A REVIEW OF OIL PALM BIOCOMPOSITES FOR FURNITURE DESIGN AND APPLICATIONS: POTENTIAL AND CHALLENGES

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This review considers the potential and challenges of using agro-based oil palm biomasses, including the trunk, frond, empty fruit bunch, and palm press fiber biocomposites, for furniture applications. Currently, design and quality rather than price are becoming the primary concern for consumers when buying new furniture. Within this context, this paper focuses on the design of innovative, sustainable furniture from agro-based biocomposites to meet the needs of future population growth and technology. This research also discusses the need for biocomposite materials that do not depend on the growth of populations, but on the growth and development of the economy. This study focuses on globally available agro-based biocomposites, especially those from oil palm biomass: plywood, medium density fiberboard (MDF), wood plastic composite (WPC), laminated veneer lumber (LVL), oriented strand board (OSB), hardboards, and particleboard. Additional positive aspects of biocomposites are their environmentally friendly character, high quality, competitive design, and capacity to improve the value proposition of high-end products. These attributes increase the demand for agro-based biocomposite furniture on the international market.

Keywords: Biocomposites; Oil palm biomass; Design; Furniture; Emerging technology

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INTRODUCTION

A wide range of raw materials, such as coconut husks, pineapple leaves, oil palm biomass, banana stems, rice straw, wood wastes, bamboo, and rattan, are abundantly available around the world and have been used to develop biocomposites for furniture applications. The chemical, physical, and mechanical properties of these renewable resources are similar to those of wood, and they may be suitable raw materials for wood-based panels (Khalil *et al.* 2010a). Both local industries and international furniture manufacturers have been responding to concerns that furniture components need to be more environmentally friendly. Biocomposites based on both wood and non-wood materials, such as plywood, particleboard, medium density fiber board (MDF), wood plastic composites (WPC), laminated veneer lumber (LVL), oriented strand board (OSB), and hardboard, are commonly used by furniture manufacturers for a variety of applications. Oil palm biomass is currently an alternative material for wood-based industries, and many researchers are developing panel products from oil palm biomass (Khalil *et al.* 2010c). Previous research conducted on oil palm fronds (OPF), oil palm trunks (OPT), oil palm empty fruit bunches (EFB), and oil palm press fibers (PPF) has shown that these

materials are suitable for generating new, sustainable, cheaper, safer, and high-value products using advanced techniques. Biocomposites (MDF, LVL, WPC, OSB, plywood, and agro-lumber) can be industrially produced as the primary raw material in furniture manufacturing (Yusoff and Koh 2001).

The mechanized manufacturing of furniture from wood was established during the Renaissance in the first half of the 15th century. Individuals who purchased such products used this furniture as a statement of their wealth, politics, origins, position, and power (Pawlak 2007). Additionally, material selection has not changed much since that time, because solid wood resources were commonly available and were shown to have excellent performance and accessibility, simple manufacturing, and an elegant appearance. Furthermore, important features in selecting wood materials for furniture in the 15th century included their trustiness, unique and authentic surface textures, and high perceived value. Solid woods were the raw material of choice at early international furniture exhibits, and the use of wood has continued to grow since the early 1870s. Around that time, solid woods were inexpensive because they were readily available.

Furniture production industries in the Association of Southeast Asian Nations (ASEAN) have grown rapidly since 1980. Over 70 to 80% of all wood-based furniture produced worldwide now comes from the ASEAN countries. The increased demand for rubberwood furniture on the international market has enhanced the ASEAN economy, which was primarily focused on the agricultural sector. To date, woods have been used as the primary materials for furniture making. However, with advancements in science and technology, the materials used in furniture have undergone several transformations. Mixtures of substances in both wood and several other raw materials from agricultural biomasses are available to substitute for pure-wood materials to increase productivity and improve availability. A previous study reported new raw materials, such as the combination of oil palm EFB with rubber wood, for furniture components (Khalil *et al.* 2010c).

The current global demand for furniture products remains strong despite the numerous economic downturns. China and Vietnam constitute strong competitors for Malaysia, Indonesia, and Thailand because of their lower manufacturing costs and original designs as well as their aesthetics and the good work ethic of their labor force. The role of the government is also crucial for nurturing industries, providing pioneer status for tax exemptions and investment tax allowances that allow businesses in the industry to become more readily established. A business-friendly environment, high quality products, and a large potential market are leading the furniture industry to exceed expectations and continue to grow at an exponential rate (Puasa *et al.* 2010; Bovea and Vidal 2004a).

Several articles have been published that report scientific findings on composites and biocomposites with interesting results (Khalil *et al*. 2011; Khalil *et al*. 2010b; Khalil *et al*. 2010c; Bhat *et al*. 2010; Yusoff and Koh, 2001). Design aspects of biocomposites and their development with respect to innovative furniture design and future furniture demand based on population growth, as well as challenges for utilization of biocomposites for furniture applications have not been adequately considered to date in a review article. In this review we provide a brief introduction to oil palm biomass applications in biocomposites, different type of oil palm biocomposites *vs.* other materials, furniture and design, and the potential and challenges faced by oil palm biocomposites with respect to growing populations and innovative design. To date, no single review is available to cover these aspects. This review, therefore, is intended to

piece together the accumulated knowledge and review the trends and some pertinent findings in this subject area.

WOOD PRODUCTS BY CATEGORY

Oil Palm Biomass

The oil palm industry has been grown at an ever-accelerating rate over the first decade of the 21st century. Indonesia, Malaysia, Thailand, and other Asian countries are considered to be agricultural countries, even though Malaysia is also known for its other plantations, such as rubber, coconut, and cocoa. The use of oil palms can vary due to recycling activities involving the use of up to 90% of the oil palm biomass (Khalil and Rozman 2004). This level is expected to increase further because of various initiatives promoting development of production enterprises. In addition, the raw materials from the oil palm industries have other uses, including the production of pulp, paper, plywood, and other biocomposites. Currently, Malaysia produces 50% more oil palm than other oil palm-producing countries; for example, Indonesia produces only 30% of the total oil palm produced by competing countries. Research programs have more than doubled the oil palm production relative to that of wild plants in Africa. This growth in oil palm production has resulted in the replacement of Nigeria by Malaysia as the world's leading producer and exporter of palm oil (Khalil and Rozman 2004).

Statistical data show that 40 million tons residual oil palm biomass wastes from oil palm trees such as EFB, OPT, OPF, and PPF are produced every year in Malaysia (Baharuddin *et al.* 2009). Based on this research, only 10% of the total oil palm biomass is used, while the remaining 90% is underutilized (Khalil and Bhat 2010; Khalil *et al.* 2011). Cellulosic raw materials produced from both dried coconut trunks and OPF can be used as alternatives to wood materials (Khalil and Rozman 2004; Amouzgar *et al.* 2010). In addition, wood products produced from OPT may affect the furniture industry. OPT has been both studied and processed as an alternative material for manufacturing wood furniture because it is comparable in quality to rubberwood (RW) and other solid wood species. In addition, OPT can assist furniture industries that completely rely upon rubberwood (RW), which can affect a nation's ecosystem. OPT lumber (OPTL) was identified as a substitute material for rubberwood because of its physical and mechanical properties, thermal stability, and high resistance to pests, such as termites. These features are essential for manufacturing furniture because they ensure the strength, resilience, quality, and durability of the furniture, allowing consumers to continue to use the products for prolonged periods of time (Bhat *et al*. 2010).

The key factors that increase the value of these furniture products are their design elements and effect on the environment, which according to previous work, is important to staying ahead of market demand (Bovea and Vidal 2004a). The initiative to increase the value of OPTL use has been highly praised and encouraged because these materials have a low environmental impact and increase innovation and technology. The primary components of an oil palm biomass are illustrated in Fig. 1, which shows both the process of using oil palm waste materials as oil palm biomass and the process flow to the final manufactured product (*i.e*., furniture). This process is similar to the conventional process that involves oil palm trunks and fronds, except that the oil palm wastes can be a mixture of empty fruit bunches and fresh fruits to produce fruit bunch fibers. Unlike other wood alternatives, every part of the oil palm tree is useful, which is important for

environmental sustainability. Research and development in making environmentally friendly bio-based products are progressing throughout the world, resulting in continued improvements.

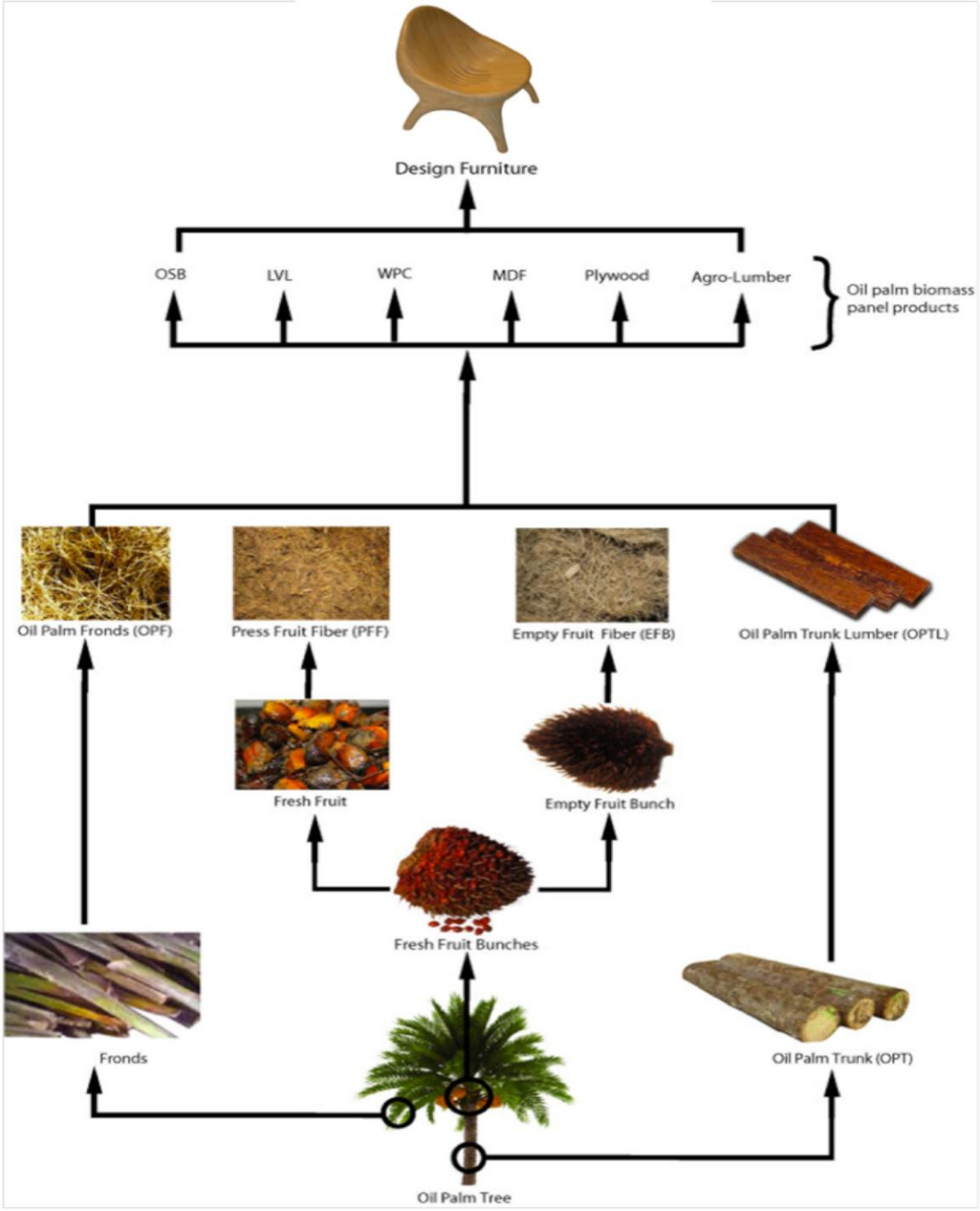

Fig. 1. Process flow of oil palm biomass materials (OPF,PFF, EFB, and OPTL)

Agro-Based Biocomposite Products

Some countries have abundant forests that produce timber and wood. Thus, the utilization of wood waste is highly cost-effective. The industrial processing of waste wood contributes to the generation of raw materials furniture production (Stark *et al.* 2010). In general, only 50% of wood wastes from a tree can be processed into a final product, and any excess wastes might harm the economy. Composite wood products are

used in both non-structural and structural applications, including as decorative paneling for both internal and external furniture and for construction. Maloney (1986) proposed a classification system to categorize various wood-based composite materials (Stark *et al.* 2010; Maloney 1986). This classification system, which is shown in Table 1, defines the various types of wood panel products that reflect the latest developments in agro-based biocomposites.

Table 1. Classification of Wood-Based Composites (Maloney 1986)

Veneer-based material	• Plywood • Laminated veneer lumber (LVL)
Laminates	• Wood-non wood composite
Composite material	• Cellulosic fiberboard • Hardboard • Particleboard • Waferboard • Flakeboard • Oriented strandboard (OSB)
Edge-adhesive-bonded material	• Lumber panel
Wood-non wood composite	• Wood fiber-plastic composite • Wood fiber-agricultural fiber composite

The long-term global impact of furniture production has forced researchers to find solutions to various problems via research and development (R&D), and this search has given birth to the idea of using biocomposite materials. Biocomposite materials have been shown to be effective as an alternative to wood and could reduce deforestation. The biocomposite industry is important for improving both the quality of manufacturing and production as well as R&D (Cai and Winandy 2005; John and Thomas 2008; Liansheng *et al.* 2002). Examples of some of the biocomposite materials that have proven their quality on the international market include medium density fiberboard (MDF), plywood, and wood-plastic composites, each of which have been widely used in manufacturing furniture and other products.

Biocomposite production from agricultural wastes has been increasing every year from 2004 to 2011 and accounts for over half of the market of wood-based production. Demand for biocomposite products has risen yearly because of the efforts of biocomposite producers and increased consumer awareness of the importance and advantages of sustainability (Leao *et al.* 2010). Table 2 shows the chronological development of biocomposites from agro-based materials. Researchers are continually studying the potential of biocomposites to determine whether they have any benefits. A successful study produced particleboard biocomposite furniture using fiber chips as the raw material. The primary advantage of particleboard produced from fiber chips is that it

possesses better machining parameters and improves the efficiency of the use of raw materials (Bhat *et al.* 2010). Innovative research combining both EFB and OPT produced a new blend of plywood with improved quality relative to existing plywood, particularly regarding flexural strength, screw withdrawal, and shear strength (Salleh *et al.* 2011; Khalil *et al.* 2010c; Khalil and Rozman 2004). For example, studies using oil palm trunks to produce molded laminated veneer oil palm (MLVOP) for furniture demonstrated that that MLVOP performed similarly to or better than normal wood veneer, and was suitable for making profitable furniture products. Even so, further research in adding fiber to biocomposite products and the use of composite materials in furniture production is still essential for improving the quality and durability of MLVOP (Leao *et al.* 2010).

Table 2. Chronology of Events in the Development of Biocomposites from Agro-based Material Manufacturing Industry

Agro-Based Biocomposites	Year	References
Plywood	1865	(Sheldon Shi 2006)
Oriented Strand Board (OSB)	1970	(Cai and Winandy 2005; Shi and Walker 2006)
Laminate Veneer Lumber (LVL)	1944	(Kairi 2005)
Medium Density Fiberboard (MDF)	1970	(Khalil and Bhat 2010)
Particleboard	1975	(Takahashi 2001)
Hardboard	1926	(Thomson 2003)
Wood Plastic Composites (WPC)	1970	(Pritchard 2004)
Agro-Lumber	2010	(Khalil *et al.* 2010a)

Since 1997, the demand for household furniture has increased more rapidly than the demand for any other wood-based product because of the yearly growth of the world population. Additionally, consumers need high-quality, long-lasting furniture (Levesque 2000). The increasing world population is the primary factor in the management of natural resources. Indonesia has the highest population density in Southeast Asia and is confronted with the problem of providing homes in friendly and safe environments despite its large quantities of fertile land. Managing natural resources rather than selling them on the global market in their raw or biocomposite form is essential to improving quality of life (Rajan and Amin 2001).

In addition, oil palm biocomposites use only 10% of the oil palm biomass produced by farms. Oil palm trees also produce residual materials that comprise large quantities of various lignocellulosic materials in the form of OPF, OPT, EFB, and PPF. Oil palm biomass residues are obtained to optimize their use as an alternative raw material for value-added products. Oil palm biomass can be processed and then used as a production material for manufacturing furniture, such as a tables, chairs, doors, flooring, and cabinetry. Wood from oil palm trees can help solve wood shortages resulting from deforestation. Ongoing research conducted by global research institutions such as SCION (New Zealand), the Biocomposites Centre (UK), CSIRO (Australia), the Forest Product Laboratory (USA), and various Malaysian research universities can simultaneously increase the use of oil palm biomass and improve the socioeconomics of local farmers; in other words, the use of old palm biomass can generate income for the country. This study

focuses on conventional biocomposites used for furniture applications. These biocomposites, such as plywood, medium density fiberboard (MDF), laminated veneer lumber (LVL), oriented strandboard (OSB), wood plastic composite (WPC), particleboard, and hardboard can be manufactured from oil palm biomass. Figure 2 shows the different types of biocomposite products (Stark *et al.* 2010).

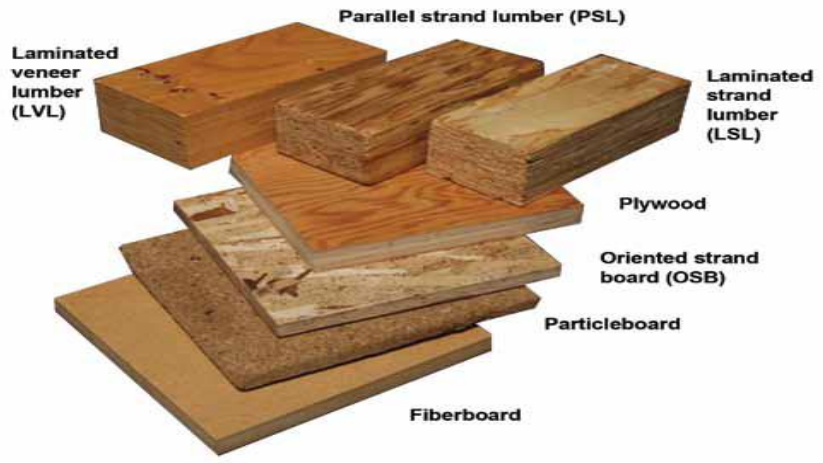

Fig. 2. Various biocomposite products.Clockwise from top left :LVL, PSL, LSL, Plywood, OSB, Particleboard and Fiberboard (Stark *et al.* 2010)

Plywood

Plywood is a flat panel made of veneer layers from either a soft or hard wood; these layers are arranged perpendicularly using odd numbers and resin spread on these layers. It is stacked together by using a clamp or pressing machine to form a panel. Each layer is identified with a different name; for example, the outer layer is the face, the inner layer is the middle or the core, and the wood grain layer that is at a right angle with both the face and back side is known as the cross layer (Khalil and Hashim 2004). The advantages of plywood relative to ordinary wood is that plywood of a similar length and width as ordinary wood has better strength against cracks and has a shape that can be used for various applications. Plywood is thin relative to typical wood; therefore, it can cover large areas using minimum fiber quantities. Plywood is graded based on the quality of the veneer used.

There are two types of plywood currently on the market, and both have different standards. These plywood types are used in the furniture manufacturing industry and for decoration. Industrial plywood is frequently used as a construction material for structures such as walls, while hardwood plywood is normally used for furniture and kitchen cabinets, among other uses. Plywood is the primary material on the market for producing wood panels because of its cost effectiveness. Plywood can be molded and formed into a variety of shapes and sizes, which helps designers understand its capabilities (Stark *et al.* 2010). Plywood has several drawbacks that could affect its use, including its low density, color appearance, and color durability, *i.e.*, imperfections, reflections in the plywood surface, poor wood compression, reduced water resistance, and the formation of silicon products that can blunt a knife. However, plywood has advantages not found in other materials, including being lightweight, easy to use, robust, and having smooth surface textures and reduced shrinking and expansion under certain conditions (Saville 2008).

Oriented Strand Board (OSB)

Oriented strand board, or OSB, is an engineered structural material manufactured from thin wood strands bonded together with a waterproof resin using heat and pressure. OSB technology and the raw material used originally evolved from waferboard technology, which predominantly used aspen. As the industry learned to control their strand size, placement, and orientation, the performance, durability, and utility of OSB products improved to the point where they performed similarly to structural plywood (Kong 2001). As a result, OSB has become accepted and its usage has expanded to replace softwood plywood in construction applications throughout the world. OSB technology and the raw material used evolved from waferboard technology, which predominantly used aspen, in the late 1970s. OSB differs from waferboards in that the OSB wood strands are oriented rather than randomly placed. OSB was rapidly accepted since debuting in the marketplace in 1970 (Youngquist 1999). In many areas of North America, OSB is used for residential construction, and both the US and Canada allow OSB panels to be used for the same purposes as plywood on a thickness-by-thickness basis. The strength of OSB primarily comes from the uninterrupted wood fibers, the interweaving of the long strands or wafers, and the degree of strand orientation in the surface layers. Diphenylmethane di-isocyanate (MDI) is a mixture of materials used to manufacture composite wood products such as OSB, particleboard, hardboard, and MDF (Youngquist 1999).

Laminated Veneer Lumber (LVL)

Wood veneer is a laminated wood composite that has been engineered using adhesives such as urea formaldehyde, phenol formaldehyde, melamine urea formaldehyde, and phenol resorcinol formaldehyde (Shi and Walker 2006). LVL is a technique that glues together longitudinally parallel veneer sheets and is a new innovation in the manufacturing industry. This technique shows that gluing veneers can increase the strength of a LVL that only uses veneers. The high demand for LVL materials demonstrates that biocomposites are able to compete with existing solid wood products. Because of R&D activities, LVL-based wood products have entered the international market. The advantages of LVL materials over ordinary plywood include their high tensile strength and the formation of new products possessing perfect characteristic combinations combined with quality assurance. In the US, LVLs have been used in the manufacturing of aircraft components since 1944.

Innovative studies have been successfully conducted on LVL molds using high-frequency technology to form LVL products into various shapes depending on the mold design. Natural fiber veneers have both physical and mechanical properties that can be used to produce higher-quality composites by reinforcing veneers with resins (Leao *et al.* 2010). In addition, the potential of timber used to produce LVL veneers that possessed one or more wood layers, usually less than 3/16 inch thick, was investigated. The LVL production methods enable the production of products with almost any dimension; the thickness of the LVL can range from 19 to 75 mm, and lengths up to 25 m are possible without limitations and are subject to the ability of operating machinery and transportation (Shi and Walker 2006).

Wood Plastic Composites (WPC)

WPC are made of wood fibers and plastics that contain lignocellulosic fibers and several non-organic filler materials. WPC are also known as natural fiber plastic composites or natural fiber reinforced plastics. The history of WPC production began in the US several decades ago (1970) and continued in Europe and Japan. The WPC industry has increased each year since the 1970s (Pritchard 2004). The reason for this growth is that manufacturers primarily produce WPC while producing mixtures of other materials. Statistics show that the WPC industry only covered a fraction of the total wood produced for the manufacturing industry at 1970; however, WPC became an important benchmark for the manufacturing sector during the transformation of the world toward the current use of significant biocomposite sources (Smith 2002).

Today, WPC are a popular alternative to natural wood biocomposites and are considered innovative and high-quality products (Rowell 2005). The high demand for wood materials as design motifs and the durability of wood enhanced by emerging technologies have enabled WPC to attract markets. WPC are part of a new generation of biocomposites that are more eco-efficient, durable, dynamic, and environmentally friendly. R&D scientists are developing WPC that possess improved properties for use in the commercial production of end products, especially in the fields of furniture design, automobiles, and building construction (Rosli 2010). The strength of WPC is nearly eight times greater than that of ordinary wood; however, it can still be recycled and either reprocessed into new products or biodegraded. WPC ingredients maintain the international standards for biocomposite materials to replace existing wood and thermoplastic-containing materials, which are easily used to make the product. Therefore, it is not surprising that WPC products are very popular in both Europe and North America; they are perceived to be of the highest quality available and, most importantly, they protect the environment.

Medium Density Fiberboard (MDF)

The term fiberboard includes high-density fiberboard (HDF), medium-density fiberboard (MDF), and low-density fiberboard (LDF), each of which is made via both dry and wet processes. Composite panels, such as particleboards, plywood, and MDF are often used in manufacturing items such as doors, flooring, and furniture because they are cost-effective and easy to produce (Khalil and Bhat 2010; Nemli 2000). MDF is a wood-based composite material containing panels composed of combinations of lignocellulosic compounds and synthetic resins, such as urea formaldehyde (Levesque 2000) and phenol formaldehyde (PF), or an isocyanate compound, which is dried at low temperatures and pressurized under humid conditions (Youngquist 1999; Khalil *et al.* 2010b). Two primary sources have been identified for making MDF: oil palm EFB pulp fibers and rubberwood. However, previous studies demonstrated that oil palm EFB pulp fibers are superior to rubberwood because they contain fibers with better pH values and buffering capabilities. This buffering feature comes from an acidic reaction agent that becomes transformed into a less reactive compound and obstructs the resin flow (Bhat *et al.* 2010). MDFs made from the suggested materials are suitable to replace those made from saw dust, which is known to be less resistant (Nadlin 2009). Originally, MDFs were covered with layers produced from mixtures of unsustainable materials, such as veneer, lacquer or laminating plastics, melamine paper, and PVC foils. These mixed layers do not share the sustain-ability characteristic, because both chemical mixtures and plastics are used to strengthen the wood and smooth its surface.

Most researchers prefer EFB as the primary raw material over the currently available resources for making MDF. The processes and materials used in making MDF significantly impact the mechanical characteristics and stability of the wood (Khalil *et al*. 2010b). MDF has been used as an alternative resource to wood in the particle industry because of rapidly growing deforestation. This annually escalating production of MDF results from the decline of natural resources and, at the same time, offers a window of opportunity for manufacturers to use more sustainable resources for producing their products. MDF is ideal because of its color, which highlights the texture and uniformity of rubberwood fibers. The medial compression of EFB fibers in MDF is highly valued and marketed at a competitive price relative to common biocomposites such as plywood, particle board, and hardboard (Thomas 1997).

Particleboard

The high demand for wooden materials and the rise in agricultural areas and forest fires have increased the importance of composite particleboards versus solid wood. Currently, particleboard provides industrial users the consistent quality and design flexibility needed for the rapid and efficient production of quality consumer products. The increasing demand for particleboard as an alternative raw material was influenced by its low cost relative to conventional solid wood. The advantages of using particleboard are not limited to possessing a consistent quality for the design of end products, but also that of optimizing the use of agricultural wastes in the manufacturing process. Particleboard is a non-structural interior product made from wood particle byproducts from the manufacturing of other wooden products. These wood particles are mixed with synthetic resins or binders and formed into a panel under heat and pressure. This board consists of several layers: a core and two outside layers or faces. Particleboard is normally used to produce products suitable for specific geometric resin levels, board densities, and manufacturing processes. Additives can be incorporated during manufacturing to enhance its specific properties, such as improving its dimensional stability and increasing both its fire and moisture resistance (Khalil and Hashim 2004). The produced particleboard is graded on its quality, and each particle is regularly tested to ensure that it is guaranteed to comply with the strict voluntary industry performance standards. Products such as kitchen cabinets, shelves, floor underlayment, office furniture, and many other wood-based products can be replaced with particleboard. The lignocellulosic fibrous nature is unique to particleboard compared with the other types of boards, which are produced from various lignocellulosic fibers, such as kenaf and jute, that improve the low resilience sound absorbance of the particleboard (Shi and Walker 2006; Youngquist 1999).

Hardboard

Hardboard is one of the best wood alternative materials on the market. Hardboard was discovered by the manufacturing industry and was a very popular material before the release of plywood into the market. Hardboard is a low-cost product that is good for making items such as speakers and electronic panels. Hardboard is produced during the wood extraction process and is comprised of lignocellulosic fibers, wood chips, and pulped wood waste; hardboard is formed using heat and steam. This process forms a fluffy brown fiber overlay in a lignum glue mixture that is pressed using a hot metal plate to obtain a smooth, glossy, medium-dark brown texture on one side with variations in thickness of 2.5 mm, 2.7 mm, 3 mm, and 4.8 mm (Youngquist 1999). Hardboard is

hygroscopic and can be easily damaged in outside applications. However, an innovative research project managed to create a hardboard-fuel mixture that is moisture resistant, scratch resistant, hard, strong, and that could be designed in various shapes, such as holes, printed areas, and plastic surfaces facing or veneered to match a variety of specific purposes.

OIL PALM BIOMASS *VS*. OTHER MATERIAL BASED BIOCOMPOSITES FOR FURNITURE

Wood from trees has been used by mankind since early human history. The use of lumber was so widespread that wood was not only used as a source of fuel but also was used in transportation, weapons, household products, furniture, and many more wood-based tools or materials to improve the quality of life. Furthermore, wood was used for alternative communications through the sound created by knocking two pieces of wood together. Without the wood provided by trees, humans may have been unable to survive their harsh environments.

In Malaysia, Indonesia, Thailand, and other countries, rubberwood trees are one of the most important sources of raw materials because their timbers are commonly used in the production of furniture. RW is an environmentally friendly wood because of its features and value, which are not possessed by other materials. Previous studies found that the demands of furniture applications for sawn timber have increased annually because consumers prefer the unique wood grain and light color of RW, which is easy to work with, easy to furnish with other materials, and durable. RW has a density between 550 and 650 kg/m^3 and has a light-straw to light-brown color. The diameter is normally between 30 and 35 cm and the trunk length between 3 and 5 m (Khalil *et al.* 2010c).

The past demand for wood was different from the current demand because previous logging was minimal and did not affect the availability of forest resources. However, because of the incremental increase in the human population, the demands for RW drastically increases every year, endangering the ecosystem through the deforestation necessary to satisfy the world market (Yusoff and Koh 2001). A shortage of rubberwood on the market has been caused by the decline of rubberwood acreage from over 2 million hectares to 1.6 million hectares (1995-2008). Now, designing furniture from wood is far more expensive than using other types of materials because wood is becoming increasingly scarce (Roger 2000). Malaysia, Indonesia, and Thailand, followed by China, Vietnam, India, and other countries, are well known for the quality of their exported furniture, which is primarily made from rubberwood. Japan, the US, and West Asia are common importers of Malaysian furniture, and markets in the European Union (EU) are also beginning to import Malaysian furniture, which provides various opportunities for Malaysian furniture makers. The introduction of better designs and technologies is required to retain the added value and increase shares in the European furniture market. In that way, exported furniture products can stay ahead of the competition and monopolize new emerging markets. For example, in Malaysia, the government's 2nd Master Plan (1996-2005), identified the furniture industry as a "target industry," and the National Timber Industry Policy (NATIP) was formed to guide the direction of the nation's timber industry from 2009 to 2020 so that it will remain sustainable and competitive in a challenging global market and environment. Other

countries (USA, UK, Holland, Sweden, *etc*.) have also followed such initiatives to boost their local industries.

Compared to rubberwood, bamboo and rattan are both versatile, low-cost, light, and environmentally friendly materials that are suitable for home furniture production (Bansal and Zoolagud 2002). However, bamboo is often mistaken for rattan because both are from the same plant type and are nearly identical, except for their plantation location, size, color, and physical properties. Bamboo stands up straight and can reach a height of approximately 30 feet in 2 to 3 years. Because bamboo can be easily planted, sources of this wood are readily accessible to the manufacturing industry for the production of bamboo-based furniture (Saville 2008). Aesthetically, bamboo has a uniquely smooth surface and can be either neutral or various colors, such as yellowish, green, and brown. Bamboo is long lasting and unique in appearance compared with other materials, and bamboo furniture has similar strength as other wood-based furniture (Bansal and Zoolagud 2002). An example of innovative bamboo research is the design of a chair based on the elements of swift motion, transforming the strength and flexibility of bamboo to produce a reaction from the design, *i.e*., a unique structure as the primary feature of a complete biocomposite material (Reis and Wiedemann 2010; Brower *et al.* 2009).

FURNITURE DEMANDS OF GROWING POPULATIONS

The demand for essential commodities is closely linked to the population density of any country. Increasing market demand creates a shortage of raw materials (Ljungberg 2007). Therefore, emerging technologies in new products have identified durable biocomposites as the best alternative for reducing unnecessary environmental impact (Larsson-Brelid *et al.* 2010). Statistics show that the world's population in 2011 was approximately 7 billion, and that number will continue to rise depending on economic growth, as well as political, health, and environmental improvements (Rohana 1999; Bureau 2011). Figure 3 shows the population in Southeast Asia in 2011, and it is estimated that Southeast Asia will support 32.3% of the world population by 2050. The increasing world population will also increase the demand for furniture and other wood-based products, which would simultaneously increase the amount of deforestation to satisfy the economy (Bureau 2011). The market shows that growth has shifted from producing products to designing them, which is a key component for driving a global market. Overseas buyers, ranging from middle to upper class, are looking for local manufacturers who can meet their production demands. Indonesia has the largest population in Southeast Asia, with a population of approximately 238.2 million in 2011, whereas Brunei has only 0.4 million people. Indonesia has the advantage of its geographical area, which is larger than any other country in Southeast Asia and also provides an advantage in the wood industry. This advantage is that Indonesia still has fertile forests with various timber plants that make it one of the largest wood exporters in the world (MIFF 2011). Approximately 80% of the exported products from Malaysia are furniture, which has placed Malaysia in the strong position of being the 10^{th} largest furniture exporter globally. The primary importers, including the US, Japan, and Australia play a key role in making Malaysia a strong contender in the furniture industry. The tremendous growth in exports to countries such as the UAE, Saudi Arabia, the Philippines, and Russia has led Malaysia to look for market opportunities in Algeria, Greece, Puerto Rica, and Libya (MIFF 2011). Due to its dependence on natural wood

resources, the government has set an annual growth of 6.5% for wood-based furniture, and the profits from wood-based furniture are estimated to reach approximately RM 53 billion by the year 2020.

The global demand for furniture is strong despite numerous economic downturns. China and Vietnam are the strongest of Malaysia's competitors because of their lower manufacturing costs; however, furniture from Malaysia continues to grow because of original designs, which add aesthetic value, and there is a good work ethic. The role of the government is crucial for nurturing the furniture industry; the government provides pioneer status for tax exemption and investment tax allowances that allow businesses in the industry to grow more easily and rapidly. The business-friendly environment, high-quality products, and large potential market can lead the furniture industry to exceed expectations and grow continually at an exponential rate (Puasa *et al*. 2010; Bovea and Vidal 2004a). There are plenty of forest areas available because of the size and vast landscape of the country. However, a large population does not contribute to product development, and the demand for wood products is lower. Figure 3 shows that the demand for wood products does not depend on the population growth but on the country's standard of living. If the population of a country increases but lacks in developmental growth, there are no changes in the demand for wood products, or the local demand may also decrease. Countries such as the Philippines and Vietnam have larger populations than Malaysia; however, the local demand for wood products favors Malaysia.

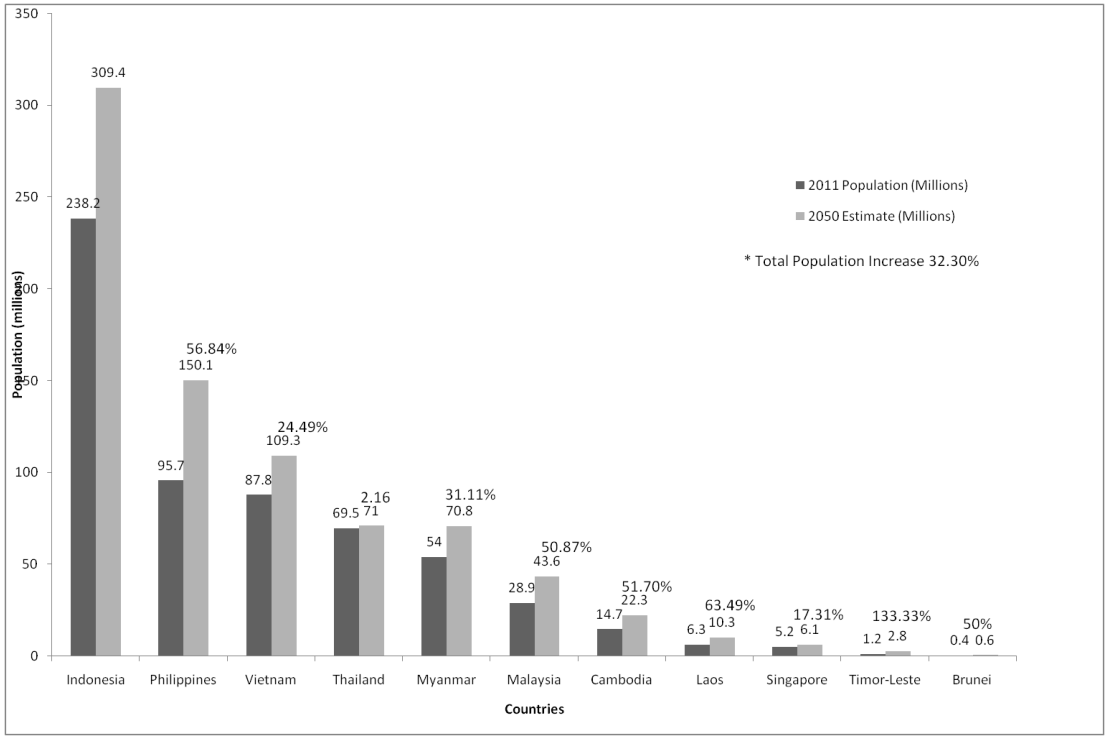

Fig. 3. World population data (Southeast Asia)

Population growth does not necessarily affect product demand. Indonesia still has fertile forests but has lower demand. This research can be used to provide alternative wood sources to Indonesia, which will decrease deforestation. The countries affected by environmental problems such as deforestation can benefit from the results of this research

to use alternative wood products and gain time for the replanting of forests. Small countries, such as Singapore, can also take the opportunity to compete with other countries in biocomposite production by importing raw materials and then generating income by exporting wood biocomposite products to other countries. Comparisons can be made between this suggested product and other wood products that may be costly and do not sustain the ecosystem or forest resources.

FURNITURE AND DESIGN

Furniture is one of the common items found in a household, and a consumer's decision to purchase household furniture is usually overwhelmed with a range of shape, size, style, colour, and material choice (Shukri *et al.* 2011). Furniture has been one of the most important items in everyday life for centuries (Khalil *et al.* 2010c). Furniture design covers a wide range of environments, including homes, offices, restaurants, hotels, public parks, bus stops, shopping centers, and hospitals (Alli and Rahman 2008). The varieties of past and present furniture are distinguished by their functionality and design. Multi-functional furniture is becoming a common trend in parallel with the modern lifestyle, which concurrently requires a practical, ecologically friendly, and attractive product. The current process of making furniture has changed significantly over time (Reis and Wiedemann 2010). Progress in both science and technology has made the process of furniture design both more efficient and faster. Furniture production has also been significantly improved, which improves the economy (Saville 2008). The furniture industry is one of the most important industries in Malaysia. Records of timber-based product exports in 2004 indicate that Malaysia had profits of RM5.4 billion, which reflects a 7.3% growth, showing that the furniture industry grew steadily and is becoming one of the most important industries in the country (Nadlin 2009). The furniture industry in Southeast Asia is a part of the nation's economy that possesses high growth and immense potential. This industry has contributed to the nation's export earnings for over two decades and has seen enormous annual growth. Currently, furniture made from Southeast Asian countries such as Malaysia, Thailand, and Indonesia has been exported to more than 160 countries worldwide and enjoyed great demand throughout the world ranging from North America and Europe to Asia and the Middle East. The global community has started to recognize the decrease in natural resources and the remainder of the world's natural resources for future generations. The key to a sustainable future depends on how the community finds ways to maintain their lifestyles by using more constructive daily habits and practicing economic values, material choices, and sustainable environmental and social lifestyles (Oosterlaken 2009).

Design is a force that continues to grow and change over time through the never-ending development of materials, techniques, forms, functions, processes, uses, trends, and styles (Brower *et al.* 2009). The designer plays an important role in developing these factors because they are responsible for determining the materials required and inspiring the consumer product production in global markets. Good design combines the capabilities of a balanced approach in terms of commercial design, culture, environment, economy, idealism, and humanitarian concerns. For centuries, people have lived entirely dependently on designers regardless of race, gender, or age. The more developed a country is, the more likely it is to be innovative in producing home furniture designs. For example, home furniture has seen extensive transformation, particularly in terms of function and use. Furniture is designed as home appliances for consumers and is

increasingly advanced and expanded in terms of functions, as well as added conceptual values, such as 'multi-functional' and 'smart design'. A design's superiority is evaluated by the satisfaction of the consumer regarding a number of factors including the design success in maintaining natural ecosystems and user friendliness. The use of proper materials during design should be highlighted for its importance to the manufacturing and disposal processes to ensure that the quality of the design and environment are maintained (Bovea and Vidal 2004b).

APPLICATION AND SUSTAINABILITY OF INNOVATIVE FURNITURE DESIGN

The rapid technological advancement of the furniture industry allows consumers to suitably choose items according to their own tastes. Designers could expand their design expertise and better apply their creativity by using more dynamic and better quality raw materials that have expanded capabilities. Figure 4 shows some innovative furniture designs that use various biocomposite types, such as MDF, LVL, OSB, WPC, and plywood, and are currently available on the market. Wood plastic composite outdoor furniture (Fig. 4a) was produced by Zhejiang Ccav Industrial Development Co., Ltd in 2008. Currently, furniture is also being manufactured using WPC, a mixture of wood waste, recycled plastic, and several other chemical additives that form a biocomposite material. The perfect combination of wood fibers and plastic is capable of producing new features with greater consumer and environmental benefits because WPC is partially recyclable and environmentally friendly. WPC is suitable for designing outdoor furniture because it is resistant to stretching, bending, water, weather, and extreme temperatures. This material also possesses anti-abrasion, anti-aging, both anti-freezing and thawing properties, as well as environmental protection testing, which includes formaldehyde content. WPC can also be used as a substitute for both wood texture and natural wood, and WPC has a variety of colors such as those of existing plastic.

The IQ Matics product shown in Fig. 4(b) uses MDF in the design of a piece of furniture known as the kiwi coffee table. In addition, MDF has been incorporated into other materials, such as glass and stainless steel, to inject elements of elegance and luxury into the design. Figure 4(c) shows the efforts of various parties to raise awareness of sustainable trends in product and furniture design using green materials, which are encouraged and essential especially for young designers. The use of recycled wood has been attempted by Philip Mambretti, a designer from Samarreda who took the initiative to use particleboard in the production of FIMA seats (Samarreda 2011). Samarreda (2011) uses different approaches that utilize recycled materials, account for the effects of the furniture lifetime on the consumer, minimize the use of raw materials during the production process, identify the environment impact, and account for the cost effectiveness of the price. Figure 4(d) shows that hardboard material has expanded its use since the era during which it was first made. This material was introduced into furniture making in 1926 and became increasingly popular over the last few years (Thomson 2003). The designer had to apply both of these areas to produce a conversation table using a combination of corrugated cardboard and hardboard made of compressed wood fiber medium without formaldehyde and resins with high recycled content elements.

Figure (4e) shows a design bench produced using laminate veneer lumber (LVL) by Mike Mindmarsh (2011). LVL was initially used in building structures; however, this technique incorporated LVL in furniture production that used plywood because of the

mass of flat materials and the low environmental impact solutions. Ergonomic factors are important to every design and require curves to be cut in the bend, installed, and sanded smooth without using a standard furniture bolt. In addition, the unique textures found on LVL prompted designers to create new designs, such as lounge chairs, coffee tables, and dining chairs, and designs that vary according to the nature of the LVL, which creates durable and robust furniture. Research has shown that LVL is 1.5 to 3 times harder and stronger than timber (Shi and Walker 2006). Designer Chris Rucker made good-quality, low-cost furniture out of waste materials. Figure 4(f) shows Chris Rucker's table design using oriented strand board materials to produce a beautiful and unusual piece of furniture (Jaime 2010). Chris Rucker is one of the designers trying to highlight sustainability in modern culture where waste is considered one of the most important world issues. The green concept has inspired and guided designers to create amazing new products from waste materials. Rucker used OSB materials, which, when combined with the manufacturing methods, produce quality designs that are aesthetic, revolutionary, and beneficial. Emphasizing the motto "everything is possible," design development creates amazing designs that incorporate different views of the current user's requirements to create more practical, strong, waterproof, and quickly manufactured furniture that allows users to maintain a modern but cost-effective design.

A stack-laminated lounge chair is shown in Figure 4(g); this is a chair designed by Julia Krantz of Brazil (Anon 2009). The chair is made from layers of stacked plywood pressed together using heat to form a thick coated plywood. The beauty of the lounge chair is the structure of the multi-layered plywood with attractive and authentic dual colors. Figure 4(h) shows a spring seat design creatively produced by Anthony Marshak, a former furniture design student, using 100% bamboo veneer material and gluing plywood by bending under pressure. A successful designer has the flexibility to explore innovative bamboo for a more ergonomic posture and balance as the primary attraction for consumers and to create a new, more flexible and greener alternative to wood (Bansal and Zoolagud 2002). In addition, the design also minimizes the material's weight and waste. The combination of both the simplicity of a classic material (bamboo) and the innovative designs using the latest manufacturing techniques produces a high-quality furniture design. The differences between bamboo and hardwood can be observed in its features, such as the arched shape, unique surface texture, natural colors, durability, moisture and strain resistance, and environmental friendliness. Researchers also agree that bamboo products have the potential to be competitive on the international markets (Nakatani 2011; Bansal and Zoolagud 2002).

CHALLENGES FOR THE UTILIZATION OF AGRO-BASED BIOCOMPOSITES FOR FURNITURE APPLICATIONS

Industry Structure: Supply of Raw Materials, Research and Development, and Progress towards Value Added Products

The industrial sectors of each country are normally divided into three parts: the permanent forest reserve, government reserve, and freehold land. In 2010, timber production from the forest area in Malaysia was expected to decline because the forested areas were smaller and the land ownerships were designated mostly for developments.

Fig. 4. Innovative design from agro-based biocomposites, (a) Wood plastic composite outdoor furniture (Zhejiang Ccav Industrial Development Co., Ltd.), (b) kiwi coffee table (IQ Matics), (c) Furniture from Particleboard by Philip Mambretti (Samarreda 2011), (d) Hardboard (Thomson 2003), (e) LVL by Mike Mindmarsh (2011), (f) OSB Table designed by Chris Rucker (Jaime 2010), (g) Chair designed by Julia Krantz (Anon 2009), (h) Spring seat design creatively produced by Anthony Marshak

Based on these expectations, the Ministry of Plantation Industries and Commodities founded several forest plantations that were expected to help solve deforestation problems. There are several other countries that prohibit the exportation of timber to preserve their remaining forests. The increasing competiveness for raw materials in the international market has not only depleted the reserve of raw materials but also increased their prices, which may negatively affect their supply for the wood industry. In these respects, the local industry should adapt their operations to supply local wood resources and restrict imports.

Many research institutions and universities globally have established support for the R&D of the wood industry. For example, in Malaysia, the government incorporated the Forest Research Institute Malaysia (FRIM) and The Fiber and Biocomposite Development Centre (FIDEC) to increase the research capabilities of the industry. However, despite the government's efforts, the R&D contributions are still below expectations. Additionally, research discoveries overlap and are redundant because of the lack of standardization between the research institutions and the industry. Most of the research and development tests conducted on various wood samples have concentrated on increasing the value of the wood (Khalil *et al.* 2010b; Leao *et al.* 2010; Waldemar and Jorissen 2004; Cai and Winandy 2005). R&D should strive to help achieve the processing skills required to grow and increase the product quality. The refusal of the industry to invest toward increasing the value of wood is due to the requirement of costly machinery and state-of-the-art technologies (Bovea and Vidal 2004a).

Raw materials have become a sustainability challenge for the wood industry. There are abundant agricultural wastes, such as oil palm trunk (OPT), oil palm frond (OPF), empty fruit bunch (EFB), and PPF, that are not currently being used. Even though these materials are considered wastes of raw materials, some of these materials, such as the OPT, have shown potential as alternative materials for the wood industry. Forest plantations are slow to produce raw materials simply because it takes a very long time for forest trees to grow. Other potential materials, such as plantation wastes, can be explored as alternative sources for the wood-based industry. Therefore, the government is actively implementing various initiatives to identify alternative materials for the wood processing industry. This research focuses on helping to generate an infrastructure for the steady supply of raw material while increasing the productivity of the nation's biocomposite materials industry.

Sustainable Supply of Raw Materials and Human Resource Development

To sustain the development of the timber industry, several steps must be taken to ensure a constant supply of raw materials. Recognizing the challenges of the timber industry, the government of Malaysia has aggressively implemented several initiatives to explore alternative materials from other sources to support the timber industry. One example of an alternate raw material is the use of other substances with the potential to form agricultural residues, which can be explored as an alternative source for the wood processing industry. Governments around the world and private organizations launched the Forest Plantation Development Program; however, due to the long gestation period, forest plantations could not meet the immediate needs of the timber industry. The biocomposite industry in Southeast Asia is still new, and the transition of a country's industry toward the use of this alternative material is likely to deplete a nation's local workforce and skilled worker supply. The government attempted to support the biocomposite industry by establishing several wood training centers, such as in Malaysia,

the Malaysian Wood Industry Skills Development Centre Malaysia (WISDEC) and the Malaysian Furniture Industry Technology Centre (FITEC), to increase the production capability and trained worker skill level so that workers can have the skills needed for the industry (Oosterlaken 2009). Further, this method could attract more highly skilled workers, especially to the managerial and supervisory levels, because the current working environments are considered to be less attractive by workers.

Marketing and Promotion: Innovative Agro-Based Biocomposites, Global Competition, and Market Access

For over a decade, concerns regarding conserving resources and protecting the natural environment have been actively debated by the global society. Demands for environmentally friendly or "green" products have grown internationally, especially in developing countries. These trends add pressure to wood producers and products in Asian markets. The problem with the wood market is that it can reduce the supply of natural materials while increasing their cost. The government should encourage the consumption of alternative wood materials to ensure sustainable growth, stability, and competitiveness. Thus, researchers are exploring biocomposite materials that can replace the currently available wood materials. Good responses have been received in the global market to using biocomposite materials made from mixtures of bio-materials or natural fibers while offering an alternative to the wood product manufacturer. Biocomposite materials should also keep up with demand and be accessible to the international market. Manufacturers are starting to have confidence in the advantages of biocomposite-based materials, which have been shown to be potentially successful and innovative materials for making furniture and other applications. Furthermore, the accessibility of natural fiber-like materials from the forest and the use of agricultural wastes in biocomposite materials are the primary factors that manufacturers consider in selecting a biocomposite as an alternative material for the manufacturing industry. Intense competition by producers from other countries in the agro-based biocomposite industry is to be expected. Furthermore, issues such as strict standards, purchasing regulations and policies, environmental issues and law enforcement could influence the demand for future trade in composite-based materials. Although Southeast Asian has a strong record in the international wood market, the Southeast Asia market has become a challenge. To stay competitive in the industry, each country should prepare several new strategies to face these issues.

Innovation and Technology

To compete in the international market, the industry should invest heavily in new machinery and the latest technology to ensure that products can be produced constantly with high quality. The efficiency includes the speed of manufacturing and reliability of the machinery to ensure that a sufficient quantity of products is produced over a given time frame and that processing costs are lowered. In the future, the industry needs to develop advanced products while also using related technologies with the support, infrastructure, manufacturing information technology, and communications given to the managerial staff (Bovea and Vidal 2004a). Manufacturing products should also retain their current product design, labeling and marketing to guarantee market capability when moving forward into the international market (Oosterlaken 2009).

The wood and biocomposite industries will face market globalization and must, therefore, have a strategic capability with sufficient science and technology to gradually

increase the use of advanced technology. In general, the use of advanced technology increases productivity to an optimum level, which encourages creativity and increases variation in the product. Worker shortage in the manufacturing, managerial, maintenance, design, and finishing techniques fields, however, affects and decreases the ability of the industry to use the latest technology. Therefore, both governments and private sectors have established an industrial group of small and medium corporations to supply various components and other parts in a short timeframe to larger manufacturers. This short cycle enables the manufacturers to be flexible with regards to the quantity of a minimum order and simultaneously open new channels for distribution and marketing. Many challenges exist for preparing manufacturing operations that are flexible because they do not provide any economic benefits; however, they can help increase the competitiveness of the market. Furthermore, the function of small and medium corporations is to work as a catalyst for growth and support services as well as other secondary tasks such as design, R&D, and testing. These corporations should also act as a training school.

Commercialization of Innovative Products

Researchers have made their own discoveries, especially regarding alternative biocomposite materials such as oil palm trunks (OPT) and other resources; they have made presentations at seminars and conferences to communicate their research achievements to consumers. However, the biocomposite industry has been slow to develop because of several factors in the current industrial climate that support current products but question new biocomposite materials. Biocomposites are considered new materials; therefore, the lack of identification of raw material resources and the inability to make investments in machinery and related tools have been obstacles. Each manufacturing industry has a certain wage percentage for R&D. Indirectly, R&D encourages certain industries to be competitive in the market by making more innovative products (Reis and Wiedemann 2010; Khalil and Bhat 2010). The R&D processes should be used throughout the process, and both participation and cooperation between R&D and any research institutions and other universities that produce innovative and high quality products should be encouraged. The importance of R&D in increasing the value of wood types that are not common to the market and applying commercial fibers and non-wood materials should be emphasized. Furthermore, R&D is encouraged to make new products that result in increased productivity. Issues such as material recycling, emission control, and the standardization and monitoring of all research activities should encourage the working committee to avoid overlaps and wastes as well as improve the delivery system.

CONCLUSIONS

A better future for the environment can only be achieved by intensifying efforts to study and increase the manufacture of products that are environmentally sustainable. Materials and their design are related and can be used to produce a sustainable product. During the manufacturing process, the concept of life-cycle assessment is the most effective means for identifying the cycle of each product from production to disposal. Factors such as education, research, and the dissemination of information to the community are crucial for a sustainable future in producing quality products. Boosting the production of biocomposite materials should be emphasized because markets are running out of wood. Manufacturers should stay abreast of the latest developments in

materials and strive harder to maintain the quality and innovative designs that appeal to consumers worldwide and to maintain the market demand momentum.

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REFERENCES CITED

Abdul Khalil, H. P. S., Nurul Fazita, M. R., Jawaid, M., Bhat, A. H., and Abdullah, C. K. (2011). "Empty fruit bunches as a reinforcement in laminated bio-composites," *Journal of Composite Materials* 45(2), 219-236.

Abdul Khalil, H. P. S., and Rozman, D. (2004). "*Gentian dan Komposit Lignoselulosik*," Universiti Sains Malaysia Publisher, Penang, Malaysia.

Abdul Khalil, H. P. S., and Hashim, R. (2004). *Komposit Panel Berasaskan Sumber Kayu*, Universiti Sains Malaysia Publisher, Penang, Malaysia.

Abdul Khalil, H. P. S., and Bhat, A. H. (2010a). "Oil palm biomass: Fibre cultivation, production and its varied applications," *In: Oil Palm: Cultivation, Production and Dietary Components*, S. A. Penna (ed.), Nova Science Publisher, Inc., 21-34.

Abdul Khalil, H. P. S., Firdaus, M. Y. N., Jawaid, M., Anis, M., Ridzuan, R., and Mohamed, A. R. (2010b). "Development and material properties of new hybrid medium density fibreboard from empty fruit bunch and rubberwood," *Materials and Design* 31(9), 4229-4236.

Abdul Khalil, H. P. S., Nurul Fazita, M. R., Bhat, A. H., Jawaid, M., and Nik Fuad, N. A. (2010c). "Development and material properties of new hybrid plywood from oil palm biomass," *Materials and Design* 31(1), 417-424.

Akihiro Takahashi, a. E. A. (2001). "Application of MDI binder towards environmental friendly wood-based industry," *Ceminar On Wood-Based Panel Products*, Forest Research Institute Malaysia, Kuala Lumpur, 6.

Alli, H. H., and Rahman, A. R. A. (2008). *Reka Bentuk Perindustrian : Pengenalan*, Dewan Bahasa dan Pustaka Kuala Lumpur.

Amouzgar, P., Abdul Khalil, H. P. S., Salamatinia, B., Zuhairi Abdullah, A., and Issam, A. M. (2010). "Optimization of bioresource material from oil palm trunk core drying using microwave radiation; A response surface methodology application," *Bioresource Technology* 101(21), 8396-8401.

Anon (2009). "15 The most unusual lounge chairs in the world," http://naturalinteriordesign1.blogspot.com/2009/09/15-most-unusual-lounge-chairs-in-world.html

Anon (2011). "2011 World Population Data Sheet," <http://www.prb.org/pdf11/2011population-data-sheet_eng.pdf>.

Baharuddin, A. S., Kazunori, N., Abd-Aziz, S., Tabatabaei, M., Abdul Rahman, N. A., Hassan, M. A., Wakisaka, M., Sakai, K., and Shirai, Y. (2009). "Characteristics and microbial succession in co-composting of oil palm empty fruit bunch and partially treated palm oil mill effluent," *The Open Biotechnology Journal* 3, 92-100.

Bansal, A. K., and Zoolagud, S. S. (2002). "Bamboo composites: Material of the future," *Journal of Bamboo and Rattan* 1(2), 119-130.

Bovea, M. D., and Vidal, R. (2004a). "Increasing product value by intergrating environment impact, cost and customer valuation," *Resources Conservating & Recycling* 41, 12.

Bovea, M. D., and Vidal, R. (2004b). "Materials selection for sustainable product design: a case study of wood based furniture eco-design," *Materials & Design* 25, 5.

Brower, C., Mallory, R., and Ohlman, Z. (2009). *Experimental EcoDesign: Product, Architecture, Fashion*, RotoVision SA, UK.

Bureau, P. R. (2011). "World Population Data Sheet 2011," http://www.prb.org/Publications/Datasheets/2011/world-population-data-sheet.aspx

Cai, Z., and Winandy, J. E. (2005). "Opportunity and development of bio-based composites," *Proc., Proceeding of International Workshop on Prefacricated Bamboo Panel Module*, Beijing, China, 11.

Jaime (2010). "Chris Rucker at Industrial Gallery," http://design-milk.com/chris-rucker-at-industry-gallery/

John, M. J., and Thomas, S. (2008). "Biofibres and biocomposites," *Carbohydrate Polymers* 71(3), 343-364.

Kairi, M. (2005). "Interaction of R&D and business development in the wood products industry, Case Kerto®–Laminated Veneer Lumber (LVL)," *Helsinki University of Technology Laboratory of Wood Technology Reports*, Helsinki University of Technology Department, Finland, 237.

Kong, H. W. (2001). "Oriented Starnd Board (OSB) - A new engineered wood product for Malaysia." *Seminar On Wood Based Panel Products*, Forest Research Institute Malaysia, Auditorium, Forest Research Institute Malaysia, 4.

Larsson-Brelid, P., Walinder, M. E. P., Westin, M., and Rowell, R. (2010). "Ecobuild a center for development of fully biobased material systems and furniture applications," *Molecular Crystals and Liquid Crystals* 484, 8.

Leao, A. L., Souza, S. F., Cherian, B. M., Frollini, E., Thomas, S., Pothan, L. A., and Kottaisamy, M. (2010). "Agro-based biocomposites for industrial applications," *Molecular Crystals and Liquid Crystals* 522, 18-27.

Levesque, Y., Lumber Manufacturing Department, Eastern Division (2000). *Lumber and Value-Added Wood Products: Special Report*, Forintek canada Corp., Canada.

Liansheng, Y., Maili, S., Tao, W., and Wu, Z. (2002). "The pretreatment of carbon fibres for 3D C/SiC composites," *Science and Engineering of Composite Materials* 10(1), 55-58.

Ljungberg, L. Y. (2007). "Materials selection and design for development of sustainable products," *Materials & Design* 28(2007), 466-479.

Maloney, T. M. (1986). "Terminology and products definitions—A suggested approach to uniformity worldwide," *Proc., 18th International Union of Forest Research Organization World Congress*, Ljubljana,Yugoslavia.

MIFF (2011). "Malaysian International Furniture Fair (MIFF)," http://www.versalink.com/news/events/malaysia-international-furniture-fair-miff-2011

Mindmarsh, M. (2011). "Custom designed furniture for NMIT," http://urbismagazine.com/articles/furniture-designed-specifically-for-nmit/

Nadlin, R. S. (2009). "Jualan Papan Gentian Sawit Disasarkan RM20j." *Utusan Malaysia*, Utusan Malaysia, Kuala Lumpur.

Nakatani, A. (2011). "Analysis of Japanese and Finnish furniture design: A consideration for product identity and the relativity of industrial development and cultural context," Master's Degree Thesis, University of Lapland, Rovaniemi, Finland.

Nemli, G. (2000). "Effects of surface coating materials and process parameters on the technologies properties of particlebboard," PhD Thesis, Karadeniz technical University, Trabzon, Turkey, Turkey.

Oosterlaken, I. (2009). "Design for development: A capability approach," *Design Issues* 25(4), 91-102.

Pawlak, J. J. (2007). "A sustainable economy," *BioResources* 3(1), 1-2.

Pritchard, G. (2004). "Two technologies merge: Wood plastic composites," *Plastic Additives & Compounding / Reinforced Plastics*(July/August 2004), 4.

Puasa, A. F., Rohana Abd Rahman, Ismariah Ahmad, L. H. F., and Roda, J. M. (2010). "EAS strategic options: Rubberwood timber decreasing, wither the wooden furniture industry?", Forest Research Institute Malaysia (FRIM), Selangor, 2.

Rajan, S., and Amin, M. N. Z. M. (2001). "International standards development activities for wood-based panel products," *Ceminar Wood Based Panel Products*, Forest Research Institute Malaysia, Auditorium, Forest Research Institute Malaysia, 8.

Reis, D., and Wiedemann, J. (2010). *Product Design In The Sustainable Era*, Taschen, Germany.

Rohana, M. (1999). "Papan Gentian Daripada Sisa Kelapa Sawit," *Utusan Malaysia*Kuala Lumpur, 1.

Roger, T. (2000). "A review of adhesives for furniture," *International Journal of Adhesion and Adhesives* 20(4), 269-272.

Rosli, M. Y. (2010). "Pilot scale feasibility study for the production of wood plastic composite (WPC) Pellet from sawdust for furniture and automotive industry," *Conference on Innovation in Biocomposite and Paper*, Malaysia Timber Industry Board (MTIB), Kuala Lumpur, Malaysia.

Rowell, R. M. (2005). "Moisture properties," *Handbook of Wood Chemistry and Wood Composite*, R. M. Rowell (ed.), Forest Products Laboratory, Wisconsin, Madison, WI 77-98.

Salleh, A. H., Kamal, I., Rashid, N. A. A., Abdul Khalil, H. P. S., Ahmad Shakri, M. S., and Mahmud, S. Z. (2011). "Preliminary study of moulded laminated veneer oil palm (MLVOP)." *Modern Applied Science* 5(4), 11-18.

Samarreda (2011). "Recycled wood chairs from particleboard by Samarreda," http://www.trendir.com/ultra-modern/recycled-wood-chairs-from-particleboard-by-samarreda.html

Saville, S. (2008). *Design Secrets: Furniture. 50 real-Life Projects Uncovered*, Rockport Publishers, United States of America.

Shi, S., and Walker, J. (2006). "Wood-based composites: Plywood and veneer-based products," *Springer*, 391-392.

Shukri, M., Shor Nahar, Y. S., Mohd Khairon, B., Ashriq Fahmy, A., Bazilah, A. R., and Ahmad Aizuddin, H. (2011). "Malaysian consumers' perceived importance and knowledge of household furniture materials," *Malaysian Forester* 74(1), 61-68.

Smith, P. M. "U.S. Woodfiber-plastic composite decking market," In: *Proc., Sixth International Conference on Woodfiber-Plastic Composites*, 13-17.

Stark, N. M., Cai, Z., and Carll, C. (2010). "Wood-Based Composite Materials: Panel Products, Glued-Laminated Timber, Structural Compoiste Lumber, and Wood-Nonwood Composite Mateirals," In: *Wood Handbook: Wood as an Engineering*

Material, United States Department of Agriculture, United States, Ch. 11, pp. 11.1-11.28.

Thomas, E. (1997). "Technology scenarios in the Asia-Pacific forestry sector," *Asia-Pacific Forestry Sector Outlook Study Working Paper* Series, Kuala Lumpur, 80.

Thomson, E. (2003). "Which hardboard Is best?" *The Gesso*, 7.

Ul Haq Bhat, I., Abdullah, C. K., Abdul Khalil, H. P. S., Hakimi Ibrahim, M., and Nurul Fazita, M. R. (2010). "Properties enhancement of resin impregnated agro waste: Oil palm trunk lumber," *Journal of Reinforced Plastics and Composites* 29(22), 3301-3308.

Waldemar, J. H., and Jorissen, A. J. M. (2004). "Wood modification developments," *Heron*, 49, 361-386.

Youngquist, H. A. (1999). "Wood-based composites and panel products," *Wood Handbook - Wood as an Engineering* Material, U.S, 463.

Yusoff, M. N. M., and Koh, M. P. (2001). "Production of medium density fibreboard (MDF) from mixtures of oil palm stem and rubberwood," *Wood-Based Panel Products*, FRIM, Malaysia, Kuala Lumpur, Malaysia, 4.

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