COMPONENTS AND IMPACT OF CANADAS WOOD PELLET INDUSTRY - A LITERATURE REVIEW

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Matthew Barber
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An Undergraduate Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Honours Bachelor of Science in Forestry

Faculty of Natural Resources Management

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ABSTRACT

Keywords: Wood-pellets, biomass, residue, parameters, production, export, emissions

Wood Pellets are biofuels made from compressed wood fibre and they can be used to generate electricity or for heating applications. They are often produced from mill residues like sawdust and shavings. Wood pellets have many parameters that influence how much energy they can produce. These parameters are measured to ensure that they meet the standards set by the Pellet Fuel Institute (PFI) which is used in North America and the European Union standard. Wood pellets are a less environmentally damaging alternative to fossil fuels due to their renewable nature and lower greenhouse gas emissions. Many countries like the United Kingdom have introduced policies and incentives to increase the use of clean energy such as wood pellets. This has led to Canada becoming the second largest exporter of wood pellets behind the United States. To meet the demand for wood pellets, Canadas production of wood pellets has increased. The production process for wood pellets has many steps and there can be with issues with storage and transportation as degradation and energy density issues can occur. This review will collect all relevant literature pertaining to the impacts and components of Canada's wood pellet industry.

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ACKNOWLEDGEMENTS

I would like to acknowledge and thank my thesis supervisor, Dr. Mathew Leitch, for advising me throughout my thesis. I would also like to thank everyone who I have consulted with for helping give me insight and assistance with this thesis in any way.

1.0 INTRODUCTION

Wood pellets are a relevant subject in the field of energy generation due to their renewable nature and lower greenhouse gas emissions compared to fossil fuels. As the need for renewable energy resources increases the market for wood pellets has also increased significantly since they are easily handled and stored compared to other biofuels. Wood pellets are made 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). They are made from forest by-products such as sawdust, wood chips, and shavings that are dried and pelletized (Jones et al., 2012).

Wood pellets have several quality parameters such as ash content, calorific value, moisture content, fines content, bulk density, and durability (NRCAN 2017). These properties can be affected by the type of biomass that is used for example hardwoods have higher ash content than softwoods making them less stove efficient (Lestander et al. 2012). These quality parameters are also measured to ensure that they meet the quality standards set by the Pellet Fuel Institute (PFI) and the European Union. These parameters ensure consistent quality among all pellets that are exported over-seas. This effects the production of wood pellets since biomass may be transported long distances to a production facility if suitable biomass in not regionally available. Many regional, operational, and economic factors as well as government mandates influence the production of wood pellets.

According to the U.S. International Trade Commission, in 2017 the United States were the largest exporters of wood pellets in the world followed by Canada and Latvia respectively (USITC 2018). The largest importer of wood pellets is the U.K. (United Kingdom) due to the EU (European union) renewable energy directive which aims to have a renewable energy target of at least 40% by 2030 (EU 2023). This has encouraged higher production and exports of pellets, namely from western Canada (British Columbia, Alberta) and southeastern United states (Virginia, North Carolina) with relatively little domestic consumption. However domestic consumption of wood pellets is expected to increase due to government incentives such as Canada's CFR's (Clean Fuel Regulations) which might reduce the quantity of exports. Degradation and low energy density issues can occur during storage and transport of wood pellets which can diminish the end of the value of the pellet.

To assess the factors that influence wood pellets from Canada, literature spanning the last 50 years was compiled. The literature includes all topics relating to the environmental, economic, and legislative factors affecting Canadas wood pellet industry. Google scholar, The Lakehead University Library Database, and the references of previous studies were primary databases used when finding literature. Key phrases such as biomass utilization, wood pellet production, wood pellet exports, wood pellet parameters, and were searched. The literature compiled primarily focuses on the production and quality of wood pellets as well as major importing markets for Canadian wood pellets.

Objective

The main objective of this research was to collect all relevant literature pertaining to the components and impact of the Canadian wood pellet industry. This literature search attempts to answer the questions: "What are the environmental, economic, and legislative components that influence Canada's wood pellet industry?", and "What advantages does the industry provide and how does our wood pellet industry impact the global market, pellet utilization, and the environment?". The main findings of the literature search will be summarized in the conclusion.

2.0 LITERATURE REVIEW

2.1 Raw Material Sources and Attributes

Canada has the third largest forest area in the world with almost 362,000,000 ha of forested land (NRCAN 2023). 75% of Canada's forested land is in the boreal region where the predominant tree species are spruce and poplar (NRCAN 2023). Less than half of 1% of Canada's forests have been deforested since 1990 (NRCAN 2023).

Among other properties, different species have different calorific values which measures the amount of heat and energy generated when the tree material is completely combusted (Kryla 1984; Singh and Kostecky 1986). Kryla (1984) found that in Canada the average calorific value of softwoods is 21.18 MJ/kg while hardwoods had an average of 19.35 MJ/kg. Additionally, the different anatomical parts of trees such as the stump, stem, treetop, bark, foliage, and branches of a tree have different calorific values (Singh and Kostecky 1986; Kryla 1984; Kelsey et al. 1979). Singh and Kostecky (1986) found that calorific value was lowest in the main stem but increased towards the stump and branches. Bark has higher calorific value than wood in addition to higher ash content (Kryla 1984). Ash content negatively impacts the combustion process and results in a lower calorific value than wood (Nosek et al. 2016). As such bark is rarely used to produce wood pellets. Characteristics of raw materials such as ash content, calorific value, moisture content, fines content, bulk density, and durability can all effect pellet quality (Filbakk et al. 2011). Table 1 shows the calorific values of predominant tree species in the eight Canadian forest regions.

Table 1. Predominant tree species by forest region and location (NRCAN 2022; Kryla, 1984; Sing and Kostecky 1986; Kelsey et al., 1979).

Forest region	Location	Predominant tree species	Calorific value	
			Stem (wood/bark)	**Branch (wood/bark)**
Acadian	Maritimes	Red spruce	-/20.07	-/-
		Balsam fir	20.04/21.72	20.57/-
		Yellow birch	19.7/21.40	20.74/20.94
Boreal	Northern Canada	White spruce	19.01/19.83	21.14/-
		Black spruce	18.78/19.47	20.67/-
		Balsam fir	20.04/21.72	20.57/-
		Jack pine	19.40/21.21	19.20/21.95
		White birch	18.82/23.98	21.11/21.50
		Trembling aspen	19.35/19.62	20.41/20.83
		Tamarack	18.78/19.49	21.46/-
		willow	19.66/18.93	19.89/-
Carolinian (Deciduous)	Southwestern Ontario	Beech	-/17.77	-/-
		Maple	18.96/19.60	20.62/20.40
		hickory	19.33/17.53	18.89/17.60
		Oak	18.12/18.33	18.09/18.44
Coast	British Columbia	Western redcedar	19.65/-	20.54/20.16
		Western hemlock	20.13/21.62	20.62/23.13
		Sitka spruce	19.79/-	20.49/-
		Douglas-fir	20.25/23.96	20.30/25.23
Columbia	British Columbia	Western redcedar	19.65/20.16	20.54/20.16
		Western hemlock	20.13/21.62	20.62/23.13
		Douglas-fir	20.25/23.96	20.30/25.23
Great Lakes–St Lawrence	Central Canada	Red pine	-/21.10	-/-
		Eastern white pine	21.01/22.4	21.36/22.51
		Eastern hemlock	-/20.68	-/-
		Yellow birch	19.77/21.40	20.74/20.94

		Maple	18.96/19.60	20.62/20.40
		Oak	18.12/18.33	18.09/18.44
Montane	British Columbia and Alberta	Douglas-fir	20.25/23.96	20.30/25.23
		Lodgepole pine	20.0/23.7	21.80/20.64
		Ponderosa pine	20.82/22.01	-/21.99
		Trembling aspen	19.35/19.62	20.41/20.83
Subalpine	British Columbia and Alberta	Engelmann spruce	18.84/20.54	21.11/22.37
		Subalpine fir	-/-	-/-
		Lodgepole pine	20.00/21.82	22.64/22.34

Each province has access to various amounts of biomass for production of wood pellets. According to Demirbaş (2003) “Biomass is only a petroleum substitute that is renewable”. This includes wood wastes, short rotation woody crops, animal wastes, and other materials (Demirbaş 2003). According to Penner et al. (1997) British Columbia has the most biomass in Canada while Saskatchewan has the lowest. Ontario has the second most biomass in the country (Penner et al. 1997). Obtaining a stable supply of biomass is essential for pellet production.

Sawdust, Shavings, and other mill residue are most often used to produce wood pellets due to their cheaper cost compared to growing crops specifically for bioenergy (Antizar-Ladislao 2010). Softwood and hardwoods can both be used to produce wood pellets (NRCAN 2017). Mostly, however wood pellets are made of pine and spruce, which are common by-products of wood processing mills (Järvinen and Agar 2014). In order to maximize value, producers will utilize every tree that is harvested (Canadian Biomass Magazine 2020). Figure 1 displays the percentage of each part of a log that is used for different products including wood pellets. Wood pellets sourced exclusively from sawmill residues can be limited however (Antizar-Ladislao 2010, Filbakk et al.

2011). In 2009 there was an economic crash in the forest industry which devasted lumber production and severely limited the amount of mill residue available (Bradley 2010). This has led too alternative sources of biomass being considered such as Scots pine (*Pinus sylvestris*) feedstock (Filbakk et al. 2011). Municipal waste such as paper/cardboard, kitchen waste, and garden waste can also be used to produce biofuels (Antizar-Ladislao 2010). Table 2 shows Biomass estimates for each Canadian province.

Table 2. Average biomass amount estimations for each Canadian province/territory (Penner et al. 1997).

Province/Territory	Softwood (ODt/ha)	Mixed wood (ODt/ha)	Hardwood (ODt/ha)	Unclassified (ODt/ha)
Newfoundland	52	76	84	80
Nova Scotia	71	70	83	-
Prince Edward Island	73	83	99	-
New Brunswick	87	87	90	16
Quebec	59	89	105	43
Ontario	83	85	101	84
Manitoba	46	74	72	-
Saskatchewan	35	67	89	-
Alberta	82	92	68	-
British Columbia	169	111	80	55
Yukon Territory	76	60	60	-

Northwest Territories	62	48	55	-
Canada	101	81	88	28

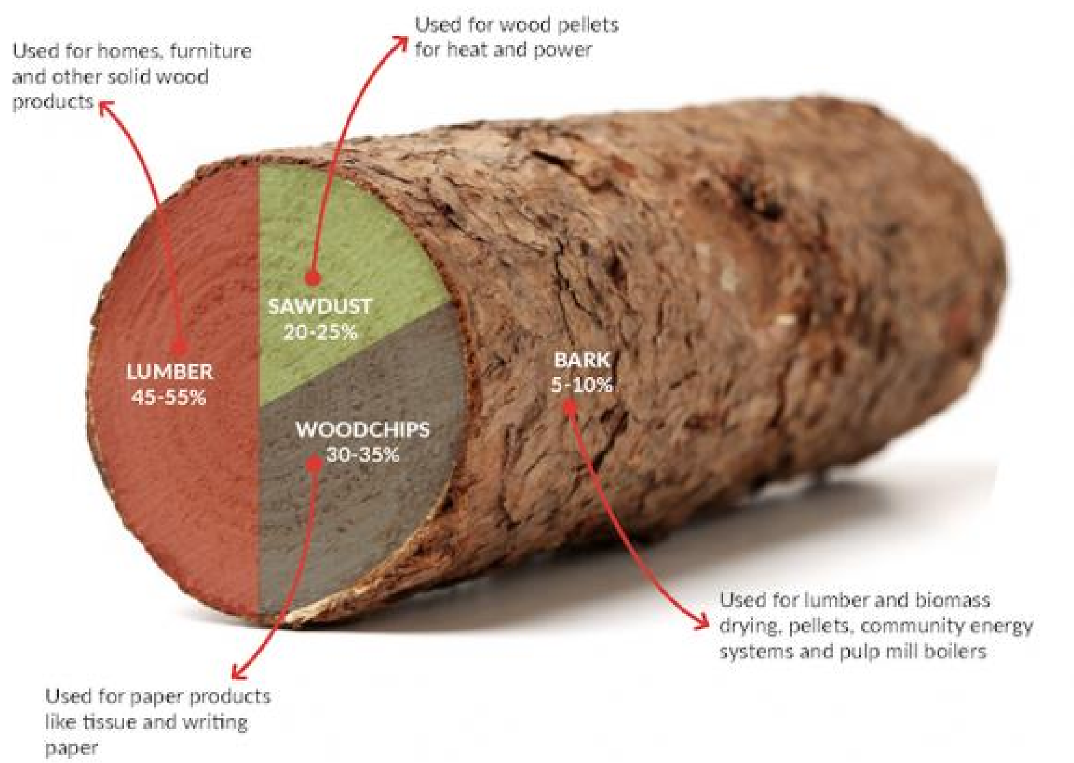

Figure 1. Percentage of the log used for different products in the sawmill (Canadian Biomass Magazine 2020).

2.2 Pellet Production process

The wood pellet production process typically involves the following steps and the order of which is shown in figure 2 (Kofman 2010).

- Raw material reception
- Drying
- Screening
- Hammer-milling
- Pellet pressing
- Cooling

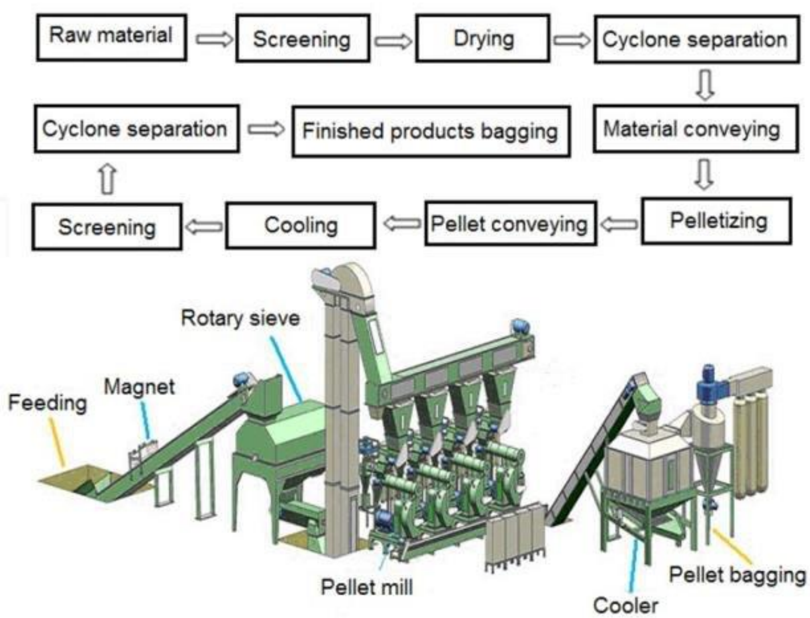

Figure 2. Pellet manufacturing process from raw materials to finished product (Omer et al. 2018).

2.2.1 Raw material reception

Wood pellets are commonly made from conifer sawdust and shavings. Hardwood material can be mixed with softwood material however, binders are often required making the production of hardwood pellets more difficult (Kofman 2007). When raw materials are received at the mill they are first weighed and tested for moisture content by taking samples. This is done to gauge if a drying process is necessary since if the material is dry (under 15% MC), no drying is required (Kofman 2007). At reception dry and wet sawdust is separated for the purpose of storage. Dry sawdust is stored indoors immediately to avoid the material getting wet while wet sawdust can be stored outside for a short period (Kofman 2007).

2.2.2 Drying

Proceeding raw material reception, the raw material with MC's above 15% must be dried to produce quality pellets. The general drying process involves the evaporation of moisture from the material into ambient air (Holubcik et al., 2012). For this to occur the vapour pressure over the material must be higher than that of the ambient medium (Holubcik et al., 2012). The drying process is the most energy intensive out of all the steps in pellet production, accounting for about 28% of pellet production prime costs (Alligno Maschinenexport GmbH, 2006).

Drying is an important process in the production process as moisture content has a very strong influence on how well pellets bind. If the moisture content is too low, then rapid thermal decomposition will occur due to high temperatures in the matrix. If moisture content is too high, then the pellet will fall apart (Filbakk et al 2011). For pellets to be considered high quality, the material must be dried to a MC of around 10%

(Filbakk et al. 2011). Since the material will not naturally dry to this level several methods such as using a drum drier and a flatbed drier are used (Kofman 2010, Fillbakk et al. 2011). Drum drying is most commonly used and involves using flue gas with temperatures between 300°C and 600°C (Louis 2011) in an inert atmosphere (Fillbakk et al. 2011). Drum drying is more suited to fine material as coarse material requires a lower temperature. The flat bed has a lower temperature between 90-110 C (Louis 2011) and is preferable to drum drying for coarser material (Kofman 2010, Fillbakk et al. 2011). Residence time for drum driers is only a few minutes due to the temperature however volatile components has been known to occur (Fillbakk et al. 2011). Drying at lower temperatures such as those used in a flatbed drier minimizes substance loss (Fillbakk et al. 2011). In addition to drier types there are also different techniques namely direct and indirect drying. Direct drying is the technique drum driers are based off and involves hot air being applied to the material surface (Mujumdar 2011). Flatbed driers are based off the indirect drying method which involves heat being exchanged through metal walls (Mujumdar, 2011).

2.2.3 Screening

Prior to hammer-milling, screening for stones, metal, plastic and other materials is completed to ensure the hammermill can properly homogenize sawdust into even-sized feedstock (Kofman 2007). If sawdust is not properly screened, foreign particles can damage the press and sparks could cause a dust explosion (Kofman 2007). During the screening process, stone is typically removed by passing sawdust through an opening of a certain size called a stone trap (Kofman 2007). Metal objects are removed through the use of magnets (Kofman 2007).

2.2.4 Hammer-milling

After the sawdust has been screened it is then sent to the hammermill where it is prepared for the pellet press. The hammermill is responsible for homogenising the sawdust into even-sized feedstock, so it is suitable for the pellet press (Kofman 2007). This is done by destroying small lumps of wood like dead knots so they can pass through the pellet press matrix (Kofman 2007). It is important to note the hammermill does not have the same capacity of the pellet press so typically there is an intermediate store of hammer-milled material (Kofman 2007). A ventilation hatch on the outside of the building is necessary due to the possibility of dust explosion. If a dust explosion occurs the pressure could be released through the hatch (Kofman 2007). Additionally, the vent must be high enough as to avoid any injury to bystanders (Kofman 2007).

2.2.5 Pellet pressing

After hammermilling, the pellet press compacts the raw ground woody material (Holubcik et al., 2012). This is done by pushing a large amount of ground wood through heated (90 - 110° C) press die holes (Holubcik et al., 2012) as seen in figure 3. At the 90 - 110° C temperature range the wood starts to release lignin which holds pellets in the right shape (Holubcik et al., 2012). Prior to pressing the raw-materials must be warmed up to 120°-130°C using dry steam (Kofman 2007). This helps the particles bind together as it makes the lignin more plastic (Kofman 2007). Then the sawdust is forced out of a matrix where the pellets are cut off on the outside (Kofman 2007). Two types of matrixes exist, standing, or lying down however both operate on the same principal of pressing wood through apertures in a matrix, where they are cut off by blades (Kofman 2007). The standing matrix has the pressure rollers moving on the inside while the horizontal matrix has the rollers moving over the matrix in a revolving fashion (Kofman 2007). At the end of a working period vegetable oil is used to lubricate the last pellets. This is done to cool off the matrix, so pellets don't get stuck making it harder start the press again (Kofman 2007).

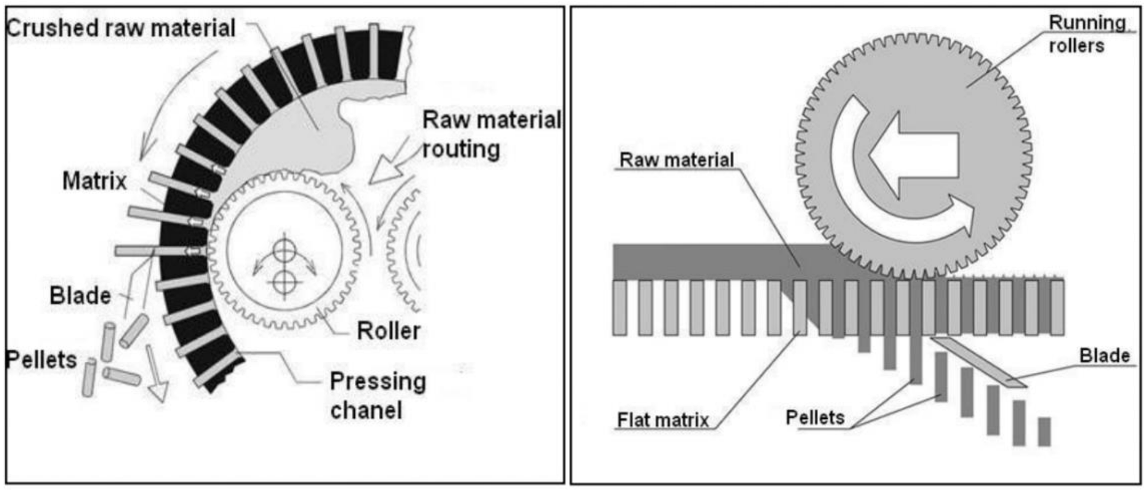

Figure 3. A diagram of a cylindrical pellet press to the left and a flat matrix to the right (Pellets Partner Group, 2006).

2.2.6 Cooling

After pellets have been pressed, they are very hot and soft in texture (Ciolkosz 2023). Pellets can reach a temperature between 80 to 130 °C after the pelletization process (Louis & Pongrácz 2011). For this reason, they require cooling which is typically done by blowing air onto the pellets while they are in a metal bin (Ciolkosz 2023). In this stage the pellets become harder as they lose their moisture (Kofman 2007). After this process the moisture content can be low as 6%, however, will stabilize between 8-10% due to moisture absorption from the surrounding air (Kofman 2007).

2.3 Wood Pellet parameters

The major physical and chemical properties that effect pellet qualities are:

- Ash content
- Moisture content
- Bulk density
- Durability
- Calorific/Heating value

These parameters are commonly measured to ensure pellets are in compliance with the pellet standards set by the Pellet Fuel Institute (PFI) (North America) and the European Union standard. The PFI standard can be seen in figure 4.

	Residential/Commercial Densified Fuel Standards See notes 1-6		
Fuel Property	PFI Premium	PFI Standard	PFI Utility
Normative Information - Mandatory			
Bulk Density, lb./cubic foot	40.0 - 48.0	38.0 - 48.0	38.0 - 48.0
Diameter, inches	0.230 - 0.285	0.230 - 0.285	0.230 - 0.285
Diameter, mm	5.84 - 7.25	5.84 - 7.25	5.84 - 7.25
Pellet Durability Index	≥ 96.5	≥ 95.0	≥ 95.0
Fines, % (at the mill gate)	≤ 0.50	≤ 1.0	≤ 1.0
Inorganic Ash, %	≤ 1.0	≤ 2.0	≤ 6.0
Length, % greater than 1.50 inches	≤ 1.0	≤ 1.0	≤ 1.0
Moisture, %	≤ 8.0	≤ 10.0	≤ 10.0
Chloride, ppm	≤ 300	≤ 300	≤ 300
Heating Value	N/A	N/A	N/A
Informative Only - Not Mandatory			
Ash Fusion	N/A	N/A	N/A

Figure 4. PFI Fuel Grade Requirements (Pellet Fuel Institute 2015).

2.3.1 Ash content

Ash content is an important chemical property of wood pellets which impacts the combustion of biomass. Higher ash content decreases stove efficiency and has the potential to damage components of the stove and leads to more cleaning (Obenberger and Thek, 2010). High ash content in wood pellets may result in the formation of an ash layer which may cause incomplete combustion (Carroll & Finnman 2012). According to Cassida et al. (2005) there is 0.2 MJ/kg decrease in calorific value for every 1% increase in ash content. Bark and herbaceous biomass such as foliage typically contains higher levels of ash than wood making them less useful to produce wood pellets (Carroll & Finnman 2012; Sing and Kostecky 1986). This is because Bark and foliage contain higher parenchyma content than wood which is known to increase ash content. Hardwoods also have more parenchyma than softwoods making them produce more ash. Softwoods have a typical ash content of 0.4 - 0.8% while hardwoods have a typical ash content of 1.0 – 1.3% (Obenberger 2007). The pellet fuel institute defines premium class pellets ash content as 1% or less (Pellet Fuel Institute, 2010) while the European Union defines it as 0.7% or less (ENplus 2015).

2.3.2 Moisture content

Moisture content (MC%) is presented as percentage of the original mass at oven dry condition. Moisture content negatively affects net calorific value (NCV) (Carroll and Finnman 2012) as well as bulk density (Filbakk et al. 2011). According to Natural Resource Canada (2017) pellets with a moisture content of 10%, roughly have a 20 MJ/kg heating value while pellets with a moisture content of 20% roughly have a 16% heating value. Stable pellets require a moisture content of 8-12% depending on the biomass type to be formed (Carroll and Finnan 2012). If the moisture content of a wood pellet is above 8-12% mould formation and pellet degradation may occur (Carroll and Finnman 2012). Conversely if pellet moisture content is too low (3%) they can crumble, generating a higher fines content (Caroll and Finnman 2012). Pellets are highly susceptible to moisture uptake and degradation during transport and storage, so it is important to store pellets in dry, watertight facilities (Carroll and Finnman 2012; Filbakk et al. 2011). By the PFI standard the MC% must be less than or equal to 8% to be considered premium grade (Pellet Fuel Institute 2010). The European ENplus standard, biomass pellets are defined as having a moisture content less than 10% (ENplus 2015). Moisture content is one of the most important factors in determining calorific value.

2.3.3 Bulk density

Bulk density is defined as the mass of a portion of biofuel divided by the volume of the container that is filled by the fuel (Obernberger and Thek, 2004). It is largely determined by pellet density and length distribution and can significantly influence combustion efficiency (Filbakk et al. 2011). Bulk density is also heavily influenced by moisture content and extractives content with higher amounts of both having a negative effect on bulk density (Filbakk et al., 2011). This is because higher moisture content decreases particle density. Particle density also decreases with higher extractive content which in turn affects bulk density (Nielson et al. 2009, Nielson et al. 2010, Rhen et al. 2005). This is likely because of a lubricant effect which occurs when pellets are being pressed (Filbakk et al., 2011, Samuelsson et al. 2009). These effects on bulk density also have implications for drying methods. Filbakk et al. (2011) found that for dry materials the extractives content did not influence bulk density.

By the PFI standard the Bulk Density must be between 40.0 – 48.0 lb./cubic foot to be considered premium grade (Pellet Fuel Institute 2010). The European ENplus standard, biomass pellets must have a bulk density equal to or between 600 – 750 kg/m^3 (ENplus 2015). This standard of bulk density ensures consistent burn across producers.

2.3.4 Durability

Another important wood pellet parameter is wood pellet durability. Durability is the parameter which describes the physical quality of solid biofuels such as wood pellets (Carroll & Finnan 2012). Physical wear and tear can occur to low durability pellets during storage and transport (Carrol and Finnan 2012). The resulting fine particles and dust can cause issues with boiler handling and combustion systems. In addition, dust and fine particles can be a health and fire hazard (Carroll & Finnan 2012, Fillbakk et al.2011 Vinterback 2004). Pellets with higher fines also have a higher slide angle due to the binding nature of fines between pellets (Fillbakk et al., 2011). Higher emissions and more residues in the stove can result when burning dust passes through the combustion chamber unburned (Fillbakk et al. 2011, Obernberger and Thek, 2004). It is important to note that pellet durability and strength are different from each other (Tarasov 2013). Durability describes the wood pellets resistance to abrasion while wood pellet strength is describing compressive resistance (Kaliyan and Morey 2009).

PFI premium pellets are stated as having a pellet durability index of less than or equal to 96.5 (Pellet Fuel Institute 2010). By the European ENplus standard A1 pellets are stated as having a durability index of less than equal to 98.0 (ENplus 2015). The most often used methods to test durability of densified biomass products are the Tumbling Can, Holmen tester and Ligno tester (Kaliyan and Morey, 2009).

2.3.5 Calorific/Heating value

Gross Calorific Value (GCV) can be defined as the specific energy amount in joules per unit of mass released from complete combustion (Obenberger and Thek, 2004, Carroll and Finnan 2012). Calorific value has the biggest role in determining the Net Calorific Value (NCV) when compared to other parameters such as moisture content and chemical composition (Carroll & Finnan 2012). Additionally, this parameter is most important in defining the value of the product as higher calorific value leads to more energy for the same unit of product (Tarasov 2014). The Calorific value can differ depending on the tree species and the composition of the raw materials in the pellet (Tarasov 2014). As mentioned previously, softwoods display higher calorific values per unit of mass (21.18 MJ/kg) than hardwoods (19.35 MJ/kg) (Kryla 1984). This is due to a higher number of extractives and lignin present in softwood which produce higher heating values (Baker, 1983). In terms of composition of raw materials, pellets made from non-resinous materials have a GCV between 18.6-19.8 MJ/kg, while those made of resinous materials range between 20.0 to 22.5 MJ/kg (Tarasov, 2014).

Calorific value is commonly determined using a Bomb Calorimeter in accordance with the ASTM E 711-87: Standard Test Method for Gross Calorific Value of Refuse-derived Fuel (ASTM E711- 87, 2004). The GCV is determined by burning a weighed sample under controlled conditions using an oxygen bomb calorimeter. Solid form refuse derived fuel is used to determine the calorific value (ASTM E711- 87, 2004).

PFI premium pellets are stated as having no specific grade requirement for heating value which is shown in figure 1(Pellet Fuel Institute 2010). According to the PFI (2010), manufactures are only required to provide a minimum higher heating value guarantee when the specification are used with PFI Residential/Commercial Densified Fuel QA/QC Handbook and the ALSC. By the European ENplus standard wood pellets are stated as having a net calorific value of greater than or equal to 16.5 MJ/kg (Obernberger and Thek 2004).

2.4 Supply chain

Once pellets have been fully formed and cooled, they will be screened for fines and packaged for delivery (Kofman 2007). They are typically packaged in bags or stored in bulk depending on the market (Jones et al. 2012, Louis & Pongrácz 2011). If the pellets are for the domestic market, they are typically packaged in bags that can be 12, 15 or 20 kg sizes that are delivered on pallets of 960 kg or one tonne (Kofman 2007, Jones et al. 2012). Pellets are also often packaged in one tonne bags (Kofman 2007). Additionally, they can be bought in bulk and stored in silos outside of the buyer's home (Jones et al. 2012). A bulk delivery of pellets is typically transported on truck which is tipped off at the receiving end. They can also be transported by a vacuum vehicle that sucks up the pellets and blows them into a silo when being received (Kofman 2007). Trucks are equipped with weigh cells to ensure the correct amount is delivered (Kofman 2007). Pellets must be dumped indoors or in very dry weather conditions to avoid damage (Kofman 2007).

Although wood pellets can be stored indefinitely, care must be taken to ensure they are kept dry to prevent damage (Jones et al. 2012). This is typically done by wrapping pallets in plastic, however small bags offer better protection from abrasion making them a better option for the consumer (Kofman 2007). According to Gunawan et al. (2020) the low density of wood pellets can increase the cost of storage, handling, and transportation, in addition to be susceptible to destructive microbes.

2.5. Production factors for Canadian wood pellets

According to a report by the U.N. (United Nations) there has been an 8.7% increase in wood pellet production and a 16.5% increase in exports year-over-year that was continued in 2022 (UNECE/FAO 2023). This continual growth of wood pellet production and exports has led to the need for the construction of new mills in Canada and the U.S. to meet the energy demands (Dwivedi et al. 2011). As seen in figure 5 most Canadian exports of wood pellets come from British Columbia (Stand.earth 2022). British Columbia is responsible for exporting 2,268,000 metric tons of wood pellets across the top eight importers according to Stand.earth (2022). This is likely because most wood pellet production mills are in British Columbia. There are 47 Canadian Pellet mills in operation as of 2022 and most are in British Columbia and Quebec (USDA 2023). British Columbia, however, has 45% of Canadas production capacity which is over double that of Quebec's (USDA 2023). However, in the coming years reductions in the annual allowable cut could negatively affect pellet production in the future (USDA 2023).

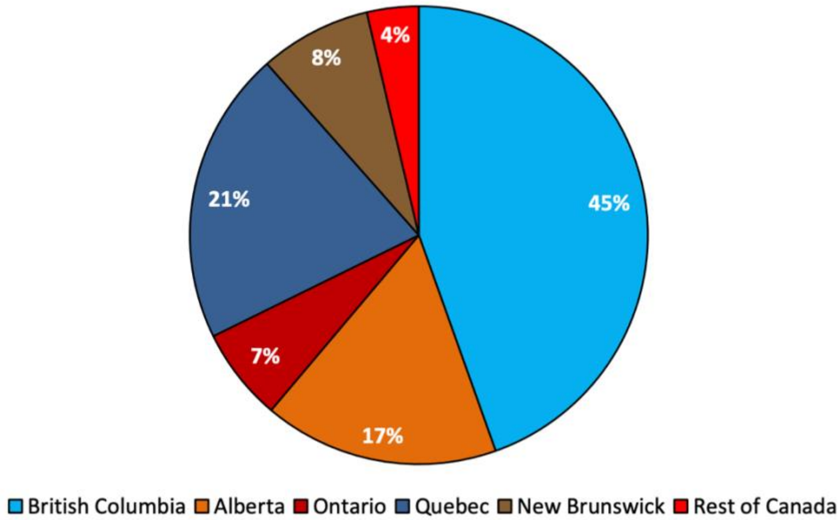

Figure 5. 2021 Canadian Pellet Mill Production Capacity by Province (Canadian Biomass Magazine 2022).

2.6 Exports factors for Canadian wood pellets

2.6.1 Markets and demand

North America is currently the leading exporter of wood pellets globally (Aguilar et al. 2023). As seen in figure 6, Canada is the second largest exporter of wood pellets only being outcompeted by the USA (Aguilar et al. 2023). Behind Canada in terms of quantity of exports is Latvia, Estonia, and Austria (Aguilar et al. 2023).

	Wood fuel		Wood pellets		Total
	1,000 m^3	$ million	1,000 tonnes	$ million	$ million
USA	71	5	8,989	1,555	1,560
Canada	101	8	3,651	576	584
Latvia	675	142	1,890	397	539
Estonia	196	37	1,418	313	350
Austria	12	2	760	293	294
Germany	247	20	882	293	313
Denmark	46	1	1,446	243	244
Russian Federation*	175	6	2,294	234	240
Croatia	547	76	433	133	209
Belgium	99	9	1048	184	193
UNECE top-10	**2,168**	**306**	**22,811**	**4,221**	**4,527**

Figure 6. Top-10 exporters of wood fuel and wood pellets in 2022 according to the UNECE (Aguilar et al. 2023).

The largest importer of wood pellets is the U.K. (Stand.earth 2022). This is in large part due to the EU (European union) renewable energy directive. The directive is part of an attempt to reduce carbon dioxide emissions. It aims to have a renewable energy target of at least 40% by 2030 (EU 2023). As a result, Europe's demand for wood pellets is very high. It makes up approximately 75% of the global demand for wood pellets and is projected to rise by 30 to 50% in the next five years (Woodworking Network 2022). In 2018, the U.K. consumed and estimated 27.35 million metric tons of wood pellets which was up from the 24.15 million tons consumed the previous year. Additionally, Europe's increasing demand for woody biomass has created a large market for wood pellet exports which Canada has capitalized on. As shown in figure 7, Canada has exported 1,578,000 metric tons of wood pellets to the U.K. in 2019 (Stand.earth 2022). Another notable market for wood pellets is Japan, which imported 622,000 metric tons of wood pellets in 2019. It is estimated that by 2030 Japan will be consuming about 20 million metric tons per year (Stand.earth 2022). Like the U.K., Japan's large demand for wood pellets is also due to its biomass energy plan (IEA Bioenergy 2021). This plan aims to have at least 20% of renewables in the primary energy supply and 36-38% of renewables in the electricity generation sector by 2030 (IEA Bioenergy 2021).

The third largest importer of Canadian wood pellets according to a report by Stand.earth (2022) is the U.S. The lack of Canadian wood pellet exports to the United States (compared to the U.K. and Japan) can be explained by the economic advantage that U.S. pellet plants have over Canadian plants (Bradley 2010). This advantage is due to the "Biomass Crop Assistance Program" introduced in the late 2010s gave American pellet producers a $50/tonne cost advantage over Canadian pellet producers (Bradley 2010). However, Canada does still export smaller amounts wood pellets to the United States.

After the United States other significant pellet markets are the Netherlands (Stand.earth 2022). In a study by Hiegl et al. (2009) it was found that after an agreement between power producers and the Dutch Ministry of the Environment to intensify co-firing biomass activities led to a large increase in wood pellet consumption. Additionally, polices were introduced in the Netherlands which promoted the production of renewable energy from biomass by providing subsidies for electricity produced from biomass (Hiegl et al. 2009). These combined reasons led to an increase in wood pellet consumption from about 200,000 tons in 2002 to over 900,000 tons in 2008 (Hiegl et al. 2009).

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 7. Canadian wood pellet exports by province and country of destination in 2022 (Stand.earth 2022).

Overall, Europe and Asian markets (specifically the U.K. and Japan) appear to be the most prominent for Canadian wood pellets. The main driving factor in determining markets for Canadian wood pellets appear to be renewable energy polices and the subsidies they provide to renewable energy use (Stand.earth 2022). Wood pellet markets have been growing at an annualized rate of about 1.66 million metric tonnes per year from 2010-2021 (Strauss 2022).

2.6.2 Domestic consumption of wood pellets

Domestic consumption of wood pellets in Canada is very low compared to exports. Natural Resources Canada estimates that only 1.4% of electricity generation comes from biomass/geothermal energy (NRCAN 2024). However, gains in domestic consumption are predicted to continue as with growth of Canada's domestic consumption of wood pellets depends on policy decisions promoting the use of biomass in the energy sector. There are currently a number of policies in place that promote the use of renewable energy one of the most recent being the clean fuels regulation (USDA 2023). Figure 8 displays wood pellet supply and distribution in Canada.

Wood Pellets (1,000 MT)											
Calendar Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022 f**
Beginning Stocks	47	64	87	129	161	129	393	548	760	758	634
Production	1,521	1,822	1,900	1,900	2,600	2,700	3,100	3,220	3,300	3,500	3,500
Imports	45	22	30	30	20	20	20	26	29	29	20
Exports	1,369	1,640	1,638	1,628	2,373	2,172	2,651	2,634	2,901	3,153	3,300
Consumption	180	181	250	270	279	284	315	400	430	500	530
Ending Stocks	64	87	129	161	129	393	547	760	758	634	324
Production Capacity											
Number of Plants	42	41	41	39	42	42	45	45	46	47	47
Nameplate Capacity	2,900	3,175	3,282	3,681	4,282	4,282	4,657	4,657	4,856	5,054	4,790
Capacity Use (%)	52.4%	57.4%	57.9%	51.6%	60.7%	63.1%	66.6%	69.1%	68.0%	69.3%	73.1%

Figure 8. Wood pellets supply and distribution in Canada (USDA 2023).

2.7 Wood pellet utilization

The burning of wood pellets to replace coal in electricity production has recently become very frequent in regions such as the U.K. (Stahl et al., 2017). According to Stahl et al. (2017) the U.K. consumed more than 75% if its pellet supply making it the largest pellet consumer in the world. In addition to electricity generation, wood pellets can be utilized in a number of different contexts. They are often utilized in domestic heating and cooking, power plants, and in industry. Depending on the context, there are three major types of pellet burners which can be used: pellet stoves, boilers and furnaces (AEA, 2012; Jones et al. 2012). For residential settings wood pellet stoves are often used due to their smaller size, while wood pellet boilers are used for large commercial use (Biomass Energy Resource Center 2007; Jones et al. 2012). The terms “boiler” and “Furnace” are often used interchangeably however there are some key differences (EcoHeatSolutions 2018). Wood pellet boilers burn wood to heat water around the combustion chamber where it is then circulated around the building via heat exchange tubes (Nichols, 2023). Wood pellet furnaces on the other hand, deliver heat via hot air that is distributed through air ducts (Nichols, 2023). Pellet furnaces are also often used for residential heating (Biomass Energy Resource Center 2007).

Wood stoves and pellet stoves are two prominent wood-heating appliances with a few key differences (NRCAN 2002). Wood stoves are the most used wood-heating stove. They work by burning solid wood logs cut to a particular size. They come in various sizes with different heat outputs which must be selected carefully based on the space that is being heating (NRCAN 2002). Wood pellet stoves on the other hand are much more efficient than traditional wood stoves and have a few advantages. Unlike traditional woodstoves, pellet stoves produce far less ash, as well as dust and debris

(Jones et al., 2012; NRCAN 2002). They also produce less smoke emissions and can be started via ignition button (NRCAN 2002; AEA 2012). Pellet stoves also have a hopper with a fuel capacity of 20-60 kg, and a fuel feed auger which can move the wood pellets from the storage hopper to the combustion chamber (NRCAN 2002; CMHC, 2008; Jones et al. 2012). One hopper load of fuel can last 24 hours or more (NRCAN 2002; AEA 2012). However, the ashpan needs to be cleaned out weekly (Jones et al, 2012) and for boilers the tubes need to be cleaned out monthly (AEA, 2012). Boilers generally serve the same function as stoves however there are some differences in the degree of fuel storage and handling automation, which are based on the needs of the user (Biomass Energy Resource Center, 2007).

In the Canada, residential heating via wood-burning stoves is not very common. According to StatsCAN Plus (2023) Only 2% of Canadian households reported having heating stoves, three quarters of which were wood-burning stoves. Biomass utilization for electricity is far more common with 1.7% of Canada’s electricity generation coming from biomass (USDA 2021). In the U.S. approximately 800,000 homes are heated using wood pellets stoves (Biomass Energy Resources Center 2007). In specific regions, such as new England there have been several successful demonstrations of wood pellet boilers replacing fossil fuels in larger buildings such as educational facilities, government buildings, and other business’ (Biomass Energy Resources Center 2007). However, most installations of this size are in Europe (Biomass Energy Resources Center 2007). As of 2021, Northern European countries such as Finland and Sweden have the highest levels of solid biomass use (per capita) (IEA Bioenergy 2021). In both countries biomass makes up more than half of their renewable energy (85% for Finland and 60% for Sweden) and most of its bioenergy comes from solid biomass (90% for

Finland and 80% for Sweden) (IEA Bioenergy 2021, IEA Bioenergy 2021). The main application of bioenergy in these countries is renewable heat (IEA Bioenergy 2021). As fossil fuels decline in many countries, the use of solid biomass is becoming a significant energy source, with the main application being heating at both the industrial and residential scale.

2.8 Advantages and disadvantages of wood pellets

Rising prices of fossil fuels like natural gas and fuel oil are causing production and use of wood pellets to increase (Jones et al. 2012). Pellets are less expensive than other fuel options like oil and propane and are more stable in pricing (Biomass Energy Resources Center 2007, Gunawan et al. 2020). Wood pellets have high energy density, which means they can produce a significant amount of heat relative to their size and weight (Artemio et al. 2018). Wood pellet production could have significant economic benefits in Canada as wood waste can be sourced locally, helping support local forestry industries and economies (Biomass Energy Resources Center 2007). Wood pellets also have lower ash content compared to other solid biofuels (Vassilev et al. 2017). This reduces the need for frequent cleaning and maintenance of stoves and boilers. According to Gunawan et al. (2020) the major advantage of wood biomass utilization is that it is more environmentally friendly due to its renewable nature and lower greenhouse gas emissions compared to fossil fuels. Gunawan et al. (2020) sites high water content, non-uniform shape and size, and increased cost of storage handling, and transportation as major disadvantages of wood pellets. The production of wood pellets relies on a stable supply of feedstock which depends on forestry practises, weather conditions, and transportation factors. Wood pellets can degrade if not stored properly leading to lost value (Dujmovic 2017).

2.9 Emissions and environmental sustainability

Wood pellets have been viewed as an environmentally friendly alternative too fossils fuel due to their renewable nature. It is necessary that renewable energy sources like wood pellets emit lesser amounts of greenhouse gases than non-renewable sources when they are required (Gunawan et al., 2020). Wood pellets do emit lower amounts of greenhouse gases during production and combustion compared to fossil fuels (Bates, 1995; Bates and Henry, 2009; Gunawan et al., 2020). Despite this fact, wood pellets still cannot be considered a carbon neutral energy source (Roth, 2006). CO_2 emissions from wood pellet production varies between 30kg/MWh to 106kg/MWh depending on the biomass species, its source, and the method of drying and pellet production (Bates and Henry, 2009). Transporting wood pellets from pellet mills to end users can also generate carbon emissions especially if they are being transported long distances. In addition, additives in wood pellets can also increase greenhouse gas emissions. The addition of lignosulphonate results in a significant increase in sulphur content of wood pellets (Kuokkanen et al. 2011). This leads to increases in SOx emissions which are harmful to the atmosphere (Lehtikangas, 2002). Additionally, the amount of greenhouse gas emissions can be affected by the type of stove used (NRC, 2002; Bafver et al., 2011). Wood stoves operate at higher emissions than wood pellet stoves. As seen in figure 9, wood stoves show higher emissions of carbon dioxide (CO_2), carbon monoxide (CO), organic gaseous carbon (OGC), and nitrogen oxides (NO_2) (Bafver et al. 2011).

Despite the reduction in greenhouse gas emissions from biomass utilization, there has been significant criticism of Canada's wood pellet export industry sector for being a poor solution to climate change. Stand. Earth (2022) released an investigation in which they argued that Canada's wood pellet industry is based on faulty carbon accounting, poor scientific evidence, weak regulations, and land use planning that jeopardizes old growth forests and threatened species habitat. Mill closures in B.C. and the resulting shortage of sawmill residuals has led more pellet plants to increase their use of logs (Canadian Biomass Magazine 2019). For wood pellets to be a renewable alternative to traditional energy sources, the detrimental impact that biomass harvesting has on old growth forests, threatened species, and wildlife habitat must be mitigated. While forest biomass does have the potential to be a perpetual source of fuel, sustainable forestry practises must be practised for wood pellets to truly be considered renewable (NRCAN 2002).

Case*	**CO_2 (%)**	**CO**	**OGC**	**NO_x**
PART I				
MoWo1	5.2	1600	150	110
MoWo2	8.8	1900	210	82
MoWo3	6.7	1400	200	74
MoWo4	5.2	1200	140	81
MoWo5	6.2	1900	170	77
MoWo6	8.7	1300	220	85
WoCook	4.2	2300	300	96
Pe1	3.1	92	4	68
Pe2	5.6	200	7	71
Pe3-wp2	8.0	180	2	83

Figure 9. CO2, CO, OGC and NO2 emissions during wood stove and pellet stove operation (Bafver et al., 2011).

3.0 CONCLUSION

The wood pellet industry in Canada is a multifaceted sector with many important components, ranging from economic and environmental to legislative factors. One of the fundamental components of Canada's wood pellet industry is its production process, which involves the conversion of wood biomass into pellets through grinding, drying, and pelletizing. Meeting pellet standards set by the PFI, and the European Union is very important to ensure consistent quality across all pellet exports. During transport and storage pellets are vulnerable to degradation so care must be taken to ensure they are protected during this process. This process requires substantial energy inputs and technological advancements to optimize efficiency and minimize value loss. Moreover, the sourcing of raw materials for pellet production is mainly affected by the availability of woody biomass. However, at times the availability of woody biomass can be limited especially when lumber production is low.

The market dynamics of Canada's wood pellet industry are influenced by various factors, including global demand, energy policies and trade regulations. International markets, particularly in Europe and Asia, present lucrative opportunities for Canadian exporters. Moreover, domestic consumption patterns and regulatory frameworks play a crucial role in shaping the industry's growth trajectory and competitiveness. In the coming years, Canadas clean fuels regulation may help increase domestic consumption at the cost of exports. Pellets are often utilized for heat via wood pellet stoves, boilers, and furnaces. Residential, and commercial heating via wood pellets is very common in Nordic countries such as Finland and Sweden and northeastern United States. Wood Pellets are most often utilized for electricity in the U.K. The main advantage wood pellets have over traditional fossil fuels namely their renewable nature, and lower emissions. They also present some disadvantages such as higher storage costs and a high-water content.

Environmental sustainability is a central concern in the wood pellet industry, given its potential to mitigate greenhouse gas emissions and transition towards renewable energy sources. However, the wood-pellet industry is still not a carbon neutral industry as emissions still occur during production, transportation, and storage. Additives such as lignosulphonate can increase greenhouse gas emissions.

Further research endeavors should aim to optimize both the production and combustion processes of wood pellets. Given the significant global demand for wood pellets, there is a need for further exploration to enhance the efficiency of this resource. It is crucial to ensure that wood pellets continue to serve as a sustainable and effective source of heat and electricity on a global scale.

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