PRODUCTION OF WOOD PELLETS FROM FOREST PRODUCT WASTE

By

Parveet Kaur

(0870220)

FACULTY OF NATURAL RESOURCES MANAGEMENT

LAKEHEAD UNIVERSITY

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Parveet Kaur

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Dr. Mathew Leitch

Major Advisor

Second Reader

Dr. Leni Meyer

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ABSTRACT

Keywords: Wood-pellets, wood- biomass, saw-dust, shavings, Torrefaction, biomass, residue.

Wood pellet production is increasing due to lower costs and supply stability as compared to natural gas and has less environmental concerns. A wood pellet is made mechanically from a uniform substance that has initially been hammered and ground into a homogenous dough-like mass by squeezing it through a press into a cylindrical shape. Wood pellets have an approximate size of 6-10 mm in diameter and lengths vary between 10-30 mm usually. The production of wood pellets from biomass is environmentally feasible and sustainable contributing to the economy of North America. Municipal waste is a modern method of energy production and, in addition to wood and agricultural products, municipal waste is the third most important biomass resource for energy production. Torrefaction is another method of converting raw material into a more energy dense fuel that could play a significant role in the production of wood pellets. Biomass fuels have received a lot of attention as a potential alternative to fossil fuels because of their ability to reduce greenhouse gas emissions. Biomass fuels, however, have storage, transportation, and energy density issues. Low density values can reduce energy density, resulting in higher transportation and storage costs. In the world, China is the largest producer of wood pellets, while United States is second followed by Canada and then Vietnam.

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1.0 INTRODUCTION

Wood pellets have become an important export of the southeast U.S. in the last decade, and they are now the third-largest wood product exported from the southeast U.S and have become economically important for North America (Kittler et al., 2020; Parish et al., 2017). Canada is the second largest producer of wood pellets in the world, and the majority of pellets it exports are sold in Europe and Asia (Forest products and applications, 2022). Wood pellets are produced in the southeast United States and shipped primarily to Europe to be used for heat and power globally (Parajuli, 2021; Kittler et al., 2020; Parish et al., 2017). Particles of wood are compressed for use as fuel and wood pellets (Jones et al., 2012). In some parts of the country, pellets are already commonly used, but as fuel prices rise and global climate change concerns grow, they are becoming increasingly popular (Jones et al., 2012).

A wood pellet is made mechanically from a uniform substance that has initially been hammered and ground into a homogeneous dough-like mass and then squeezing it through a heated press to form a cylindrical shape (Kuokkanen et al., 2009). Wood pellets have an approximate size of 6–10 mm in diameter and lengths vary between 10–30 mm usually (Kuokkanen et al., 2009). In the beginning, wood pellets were only designed for small-scale and for local domestic uses, and bark and sawdust, which are two products of the forest industry, were primarily used as a raw material for pellet production (Kuokkanen et al., 2009). In the wood pellet production process, wood residue from primary wood processing industries is preferred because it requires low resizing and is relatively dry and clean and is also easily available and affordable (Hoefnagels et al., 2014). In the current production process of wood pellets, a large amount of forest wood waste is accumulated during logging operations (slash and underutilized tree species) in the forest and wood processing industries (Tyurin et al. 2020). An environmentally friendly alternative to the disposal of waste could be the use of wood biomass in wood-fuel pellets as a renewable energy resource for domestic and industrial use (Tyurin et al. 2020). In reducing CO_2 emissions, biomass co-firing might play an important role because it is an efficient way to convert biomass into electricity with the help of a boiler system with less greenhouse gases emission (Tsuchiya & Yoshida, 2017). Different types of biomass residues have been investigated such as logging waste, woodworking, and disposal wastes as sources for making biomass wood pellets (Tsuchiya & Yoshida, 2017). Wood pellets are more in demand because natural gas prices are generally higher and more unstable than those of wood residues and wood pellets (Chau et al., 2009). Among the key characteristics of pellet producing companies are the vital role of raw materials (produced from the forest and forest product manufacturing waste), quality indicators (Tyurin et al., 2020). The environmental impact of such companies is mainly due to geographic location of the raw materials (such as logging waste) to the processing facility that are used in the production of wood pellets (Tyurin et al., 2020). The waste wood from large forest regions with a low transport density and a limited number of roads will require supply chain optimization to enable industrial operations for pelletization to be financially feasible (Tyurin et al., 2020). Municipal waste such as waste generated from the sewage, the urban areas and roadside vegetation, etc., could play an important role as biomass in the production of pellets (Greinert et al., 2019). The production of biomass pellets from municipal waste could be very feasible as it could require less energy to produce pellets as compared with fresh biomass (Greinert et al., 2019).

The main objective of this study is to investigate how wood pellets are made up from forest operations, from municipal waste, and other fresh biomass in the forest industry. The study also shows how biomass wood pellets are used in a heat and power system.

2.0 LITERATURE REVIEW

2.1. PRODUCTION OF WOOD PELLETS FROM WOODY BIOMASS

Wood-pellet production is increasing due to lower costs and supply stability compared to natural gas and has less environmental concerns (Chau et al., 2009). Wood pellets are typically made from sawmill residues including wood chips, sawdust, planer shavings, bark, and hog fuel (Chau et al., 2009) as well as whole trees. In pellet production, biomass is typically compacted under high pressure to produce wood pellets (Chau et al., 2009). There is a range of pellet sizes in North America, ranging from 6 to 24 mm in diameter, with a specific density of 1200 to 1400 kg/m3 and a bulk density ranging from 650 to 775 kg/m3 (Chau et al., 2009; Alakangas and Virkkunen, 2007). The pellets have a relatively consistent moisture content of 5–7% and are easier to transport, store, and burn (Chau et al., 2009). To produce pellets, for one ton of pellets 1.33 tons of dry raw materials or 2.33 tons of wet raw materials (50% moisture content) is required (Chau et al., 2009). The manufacturing of forest wood products produces residues such as sawdust that is used to produce wood-pellets, where these materials typically have little commercial value (Clauser, 2018). Therefore, the forest industry produces a large amount of biomass (Clauser, 2018), that can be utilized in the production of wood pellets. The forest residues can be difficult to handle economically from a collection and transport point of view, so there is a great opportunity within the forest products manufacturing industries to produce wood pellets as another wood product, while at the same time utilizing a waste stream that would otherwise cost money to deal with, (Clauser, 2018; Dwivedi et al., 2014). Pellets are made by grinding, conditioning, and forcing the ground sample through a die that ranges in diameter from 4 to 12 mm or larger (Fasina, 2008). In the production of wood pellets from biomass, sawdust and shavings are considered a primary product used to make wood pellets (Hoefnagels et al., 2014]. However, even though the availability of large amounts of wood waste exists, the North American market is still lagging the European and other global markets where pellet use has been increasing in an attempt to get off fossil fuels (Kuokkanen et al., 2009). This aspect of the wood pellet industry has been variable as the price of oil drops, the incentive to move to wood pellets is low and when the price of oil rises then the incentive to use wood pellets rises (Kuokkanen et al., 2009). The use of wood pellets has risen dramatically over the last decade as oil prices become more volatile and people are looking to move away from dependence on fossil fuels for the sake of the environment (Kuokkanen et al., 2009).

2.2 PRODUCTION OF PELLETS FROM MUNICIPAL WASTE

Municipal solid waste represents an important source of biomass that can be used to produce biofuels, and this strategy will lead to a reduction in the number of greenhouse gases generated by landfills (Antizar-Ladislao, 2010). Most of the major energy producers in the world, including the United States, China, India, and most of the European Union (EU) countries, produce energy by burning solid fuels (Greinert et al., 2019). It is anticipated that coal will remain an important part of their economies, however biomass is also becoming an important part of the economy and energy systems (Tchapda & Pisupati, 2014). Biomass is an excellent source of energy, as it combines low costs and high availability, lowering transport costs and reducing its impact on the environment (Greinert et al., 2019; Islas et al., 2019; Antizar et al., 2010; Simões Amaral et al., 2016).

Municipal waste is a modern method of energy production and, in addition to wood and agricultural products, municipal waste is the third most important biomass resource for energy production (Greinert et al., 2019). Various municipal solid wastes such as food, paper, roadside vegetation, textiles as well as sewage sludge is used as fuel in a variety of fuel mixtures with other biomass for combustion with coal, which are two methods for producing energy from these resources (Greinert et al., 2019). Municipal solid waste management is particularly complex because it consists of a heterogeneous mixture that varies according to where the waste is generated, the habits of the urban population, and their culture (Lopes et al., 2018). A waste stream includes recyclable and non-recyclable elements, with an average of 50% organic components that can be processed into energy (Lopes et al., 2018). The benefits of producing pellets from municipal solid waste are the significant reduction of mass and volume of waste, where it reduces mass by 75% and volume by 85% (Lopes et al., 2018). According to Greinert et al. (2019) and Jian et al. (2016), in the production of pellets, biosolids such as sewage sludge are very useful as biomass binder materials. Additionally, there is a reduction in energy required to compress and extrude materials at the time of pellet production, and the sewage sludge enhances the hardness and density of pellets by reducing dust during transportation and operation, which in turn increases combustion efficiency (Greinert et al., 2019; Jian et al., 2016). There is a significant difference between the energy used in the production of municipal solid waste pellets compared to that used for biomass pellets where municipal solid waste (sewage sludge) pellets use 50% less energy in their productions compared to woody biomass (Greinert et al., 2019). The pellets made up from either municipal waste or woody biomass have environmental, economic, and social advantages and are easy to store, transport and are efficient, cheap and help to mitigate climate change (Moreira et al., 2020).

2.3 PROCESS OF MANUFACTURING WOOD PELLETS

Wood pellets are cylindrical in shape, shiny and white to brown in appearance. The generation of raw materials is the first step in the production of wood pellets (Jones et al., 2012). The raw material is usually a by-product of another wood manufacturing operation (Jones et al., 2012). Wood industries produce a large amount of wood residues, such as sawdust, bark, planer shavings, woodchips, whole ground trees etc. which can be used in the production of wood pellets (Jones et al., 2012). Another example is hardwood flooring mills, in their activities, they create enormous quantities of clean (no bark or dirt), dry sawdust, and small scrap blocks (Jones et al., 2012). This wood residue is a suitable raw material for pellet manufacturing, however, as pellet use becomes more popular, some mills are creating pellet-making raw materials directly from grinding whole trees (known as "Roundwood") (Jones et al., 2012).

Pelletizing machines are reasonably priced at about $50,000 and can generate 5-10 tonnes of pellets per hour (Jones et al., 2012). Complete production facilities, on the other hand, can cost upwards of $3 million and necessitate significant operational costs and manpower inputs (Jones et al., 2012).

The pellet production from woody residues follows the processes as shown in figure 1 (Nunes et al., 2013). These processes are:

2.3.1 Drying

2.3.2 Hammer-milling

2.3.3 Pelletizing

2.3.4 Cooling

2.3.5 Screening

2.3.6 Packing

(Nunes et al., 2013)

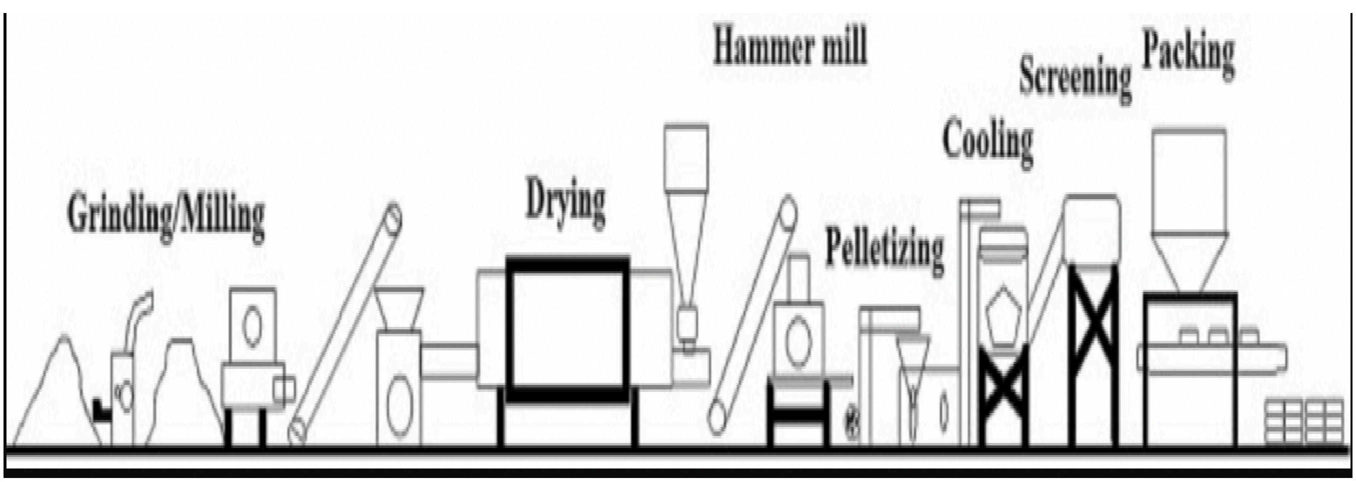

Figure 1. The processes in production of pellets from raw materials (Source: Nunes et al., 2013).

i. Drying

The process of drying involves moisture passing into the ambient air via evaporation from the materials surfaces (Holubcik et al., 2012). Thermal energy is used for this process (Holubcik et al., 2012). It is important to understand that the main aspect of drying is the progress of moisture from the solid and liquid phase to the gaseous state, which can only be accomplished if the vapour pressure over the material is higher than the vapour pressure of the ambient gaseous medium (Holubcik et al., 2012; Jones et al., 2012). The pellet source material must be uniformly dried to produce a feedstock with a moisture content below 4 percent on a dry-weight basis (Jones et al., 2012). Excess moisture can cause issues in the production process because of the high temperatures and pressures used, such as poor pellet consolidation resulting in dust in the final product (Jones et al., 2012). However, it is because of this low moisture content that wood pellets burn so well (Jones et al., 2012). Material processing after the feedstock has been dried, is fed into a hammer mill to generate uniformly sized wood particles (Jones et al., 2012).

It is possible to dry naturally or artificially with the use of flue gas, air, or steam, which absorb moisture and are then vented by a fan (Holubcik et al., 2012). The relative humidity of entering particles such as chips, fibres, sawdust, wood shavings, etc. is usually greater than 30% in conventional dryers (Holubcik et al., 2012). In wood drying, the temperature is controlled by dwell time in the drying medium and by the spontaneous ignition temperature of the dried material (Holubcik et al., 2012). It is possible to dry in either a drum drier, also known as a flash drier, which operates at high temperatures, or on a flatbed drier, which works at relatively low temperatures (Kofman, 2007). Biomass can be dried using a low-temperature process using secondary heat flows prior to combustion/gasification in a way that increases the amount of energy generated (Svoboda et al., 2009). The plant operation will also be improved in the case of a broader thermal load regime as a result of reducing emissions (Svoboda et al., 2009). Wood pellets produced by drying raw wood chips and sawdust before pelletizing are a secondary standardized solid biofuel with a low MC and high calorific value (Svoboda et al., 2009; Stahl et al., 2004).

ii. Hammer – milling

The hammermill homogenizes the biomass to an even size that can be fed to the pellet press (Kofman, 2007). Pulverized wood, dead knots, etc., can pass through the matrix of the presses after the material is mixed during the hammermill stage (Kofman, 2007). Ventilation should be provided on the building of the hammermill to prevent the possibility of an explosion caused by dust, where pressure would be released (Kofman, 2007). It is important that the vent opening on the outside of the building is high enough or should be cordoned off in such a way that bystanders or passersby are not likely to be hurt in the event of an explosion (Kofman, 2007). There should be a store where the hammer-milled material can be stored in between the press time and the hammer-milled time as the material is very fine and very dry, therefore fire precautions should be taken (Kofman, 2007).

Hammer-milling wet material requires a lot more energy than hammer-milling dry material because wet material requires more energy to reduce particle size than dry material (Kofman, 2007). Furthermore, screens may become clogged and smeared (Kofman, 2007).

iii. Screening

A hammer mill cannot homogenize sawdust without screening it for stones, metal pieces, plastics, etc. (Kofman, 2007). A stone trap is typically used to remove the stones, where sawdust is deposited over a fast-moving opening (Kofman, 2007). In addition, passing sawdust over/under a magnet, metal objects should also be removed (Kofman, 2007). In the hammermill, sparks caused by foreign particles might cause a dust explosion (Kofman, 2007). During pelletizing foreign particles in the sawdust could damage to the press or sparks could be caused (Kofman, 2007).

iv. Pelletizing

The pelletizing operation in the pellet mills is the most important (Holubcik et al., 2012). Raw ground woody material is compacted during this process (Holubcik et al., 2012). A large amount of ground wood is pushed through the press die holes which are at a temperature of 90 - 110° C (Holubcik et al., 2012). The wood starts to release binding agents (lignin) at this temperature, which holds the pellet in the correct shape

(Holubcik et al., 2012). During this process, the material is compressed which creates pressure by the cylindrical rollers and takes the form of the pellets (Holubcik et al., 2012).

Steam is often used to warm sawdust up to 120 - 130° C before putting it into a press (Kofman, 2007). The wood's lignin becomes more plastic when heated, which helps to bind the particles together (Kofman, 2007). Press dies are used to extrude saw dust, and pellets are formed by rotating rollers on the outside of the press die (Kofman, 2007). A press die can be upright with rollers moving on the inside, or it can be positioned lying down with the rollers rotating over the press die (Kofman, 2007). High pressure is used to press the wood through the press die (Kofman, 2007). Once the pellets are pressed through the press die they need to be cooled.

v. Cooling

The pellets become rigid and lose moisture while cooling, so that it is possible for the final moisture content to be as low as 6% after cooling (Kofman, 2007). Their moisture content will stabilize at between 8 and 10% once they absorb moisture from the surrounding air (Kofman, 2007). Pellets that have been cooled are transported by conveyor belt to the storage shed, where they are conditioned (Kofman, 2007).

vi. Packaging and Delivery

Fines should be screened before packaging or delivery of pellets (Jones et al., 2012). The pellets are packaged in bags or stored in bulk after they have been manufactured and cooled (Jones et al., 2012). Pellets are often purchased by the tonne, which consists of 50 40-pound bags placed on a pallet (Jones et al., 2012). A delivery truck may also store the pellets in small silos outside the user's residence (Jones et al., 2012). Pellets can be stored for an endless period, but they must be kept dry to avoid degradation (Jones et al., 2012). Pellets can also be shipped in one-ton bags or in bulk (Kofman, 2007). Normally, small bags arrive on pallets weighing 960 kg or a tonne (Kofman, 2007). They are wrapped in plastic and have good moisture resistance (Kofman, 2007). Pellets delivered in small bags are, however, more likely to be of a high quality since they are less prone to abrasion during transit (Kofman, 2007). Bulk pellets are delivered by truck and can be tipped off at the receiving end, or they can be transported by vacuum trucks sucking pellets up in the factory and blowing them into a silo at the receiving end (Kofman, 2007). The weighing cells on these trucks enable them to determine the exact amount of shipping that has been done (Kofman, 2007).

2.4 RAW MATERIALS USED IN WOOD PELLET PRODUCTION

There were about 12 million metric tons of wood pellets produced in 2008, now there are 56 million metric tons of wood pellets produced in 2018 (Toscano et al., 2022). The European Union consumed more than 27 million metric tons of wood pellets in 2018, more than 45 percent of which were used for industrial purposes such as heating or process heat (Toscano et al., 2022). The latter, in addition to implicitly defining the pellet quality, is also creating a signal for the presence of matrices not permitted by some jurisdictions (Toscano et al., 2022). Examples are wood from whole trees or trees without roots, wood with or without bark, wood from vine gardens, etc. (Toscano et al., 2022). It is a common practice in Italy to chemically treat wood by-products, residues, wood fibers, and wood constituents, that is, glue-laminated wood, oriented strand board (OSB), plywood, and chipboard (Toscano et al., 2022; Mancini et al., 2019), which are not allowed for use as fuel biomass in domestic systems (Toscano et al., 2022). Additionally, knowing the origin and source of the solid biomass is vital to determining whether a pellet or solid biofuel can be traced and is sustainable (Toscano et al., 2022). Currently, the pellet manufacturer must declare this information and it is difficult to determine by visual inspection as the raw material is condensed during pelletizing, losing the macro and microscopic characteristics of the original product (Toscano et al., 2022). Detecting woody materials traditionally requires time-consuming and expensive techniques, such as scanning electron microscopy (SEM) (Toscano et al., 2022). The infrared spectroscopic method has been proposed (Toscano et al., 2022; Mancini et al., 2019).

Sawmill residues are traditionally used to make pellets (Filbakk et al., 2011). However, there are limited resources available in some regions (Filbakk et al., 2011), therefore, industry is seeking alternative sources of raw materials (Filbakk et al., 2011; Stjørdal, 2006). Scots pine (*Pinus sylvestris* L.) pulpwood is a potential feedstock in the Norway pellet industry, as it is available in certain areas and costs less than Norway spruce (Filbakk et al., 2011). In some districts in Canada whole trees that are underutilized by industry are being used, for example white birch and trembling aspen in Northern Ontario.

2.5 SOURCES OF RAW MATERIAL FOR WOOD PELLET PRODUCTION

The reduction of greenhouse gas emissions and environmental pollution is necessary where the use of renewable energy sources such as wood pellets, instead of natural gas, coal, and petroleum, which are non-renewable resources, is required (Gunawan et al., 2020). In the world, China is the largest producer of wood pellets, while the United States second, Canada third and Vietnam forth. Vietnam is the leading producer in the ASEAN region (Gunawan et al., 2020). Comparing Indonesia with Vietnam in terms of agriculture and plantations, Indonesia is excelling (Gunawan et al., 2020). Indonesia also has a unique diversity of plants that have the potential to be used as raw materials for wood pellets (Gunawan et al., 2020; Sidabutar, 2018).

The forest resource base in China is not extensive. Forest coverage in the country is inequitable, and natural stands support only marginal quality (Roos & Brackley, 2012). The U.S. has planted more than 115 million acres of softwood and hardwood plantations since the mid-1960s (about 20 percent of the total commercial forest land) (Roos & Brackley, 2012). The effort is impressive, but the planted material doesn't meet the standards for many solid wood products; it will, however, provide some fiber for pulp and paper and some energy (Roos & Brackley, 2012). Furthermore, China is utilizing agricultural and domestic waste materials as energy sources (Roos & Brackley, 2012). Most of the pellets that are produced in the country come from agricultural products (Roos & Brackley, 2012). These are the sources of wood biomass that can be used to fuel and/or produce pellets, listed from the most readily available and the least expensive, based on North American standards: Materials left over from mills producing solid wood products (specifically lumber); materials leftover from forest areas currently being harvested, including poor quality trees, small stems, and trees with no market; and materials from intensively managed, short rotation forests (Roos & Brackley, 2012).

In the USA, Wood fibers are sourced directly from forests or indirectly from other wood-consuming industries, so wood pellet mills can impact forest conditions (Aguilar et al., 2020). Approximately 3.5 million metric tons of wood pellets are produced by Enviva's seven plants in the southeastern United States each year, where North Carolina is home to half of these plants.

There were 28 million tons of wood pellets produced globally in 2015 (Gunawan et al., 2020). The global market for the sale of wood pellets to power plants for electricity and heat remains steady at 14.1% per year (Gunawan et al., 2020). It is estimated that wood pellet demand will reach 80 million tons by 2020 (Gunawan et al., 2020). The government of South Korea, Japan, Europe sought to obtain raw materials from tropical countries such as Indonesia (Gunawan et al., 2020). Indonesia is a location that could become a wood pellets producer due to its vast number of forests and biodiversity as a source of raw materials (Gunawan et al., 2020). These wood pellets are made from JPP Teak wood that is over 5 years old (Gunawan et al., 2020). Pellets produced from JPP teak wood could a potential source of quality of biomass if certain parameters were improved upon (Gunawan et al., 2020). Figure 2 below represents the characteristics of the 5-year-old JPP Teak wood that could be a source of wood pellets in countries like Indonesia (Gunawan et al., 2020).

No.	Characteristics	5 Years old JPP teak	SNI WP 8021-2014
1	*Calorific value (Kcal/kg)*	4,062.0	Min. 4,000
2	*Density (gr/cm³)*	0.9	Min. 0.8
3	Water content (%)	19.3	Max. 12
4	*Ash content (%)*	2.5	Max. 1.2
5	Fly ash level (%)	80.3	Max. 80

Figure 2: Represents the characteristics of 5 years old JPP Teak wood. Source: Gunawan et al., 2020

The wood pellets made from 5-year-old JPP Teak wood do not meet the requirements of the SNI Wood Pellet Standard (SNI 8021: 2014) with respect to water content, ash content, fly ash content, and sulfur content (Gunawan et al., 2020). Carbon content influences calorific value (Gunawan et al. 2020). So, if the carbon content is high, it means the calorific value is also high (Gunawan et al., 2020). The density of a substance depends on the amount of secondary wall material in the biomass and the densifying during the pressing process (Gunawan et al., 2020). There is potential for this biomass resource to be utilized in pellet manufacturing with more research into process optimization.

Canada has more sustainable, resilient forests as well as well-managed forests ("Canada's wood pellets: a responsible source of clean energy", 2022). Canada has a forest policy that provides environmental regulation and careful management and third-party certification ("Canada's wood pellets: a responsible source of clean energy", 2022). In Canada, wood pellets are primarily produced to optimize the use of already harvested forests ("Canada's wood pellets: a responsible source of clean energy", 2022). The increased ability to process a wider range of wood fibre has led to a reduction of not just sawmill residues, but harvest residues as well, enabling us to support government-led initiatives to rehabilitate damaged, dead, or understocked forests, thus increasing wildlife habitat and carbon capture ("Canada's wood pellets: a responsible source of clean energy", 2022). In the Canadian forest industry, forest products such as lumber, structural panels, paper and pulp, tissue and newsprints are quite popular whereas, the wood pellets are relatively new in the industry as well as not widely developed ("Canada's wood pellets: a responsible source of clean energy", 2022). In the mid-1990s, a provincial law forced sawmills to close their waste-wood beehive burners in British Columbia, which sparked the Canadian wood pellet industry ("Canada's wood pellets: a responsible source of clean energy", 2022). The public was tired of the smoke, particulate emissions, and wasted wood fibre from these wood burners in communities all over B.C ("Canada's wood pellets: a responsible source of clean energy", 2022). Pellet plants began to appear throughout British Columbia and Canada as beehive burners closed and a new product was being made from sawmill waste ("Canada's wood pellets: a responsible source of clean energy", 2022). Canada now has over 50 pellet plants selling their product for heating in homes and businesses as well as replacing coal in electric plants around the world with low-carbon, renewable energy ("Canada's wood pellets: a responsible source of clean energy", 2022). As the demand for wood pellets is expanded, the wood pellet producers started using sawdust and shavings from the sawmills that were previously used to burn and wasted in the beehive burners ("Canada's wood pellets: a responsible source of clean energy", 2022). In the current environment, more and more pellets are being made from harvest residues, which are tree-tops, branches, and low-quality logs that are left after primary harvesting ("Canada's wood pellets: a responsible source of clean energy", 2022). These are materials that are rejected by sawmills, panel board plants, and pulp mills ("Canada's wood pellets: a responsible source of clean energy", 2022). In Canada's forest industry, the producers assess the tree quality to determine which products will be produced from each log ("Canada's wood pellets: a responsible source of clean energy", 2022) and as a result, the producers utilize every tree harvested to maximize its value (Figure 3).

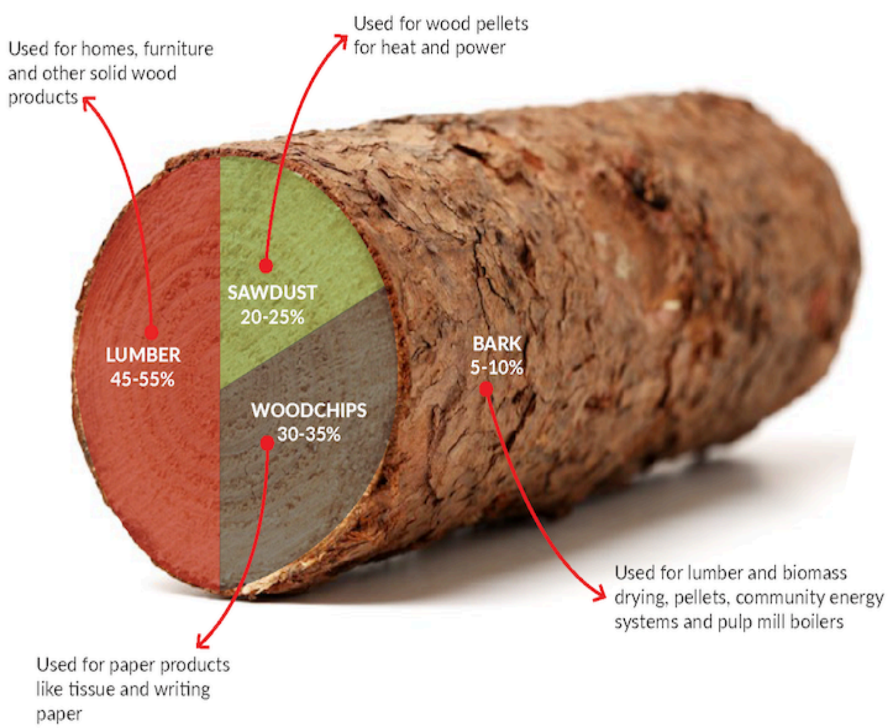

Figure 3: The log used to create the products in the sawmill. Source: "Canada's wood pellets: a responsible source of clean energy", 2022)

It is shown in the above figure that the majority of the logs are used for lumber - about 45 percent of each log and, 30 to 35 percent are used to make pulp chips, which are used in pulp mills, 20 to 25 percent are sawdust and shavings, which could be turned into pellets; and 5 to 10 percent is for bark, which is primarily used for producing energy and heat, but could also be used in the manufacturing of pellets potentially ("Canada's wood pellets: a responsible source of clean energy", 2022). Sawmill residues account for nearly 90 percent of the fibre input to pellet plants today, but there are individual plants that use more or less ("Canada's wood pellets: a responsible source of clean energy", 2022).

2.6 ADVANTAGES OF WOOD PELLETS

Pellets are made from wood, which makes them sustainable, low-cost, and local (Jones et al., 2012). As wood pellets contain less water and ash, they burn hotter and cleaner than many other fuels (Jones et al., 2012). There is no more than 0.5% (Premium grade) or 1% (Standard grade) of ash in the fuel pellets (Jones et al., 2012). There is a higher concentration of ash in firewood, because of its bark (Jones et al., 2012). Furthermore, wood pellets have small sizes and can be transported easily (Jones et al., 2012). Bulk bags of these items can be found in some areas, but generally, they are sold in 40-pound bags (Jones et al., 2012). They are essentially dust free (standards require a durability of 96.5 to 97.5%, which essentially means no dust) and bark-free. When fuel is needed in the burning system, pellets are automatically fed to the fire from feed screws in pellet-burning stoves (Jones et al., 2012), which is much easier than feeding a woodstove regularly.

There are large furnaces that have larger storage silos that also automatically feed fuel into the furnace when it is needed in a similar manner to pellet stoves via a fed screw system (Jones et al., 2012). The pellets burn very cleanly, so both systems are low maintenance (Jones et al. 2012). There are several environmental benefits to pellet burning such as the product is made from wood-processing by-products (such as sawdust), so it is a potential waste material that is converted into a marketable product (Jones et al., 2012).

In recent years, foresters have been thinning and salvaging low-quality trees to use them in the pellet manufacturing process (Jones et al., 2012). Firewood contains more water than pellets and are generally less dense than pellets, which makes pellets easier to transport (Jones et al., 2012). As far as contributing to global climate change, wood and wood pellets are "carbon-neutral," since all the carbon dioxide released during the combustion of wood was absorbed from the atmosphere when the tree grew the wood (Jones et al., 2012), and a newly regenerating forest will again sequester carbon. It is important, especially in some European countries where carbon emissions are restricted, to have this characteristic (Jones et al., 2012).

Compared to wood-burning stoves ($1,000 to $3,000), pellet models are slightly more expensive ($1,600 to $5,000) but require less maintenance, do not create much mess, and are easier to operate (Jones et al., 2012). A pellet stove generally meets the same requirements, or fewer, as a wood stove because the fuel is burned more completely (Jones et al., 2012). A wood burning stove is a bit different from a pellet stove in how it produces heat (Pellet Stove or Wood Stove: Which Is Best for Heating Your Home?, 2022). Pellet stoves can vary in their heating output, depending on quality, design, and type of pellets they use, but they are able to maintain a more consistent temperature (Pellet Stove or Wood Stove: Which Is Best for Heating Your Home?, 2022). There may even be a programmable thermostat included so that you can control the heat output (Pellet Stove or Wood Stove: Which Is Best for Heating Your Home?, 2022).

It is important to note that wood burning stoves and pellet stoves require different types of fuel (Pellet Stove or Wood Stove: Which Is Best for Heating Your Home?, 2022). Wood pellets are needed to fuel a pellet stove, and dried firewood for a wood burning stove (Pellet Stove or Wood Stove: Which Is Best for Heating Your Home?, 2022). The burning of wood or wood pellets is more environmentally friendly than using fossil fuels (Pellet Stove or Wood Stove: Which Is Best for Heating Your Home?, 2022).

Before installing, however, local codes should be checked (Jones et al., 2012). In some places, the supply of appliances and fuels may be restricted (Jones et al., 2012). Pellet stoves, like all other appliances, run on electricity and will not work if the power goes off (Jones et al., 2012), unlike a woodstove which will work without power. When compared to other fuels, wood is a bargain (Jones et al., 2012). Pellets are more costly than sawdust or firewood, although they are typically cheaper than oil, natural gas, or electricity (Jones et al., 2012). Pellets are currently selling for around $200-$250 per tonne. Spending $200 per tonne for wood pellets is like paying 4.9cents/kwh or $1.06 per gallon of propane in terms of cost per unit of energy (Jones et al., 2012). Pellets also have a consistent density and hence deliver a consistent heating value (Jones et. al., 2012).

2.7 USES OF WOOD PELLETS

Pellets made of wood have been used more frequently throughout the world in recent years; especially in the United Kingdom where pellets are replacing coal in electricity production (Stahl et al., 2017). The use of biomass for energy conversion is one option, but the resources must be used efficiently (Stahl et al., 2017). The largest pellet consumer in the world was Europe, which consumed over 75% of its pellet supply in 2014 (Stahl et al., 2017). Pellets are being used in increasing numbers because of the EU 2020 renewable energy targets (Stahl et al., 2017). Wood pellets are often burned for heat, but they can also be used to generate steam and/or power in the process (Jones et al., 2012; 5 Different Uses for Wood Pellets » Residence Style, 2022). Pellet burners can range in size from big commercial boilers to modest home warmers (Jones et al., 2012). Industrial boilers use wood pellets as a substitute for natural gas and coal, making them environmentally friendly (5 Different Uses for Wood Pellets » Residence Style, 2022). The traditional fuel is costly and polluting, while wooden pellets do not contain a lot of nitrogen or sulfur and are essentially carbon neutral (5 Different Uses for Wood Pellets » Residence Style, 2022).

Many pellet stoves incorporate hoppers and thermostatically controlled augers that automatically feed pellets into the fire (Jones et al., 2012). Unlike traditional firewood-burning appliances, these stoves require less frequent loading (Jones et al., 2012). In smaller businesses, once the pellets have been burned, the leftover ash from the stoves must be removed on a weekly basis (Jones et al., 2012; 5 Different Uses for Wood Pellets » Residence Style, 2022). When compared to typical firewood with bark, the amount of ash following the burn is minimal, as well dust and debris will be minimal if the pellets are well-formed [Jones et al., 2012]. In comparison to traditional wood fuels, all these qualities make burning wood pellets a clean and convenient way to heat [Jones et al., 2012]. The calorific value of wood pellets (average 18 MJ/kg) makes them a potentially reliable fuel, which can reduce the dependency on fossil fuels [Gunawan et al., 2020]. For power plants, heaters, biomass stoves, and dryers in laundry centers, wood pellets can be used as a coal substitute [Gunawan et al., 2020]. Pellets can be used in fire pits and patio heaters, representing more uses for pellets (5 Different Uses for Wood Pellets » Residence Style, 2022).

The coal-importing countries (South Korea, Japan, China, and India) are slowly switching over to wood pellets because of their quality, environmental friendliness, and renewable nature (Gunawan et al., 2020).

In Canada, wood pellets are gaining popularity in the production of electricity and power for both businesses and households (Dwivedi et al., 2014). Wood pellets are a woody-biomass product that essentially does not contribute to greenhouse gases (Dwivedi et al., 2014). The burning of wood pellets produces less carbon dioxide and therefore contributes less to greenhouse gase emissions than other fossil fuel burning systems (Dwivedi et al., 2011; Kittler et al., 2020). The production of electricity from biomass has several advantages such as low costs and high availability and less impact on the environment as well as ease to transport (Greinert et al., 2019). One of the main benefits of wood-pellet production is the use of forest and mill wood residues that have little use in other products (Jiang et al., 2016). As an example, the power generation station, in Atitkokan, Ontario, Canada converted from coal to wood pellets and produces electricity from biomass (wood pellets) and delivers electricity to nearby houses and industries. The power station in Atikokan generally gets its woody biomass in the form of wood pellets from the Thunder Bay Resolute Forest Product Sawmill.

2.8 PHYSICAL PROPERTIES OF WOOD PELLETS

i. DURABILITY

The durability of pellets is among the most important properties (Filbakk et al., 2011; Carroll & Finnan, 2012). Fines produced by low durability are more likely to cause problems in transport, storage, cooking, and combustion (Filbakk et al., 2011; Carroll & Finnan, 2012). Pellets with fines have a significantly higher slide angle since the fines act as a binder between the pellets (Filbakk et al., 2011). Dust exposure from fines reduces user comfort as well (Filbakk et al., 2011). Burning dust often passes through the combustion chamber unburned, resulting in higher emissions and fuel residues in the boiler or stove (Filbakk et al., 2011; Johansson et al., 2003; Obernberger & Thek, 2004). Transport and storage of pellets can result in fine dust or particles being produced due to physical wear and tear (Carroll & Finnan, 2012).

Wood pellet durability refers to the abrasion resistance and impact resistance of wood pellets, whereas fines content refers to the loose powder content in wood pellets (Lee et al., 2020). Accumulation of fine particles prevents pellets from flowing freely (Lee et al., 2020).

European standards specify a durability of high-quality pellets of 97.5% (Obernberger and Thek, 2010), but the PFI standard sets a value of 96.5% as shown in figure 4 (Pellet Fuel Institute, 2010; DURABILITY OF WOOD PELLETS, 2003; Tarasov, 2014). This is to prevent the build-up of dust and potential fires/explosions (Pellet Fuel Institute, 2010; Tarasov, 2014). There is also a standard for measuring the fines content of pellets following EU standard (Pellet Fuel Institute, 2010; Tarasov, 2014).

ii. BULK DENSITY

Bulk density is also an important property because fuel is fed by volume, not weight (Filbakk et al., 2011). Bulk density can cause significant variations in combustion efficiency (Filbakk et al., 2011). Over time, it is preferable that volume-to-weight ratios remain stable (Filbakk et al., 2011). As per the European standard, bulk density should be greater than or equal to 600 kg/m^3 (Obernberger and Thek, 2010). The bulk density of softwood pellets increases by 20-25 kg/m^3 when bark is added as an additive (Filbakk et al., 2011). The reason for this is that bark contains 8-10 times more metals, such as aluminum, iron, and sodium, than stem wood. (Obernberger, 2006). The bulk density of pellets is determined by the North American standard PFI as shown in figure 4 and is required to fall between 640 kg/m^3 and 736 kg/m^3 (DURABILITY OF WOOD PELLETS, 2003).

It is important to consider the bulk density of the input material when pelleting since the mills are fed by volume instead of weight (Filbakk et al., 2011; Artemio et al., 2018). This property contributes to estimating pellet quality in fuel applications because it equates to more energy per volume, ensuring more economic fuel use, transportation, and storage (Rollinson & Williams, 2016; Artemio et al., 2018).

iii. MOISTURE CONTENT

For determining the moisture content of bulk solids (granular and powders), oven drying is commonly used, which is destructive and time-consuming and involves sampling the material (Fuchs et al., 2008). Agricultural products and granular materials can be determined to the level of moisture content using microwave spectroscopy (Fuchs et al., 2008). A material's moisture content can be determined by using electrical time domain reflectometry (ETDR), in which an electromagnetic pulse is used to travel from one probe to another twice (Fuchs et al., 2008). Neutron moisture gauges are also useful for determining the moisture content because they are based on the relation between neutron parameters and the average hydrogen concentration (Fuchs et al., 2008). There are various techniques for measuring surface moisture content, including the use of infrared and laser light absorption spectroscopies (Fuchs et al., 2008). By the European ENplus standard (Oberberger and Thek, 2010; DURABILITY OF WOOD PELLETS, 2003; Tarasov, 2014), the MC% must be less than 10%; by the PFI standard it has to be less than or equal to 8% (Pellet Fuel Institute, 2010; Tarasov, 2014).

Moisture content of pellets plays an important role in their storage and transportation. In pellets with a high moisture content of 15% or more, the moisture can lead to microbial decomposition during storage, whereas pellets with a low moisture content of 3% end up crumbling, generating fines during storage and transportation (Carroll & Finnan, 2012).

iv. CALORIFIC VALUE

The Gross Calorific Value (GCV) of a solid biofuel combusted in pure oxygen in a bomb calorimeter under the specified conditions is defined as its specific energy of combustion in joules per unit mass (Carroll & Finnan, 2012). Although moisture content and chemical composition play a role in determining the Net Calorific Value (NCV), the calorific value plays a major role in determining how much energy is present in each volume of biomass (Carroll & Finnan, 2012). The calorific value in softwoods displays a higher heating value per mass than hardwoods due to the extractives present in softwoods that produce high heating values themselves (Baker, 1983; Tarasov, 2014). Hardwoods have an average calorific value of 19.35 MJ/kg and softwoods have an average of 21.18 MJ/kg in Canada (Tarasov, 2014).

Pellets have a different calorific value depending on the composition of their raw materials (Tarasov, 2014). The heating values for pellets made from non-resinous raw materials range from 18.6 to 19.8 MJ/kg. Gross calorific values range from 20.0 to 22.5 MJ/kg for resiniferous species (Tarasov, 2014). The yield of bark pellets made from non-resinous and resinous species varied between 18.6 and 19.8 MJ/kg and 20.4 to 25.1 MJ/kg respectively (Tarasov, 2014; Resch, 1989). The PFI standard specifies a pellet heating value of +2% (Durability of Wood Pellets, 2003), which is shown in figure 4, however, according to the EU standard, the parameter must be >16.5 MJ/kg (Obernberger and Thek, 2010; Tarasov, 2014).

A Bomb Calorimeter was used to determine the calorific value in accordance with ASTM E 711-87: Standard Test Method for Gross Calorific Value of Refuse-derived Fuel (ASTM E711-87, 2004; Tarasov, 2014). A solid form of refuse-derived fuel is used for determining the gross calorific value using the bomb calorimeter (ASTM E 711-87, 2004; Tarasov, 2014). By using the oxygen bomb calorimeter (ASTM E 711-87, 2004; Tarasov, 2014), calorific value is determined by burning a weighed sample under controlled conditions (Tarasov, 2014).

v. ASH CONTENT

Compared to wood, herbaceous biomass typically contains a higher percentage of ash (Carroll & Finnan, 2012). The right combustion and ash-cleaning technologies require an understanding of ash content (Carroll & Finnan, 2012; Obernberger et al., 2006). Underfeed stokers are not suitable for fuels with high ash content because they could result in the formation of an ash layer, which could result in irregular air flow resulting in incomplete combustion and increased emissions (Carroll & Finnan, 2012; Obernberger et al., 2006). The type and melting point of ash also has a major influence on the combustion process for these types of fuels (Carroll & Finnan, 2012). The European Union defines premium class pellet ash content at 0.7% or less (Thek and Obernberg, 2010), while the Pellet Fuel Institute defines it at 1% or less (Pellet Fuel Institute, 2010; DURABILITY OF WOOD PELLETS, 2003; Tarasov, 2014).

Specification		U.S. Grades for Residential Pellets			
S. No.	Pellet Property	Super Premium	Premium	Standard	Utility
1	Moisture content (%, w.b.)	<8	<8	<10	<10
2	Length (mm)	<38	<38	<38	<38
3	Diameter (mm)	6.35-7.25	6.35-7.25	6.35-7.25	6.35-7.25
4	Bulk density (kg/m^3)	640-736	640-736	640-736	576-736
5	Durability (%)	>96.5	>96.5	>95	>95
6	Fines at mill gate (%)	<0.5	<0.5	<1.0	<1.0
7	Calorific value (MJ/kg)$^+$	<+2%	<+2%	<+2%	<+2%
8	Ash content (%)	<0.5	<1.0	<2.0	<6.0

Figure 4: North American standards of Wood Pellets. Source: DURABILITY OF WOODPELLETS, 2003

2.9 MARKETS OF WOOD PELLETS

North America, especially the USA and Canada produce wood pellets and export most of the production to Europe [Dwivedi et al., 2011]. The studies show that to meet the requirement of Europe to produce electricity from wood pellets, new mills need to be built in the United States and Canada to meet this demand as well as the North American and other markets [Dwivedi et al., 2011]. According to Dwivedi et al. [2011], about 80% of total wood-pellet production is exported to European countries from the Southern part of the United States. According to a report released by Wood Resources International, Europe's demand for wood pellets is expected to rise by 30 to 40 percent in the next five years (Woodworking Network, 2022). In terms of global demand for pellets, Europe accounts for about 75% (Woodworking Network, 2022). Pellets are used for residential heating in 40 percent of European countries; for power plants in 36 percent; for commercial heating in 14 percent; and for combined heat and power plants in 10 percent (Woodworking Network, 2022). Residential and industrial demand is strong and is expected to continue even beyond 2025 (Woodworking Network, 2022).

USDA's Foreign Agricultural Service's Global Agricultural Information Network estimates that the EU (European Union) consumed 27.35 million metric tons of wood pellets in 2018, more than double the amount consumed the year before (Wood Pellet Market Size, Share & Trends: Industry Report, 2020-2025/, 2022). Wood pellet consumption in this region is expected to increase to 30 million metric tons in 2019, with imports increasing to 12.2 million metric tons from 10.355 million metric tons last year (Wood Pellet Market Size, Share & Trends: Industry Report, 2020-2025/, 2022). As of 2017, there were 656 pellet plants in the EU, with a combined capacity of 2.75 million metric tons (Wood Pellet Market Size, Share & Trends: Industry Report, 2020-2025/, 2022). As of 2019, the capacity is expected to increase from 70 percent in 2018 to 72 percent (Wood Pellet Market Size, Share & Trends: Industry Report, 2020-2025/, 2022). With 8 million metric tonnes consumed in 2018, the United Kingdom became the biggest user of wood pellets in the EU region, followed by Italy (3.75 million metric tonnes), Denmark (3.5 million metric tonnes), Germany (2.19 million metric tonnes), and Sweden (1.785 million metric tons) (Wood Pellet Market Size, Share & Trends: Industry Report, 2020-2025/, 2022). The European region's dominance in the worldwide wood pellets market is mostly due to strict environmental legislation and ongoing efforts to meet emission objectives within the given time frame (Wood Pellet Market Size, Share & Trends: Industry Report, 2020-2025/, 2022). The rise of the wood pellets market in this region is also fueled by supportive government efforts and EU member state incentives (Wood Pellet Market Size, Share & Trends: Industry Report, 2020-2025/, 2022). Figure 5 presents the global wood pellet market share from 2019 to 2025.

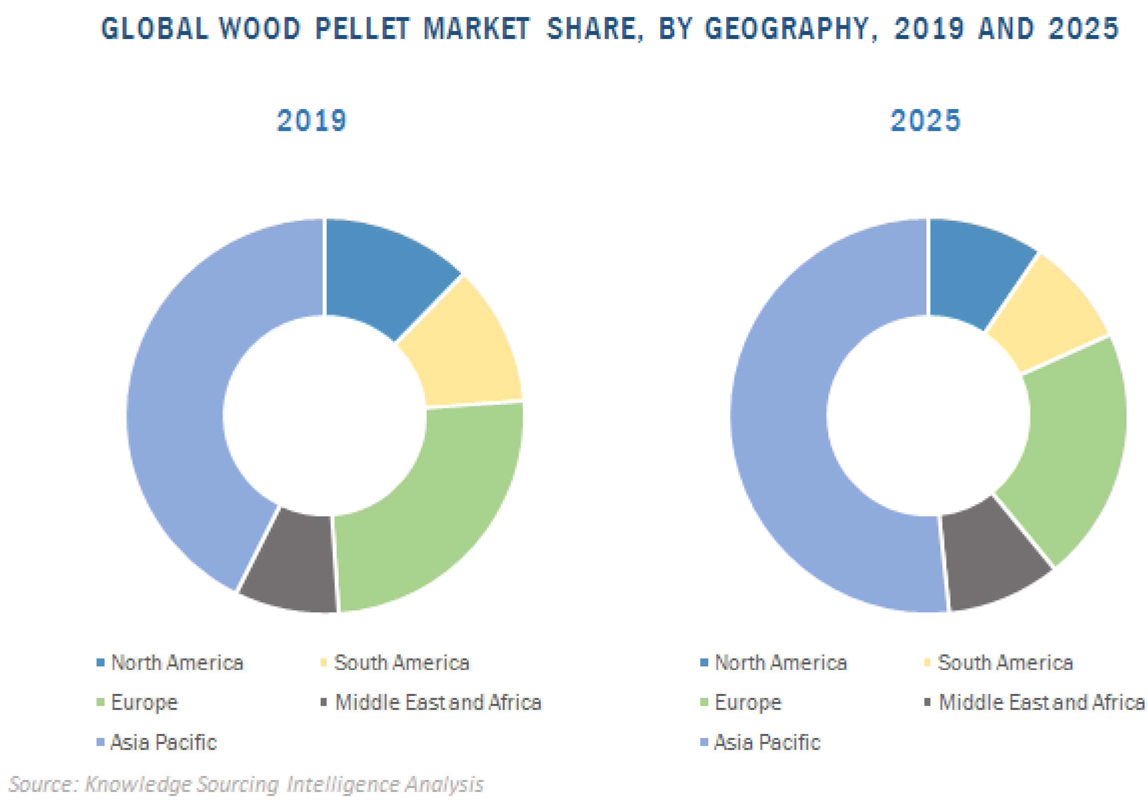

Figure 5: The global wood pellets market share from 2019 to 2025. Source: (Wood Pellet Market Size, Share & Trends: Industry Report, 2020-2025/, 2022).

Today, wood pellets rank among the highest-volume, internationally traded commodities of solid biomass used for energy purposes (Sikkema et al., 2020). Pellets require care to handling, but they are easier to store and handle in comparison with other types of solid biomass, such as wood chips and agricultural residues (Sikkema et al., 2020). The wood pellets are economically feasible to transport compared to wood chips and other wood residues (Sikkema et al., 2020).

Canada exports most of its wood pellets to Europe and Asia (Canada's growing wood pellet export industry threatens forests, wildlife, and our climate, 2022, Figures 6 and 7). United Kingdom and Japan are two of the biggest customers where wood pellet consumption in Japan is projected to reach 20 million metric tons per year by 2030 (Figures 6 and 7). Biomass made up 11% of electricity production in the UK, Canada's largest market for wood pellets. This amounts to about a third of all renewable energy sources in the country (Canada's growing wood pellet export industry threatens forests, wildlife, and our climate, 2022). Seventy-six scientists wrote to the European Union in 2018 stating that to provide an additional 3% of global energy through biomass, global logging rates would have to double (Canada's growing wood pellet export industry threatens forests, wildlife, and our climate, 2022).

Largest export provinces and import countries in 1,000 metric tons

IMPORTER	EXPORTER						Total
	British Columbia	Quebec	New Brunswick	Nova Scotia	Alberta	Ontario	
United Kingdom	1,492		81	5			1,578
Japan	622	0					622
United States	23	158	11	0	24	1	217
Netherlands	50			7			57
Italy		41		15			56
South Korea	41						41
Belgium	40	0		1			41
Denmark		28		11			39
Exporter total	2,268	227	92	39	24	1	2,651

Figure 6: Largest export provinces and import countries in 1,000 metric tons. Source: Canada's growing wood pellet export industry threatens forests, wildlife, and our climate, 2022.

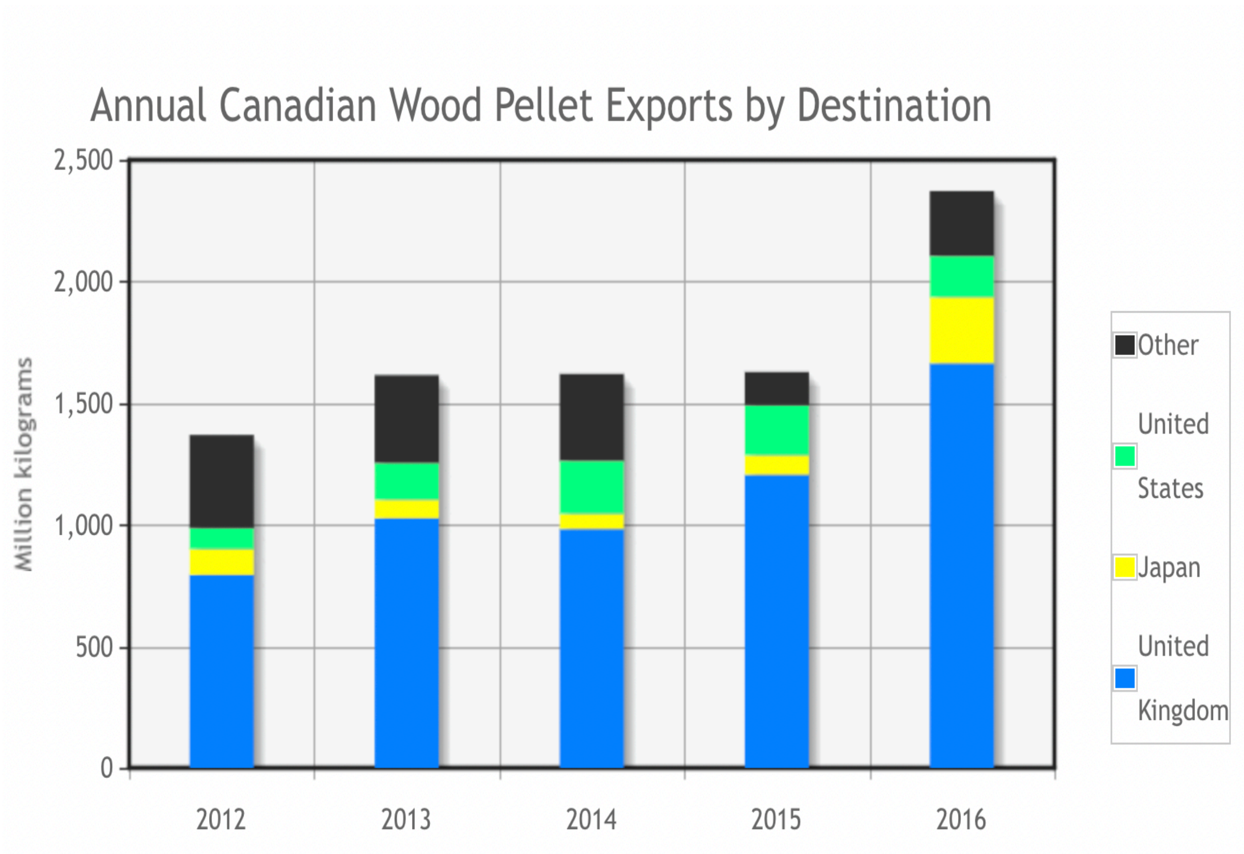

Figure 7: A annual Canadian Wood Pellets Exports by Destination. Source: CER – Market Snapshot, 2022

Wood pellet exports are increasing, with a 46% increase in 2016 over 2015 (CER – Market Snapshot, 2022). Wood pellets produced in Canada are used as a fuel source for producing electricity and heating and are exported almost exclusively to foreign countries (CER – Market Snapshot, 2022). Biomass-fired electricity generation was more in demand in 2016 as a replacement for coal-fired generation (CER – Market Snapshot, 2022). Wood pellet exports jumped by 73% in the last five years, from 1.369 million kilograms (kg) in 2012 to 2.373 million kg in 2016 (CER – Market Snapshot, 2022). Wood pellets from Canada are now the second largest wood pellet exporter in the world (the United States is the largest by weight) (CER – Market Snapshot, 2022).

3.0 IMPACTS OF WOOD PELLET PRODUCTION ON CLIMATE CHANGE

Forest ecosystems globally are under threat when non-sustainable forestry practices are used. In Canada we have the most certified forests in the world and practice some of the most rigorous sustainable forestry practices in the world. As a result, much of our forestry operations promote healthy forests and ecosystems. Many countries do not have the rigorous regulations and policies that protect Canadian forests. Therefore, there are many areas around the world that are depleting forests for short term gains and as a result are contributing to climate change. In Canada it is a requirement that if a forest is cut it must be replaced by natural regeneration or plantations. This ernsures that the forest coverage remains and that harvested forests that sequestered carbon their whole lives are replaced so the regenerating forests continue to sequester carbon, creating a close to carbon neutral system. Additionally, many harvested trees go into solid wood products such as lumber where the sequestered carbon remains as long as the wood is in service, further balancing the carbon "in and out" equations.

Therefore, producing wood pellets can be incorporated into logging practices that promote sustainable forestry practices protecting or regenerating carbon-rich forest areas.

3. CONCLUSION

It has been widely reported that biofuels could be an alternative to fossil fuels because they could reduce greenhouse gas emissions by partially replacing coal and other fossil fuel systems for heating and electricity. Integration and optimization of bioenergy systems can significantly reduce greenhouse gas emissions as well as provide positive effects on the environment and society at large (Antizar & Turrion, 2010).

In the EU, the goal is to contribute 20 percent of final energy consumption from renewable sources by 2020 (Sikkema et al., 2020). Pellets and other kinds of woody biomass could contribute significantly to the achievement of this goal (Sikkema et al., 2020). In the EU, about 10 million tonnes of pellets are used as an energy source (0.2% of GEC), while total wood and wood waste use (including pellets) is around 170 million tonnes (3.9%) (Sikkema et al., 2020). It is likely that pellets and other woody biomass for energy will increase in bulk considerably (Sikkema et al., 2020). With 8 million metric tonnes consumed in 2018, the United Kingdom became the biggest user of wood pellets in the EU region, followed by Italy (3.75 million metric tonnes), Denmark (3.5 million metric tonnes), Germany (2.19 million metric tonnes), and Sweden (1.785 million metric tons) (Wood Pellet Market Size, Share & Trends: Industry Report, 2020-2025/, 2022).There has been a steady increase in prices for pellets on most EU-27 markets since 2007 (Sikkema et al., 2020). There is a growing demand for pellets across Europe, but pellet production capacity remains largely unchanged (Sikkema et al., 2020). Additionally, industrial pellets are also sourced outside of the EU, primarily from North America and northern Russia, and their volumes have steadily increased (Sikkema et al., 2020). It is difficult to predict future demand, especially since EU-27 markets are heavily subsidized (Sikkema et al., 2020). The greatest impact of the energy conversion trend is from public support (Sikkema et al., 2020), where in countries like the Netherlands and Sweden, two of the most important markets for industrial pellets, rely mostly on feed-in tariffs and carbon-sulphur levies, respectively, but both may not last beyond 2020 (Sikkema et al., 2020).

The European Union was the first region to aggressively subsidize burning wood instead of coal (Canada's growing wood pellet export industry threatens forests, wildlife, and our climate, 2022). Throughout history, billions of dollars have been spent on subsidies and other financial incentives to regress energy production from coal to wood (Canada's growing wood pellet export industry threatens forests, wildlife, and our climate, 2022).

Raw materials dried at a high temperature require more energy to pelletize than raw materials dried at a low temperature (Filbakk et al., 2010). There may have been an increase in press die friction due to the loss of extractives from the former (Filbakk et al., 2010). Pellets from fresh material that was dried at low temperatures uses little energy and produces pellets that display superior durability and density (Filbakk et al., 2010). Drying at low temperatures has a minor effect on the concentration of extractives in fresh wood, which may improve pellet binding and the lubricating effect in the pellet press (Filbakk et al., 2010). There may be a relationship between durability and energy consumption (Filbakk et al., 2010).

There is still research to maximize the efficiency of production and burning of wood pellets. The demand globally for wood pellets justifies further research to ensure this energy system is as efficient as possible and remains as a viable source of heat and electricity globally.

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