Converting wood-related waste materials into other value-added products: A short review

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Abstract. This paper reviews converting wood-related waste materials from forestry, wood-based industry, and agriculture activities into other value-added products such as bio-energy, construction materials, agricultural compost, and handicraft application. The wood waste, however, needs to be processed before it can be utilized. The information obtained is reviewed in order to enable them to be useful to the government planners and those involved in the wood-based industry. The gross domestic product from the forest-related industry reached RM6.38 billion in 2019. This resulted in a large amount of waste produced annually. Utilizing these waste materials instead of letting them rot or deteriorate in the forests or at the factory yards sites could generate income and create job opportunities for the local community. A proper and systematic study needs to be undertaken in order to make them into reality.

Keywords: Forestry; wood-based industry; wood-related waste; energy wood pallets; wood waste composts.

1. Introduction
Malaysia is rich in biodiversity and natural resources, and it has been named one of the world's 17 mega-diverse countries by Conservation International (CI) [1,2]. The total energy generated from the waste in 2012 is 0.720, 0.381, and 1.657 Mtoe (One Million Toe). Wood waste in the form of peat could be useful in the horticulture industry. The peat is most suitable as a growing medium by the urban community, especially those living in high-rise buildings. Wood waste can also be used to produce biomass energy [3]. This form of energy is considered renewable. This energy although produces carbon dioxide does not add to the earth's net carbon dioxide volume [4]. This is due to the fact that biomass is produced from solar energy, water, and carbon dioxide.

The biomass material in the forestry sector comes from natural, plantation forests and the wood-based industry. They are accumulated during logs production, primary wood processing, and wood processes [5]. Malaysia's timber processing and manufacturing businesses are ideally positioned to deliver goods that contribute to long-term environmental, economic, and social sustainability. Sustainably manufactured wood and paper-based goods may be preferable to other materials since they are made from renewable resource trees, grown using sunlight, soil nutrients, and water. Second, they store carbon: during photosynthesis, most trees extract carbon dioxide from the atmosphere and replace it with oxygen, lowering greenhouse gas emissions. In sustainably managed forests, the carbon emitted during harvesting is offset by carbon taken up via regeneration and regrowth, making them carbon neutral. Third, they can store carbon for decades, if not centuries. Solid wood and paper-based materials can store carbon for decades, if not centuries. Finally, they're recyclable, which means they may be repurposed into new products, extending their useful life and contributing to the wood fibre resource pool [6]. This study aims in reviewing the potential utilization and converting of the wood-related waste materials into value-added products.
2. Materials and processes involved
The primary sources of wood-related waste were wood packaging (21%), demolition and construction (26.7%), wood processing industry (14%), municipal wastes (20.7%), imported wood (9.7%), and others such as private households and railway construction (8%) [7]. The term "waste" is defined as "any substance which the holder discards or intends or is required to discard" [8]. Waste from other sources includes tree bark, peeling core, veneer waste, and panel coatings are primarily used in the plywood business. The particleboard waste is primarily ignored and consists of chip waste from panel cutting and dust from sanding machines [9].

Agricultural leftovers are an ideal alternative waste material to wood since they are abundant, widely distributed, and readily available. Agricultural waste also has economic, environmental, and technological benefits [10]. The wastes derived from agricultural activities are straw, stalks, stalks, leaves, husks, fibres, seeds, stones, pulp or trees from fruits, legumes or grains, bagasse produced from sugar cane or sweet sorghum milling [7].

3. Biomass waste management and wood-related waste
Wood is a natural and renewable resource that is biodegradable and has exceptional mechanical and thermal properties [11]. Minimal wood waste can contribute to energy, construction, agriculture, and craft. Therefore, researchers need to find alternative renewable energy resources and effective technologies for humankind [12]. As a result, increased emphasis is placed on finding alternative waste management methods. Landfilling is still the most common technique of garbage disposal, although there are concerns about odour, soil availability, greenhouse gas emissions such as methane, and waste products. Composting and anaerobic digestion are effective methods to reduce the amount of organic waste [13]. If properly handled, biomass has numerous advantages, the most important of which is that it is a renewable and sustainable energy source. When compared to fossil fuels, this approach can dramatically reduce net carbon emissions, making it a more environmentally friendly way to reduce greenhouse gas emissions [14]. One of the most pressing issues in Russia is the use of wood waste in the forestry and woodworking industries, as well as wood waste generated during the pruning of trees and bushes on city streets and park zones [15].

Biodiesel, ethanol, butanol, methane, hydrocarbons, and natural oils are among the products made from biomass, which can then be converted into a variety of fuels [14]. For instance, agricultural waste such as bagasse, sap, stalks, cobs, and husks can be converted into biofuel [7]. Because of its global distribution and affordability, biomass is frequently referred to as the most promising renewable energy source [16]. Approximately 90% of lignocellulosic biomass is made up of a complex structure of lignin, cellulose, and hemicelluloses [17,18]. It also includes starch, oils, waxes with influential functional groups [19]. Because lignin is one of these elements resistant to chemical and biological breakdown, digestion of organic fractionation of lignocellulose biomass/lignocellulosic waste for biogas production remains a major challenge. However, the organic portion of lignocellulosic waste biomass, cellulose, and hemicelluloses, has been widely employed as a biogas feedstock [18].

On the one hand, using waste biomass as a feedstock can lower feedstock costs while simultaneously resolving waste management concerns. However, on the contrary, compared to standard fuel oil, the cost of producing bio-hydrogen is still higher. Furthermore, due to the complicated wood-related waste structure, it is necessary before using it as a biogas and bio-hydrogen production substrate, it should be pre-treated. Therefore, the biomass must undergo a pretreatment process to convert wood-related biomass waste into a product. In this process, biomass's physical and chemical structure is altered, and the cellulose content undergoes hydrolysis at various rates [7]. Pretreatment removes lignin and hemicellullose effectively, reduces structural crystallinity, and increases lignocellulose biomass/lignocellulosic waste biomass. [18]. As a result, cellulosic materials must be pretreated in order to obtain highly crystalline and pure cellulose for advanced applications [19].

4. Wood-related waste processes
For cellulose conversion processes, pretreatment is critical. It is critical to alter the structure of cellulosic biomass in order to increase the availability of cellulose to enzymes that convert carbohydrate polymers into fermentable sugars [20]. Several pretreatments for lignocellulosic waste materials have been
proposed to improve biogas generation. All of these treatment procedures have advantages and disadvantages when used in industrial settings. Chemical and physical pretreatment methods are quite effective, but they are also very expensive. Biological pretreatment is less expensive, but it takes longer. To be standardised effectively for the substrate utilised, proper selection of any one or combination of these processes is essential. Furthermore, waste composition and contamination may vary from batch to batch, implying the need for a large-scale, low-cost, and simple waste biomass pretreatment process [21].

Wood is a naturally occurring material with distinct physical and chemical properties [22]. A recent study found that precise understanding of wood waste quality is essential for improving clean wood waste recycling and circular economy wood solutions. Furthermore, wood waste contains a variety of wood species as well as varying amounts of contamination. As a result, the preceding study is significant in that it provides extensive sampling and characterisation of wood waste based on its source, type, and resource quality grade [23]. In addition, in the batch test, the previous researcher evaluated the electro hydrolysis pretreatment conditions (applied voltage and time) and anaerobic digestion process for the biological bioconversion of pulp and paper mill sludge into biogas. According to [24], pretreatment with electro-hydrolysis has a significant impact on lignocellulose content and speeds up the hydrolysis phase of the anaerobic digestion process.

Regardless of the waste pretreatment technology used or the conditions under which it is used, the production of inhibitors that endanger bio-hydrogen-producing organisms is one of the most serious issues [25]. Technical challenges such as hydrogen fuel storage, compression, and distribution, as well as integration with existing infrastructure, need to be addressed. As a result, the development of leap forward innovation that allows for successful and less expensive pretreatment of lignocellulosic feedstock is critical to achieving cellulbio-hydrogen. To summarise, thorough examination of industrial feasibility and laboratory inquiry are required to overcome flaws and combine the best options [21].

5. Wood-related waste as bio-energy application

Energy generation is one of the most common uses for logging and wood processing waste. The calorific value and thermal decomposition products are critical; nevertheless, using such waste as fuel directly is difficult [26-28]. A previous study has reported that wood waste can be turned into energy potentials and bioresources utilization. Energy systems (internal combustion engines) are used for numerous permanent applications in rural parts of developing countries such as Nigeria. Gasification of biomass wood fuel into power could play a significant role in utilising waste wood [29]. It also occurs in urban settings, where wood waste can be exploited as an energy resource to give heat and electricity to consumers. By minimising waste at urban landfills and producing useful energy from renewable sources of wood waste, such a strategy will improve environmental performance [15].

Thus, if this massive amount of wood waste could be gathered, moulded into briquettes, and carbonised into charcoal, that would be preferable. The heat value of the charcoal produced is higher than that of the wood. The charcoal can then be used to generate heat or steam in specifically constructed equipment, resulting in hundreds of megawatts of power being added to the national grid and distributed to houses [30].

6. Wood-related waste in construction

The level of science and technological development and the type and concentration of waste all affect waste utilization [31]. Sawdust and chips can be used as fillers in construction to make xylolite, wood concrete, fibreboard, sawdust concrete, wood concrete, and cement-bonded particle boards, as well as piezo-thermoplastics and whole-pressed goods [32-35]. It has already been reported on the effects of wood waste on the characteristics of silicone-based composites. The best test results were obtained for composites loaded with spruce waste, both 10% and 20% by weight, according to multicriteria analysis [36]. A study conducted by [36] in 2021 assesses the impact of wood-related waste on the properties of silicone-based composites polymers. This study aimed to see how wood waste from deciduous (beech, oak, and hornbeam) and coniferous (spruce) trees affected the mechanical and biological properties of
silicone composites used for structural elements protection. Achieving this goal necessitated a series of physical and mechanical tests and biological tests.

7. Wood-related waste materials as product potential and agricultural medium

The wood-related waste can be turned into handicrafts products. The craft sector has relatively demonstrated its actualization that synergizes intellectual capital, wisdom, and local resources from natural and waste-based sources. However, craft art product development is loaded with complex technical aspects which require surveys, observations, explorations, and experiments related to the design and use of materials. The complexity in the question posed a challenge to [37]. He developed a centre for producing environmentally friendly artworks through wood waste into sling bags, wallets, frames, and paintings with the ‘Borna’ business brand [37]. The basic material of these products is wood-related waste combined with other materials such as leather and plywood to form an intact pattern of sling bags.

The treatment, disposal, and recycling of wood wastes and residues are one of the most pressing issues confronting the global wood-based panel industry [38]. Biodegradable materials make up the majority of the trash from the wood sector. Solid wastes, including wood wastes, are disposed of using various means. It necessitates selecting an appropriate disposal strategy that emphasizes efficiency and environmental safety. New technologies are being developed to help treat organic solid waste while adhering to tight environmental requirements and employing effective microorganisms (EM). Composting is a natural phenomenon and pervasively relates to organic farming [39].

Compared to the well-known rock wool and coconut coir waste substrates, the suitability of coast made from horticulture waste as a growing medium for vegetable crops. This substrate’s physical and physicochemical features were first investigated to modify its management for horticultural objectives. Then, leaching studies were carried out using an acid solution and a standard nutrient solution. A melon crop’s productivity and fruit quality were compared in two studies using this compost, rock wool, and coconut coir waste. The compost had a high salt content and a high pH when it was first discovered. The findings suggested that compost might be used as a growing medium for soilless crop cultivation if it is leached first.

Recovered wood is recognised as a large volume resource for recycled products and new innovative materials. Wood waste was classified into three categories: application, type, and quality grade. Wood waste includes a variety of uses/types of wood as well as varying levels of contamination. One of the types of wood is composite wood. From a previous study, wood waste can be compost material. However, it depends on the type of wood. Fibreboards are nearly always a no-no when it comes to composting. Hardboard is made up of compressed wood fibres that can be composted, but it can also include a binding agent such as resin. It is probably best to leave it out as it is hard to tell. Synthetic binding agents are always used in plywood, particleboard, and medium-density fibreboard (MDF), therefore dust from those should never be added to a compost heap. There is a growing concern about environmental impacts [40]. In addition, the waste from timber or engineered wood products can contribute to the horticulture industry for media in planting. Because of its physicochemical properties, peat is employed as a growing medium in horticulture. In the short-medium term, however, peat moss is a non-renewable resource, and its extraction and use have a negative impact on wetland ecosystems and cause greenhouse gas emissions.

8. Conclusion

More in-depth research especially in converting the wood-related waste into various useful products is needed to study. The vast amount of wood waste produced from forest biomass and the furniture sector raised various environmental issues. From an ecological standpoint, the sustainability of manufacturing processes is a critical global concern, notably in the furniture industry, where wood waste is a big issue. This is a sector that produces products from renewable forest resources. Thus, it is well-positioned to create items that must contribute to environmental sustainability. Although producing bio-hydrogen from waste biomass appears to be a fantastic idea, numerous obstacles stand in the way of this method being scaled up and popularized.
On the one hand, using waste biomass as a feedstock can lower feedstock costs while simultaneously resolving waste management concerns. However, on the contrary, compared to standard fuel oil, the cost of producing bio-hydrogen is still higher. Furthermore, the complicated lignocellulosic waste structure is necessary before using it as a biogas and bio-hydrogen production substrate; it should be pre-treated.

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