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| Original Article |
| Current energy recycling technology for agricultural waste in Malaysia |
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| **Abstract**This article examines the production and use of biomass as a renewable energy source in Malaysia, focusing on the agricultural processing industry. Malaysia produces approximately 168 million tonnes of biomass, including palm oil waste, rice husks, coconut debris, sugar cane waste, urban waste, and forestry waste. The abundance of biomass resources provides a competitive advantage over other renewable energy sources. However, the industry faces restrictions and challenges, such as high disposal costs, high electricity consumption, and related expenses. To address these issues, it is crucial to study the types of biomass available, current technology for biomass energy production (waste-to-energy), and relevant environmental motivations, initiatives, and legislation. This paper analyses the agricultural waste available for energy generation, existing technologies for converting waste into energy, and the role of environmental policies in the agricultural processing business. Energy recycling, which involves utilizing agricultural waste to generate electricity and thermal energy, is proposed as a viable solution. Several technologies are explored, including anaerobic digestion, gasification, incineration/combustion, and pyrolysis, each with advantages and disadvantages. Thermochemical processes are highlighted for their effectiveness, requiring minimal pre-treatment, shorter reaction times, and adaptability to various biomass feedstocks and climatic conditions. The implementation of incentives, initiatives, and policies by the Malaysian government serves as guidelines for the agricultural processing industry to adopt energy recycling practices. By emphasising energy sustainability and promoting green building initiatives, the industry can contribute to a more sustainable and environmentally friendly energy landscape. **Copyright © 2024 PENERBIT AKADEMIA BARU - All rights reserved** | **Article Info**Received xxxxxxxxx Received in revised form xxxxxxAccepted xxxxxxx Available online xxxxxxx**Keywords**BiomassEnergy sustainability Sustainable AgriculturalGreen building |

# 1 Introduction

Energy is essential to life, and fossil fuel depletion has become a global issue. Coal, oil and natural gas are widely used fossil fuels in developed and developing countries. The agricultural processing industry heavily depends on fossil fuels and contributes significantly to greenhouse gas emissions (GHG). The bulk of CO2 emissions from fossil fuel burning are emitted by power production, industrialization, mobility, and commercial and residential construction, contributing to approximately 66% of global

CO2 emissions [[1](#_bookmark6)]. In 2019, the gross final energy usage of all energy sources worldwide was 379 EJ; renewable energy accounted for 17% of the total [[2](#_bookmark7)].

Renewable energy is central to achieving international goals: increasing energy efficiency and access to renewable energy [[3](#_bookmark8)]. Renewable energy sources have emerged as a significant contributor to global energy production, accounting for approximately 50% of new energy capacity, according to the International Energy Agency (IEA). These sources have become the second most vital electricity supply after coal. Furthermore, the IEA projects a substantial increase in global electricity demand, estimating a 70% surge by 2040 [[4](#_bookmark9)].

# Biomass waste for energy in the agricultural processing industry

Biomass, the fourth largest global energy source comprising 51 EJ of global energy supply, contributes around 16% of the total energy consumption, with palm oil accounting for 51% and agricultural waste accounting for 22%. There are massive benefits of using biomass resources as a fuel in generating renewable energy, including the fact that biomass resources are carbon neutral, reduce overreliance on fossil fuels, save money on fossil fuels, provide a source of revenue for manufacturers, and reduce garbage in landfills. Biomass is a carbon-neutral resource; the amount of carbon released into the atmosphere is equivalent to the amount absorbed by plants over their life cycle.

Researchers have shown significant interest in converting biomass into biochar as an economically viable and environmentally sustainable approach for waste recycling and environmental protection [[7](#_bookmark12)]. Biomass, the fourth largest global energy source, contributes 51 EJ to the global energy supply [[8](#_bookmark13)]. This resource accounts for approximately 16% of the total energy consumption, with palm oil constituting 51% and agricultural waste representing 22% of the biomass composition. Utilizing biomass resources as fuel for renewable energy generation offers substantial advantages, including carbon neutrality, reduced reliance on fossil fuels, cost savings, revenue generation for manufacturers, and waste reduction in landfills. It is worth noting that biomass is a carbon-neutral resource, as the carbon released during its use is offset by the carbon absorbed by plants throughout their life cycle [[9](#_bookmark14)[,10](#_bookmark15)].

**Table 1** Malaysia biomass production [[11](#_bookmark16)–[13](#_bookmark18)].

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Source** | **Source (kilo tonne)** | **Components for RE** | **Quantity (kilo tonne)** | **Moisture content (wt%)** |
| **Oil Palm** | 95700 | Oil palm fronds | 1150 | 60 |
| EPFB | 76560 | 50-75 |
| POME | 57420 | 80-95 |
| **Coconut** | 561 | Coconut husk | 190 | 11.5 |
| **Cocoa** | 0.76 | Cocoa pod | 0.56 | 12.58 |

However, biomass resources with high moisture content, such as oil palm trunks with a moisture content of 75%, require additional drying processes before they can be effectively utilized as a fuel in the green industry for renewable energy generation [[12](#_bookmark17)]. These drying procedures ensure that the moisture content of the biomass is reduced to an optimal level, enhancing its suitability for efficient energy conversion. By addressing the moisture content, biomass resources like oil palm trunks can be effectively harnessed as a valuable fuel source in the green industry, supporting renewable energy

generation.

# 2 Energy recycling

Electricity energy in Malaysia is generated both by fossil fuel and renewable resources. Fossil fuel energy consumption comprises biodiesel, coal, petroleum, and natural gas products. International Energy Agency, Energy Balance for Non-OECD Countries – 2012 Edition reported that the rate of energy imports had grown rapidly at 7.2% per year to accommodate rising energy demands of 5.8% per year [[18](#_bookmark22)]. Malaysia will have to import fossil fuels to offset its dependency due to its heavy demand for fossil fuels and the decrease of local fossil fuel reserves. It is critical to have a well-balanced fuel mix of fossil and renewable sources. Besides, it was published in Malaysia Energy Statistics Handbook 2020 that the total energy consumption increased rapidly year by year from 13,122 ktoe in 1990 to 64,658 ktoe in 2018 [[19](#_bookmark23)].

Energy recycling (waste-to-energy) restores energy that would otherwise be lost in industrial processes by flaring, releasing it to the surroundings, or using less efficient machinery. It can be converted instead into usable energy, such as electricity or heat (steam or heated water) [[20](#_bookmark24)].

Malaysia possesses abundant biomass resources and encompasses a land area totaling 32.90 million hectares, presenting a significant opportunity for the agricultural processing industry to contribute to energy recycling. The distribution of crops in Malaysia is as follows: oil palm accounts for 35.2%, rubber for 2.3%, and other crops such as cocoa, coconut, paddy, and others collectively contribute 29.3% [[21](#_bookmark25)[,22](#_bookmark26)]. In recent scientific discourse, considerable attention has been directed toward plant biomass as an alternative to fossil fuels. The renewable nature of biomass has emerged as a significant factor in this interest [[23](#_bookmark27)]. Notably, biomass possesses distinct advantages over other renewable energy sources as it has the potential to cater to the entire spectrum of energy requirements, encompassing heating/cooling, electricity, and fuels, without encountering significant storage challenges. Additionally, biomass exhibits versatility in its conversion into solid, liquid, and gaseous energy sources through various thermo-chemical, physical-chemical, and biochemical processes. These processes enable the generation of power, fuels, and heating/cooling through combustion or complete oxidation.

# 3 Types of technology for energy recycling

Agro-based industries produce agricultural waste as a result of agricultural activities. One of the agricultural wastes in Malaysia is biomass which produces at least 168 million tonnes annually [[24](#_bookmark28)]. Malaysia critically requires effective waste treatment facilities and infrastructure to address its waste issues, as recycling alone might not be sufficient. Previously, waste incineration was the preferred method for reducing waste volume and destroying dangerous substances, minimizing human health risks [[25](#_bookmark29)]. These include material recovery facilities or recycling plants, composting plants, anaerobic digesters, and waste-to-energy plants in the current era [[26](#_bookmark30)]. When considering electricity yields and heat, incineration seems to be the best option; however, if solely considering electricity production, anaerobic digestion might be better [[27](#_bookmark31)]. As a result, appropriate utilization of waste's energy potential through economically and technically viable solutions can aid in promoting sustainability and fulfilling global renewable energy demand [[28](#_bookmark32)]. [Table 2](#_bookmark2) summarises the possible energy recycling technology in its respective industry and fields.

**Table 2** Types of technology and the related industry/field.

|  |  |
| --- | --- |
| **Technology** | **Industry / Field** |
| **Anaerobic digestion plant** | Palm oil biomass, food processing industry |
| **Gasification** | Household waste, coconut, palm kernel shell |
| **Direct combustion** | Municipal solid waste (MSW), palm oil biomass |
| **Combined heat process plant (CHP)** | Municipal solid waste (MSW), palm oil biomass |
| **Pyrolysis** | Palm oil biomass |

[Fig. 2](#_bookmark3) shows the conversion process flow of the biomass-to-energy technology for energy recycling to heat and electricity generation, including the fuel produced from each technology.

Biomass may be converted into liquid or gaseous fuels and then used to produce power, heat, chemicals, or liquid or gaseous fuels. Biomass can be turned into biofuels in many ways, roughly categorized into thermochemical conversion and biochemical conversion. Thermochemical conversion is an effective method for turning biomass into biofuels that may be categorized into two groups: dry (nonaqueous) and hydrothermal methods. Temperature, heating rate, residence time, particle size, and other physical properties are utilized to determine whether thermochemical conversion methods are appropriate [[29](#_bookmark33)]. The fundamental for biochemical conversion is the enzymatic hydrolysis of lignocellulosic materials to sugars, which are subsequently fermented and distilled to make cellulosic ethanol [[30](#_bookmark34)]. [Table 3](#_bookmark4) provides a broad comparison of thermochemical and biological processes.

**Fig. 2** Biomass-to-energy conversion for energy recycling.

Biomass to energy conversion

Biochemical Conversion

Thermochemic al Conversion

Biogas,

Liquid oil, gases, char

Syngas

Biogas, hot

Anaerobic

Heat & Electricity

Pyrolysis

Gasification

Combustion

## 3.1 Gasification

Biomass gasification reduces reliance on fossil fuels by substituting biomass resources for fossil fuels, assuming that adequate biomass feedstock is available abundantly. Biomass gasification is a biomass energy-based system that produces energy through the combustion of biomass resources in the gasifier at a high temperature of about 1000°C [[38](#_bookmark42)]. The first reported use of gasification for electrical generating occurred in 1792. However, Siemens erected the first operational gasifier device in 1861, establishing the first industrial coal gasification station at Wabash River, United States of America, 1999. Since 2001, biomass gasification has attracted substantial interest due to variable oil costs and global warming concerns [[39](#_bookmark43)].

The products of biomass gasification are combustible gaseous gas called syngas/producer gas production, hydrogen-enriched gas production, electricity production, and biomass gasification co- generation. Syngas/producer gas is a combustible gaseous gas produced from the inadequate combustion of solid biomass fuel to create syngas. As a result, flammable gases such as carbon monoxide (CO), hydrogen (H2), and traces of methane (CH4), as well as byproducts like tar and dust, are created. Syngas/producer gas may be used to power internal combustion engines and can also be utilized to manufacture methanol, which can be used as a fuel for heat engines and as a chemical feedstock for industrial. The thermochemical route of biomass gasification produces hydrogen at a lower cost with higher efficiency than biochemical routes, which face a significant challenge – a low rate of hydrogen production. However, they are less energy-intensive and better for the environment [[40](#_bookmark44)]. Co-generation is a technique for enhancing biomass gasification's economic and environmental elements, whereas electricity resulting from co-generation is a widespread potential use of biomass gasification [[41](#_bookmark45)].

Biomass gasification's benefits include sustainability and being environmentally friendly - better efficiency, lower CO2 emissions, and improved soil fertility as the biochar produced can act as a medium for carbon storage and sequestration [[42](#_bookmark46)]. In Malaysia, waste-to-energy (WTE) plays a critical role in household solid waste management, eliminating roughly 95% of municipal solid waste (MSW) by volume entering landfills through thermo-chemical waste treatment pathways such as gasification [[43](#_bookmark47)]. With the fluidization method, the study demonstrated that considerable quantities of hydrogen gas (up to 67 mol%) may be produced from agricultural waste such as coconut and palm kernel shells [[44](#_bookmark48)].

## 3.2 Direct Combustion

The primary method employed for waste management involves the combustion and conversion of waste materials at a minimum temperature of 850 °C, generating heat and energy [[32](#_bookmark36)]. However, large-scale industries often utilize non-conventional power plants that exhibit inefficiencies in electricity production. This inefficiency arises from the significant energy loss (60-70%) during the process, as well as the time required for the cooling tower to lower the temperature of the boiled water and initiate the cycle again. Compared to landfill gas recovery systems (LFGRS) and anaerobic digestion, a case study conducted at the Taman Beringin dump in Malaysia demonstrated that incineration has the highest potential for energy output, heat generation, and electricity production. Notably, incineration yielded the most significant profit increase, reaching 287% (450 TUSD/d), followed by anaerobic digestion and

LFGRS. Based on the analysis, incineration is the most cost-effective and environmentally sustainable option among the available alternatives [[45](#_bookmark49)].

Conventional power plants (CHP) typically generate 30-40% of electricity [[46](#_bookmark50)]. In contrast, CHP systems capture and utilize the heat that would otherwise be wasted during electricity generation, distributing it to nearby buildings for various heating purposes. CHP, also known as co-generation, enables simultaneous electricity and heat production, providing users with power and hot water. CHP systems can achieve an impressive efficiency of approximately 90% for electricity and heat generation [[46](#_bookmark50)]. The size of a CHP system may vary depending on individual user requirements. In Brazil, a study evaluated the feasibility of utilizing agricultural and agro-industrial wastes as renewable resources for combustion in centralized power plants to generate electricity. The research findings revealed a significant potential for renewable energy production, estimated at 141 TWh per year [[47](#_bookmark51)].

## Pyrolysis

Pyrolysis is a highly efficient thermochemical conversion process that enables the conversion of lignocellulosic biomass into valuable gaseous and liquid fuels through the decomposition of biomass into charcoal and volatile matter. To ensure effective conversion, municipal solid waste (MSW) needs to be reduced to a maximum size of 300 mm, requiring pretreatment methods [[49](#_bookmark53)]. Pyrolysis encompasses slow and rapid conversion processes characterized by specific parameters such as temperature, heating rate, and process duration. In the absence of oxygen, pyrolysis occurs at temperatures around 500°C, initiating a gradual chemical reaction that transforms the biomass into three primary products: oil, gas, and char. These products find applications in various industrial processes and refining operations [[50](#_bookmark54)]. The gas produced during pyrolysis is a mixture of hydrocarbon-rich gases, including CO2, CH4, and H2. This gas mixture can be utilized in industrial applications, such as heat and power generation, or further processed to produce valuable chemicals and fuels [[50](#_bookmark54)]. Additionally, pyrolysis generates a fluid oil product that can be readily employed in different applications without further upgrading. This oil can be used in boilers, furnaces, turbines, and diesel engines, providing a versatile and readily available fuel source [[51](#_bookmark55)].

# 4 Conclusion

This paper provides a comprehensive review of the available biomass waste in Malaysia, including oil palm, coconut, cocoa, rice, and sugarcane, highlighting their potential for energy utilization in the agricultural processing industry. Malaysia's abundance of biomass resources signifies a significant opportunity for energy recycling and sustainable waste management practices. Among the various biomass waste sources, oil palm stands out as the country's primary contributor to biomass waste production. The paper also examined different technologies for energy recycling, encompassing thermochemical conversion methods such as combustion, gasification, and pyrolysis, as well as biochemical conversion methods like anaerobic digestion. The advantages and disadvantages of these technologies were thoroughly assessed.

The Malaysian government has also implemented attractive incentives, initiatives, and policies to promote adopting sustainable energy practices, fostering awareness and participation in developing a greener future. Energy recycling benefits the environment and offers industry advantages, including waste reduction, energy savings, and cost efficiency. Based on the extensive literature review, it was observed that anaerobic digestion plants had gained prominence as the preferred technology for energy recycling and the generation of renewable energy through waste-to-energy conversion in the agricultural processing industry. However, it is worth noting that pyrolysis, although a promising technology, remains relatively less explored and adopted compared to other reviewed technologies. Further research and development efforts should be directed towards investigating and promoting the potential of pyrolysis in the Malaysian context, given its ability to convert biomass waste into valuable energy resources effectively.

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# Declaration of Conflict of Interest

The authors declared that there is no conflict of interest with any other party to the publication of the current work.

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