuel/ biochar and renewable energy. Pyrolysis is a thermal process used to handle biomass wastes, creating liquid, solid, and gaseous products. Regrettably, a high level of heat is required to dismantle the intricate composition of biomass resources to obtain useable products. Microwave heating shows excellent potential as a viable alternative to existing heating technologies. Pyrolysis has recently gained significant popularity due to its user-friendly nature and rapid heating capabilities. Biomass can be assessed by microwave-assisted pyrolysis, which reduces temperature and minimizes energy use. Nevertheless, the lack of a complete understanding of low-temperature behaviors and the absence of scale-up demonstrations restrict the potential for industrial utilization. Laboratory investigations have shown that rice straw pyrolysis-using microwave heating occurs within a temperature range of 250–300 oC. Additionally, the activation energy for this process is around 40–150 kJ/mol lower compared to conventional pyrolysis. The discovery revealed that interlinking had a beneficial effect on reducing activation energy, temperature, immediate hotspots, and the dielectric loss factor of biomass. A pilot scale microwave-aided pyrolysis auger reactor, capable of processing 80 kg/h, will be created based on the obtained results. The reactor will operate continuously within the temperature range of 200-300 oC, achieving a net energy ratio of 72%. The practicality of a small-scale operation will be proved by the capacity to generate enough heat and by an economic study. This analysis has determined that this technology is suitable for a portable and decentralized biomass conversion system.

INTRODUCTION

Biomass refers to any substance derived from plants or animals that can be converted into usable forms of energy (such as electricity or heat) or used in various industrial operations as a raw material for multiple goods. It may be purposefully planted energy crops (such as miscanthus or switchgrass), wood or forest leftovers, waste from food crops (such as wheat straw or bagasse), horticulture (such as yard waste), food processing (such as maize cobs), animal farming (manure, which is rich in nitrogen and phosphorus), or even human waste from sewage treatment plants [1].

Even though the combustion of biomass derived from plants results in carbon dioxide emission, this type of fuel is nevertheless considered a renewable energy source within the legal frameworks of the European Union and the United Nations. This is because photosynthesis recycles the CO_2 back into new plant life. This cycling of CO_2 from plants into the atmosphere and then back into plants can sometimes even result in a net loss of CO_2 because a sizeable percentage of the CO_2 is transferred from the atmosphere into the soil throughout each cycle. Co-firing with biomass has become more common in coal power plants since it enables these facilities to reduce their CO_2 emissions without incurring the costs that come along with the construction of new infrastructure. However, co-firing is not without its drawbacks; frequently, an improvement to the biomass would be beneficial. Fluctuating fuels to ones of a higher quality can be accomplished through a variety of processes, the most general of which are thermal, chemical, and biological [1,2].

Bioenergy refers to renewable energy that is generated from organic resources. Biomass refers to any organic substance that has accumulated solar energy in the form of chemical potential. As a fuel, it can consist of wood, wood waste, straw, crop leftovers, manure, sugarcane, and other by-products derived from different agricultural operations. As of 2010, the total global bioenergy capacity for generating electricity was 35 GW (equivalent to 47,000,000 horsepower), with the United States accounting for 7 GW (equivalent to 9,400,000 horsepower) [2].

In its strictest sense, it is a term that can be used interchangeably with biofuel, which refers to fuel that, is obtained from biological sources. In a more comprehensive context, it encompasses biomass, which refers to the organic matter utilized as a biofuel, along with the social, economic, scientific, and technical domains linked to the utilization of biological resources for energy purposes. There is a widespread misunderstanding that needs clarification. Bioenergy refers to the energy derived from biomass, which serves as the fuel. Bioenergy represents the energy content within the fuel itself [2,3].

BIOMASS CONVERSIONS

Thermal conversion

The use of heat as the primary catalyst in conversion processes makes biomass into a fuel that is superior in quality and more applicable to real-world applications. Torrefaction, pyrolysis, and gasification are the three primary options, and they are distinguished from one another primarily by the degree to which the chemical reactions involved are allowed to occur (this is mainly controlled by the amount of oxygen that is present and the temperature at which the conversion takes place) [4,5,6].

Chemical conversion

The conversion of biomass into various forms can be accomplished by a variety of chemical processes. These processes might be utilized, for example, to produce a fuel that is easier to store, transport, and use, or they can be used to take advantage of a quality that is inherent to the process itself. The Fischer-Tropsch synthesis is one example of several of these processes that are largely derived from coal-based technologies that are very similar to one another. The conversion of biomass into a variety of different commodity chemicals is possible [7,8].

Biochemical conversion

Since biomass is a naturally occurring substance, the molecules it is made of are broken down by numerous highly efficient biochemical processes that can be exploited. Anaerobic digestion, fermentation, and composting are all examples of conversion processes that typically rely on the activity of microorganisms [9].

Electrochemical conversion

Electrochemical (electrocatalytic) oxidation of biomass can be used to produce electricity straight from the feedstock. Direct carbon fuel cells, direct liquid fuel cells like an ethanol fuel cells, methanol fuel cells, formic acid fuel cell, vitamin C fuel cell, and even microbial fuel cells are all capable of doing this task directly. Indirectly, the fuel can be used in a fuel cell system by first being converted into a combination of carbon monoxide and hydrogen gas via a reformer [10,11].

SOLID BIOMASS

A benefit of biomass fuel is its frequent derivation from by-products, residues, or waste-products of various industries, such as farming, animal husbandry, and forestry. Conceptually, this implies that there is no rivalry between the production of fuel and food, although this is not universally true. When assessing the viability of using biomass as a source of energy, it is important to take into account factors such as land usage, current biomass companies, and appropriate conversion technologies [11,12].

Biomass refers to the substance obtained from organisms that have recently been alive, encompassing plants, animals, and their byproducts. Manure, yard trash, and crop leftovers are all forms of biomass. Renewable energy is derived from the carbon cycle, distinguishing it from other natural resources like petroleum, coal, and nuclear fuels. Animal waste is a chronic and inescapable pollution that the animals mostly create kept in large-scale farms [10, 13].

ENVIRONMENTAL IMPACT OF BIOMASS

The process of combustion results in the emission of carbon dioxide (CO_2) into the atmosphere from biomass. After an extended duration spanning from several months to decades, vegetation and trees absorb the carbon dioxide (CO_2) emissions generated during the combustion process [13]. Nonetheless, destructive forestry practices may result in a reduction of the overall carbon storage capacity of forests. Every biomass produced is a carbon sequester. As an illustration, it has been noted that the concentration of soil organic carbon is higher beneath switch grass crops as opposed to cultivated cropland, particularly at depths below 30 cm (12 in). McCalmont et al. discovered accumulation rates for Miscanthus and giganteus that varied between 0.42 and 3.8 tonnes per hectare per year, with an average rate of 1.84 tonnes (0.74 tonnes per acre per year), which corresponds to 20% of the total carbon harvested annually. The effectiveness of forest-based biomass initiatives in mitigating greenhouse gas emissions has been called into question by several environmental organizations, such as the Natural Resources Defence Council and Greenpeace [9]. Furthermore, environmental organizations contend that the process of carbon capture by newly planted trees from the carbon emissions generated during biomass combustion could potentially span decades. Air pollutants such as carbon monoxide, volatile organic compounds, particulates, and others are emitted when biomass is burned [10,14].

ENVIRONMENTAL IMPACT OF BIOENERGY

Several environmental organizations, such as Greenpeace and the Natural Resources Defence Council, have recently criticized certain types of forest bioenergy due to their detrimental effects on forests and the climate. Greenpeace has recently published a paper titled "Fuelling a Biomass" that details their worries over forest bioenergy [15]. Utilizing trees for energy generation promotes Whole-Tree Harvesting, as any portion of the tree can be burned. However, this practice extracts more nutrients and soil cover than ordinary harvesting, posing a potential threat to the forest's long-term well-being. Forest biomass in certain areas is progressively composed of vital components for the proper functioning of forest ecosystems. These components include intact trees, naturally disturbed forests, and remnants of conventional logging activities that were previously left within the forest [14]. Environmental organizations also reference recent scientific studies that have revealed the prolonged timeframe required for re-growing trees to recapture the carbon emitted from burning biomass, particularly in areas with low productivity. Additionally, logging activities have the potential to disrupt forest soils and trigger the release of stored carbon. Given the urgent necessity to promptly decrease greenhouse gas emissions to alleviate the impacts of climate change, several environmental organizations object to the extensive utilization of forest biomass for electricity generation [15].

IMPORTANCE OF BIOMASS & BIOENERGY

Biomass is a sustainable and environmentally friendly energy source that has the potential to significantly enhance our environment, economy, and energy stability. Biomass energy exhibits significantly lower air emissions than fossil fuels, diminishes the quantity of waste directed to landfills, and lessens our dependence on foreign oil [9,10]. Biofuels are crucial as they serve as substitutes for petroleum-based fuels. Biomass and biofuels can be an alternative to fossil fuels for producing heat, electricity, and chemicals [8].

ADVANTAGES OF BIOMASS ENERGY

Bioenergy systems have the potential to significantly reduce greenhouse gas emissions by replacing fossil fuels in energy production. Biomass mitigates emissions and improves carbon sequestration by allowing short-rotation crops or forests to deposit carbon in the soil of abandoned agricultural land [7,11,15]. Bioenergy often permanently reduces carbon dioxide emissions by decreasing them at the origin. However, it has the potential to release more carbon per unit of energy compared to fossil fuels unless the production of biomass fuels is done in an unsustainable manner. Biomass has the potential to significantly decrease dependence on fossil fuels through the utilization of thermochemical conversion technology.

Furthermore, the enhanced utilization of biomass-derived fuels will play a crucial role in protecting the environment, creating new employment prospects, promoting sustainable development, and improving health conditions in rural regions. Efficient biomass handling technology, enhanced agro-forestry systems, and small and large-scale biomass-based power plant installation can significantly contribute to rural development. Biomass energy has the potential to facilitate the modernization of the agricultural industry [8,13].

LIMITS TO GROWTH

Various limitations, conflicts, and competition will restrict the development and use of bio-energy. As bio-energy utilization expands to become a substantial energy source, it faces escalating conflict and eventually reaches its maximum capacity. Other purchasers of biomass feedstocks, such as those in the food, textile, construction, and paper industries, may be willing to offer higher feedstock prices than the energy sector. As per the National Renewable Energy Lab, food constitutes 62 % of the annual usage of 6 billion metric tonnes of biomass, with wood products being the majority of the remaining portion [16].

Bio-energy faces land use constraints due to conflicts arising from competing demands for food production and the preservation of natural habitats and forests. There is a limited amount of biomass waste and a finite number of unusable "degraded" sites from which it can be obtained. Wildlife advocates have valid concerns about the potential negative impact of an uncontrolled bio-energy business on natural habitats, particularly in nations with inadequate safeguards [6,9,13].

Optimal efficiency is essential when utilizing any biomass for energy purposes. Although utilities frequently attempt to convert, outdated and inefficient coal plants into biomass facilities, this strategy results in excessive wastage of valuable biomass resources and poses complex logistical challenges. An optimal biomass plant efficiently generates thermal energy and electricity, incorporates particulate scrubbers to capture fine particles, and relies on a sustainable and locally sourced feedstock [12].

THE ROLE OF BIOMASS AND BIO-ENERGY IN THE FUTURE

The European Commission has established a 2050 objective to cultivate a competitive, resource-efficient, and low-carbon economy. The bioeconomy is anticipated to significantly impact the low-carbon economy [5, 10]. This research study offers an analysis of the policy framework in place for developing a bioeconomy in the European Union. The areas covered include energy and climate, agriculture and forestry, industry, and research. Europe is home to several established traditional bio-based industries, including agriculture, food, feed, fiber, and forest-based sectors. This report aims to analyze the present state of the bioeconomy in the European Union and globally, up until 2020 and beyond [11]. The current valuation of the bio economy market is approximately €2.4 billion, encompassing sectors such as agriculture, food and beverage, agro-industrial products, fisheries and aquaculture, forestry, wood-based industry, biochemicals, enzymes, biopharmaceuticals, biofuels, and bioenergy. This market utilizes around 2 billion tonnes of resources and employs 22 million individuals [12,14]. Emerging sectors, such as biomaterials and green chemistry, are now being developed. The shift towards a bioeconomy will hinge on the progress in technology across various processes, the attainment of a significant improvement in terms of technical capabilities and cost efficiency, and will be contingent upon the accessibility of sustainable biomass [16].

HIGHLIGHTS

The European Union has established the objective of cultivating a low-carbon economy by 2050.

The bioeconomy has the potential to be a significant contributor to the development of a low-carbon economy.

The European Union possesses several firmly established conventional bio-based sectors.

The EU's current bioeconomy market has been projected to be approximately €2.4 billion.

The success of the bio-economy hinges on advancements in technology, economic efficiency, and biomass availability.

THE RESEARCH AIM AND OBJECTIVES ARE AS FOLLOWS: FOR NON-EDIBLE VEGETABLE OIL BIOFUEL

Using morphological and palynological characteristics, verify plant species' correct identification and taxonomic classification.

To evaluate the output, byproduct, and characterization of oil from plant species to assess their biofuel potential.

We need to look into the viability of new plant species that provide oil for use in biofuels and biodiesel.

To optimize the transesterification process for biodiesel production, learning the effects of using homogenous solid-base catalysts is necessary.

Optimum biodiesel/biofuel yield can be achieved by analyzing the effects of various reaction factors.

Using GC-MS, LC-MS, FT-IR, NMR, and AAS, characterize the composition and confirm the prepared biodiesel/biofuel synthesis.

Oil extracted from non-edible plants will be tested using the aforementioned methods to ensure its authenticity and quality.

To assess the fuel compatibility of prepared biodiesel in comparison with mineral diesel utilizing ASTM D6751 and EN14214 biodiesel standards for future deployment in diesel engines.

Based on fuel characteristics and metal analysis, the research will be compare plant biofuel to HSD (High Speed Diesel).

This study aims to thoroughly assess the pros and cons associated with synthesizing biodiesel from non-edible plant seed oil. Initial investigations suggest that the production of plant seed oil that is unsuitable for consumption holds significant promise for the manufacture of biodiesel; however, it does come with certain obstacles.

THIS RESEARCH AIMS TO ANSWER THE FOLLOWING QUESTIONS

1. Does non-edible plant seed oil biodiesel possess the characteristics of a high-quality biodiesel fuel?

2. What is the comparative analysis between biodiesel derived from non-edible plant seed oil and biodiesel produced from other energy crops?

3. Some legal and market difficulties that limit biodiesel production from non-edible plant seed oil include regulatory restrictions and barriers, as well as challenges related to market demand and competition.

4. Can non-edible plant seed oil be utilized for extensive biodiesel production?

5. What are some suggestions to tackle the obstacles impacting biodiesel manufacture from non-edible plant seed oil?

AIMS AND OBJECTIVES: FOR ALGAL BIOFUEL

This research aims to create and evaluate a specialized impact assessment tool for algal biofuel production technologies. The tool will be used to identify and compare potential impacts and assess the effectiveness of current biofuel policy in managing risks. The UK is a significant benchmark because of its current position as a leader in technology advancement in this field, along with its well-established environmental regulation structure. To achieve this goal, it was necessary to tackle several interconnected objectives:

This research aims to create and evaluate a specialized impact assessment tool for algal biofuel production systems to detect and compare potential effects.

(i) To evaluate the prospective ecological and broader sustainability consequences and hazards associated with algae biofuel production by analyzing literature, pertinent policy frameworks, and interviews with specific experts. The effects have been widely classified and encompass biodiversity effects, water discharges, water consumption, global warming potential, waste, air pollutants, and accidents.

(ii) Create a weighted quantitative matrix as an analytical tool to estimate the impact of prospective impacts.

(iii) Utilise this impact assessment technique to evaluate and compare the potential risks associated with five hypothetical scenarios involving distinct production sites (land, intermediate coastal and offshore). This assessment will be conducted statistically to determine which option has a higher level of risk.

(iv) The objective is to evaluate the effectiveness of existing policies in controlling these related effects and provide suggestions on areas where current rules may need to be modified to promote the long-term viability of the future algal biofuel business.

This paper will provide a comprehensive overview of algae as a biofuel, including the rationale behind the solid commercial interest and the notable consequences associated with the algal biofuel business. The existing policy will be evaluated on five of the most extensively debated prospective algal biofuel production systems. The review will provide a summary and evaluation of the current policy's sufficiency in relation to the microbiological level of the organization. It will identify any shortcomings and provide recommendations for improvement. The subsequent primary sections of this report are delineated in the subsequent literature review, materials and techniques, results, discussion, and conclusions [14,15,16].

AIMS AND OBJECTIVES REVISITED FOR ALGAL BIOFUEL

The research aimed to thoroughly assess the limitations that policies impose on major industrial projects, such as algal biomass production systems [4]. The purpose of environmental policy is to uphold environmental standards. While commercial algal biofuel interest groups may not see these regulatory limits favorably, they are essential for preserving a sustainable planet [1,2]. The findings of this paper indicate that policy may not always be as impervious as it should be. This study explores the variation in governance across different levels of organization as a recurring subject. This is particularly significant when analyzing the policy explicitly implemented to uphold microbial-level standards in a maritime environment [7,8,9]. Here, a higher level of care is necessary to ensure sufficient management of algal modification. This research aims to offer a comprehensive understanding of the diverse effects linked to the algae biofuel business and the key policies involved. It also highlights areas where legislative adjustments may be necessary to facilitate the transition towards this kind of commercial energy generation [10].

ENVIRONMENTAL CONCERNS AND FUTURE DIRECTIONS

From a critical perspective, there is ongoing research on biofuel/biochar, although its widespread implementation has not yet been achieved. The limited adoption of biochar is mostly due to significant environmental concerns and the lack of adequate industrial infrastructure in many underdeveloped countries [3,6,7]. To effectively tackle potential environmental concerns and promote the adoption of biochar in developing countries, extensive and rigorous research is necessary. This research should provide practical advice for utilizing biochar. We shall concisely examine and evaluate the presented themes from multiple perspectives, encompassing any possible ecological apprehensions and recommended areas for further research [7]. While there are numerous readily available sources of raw materials for biochar synthesis, these materials must undergo initial processing (such as grinding, washing, and drying) before pyrolysis. To achieve optimal sorption, additional modification steps are required. Implementing these treatments will inevitably lead to an increase in the production cost of biochar compared to conventional activated carbon. Hence, to minimize expenses, forthcoming investigations should aim to achieve an equilibrium between augmenting the utilization of biochar and optimizing the manufacturing procedure [9]. It is crucial to carefully analyze the choice of feedstock's, production conditions, and modification procedures to achieve biochar with enhanced performance. Compiling a substantial amount of previous study findings can assist in pursuing the most efficient solutions. For example, when carbonized at the same temperature, cellulose biochar had a greater micropore area (280 m_2g^{-1}) compared to lignin biochar (200 m_2g^{-1}) due to lignin's resistance. This suggests that cellulose biomass is more suitable than lignin biomass for biochar formation [13]. Moreover, the biomass/plant straw (pinewood) biochar that underwent pyrolysis at elevated temperatures exhibited increased surface area and total pore volume. When utilizing biochar in actual scenarios, it is crucial to consider its stability. Research has found that organic materials' strong aromaticity and durability can lead to the dissolution of organic matter from biochar when it interacts with heavy metals. This process has the potential to increase the carbon content in water. Moreover, it is plausible that the biochars, especially those derived from sewage sludge, may include substantial amounts of heavy metals that have the potential to leach out during usage, resulting in additional heavy metal contamination [11]. In the context of biochar-based composites, inadequate fixation of the embedded components may result in the potential leaching of some of these components from the biochar matrix. Considering that the stability of biochar is closely linked to the stability of its carbon structure [9, 13], it is imperative to conduct a study on the impact of carbonization conditions on the carbon content and structure. Hydrothermal carbonization yields biochar with a higher carbon content [14] when compared to biochar produced through gasification and pyrolysis. Furthermore, it is highly recommended to consistently monitor the water quality throughout the whole lifespan of the sorbents' application. In order to assess toxicity or leaching, it is recommended to use water fleas, algae, fish, or luminous bacteria as indicators to determine if the biochar contains any hazardous compounds [15]. Prior research has primarily focused on the adsorption of a particular pollutant in water-based systems. However, in real-world water scenarios, many contaminants are present simultaneously, leading to the observation of both synergistic and antagonistic sorption effects. The presence of various contaminants can lead to ionic interference and competition for sorption sites, resulting in a decrease in removal efficiency. Currently, there is a scarcity of empirical investigations on co-

contaminant sorption. This makes simultaneous sorption models appealing since they have the potential to reveal the synergistic or antagonistic sorption mechanisms involved. Reports on biochar sorption should provide comprehensive information regarding the sorption conditions and properties of the sorbent to facilitate future research. Several endeavors to create prospective sorption models have been documented, such as employing simulated molecular equations to investigate the competitive sorption of co-contaminants [8,9], novel meta-analysis techniques [14], and comprehensive analysis [4]. While there is a consensus that biochar is more cost-effective, renewable, and environmentally friendly than activated carbon [16], exploring methods for recovering and desorbing waste biochar remains important. An effective approach involves magnetizing the biochar, allowing an external magnetic field to separate the biochar, which contains contaminants, from water. Nevertheless, the process of removing spent biochar could incur significant costs. Alternatively, waste biochar can be utilized as a valuable resource, enabling the recycling of waste biochar distinctly when it is not feasible to desorb and recover pollutants sorbed onto the biochar. For example, biochar that contains high levels of nitrogen (N) and phosphorus (P) might be used as a slow-release fertilizer in agriculture or ecological restoration [17]. Hence, biochar exposed to Cu or Zn can also serve as a micronutrient fertilizer. Nevertheless, assessing the potential for any noxious compounds to seep out of the biochar and subsequently be assimilated by crops, finally entering the food chain, is crucial. Hence, further investigation is required to ascertain the safety of utilizing waste biochar for soil application.

CONCLUSION

Based on the research and analysis conducted for the literature review, the following findings and suggestions can be made. Microwave-assisted pyrolysis is a cutting-edge method for treating biomass waste on-site by efficiently using microwave heating. Many researchers have turned to microwave heating to recover energy from biomass wastes and convert them into marketable commodities to solve this issue. The oils and charcoal obtained using this approach yield more compounds of interest to industry and give less hazardous substances than those acquired by conventional pyrolysis. It is equally desirable and valuable that the gas component delivers hydrogen or syngas at higher rates. Instead of sending trash to a landfill or burning it, as is commonly done, microwave-assisted pyrolysis provides a viable alternative that can be used to recover valuable materials from rubbish for commercial purposes. This process is controlled by several parameters and environmental factors, many of which continue to cause issues and may benefit from further optimization. Process optimization can be used to determine the optimal values for the many parameters involved in the microwave-assisted pyrolysis process, paving the way for its eventual industrialization. New technologies benefit significantly from base cost analysis. The commercialization of microwave-assisted pyrolysis would also benefit from a thorough mass-energy balance and cost-benefit study.

Conflicts of interest

I (Dr. Inam Ullah Khan) confirm as an author and declare that there are no known conflicts of interest associated with this publication.

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