PROPERTIES OF FIRE-SALVAGED WOODY BIOMASS IN NORTHERN

ONTARIO AND POTENTIAL UTILIZATION

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ABSTRACT

Towell, D.A. 2020. Properties Of Fire-Salvaged Woody Biomass In Northern Ontario And Potential Utilization

Key Words: salvage logging, biomass, biofuel, bioenergy, pyrolysis, carbon, charcoal, forest fires, downed woody debris.

Due to the suppression of forest fires and lack of implementation of management tools such as prescribed burning, there has been a change in the fire regime of Northern Ontario. This has led to larger, more intense fires which are further influenced by climate change. There has been interest in recent years into the potential to utilize salvaged wood from such fires, especially for biomass because of the dryness of the wood. However, there is need for more information on the properties of salvaged wood as it relates to fire intensity, and time since fire. Downed woody debris also provides habitat for insects and other wildlife, so it is important to understand what negative affects there may be from harvesting this resource. In this study, samples of Northern Ontario tree species were taken from stems with varying levels of burn and insect damage to determine their moisture content, calorific qualities, and other general properties. Sample plots from the locations where the samples were collected were taken to provide information on estimated total volume based on fire intensity and pre-fire stocking. The sample plots also provided information on the presence (or lack of) of wildlife, specifically feeding excavations made by woodpeckers in burned stems. The results of this study concluded that salvaged wood from forest fires in the Boreal have properties which are advantageous in their use as biomass, however more information is needed on utilizing this resource without causing negative effects to wildlife habitat.

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INTRODUCTION

The transition to renewable energy sources is a challenge faced by everyone and is unavoidable as the world addresses climate change. It is necessary that our energy sector is diversified to include as many different sources of renewable energy as possible. Biomass is considered a renewable energy because the carbon it releases is replaced when trees are replanted. Bioenergy makes up 6% of Canada's total energy sources, and is a sector showing growth potential (NRCAN, 2019). An advantage that biomass has over other sources of clean energy is the diversity of products that it can provide. Biomass can be directly converted into heat and electricity or can be refined into biofuels which can be used to replace petroleum used for transportation and petroleum-based products. One of the challenges associated with the industry is finding enough sources of biomass to support large scale biorefineries.

Woody biomass from forestry and arboriculture operations currently accounts for the majority of Canada's available biomass. Residues from logging and the wood processing industry provide biomass in the form of hog fuel, slabs, sawdust, shavings, and bark. Other sources include plantations and used wood (pallets, wood packages, other wood waste). One possible source of biomass that is not being harvested is residue from forest fires and other natural disturbances. This potential biomass feedstock could be utilized through salvage logging. Salvage logging faces some challenges due to ecological concerns and economic viability which will be covered in the literature review section.

1.1. OBJECTIVE

The objective of this study is to find what the properties of salvaged wood from forest fires are and how it relates to utilization of salvaged wood compared to other sources of biomass. The physical properties of salvaged wood such as density, moisture content, and calorific value will be tested. Samples with varying degrees of burn and insect damage will be tested to determine how these factors may affect physical properties. The Dog River- Matawin forest located in the boreal forest North of Thunder Bay will be the focus area for this study as forest fires occur here frequently and often near roads which can be used to transport the biomass. Three species will be tested; Jack pine, trembling aspen, and black spruce, which are abundant species in the area with commercial importance in the forest industry.

1.2. HYPOTHESIS

The null hypothesis of this study is that tree species, component of tree (upper stem, lower stem, branches, cones, knot wood), and level of burn does not influence moisture content, density, or calorific value of fire-salvaged wood. An alternative hypothesis is that the properties of fire-salvaged wood are dependent on one or more of these factors. This will be tested using a series of one-way ANOVAS using tree species, tree component, and level of burn as each of the factorials, and a post-hoc test will be used if the null hypothesis is rejected.

LITERATURE REVIEW

2.1. BIOMASS ENERGY

Wood has been one of the most important sources of heat and energy in the world for a long part of human history. Wood is still regarded as the most vital source of energy in many countries who rely on it for cooking and heating. With the uncertainty of future energy supply from oil and a need to reduce greenhouse gas emissions to meet climate objectives, many have suggested the use of biomass and biofuels to decrease dependence on fossil fuels (Pandey 2011; Hakeem 2014; Wetzel 2006). Carbon emissions from the use of biomass are considered to be neutral because the same emissions would be made if the biomass was left to decompose, and the carbon dioxide emissions are sequestered from the atmosphere as long as the biomass source is replanted or renewed (Hakeem et al. 2014; Rosillo-Calle 2007).

The annual production of biomass created from photosynthesis is estimated to be eight times the world's current energy use from all other sources (of course not all of this biomass can be utilized as this would not be sustainable), while only 7% of this annual production is utilized (Hakeem et al. 2014). In Canada, biomass is the second largest source of renewable energy after hydro and provides heat and electricity to industry and residential needs (NRCAN 2019). In 2017 there were 36 pulp and paper mill co-generation units with a total electrical capacity of 3,427 MW, total heat capacity of 1,384 MW, and 41 Independent Power Providers (IPP) with capacities of 794 MW and 400 MW for electricity and heat (NRCAN 2019). Woody biomass is by far the most

abundant and utilized source of biomass in Canada, coming from sources such as trees that are not suitable for lumber or other uses, material from forest thinning, harvest residues, trees killed by disturbance (fire, insect, disease), trees from energy plantations, and from by-products of the forest processing industry in the form of sawdust, bark, chips, etc. (NRCAN 2019). The Canadian production of biomass in 2017 can be seen in figure 1, which shows a slow increase in pellet production while other production has been relatively steady
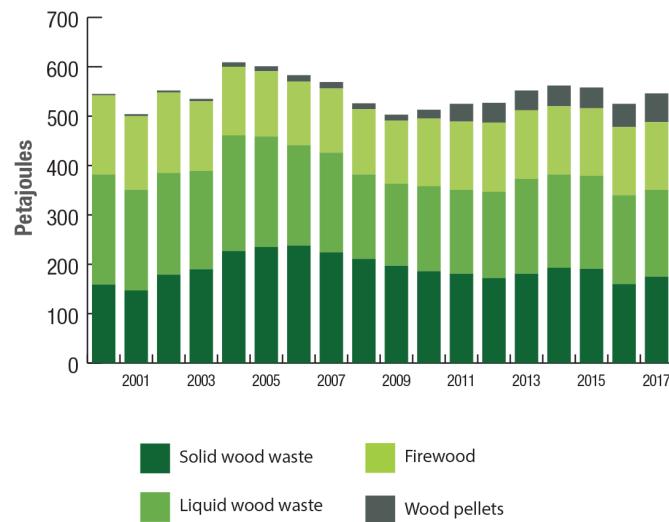
Figure 1.0. Canadian Production of Biomass 2017 (NRCAN 2019).

In order to be used effectively, the quality of biomass must be optimal, it must be supplied at as low a cost as possible and in a sustainable manner which causes minimal ecological damage (Rosillo-Calle 2007; Wetzel 2006; NRCAN 2019). The major costs associated with biomass are transportation, storage, and energy needed for the conversion process (Wetzel et al. 2006).

2.1.1. <u>Properties of Woody Biomass</u>

Biomass is created through the process of photosynthesis, where trees and plants store energy from the sun in the form of chemical bonds (Hakeem et al. 2014). The elementary chemical composition of wood is 49-50% carbon, 6% hydrogen, 44-45% oxygen, a small amount (<1%) of nitrogen, plus small amounts of minerals such as calcium, potassium, and magnesium in the ash content of wood (Tsoumis 1991). During photosynthesis carbon dioxide from the atmosphere reacts with water from the earth to produce carbohydrates (sugars such as glucose) and oxygen, the formula for this reaction is $6H_2O+6CO_2 \rightarrow C_6H_{12}O_6+6O_2$ (Hakeem et al. 2014). The premise of bioenergy production from biomass is the reversal of the photosynthesis process, i.e. CO_2+2H_2O subject to light and/or heat $\rightarrow ([CH_2O] + H_2O) + O_2$ (Hakeem et al. 2014:192-193). The main components of woody biomass are cellulose (main component, makes up 40-50%), hemicellulose (15-30%), and lignin (15-30%), collectively known as lignocellulose (Pandey et al. 2011). There are also a small percentage (4%) of extraneous organic compounds such as extractives, proteins, and inorganic constituents (Tsoumis 1991).

2.1.1.1. <u>Cellulose</u>

Biomass is 40-50% cellulose on average (Pandey et al. 2011), 30-60% in softwoods and 31-64% in hardwoods (Tsoumis 1991). Cellulose is a compound of long chains of glucose ($C_6H_{12}O_6$) which is a monosaccharide created through photosynthesis of carbon dioxide (Desche and Dinwoodie 1996) and has a heating value of 4150-4350 kcal / kg (Tsoumis 1991). Cellulose is extracted

during the pulp process to make paper, and has other applications such as a non-binding agent in shredded cheese and a thickener for ice cream (CIF 2020).

2.1.1.2. Hemicellulose

Hemicellulose is related to cellulose as it is also a carbohydrate, the two are distinguished based on their solubility in alkali (Tsoumis 1991). Hemicellulose is composed of different monosaccharides, while cellulose is only composed of glucose (Desche and Dinwoodie 1996). In softwoods, hemicellulose is mostly composed of mannose and some xylose, and hardwoods are mostly xylose with little mannose (Tsoumis 1991) with hardwoods generally having a larger percentage of hemicellulose than softwoods (Desche and Dinwoodie 1996).

2.1.1.3. Lignin

Lignin is a cell wall component that separates wood from other cellulosic materials in nature (Tsoumis 1991) and is concentrated around the outer layers of fibers leading to structural rigidity (Pandey et al. 2011). Softwoods generally contain more lignin than hardwoods (Pandey et al. 2011; Tsoumis 1991), the composition of lignin differs between hardwoods (syringyl lignin) and softwoods (guaiacyl lignin), and between species (Tsoumis 1991). Unlike cellulose and hemicellulose, lignin is not a carbohydrate, it is mostly aromatic however the chemical structure of lignin is still partially unknown, which is why there is much interest in its use as a base for other chemicals (Pandey et al. 2011; Tsoumis 1991).

2.1.1.4. Extractives

Extractives are the waxes, fatty acids, resins, and terpenes produced by the tree that can be extracted with solvents (Pandey et al. 2011). These compounds are responsible for imparting colour to the heartwood of some species, as well as odor and taste to wood. The literature suggests that the fuel value of extractives is as much as two times that of regular wood substance (Desche and Dinwoodie 1996). For this reason, softwoods with high resin content (such as pines) can have a higher calorific value than some hardwoods, despite the general rule that hardwoods have a higher calorific value than softwoods (Tsoumis 1991).

2.1.1.5. Density

Biomass quality depends on four main factors: moisture content, ash content, density and energy value (Rosillo-Calle 2007). Density and moisture are the two main factors affecting net energy contents of a biomass feedstock (Rosillo-calle 2007). Density refers to the mass of a material per a certain unit of volume, using the metric system it is usually expressed as kg/m^3. This is determined by weighing a sample of wood on a scale, and then submerging the sample in a beaker of distilled water that has been tared on a scale to get the volume from the weight of displaced water (water has a density of 1 g/cm^3), the mass is then divided by the volume of water displaced to give the specific gravity, that is the relative density of the sample to the density of water (Hoadley 1990).This property is dependent on both moisture content, and chemical composition (presence of extractives) (Desche and Dinwoodie 1996). Density of

wood varies from species to species and from heartwood to sapwood in trees, and therefore if weight is used to determine volume, density must also be considered (Rosillo-calle 2007). The physical state of wood can be logs, split firewood, wood chips, pellets, sawdust etc. which all have different weights/volume when stacked or piled together (Rosillo-calle 2007). Therefore, the actual density of wood as well as the state at which it is collected for transport is important in the utilization of woody biomass, as transportation costs are one of the biggest bottlenecks to the biomass industry. Because density has a high influence on energy content, one way of improving the energy content of biomass is through different densification processes. A promising technology for increasing the density of wood is torrefaction, which heats wood between 200-300°C in an inert atmosphere releasing volatile compounds and increasing carbon content (Niu et al. 2019). This process also lowers moisture content, improves water repelling properties, and increases the grindability of biomass.

2.1.1.6. Moisture Content

Perhaps the most influential property of wood as it relates to heating value is moisture content. When wood is burned some of the energy is lost as the heat transforms water into steam, therefore the higher the moisture content (MC) the less energy produced from the biomass (Rosillo-Calle 2007). This difference can be as much as a 15% loss of heating value between air-dry and oven-dry wood (Tsoumis 1991). MC can either be measured on a wet or dry basis, for example a 100 tonnes of woody biomass at 15% MC would have 15 tonnes of water (Pandey et al. 2011). Moisture content on an oven-dry basis is

calculated from the formula: : $MC\% = (\frac{Wet\ Weight\ of\ wood - Dry\ Weight\ of\ wood}{Dry\ Weight\ of\ wood}) x 100$

and is determined by first weighing a sample of wood in the "green" condition or

at another level of dryness, and then drying the wood in an oven before cooling

the sample and weighing again to get the "dry weight" (Desche and Dinwoodie

1996). Other methods of determining moisture content include the distillation

method and electric moisture meters. In the distillation method water and

extractives are removed from the sample in a special lab apparatus and

weighed separately, then taken as a percentage of the initial weight of the wood

sample (Desche and Dinwoodie 1981). This method is useful for woods with

high resin / extractive contents, giving a more accurate measure of the

percentage of moisture without the influence of extractives. Electric moisture

meters determine moisture content by measuring an electrical property of wood

that is affected by moisture (Desche and Dinwoodie 1981).

2.1.1.7. Heating Value

Heating value is either expressed as gross calorific value or high heating

value (HHV), that is the heating value of biomass without moisture, or as net

calorific value / low heating value, the heating value of biomass and included

moisture (Pandey et al. 2011). Heating value is affected by density, moisture

content, extractives, chemical composition of wood, and varies between species

and regions (Tsoumis 1991; Rosillo-calle 2007). Hardwoods are generally

denser than softwoods and have a higher calorific value (Desche and Dinwoodie

1981) however extractive content can influence the heating value of wood, and

softwoods with high resin content can burn hotter than hardwoods (Tsoumis

1991). The heating value of wood also varies by region and climatic conditions, the heating values of tree species and their components in Northwestern Ontario where this study was conducted were explored by Hosegood (2010) and are shown in Table 1.0.

Table 1.0. Average Heating Value of Northwestern Ontario Tree Species.

| Species | Tree Components | | | | | |
| | Lower | Lower | Upper | Upper | | |
Thunder Bay Site	Bole	Bark	Bole	Bark	Branch	Foliage
Ab	19.21	18.35	19.41	18.85	19.64	19.36
Bf	19.88	21.13	19.97	21.74	20.47	22.57
Bw	19.78	24.54	19.77	24.64	20.69	21.10
Pj	19.56	21.58	19.73	21.01	20.27	22.45
Po	19.68	22.25	19.59	21.57	21.03	21.68
Sb	19.18	20.58	19.26	20.24	21.41	21.35
Ta	19.98	21.10	19.97	21.41	20.15	21.47
Atikokan Site						
Ab	18.99	18.07	19.17	18.27	19.12	19.13
Bf	19.90	21.52	20.24	20.83	21.04	23.06
Bw	19.67	26.80	20.12	24.37	21.28	20.97
Pj	20.25	21.78	20.03	20.30	20.57	22.19
Po	19.44	22.63	19.90	22.52	21.20	21.40
Sb	19.56	19.88	19.51	19.59	20.55	20.74
Ta	19.44	20.94	19.71	20.73	20.12	21.13

Source: Hosegood (2010).

2.1.1.8. Ash Content

Ash is the leftover material after combustion, therefore the higher the ash content, the lower the energy value of biomass (Rosillo-calle 2007). Ash poses another issue, the leftover organic compounds that do not fully combust cause corrosion, slagging, and fouling of the components of biomass systems leading to increased maintenance costs and a decreased life span (Monti et al. 2008).

Wood ash is questionably viewed as a waste product and in many cases ends up in a landfill. However, ash produced from contaminant-free woody biomass has been suggested as a liming agent and source of nutrients for plants (e.g., calcium magnesium, potassium, and phosphorous) and could therefore be used as a soil amendment to return nutrients to the soil and raise pH levels, emulating the effects of wildfire (Hannam et al. 2016).

2.1.1.9. Stock and Yield

Stock, the total weight of dry biomass, and yield, the increase in biomass over a certain time period and area including removed biomass, are important factors to consider when estimating availability of biomass (Rosillo-Calle 2007). For biomass to be considered a renewable source of energy, the annual increment cannot be exceeded by the amount of biomass harvested (Rosillo-Calle 2007). Yield is expressed as current annual increment (CAI), the total yearly production of biomass for an area, or as mean annual increment (MAI), the total production of biomass of an area divided by the time taken to grow (Rosillo-Calle 2007)

2.1.2. <u>Heat and Energy</u>

      With modern technology biomass can be converted into heat, electricity, and liquid or gaseous biofuels, these processes are summarized in Table 2.0. Technologies available for biomass are direct combustion, co-firing, gasification, pyrolysis, Combined Heat and Power (CHP), etherification / pressing, fermentation / hydrolysis, and anaerobic digestion, all of which except etherification and anaerobic digestion, generally utilize woody biomass (Rosillo-Calle 2007).

    2.1.2.1. <u>Direct combustion</u>

      Direct combustion is the most basic and most utilized technology for processing woody biomass. It is any system which burns wood directly for heat and can be paired with a steam turbine that, as generated heat boils water into steam, the force of steam turns the turbine creating electricity. While direct combustion is the most basic and most commercialized process, the efficiency can be much lower than other systems especially if the focus is on electricity generation rather than heat (Rosillo-calle 2007). Nevertheless, direct combustion makes up 90% of all energy produced from biomass, and it is a low-cost, reliable, and well understood technology (Pandey et al. 2011). During combustion of wood the chemical components of wood are broken down and flammable gas is released (Tsoumis 1991).

Table 2.0. Summary of the main characteristics of biomass technology

Conversion Technology	Biomass Type	Example of fuel used	Main Product
Combustion	Dry Biomass	Wood logs, chips, pellets, other solid biomass	Heat
Co-firing	Dry Biomass (woody and herbaceous)	Agro-forestry residues (straw, waste)	Heat / electricity
Gasification	Dry Biomass	Wood chips, pellets and solid wastes	Syngas
Pyrolysis	Dry Biomass	Wood chips, pellets and solid wastes	Pyrolysis oil and by-products
CHP	Dry Biomass, Biogas	Straw, forest residues, wastes, biogas	Heat and electricity
Etherification / Pressing	Olaeginous crops	Oilseed rape	Biodiesel
Fermentation / Hydrolysis	Sugar and starches, cellulosic material	Sugarcane, corn, woody biomass	Ethanol
Anaerobic Digestion	Wet biomass	Manure, sludge, vegetable waste	Biogas and by-products

Table 2.0. (Continued)

End-use	Technology Status	Remarks
Heat and Electricity (steam turbine)	Commercial	Efficiencies vary e.g. >15-40% electrical; >80% thermal
Electricity and Heat (steam turbines)	Commercial (direct combustion), demonstration stage (advanced gasification and pyrolysis)	Large potential for use of various types of biomass; reduced pollution, lower investment costs, Some technical, supply and quality problems
Heat (boiler), electricity (engine, gas turbine, fuel cell, combined cycles), transport fuels (methanol, hydrogen)	Demonstration to early commercial stage	Advanced gasification technologies offer very good opportunities for using a range of biomass sources for different end-uses
Heat (boiler), electricity (engine)	Demonstration to early commercial stage	Issues remain with the quality of pyrolysis oil and suitable end uses
Combine use of heat and electric power (combustion and gasification processes)	Commercial (medium to large scale) Commercial demonstration (small scale)	Political priority in UK, high efficiency, e.g. c.90%; potential for fuel cell applications (small plants)
Heat (boiler), electricity (engine), transport fuel	Commercial	High costs
Liquid fuels (e.g. transport) and chemical feedstock	Commercial. Under development for cellulosic biomass	Cellulosic 5-10 years for commercialization
Heat (boiler), electricity (engine, gas turbine, fuel cells)	Commercial, except fuel cells	Localized use

Source: Rosillo-Calle (2007)

The steps involved during combustion of wood according to Tsoumis (1991) are:

a. Evaporation of moisture (up to 100°C)
b. Evaporation of volatile substances (95-150°C and higher)
c. Superficial carbonization and slow exit of flammable gas (150-200°C)
d. Faster exit of flammable gases, followed by ignition and glow (200-370°C)
e. Fast ignition of flammable gases and formation of glowing charcoal (370-500°C)

Direct combustion reactors can be categorized as fixed-bed combustion systems or fluidized-bed systems (Pandey et al. 2011). Two main types of fixed-bed systems exist, underfeed stokers and grate firings, both systems involve air being supplied mostly from underneath through the grate and combustion of solid fuel occurs on top of the grate with some gasification that /can be combusted in a secondary chamber (Pandey et al. 2011). Fixed-bed systems utilize biomass with low ash content and are generally used in small scale applications (Pandey et al. 2011). Underfeed stokers have a mechanism that feeds biomass from below, pushing them onto the grate where combustion occurs (Pandey et al. 2011). These systems require biomass with low ash content as ash can build up and block the flow of air into the combustion chamber (Pandey et al. 2011).

2.1.2.2. <u>Co-firing</u>

Co-firing involves the substitution of a certain percentage of coal with biomass (between 2 and 25 percent but possibly more) in conventional coal-fueled boilers, reducing carbon emissions and possibly costs (Rosillo-Calle 2007). The main advantages of co-firing are; an established market, a smaller investment required to modify existing coal plants to use biomass, lower environmental impact, lower feedstock costs if sourced locally, potentially large

amounts of biomass feedstock available, and higher efficiency (between 33-37

percent for electricity conversion (Rosillo-calle 2007).

2.1.2.3. Gasification

Gasification is not by any means a new technology and has been used

for almost two centuries, as it was used in the mid 1800's to produce gas to

power city lights in London which they called "town gas" (Rosillo-calle 2007) and

as a secondary source of fuel during World War II when resources were being

prioritized to the war effort (Lafontaine and Zimmerman 1989). The process

involves solid fuels such as woody biomass being converted into a gaseous fuel

called syngas or "producer gas" through an endothermal reaction that slowly

combusts wood at atmospheric conditions with a small amount of oxygen

separating volatiles and moisture from carbonic materials (Rosillo-calle 2007;

Lafontaine and Zimmerman 1989). The process is more efficient in producing

electricity compared to direct combustion (40 percent or more compared to 26-

30 percent for direct combustion) (Rosillo-calle 2007). Wood gas could

potentially be used as a replacement of fuels such as gasoline, natural gas, and

diesel in internal combustion engines (Lafontaine and Zimmerman 1989) or for

more advanced uses such as gas turbines and fuel cells (Rosillo-calle 2007;

Kozlov et al. 2019). While gasification is not at a full commercial level now

(Rosillo-calle 2007) it can be easily applied on a small scale as gasification units

can be made with widely available materials with some general knowledge of

fabrication (Lafontaine and Zimmerman 1989). Kozlov et al. (2019) provided an

overview of modern wood biomass gasification technologies, pointing to multi-

stage gasification as the most economically efficient and most promising technology available. This process involves a separation of the initial fuel pyrolysis stage and charcoal gasification stage to reduce tar content in syngas which is one of the biggest technological issues that gasification faces (Lafontaine and Zimmerman 1989). Besides producing syngas, gasification also results in by-products of biochar and pyro-oil (also known as bio-oil) which have their own uses for energy production, chemicals, and other applications. There are about 160 projects in OECD countries using biomass gasification technology, which mostly use a layer or fluidized bed reactor (Pandey et al. 2011).

2.1.2.4. Pyrolysis

Pyrolysis is another promising technology available to process woody biomass into fuels, either liquid or solid (Rosillo-calle 2007; Pandey et al. 2011). There is little to no oxygen present during thermochemical reaction of the woody biomass resulting in products such as syngas, bio-oil, and bio char (Pandey et al. 2011). While gasification is a form of pyrolysis, it introduces a higher amount of air to the reaction resulting in higher yields of syngas and bio-oil rather than char. These products are useful to replace liquid petroleum fuels, or pyrolysis oil can be refined into biochemicals (which will be further discussed in the next section) (Pandey et al. 2011). Biochar has seen a recent surge in research and development as a soil amendment, along with other uses such as a carbon neutral coal replacement (bio-coal), as a de-odorizer, water filtration medium, and in beauty products, to name a few (IBI 2018). Biochar has the potential to

store large amounts of carbon in the soil for hundreds, if not thousands of years, while also improving soil fertility and inherently food security (IBI 2018). It is worth mentioning here the process of torrefaction is the slow pyrolysis of woody biomass at temperatures between 200-300 degrees Celsius, to create a more energy dense product when combined with densification (Niu et al. 2019). Torrefied wood has an increased heating value and is more easily grindable, making it possible to densify the product into wood pellets or briquettes which have better hygroscopic properties, higher energy densities, and more resistance to decay from biological properties than the parent biomass (Niu et al. 2019).

2.1.2.5. Combined heat and power (CHP)

Combined heat and power is a process that generates heat and electricity at the same time, and is also referred to as co-generation (Pandey et al. 2011; Rosillo-calle 2007). CHP systems capture the exhaust heat released from combustion using a heat exchanger that then converts the heat energy into electricity by turning an electric generator (Rosillo-calle 2007; Pandey et al. 2011). Cogeneration is an attractive technology as it is more efficient than direct combustion generators and reduces carbon emissions (Rosillo-calle 2007). This technology is especially attractive to wood processing industries as they can produce electricity and heat to supply their needs while also selling heat and electricity back to the grid (NRCAN 2019).

2.1.3. <u>Biorefinery / Biochemicals</u>

        The chemicals industry today largely relies on petroleum-based products

that have been shown to be unsustainable and problematic in terms of

environmental and economic concerns (Pandey et al. 2011). Through recent

research and technology, there is growing interest in the wide range of

biochemicals that can be refined from the chemical components of wood that

are cellulose, hemicellulose, and particularly of interest, lignin. While there are

numerous renewable energy technologies for electricity production, biomass is

now perceived as possibly the only renewable source for transportation fuels

and chemicals (Pandey et al. 2011). Ethanol and biodiesel converted from

cellulose has shown some potential for the replacement of fossil fuels, however

it has also raised concerns about the allocation of land, water usage, and

pressure added to food security (Rosillo-Calle 2007; Gerbens-Leenesa et al.

2009). The use of non-food crops and woody biomass for production of biofuels

and chemicals might reduce the strain on food supplies and increased prices,

however, lignocellulosic biomass presents its own set of challenges and issues.

The chemical components of wood make it a strong and light material, however

it is also what makes it difficult to break down, separate, and extract chemicals

from woody biomass (Pandey et al. 2011). For most of the technologies

available for biomass conversion into biofuels and chemicals, a pretreatment

process is required beforehand to separate the lignin, cellulose, and

hemicellulose so that they can then be further refined into chemicals such as

benzene, toluene, xylene (BTX), ethylene, propylene, butane, and other bulk

chemicals (Pandey et al. 2011). The range of chemicals that can be derived

from wood are shown in Table 3.0.

Table 3.0. Chemicals Derived from Forest-based Feedstocks.

Raw Material	Process	Platform Chemicals	Biochemical	Potential Uses
Wood	Hydrolysis	Ethanol	Ethylene	Precursor to many industrial chemicals
Waste cellulose Waste paper	Hydrogenation	Levulinic acid	MTHF	Fuel additive
			DALA	Pesticide
			Tetrahydrofuran	Solvent
			Alpha-angelicalactone	Fuel extender
			1,4 butanediol	Polymer intermediate
			succinic acid	Specialty chemical
			Alpha-methyltetra-hydrofuran	Solvent, chemical intermediate, fuel additive
			Ethyl levulinate	Diesel fuel
			Sodium levulinate	Antifreeze
Levulinic acid	Hydrogenation	Valeric g-lactone	1,4 pentandiol	Solvent
	Dehydration	1,4 pentandiol	1,3-pentadine (piperylene)	Synthetic rubber
	Condensation	Levulinic acid + phenol	Diphenolic acid	Resins
Cellulose (glucose)	Fermentation	Lactic acid	PLA	Bioplastic
			Lactate esters	Specialty chemicals
			Ethyl lactate	Solvent, Degradable plastic polymers
Cellulose from wood waste (glucose)	Fermentation	Succinic acid	PVP	Pharmaceutical toiletries, paper, beverages, detergents
			Itaconic acid	Polymeric fibre blends

Source: Wetzel et al. (2006)

A pretreatment is required to separate the cellulose, hemicellulose, and lignin components, these include mechanical, thermal, chemical, biological, or a combination of these methods (Pandey et al. 2011). Once pretreated the biomass can then be converted to liquid or gaseous form through processes such as gasification, pyrolysis, hydrolysis, hydrogenation, fermentation, etc. (Pandey et al. 2011; Rosillo-Calle 2007). The pretreatment and conversion processes are one of the bottlenecks to producing biofuels or chemicals at a cost that could compete with the highly developed petroleum industry. Nevertheless, research and development is now going into the conversion of lignocellulosic biomass into biofuels and chemicals, and with time and continued development this will likely lead to the replacement of petroleum based products as the world slowly transitions away from fossil fuels (Pandey et al. 2011; Wetzel et al. 2006)

2.2. SALVAGE LOGGING

Natural disturbances and tree mortality are a natural part of the boreal forest ecosystem, requiring forest managers to plan and adapt to these factors (Mansuy et al. 2015; Barrette et al. 2017). A management strategy that has become increasingly popular in recent years is salvage logging, which is the harvesting of dead trees from areas that have been disturbed, either by fire, insect, or windstorm (Purdon et al. 2002; Thorn et al. 2018; Barrette et al. 2017). Salvage logging utilizes similar equipment to that used for roundwood harvesting, while other feedstocks such as harvesting residues are collected using a grapple on a forwarder or slash bundler (Barrette et al. 2017). Dead

trees generally have different properties than live, mainly lower moisture content and more decay or rot making them unappreciated for conventional uses such as lumber and pulp (Mansuy et al. 2015; Barrette et al. 2017). This leads to other possibilities for utilizing vast volumes of dead trees from disturbances in the bioenergy sector, either in the form of wood pellets (Mansuy et al. 2015; Dymond et al. 2010) or in the emerging biofuel market (Barrette et al. 2017). While biomass feedstocks are primarily from industrial residues or harvesting residues, these supply chains can be disrupted with a downturn in the market (Mansuy et al. 2015; Barrette et al. 2017). Many have suggested that diversification of feedstock options is an important factor in growing Canada's bioenergy sector (Wetzel et al. 2006; Leduc et al. 2015; NRCAN 2019). However, there are challenges related to salvage logging for biomass, mainly cost of supply, ecological concerns, and policies.

2.2.2. <u>Salvaged Wood Properties</u>

The properties of salvaged wood vary from type, time since, and intensity of disturbance (Thorn et al. 2018; Barrette et al. 2017; Meincken et al. 2010) and with stand level factors such as tree species and age class (Barrette et al. 2017). Structure of salvageable volume also depends on type of disturbance, for example a windstorm may create uprooted trees, a forest fire may create standing dead stems, and an insect outbreak may leave dead or partially dead trees (Thorn et al. 2018). Dead trees have been found to be dryer and susceptible to varying amounts of decay, which has deterred their use in the major industries of pulp, paper, and lumber (Barrette et al. 2017; Mansuy et al.

2015). The dryness of dead wood makes it attractive as a biomass feedstock, as this reduces the cost of drying (Barrette et al. 2017), and the loss of energy during combustion to evaporate moisture is much lower (Rosillo-calle 2007). Furthermore, decay has adverse effects on using wood for pulping and lumber, however Barrette et al. (2017) found that degradation caused by certain fungi, specifically brown-rot fungus, can increase the portion of lignin in wood, which serves as a natural binding agent and could save costs related to pelletizing.

Wood salvaged from forest fires exhibits different physical and chemical properties depending on the temperature of burn as well as the duration (Meincken et al. 2010; Watson and Potter 2004). Immediately after fire, there is minimal effects on wood properties other than charring and some chemical changes in the outer layers of the wood (Watson and Potter 2004). This is due to the fact that wood has a low thermal conductivity and insulating properties especially in live stems containing moisture, which protects the inner stem of wood from fire damage (Watson and Potter 2004). It is generally understood that salvage of fire-damaged wood should be done within the first year after fire, as wood begins to dry to the fiber saturation point after this point, causing checking, which produces entrances for biological agents such as fungi causing further decay of the wood (Watson and Potter 2004). Smaller diameter trees should be harvested first as they degrade quicker than large diameter stems (Watson and Potter 2004)

Meincken et al. (2010) studied the affects of different levels of burn after a forest fire on mechanical and physical properties in samples of Patula Pine

Pinus Patula. Specifically, they found that burnt wood may require a different drying schedule than green or slightly burnt wood, which they attributed to chemical and structural modifications in the wood cell such as plastification and densification that happen at elevated temperatures. Meincken et al. (2010) also observed thickening in the cell wall accompanied by a decrease in lumen diameter (Figure 2.0.) while another finding from the study was the darkening of boards caused by the migration of extractives and other degradation products to the surface during heating. A lowered MOR and higher MOE as a result of chemical changes were also observed by Meincken et al. (2010).
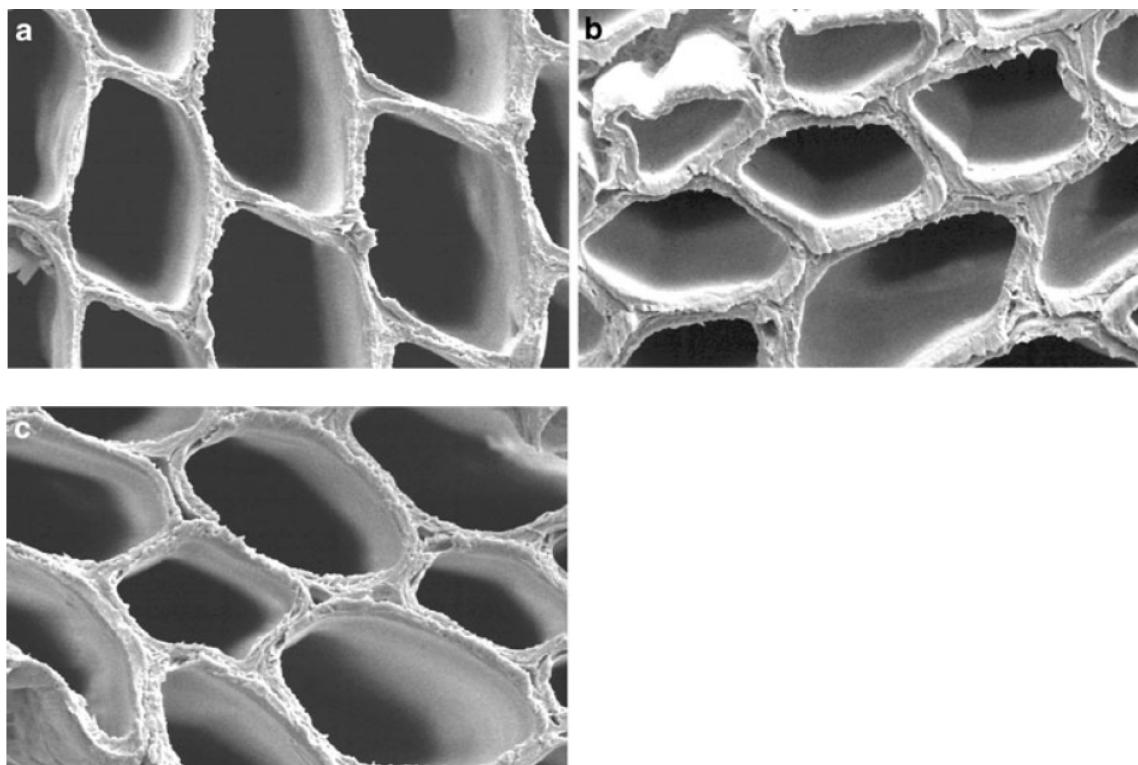

Figure 2.0. SEM Images of (a) green wood (b) slightly burnt wood and (c) burnt wood (Meincken et al. 2010).

Araki (2002) found a higher recovery of chips from burned aspen logs as the trees aged, which they attributed to the deterioration of the bond between the bark and stem that allowed debarking without damaging wood fiber. Watson and Potter (2004) also observed a demarcation between the outer and inner layers of burnt wood. For wood to be used in the pulp industry it must contain as little charcoal as possible, therefore aggressive debarking is required to remove the charred outer layer of burnt stems (Watson and Potter 2004; Araki 2002). It was also observed that after long periods left after fire, moisture content of chips from small diameter conifers was too low to use for pulping, while large diameter conifers were also too dry and produced over-thick and over-sized chips (Araki 2002). Small diameter aspen had acceptable moisture contents for pulping and chip size, and large diameter aspen had acceptable moisture content for pulping but produced unacceptable levels of over-sized chips (Araki 2002).

2.2.3. Legislation and Costs

Salvaging logging of disturbed stands has become an increasingly popular management strategy to recover lost value of damaged timber, and to reduce spread of disturbance causing insects (Barrette et al. 2017; Thorn et al. 2018). Fires cause a sudden loss of available volume for harvest when they occur within a management unit, requiring managers to respond with strategic solutions (Leduc et al. 2015; Mansuy et al. 2015; Purdon et al. 2002). This has led to some concern from the public and other stakeholders who are required to be included in management plan objectives (Purdon et al. 2002). However, current management strategies are based on the emulation of natural

disturbances (in the boreal forest this is mainly fire), which includes the retention

of downed woody debris and standing dead timber, therefore salvage logging

has been generally discouraged to promote these elements of forest structure in

manuals such as *Forest Management Guide for Natural Disturbance Pattern*

Emulation (OMNR 2001). More recent guides such as the *Stand and Site Guide*

(OMNR 2010) outline the guidelines and best management practices to follow

during salvage logging operations to reduce negative effects.

2.2.4 Ecological Impacts of Salvage Logging

     Many studies have been done to quantify the effects of salvage logging

on species biodiversity, stand regeneration, and soil health (Purdon et. al. 2002;

Lamers et al. 2013; Thorn et al. 2018). A specific concern when considering the

use of salvage logging on disturbed stands is the influence of habitat

fragmentation of otherwise untouched forest patches by roads and logging

activities changing predator prey relationships and threatening survival of

endangered species (Lamers et al. 2013). This fragmentation can also occur on

areas where regular harvesting is not allowed such as in protected areas and

parks (Thorn et al. 2018). Salvage logging can also alter the amount of habitat

for wood-boring beetles such as the white-spotted sawyer *Monochamus*

scutellatus, which lay their eggs in the moist inner wood layer of standing dead

trees (Purdon et al. 2002; Thorn et al. 2018). Type of disturbance influences

potential soil impacts, for example windthrow salvaged wood may have foliage

but fire salvaged wood may not, leading to different effects on nutrient

availability in soil after harvest of biomass (Lamers et al. 2013). Thorn et al.

(2018) recommended an inclusion of green tree retention such as that done during regular harvests to reduce the negative environmental effects of salvage logging. Lamers et al. (2013) suggest that sites with only a low number of killed trees should not be salvaged, because of the carbon storage and potential products from trees which have survived a disturbance.

MATERIALS AND METHODS

3.1. TREE SPECIES SAMPLED

3.1.1. Jack Pine *Pinus banksiana*

Jack pine is a fast-growing, shade-intolerant conifer species commonly found in the Boreal forest and Great Lakes Region. The size and form can range from short and bushy on dry sites to tall straight trees with short conical crowns on good sites (Barnes and Wagner 2004). The wood is light, moderately hard, close-grained, light brown, with a wide layer of whitish sapwood (Barnes and Wagner 2004). The maximum heating value of pine wood is between 4780-6790 kcal/kg and between 5040-5980 kcal/kg for Bark (Tsoumis 1991). The high resin content of pine gives it a higher heating value compared to other softwood species and some hardwoods (Tsoumis 1991). Jack pine is a fire adapted species as it has serotinous cones that may persist on branches for 10-20 years until opened by heat, such as that released during a forest fire. Jack pine was selected for this study because of it's abundance in the region, and because it is one of the major fuel types susceptible to forest fires. It is also one of the major tree species regularly harvested in the DRMF. Another attractive property of jack

pine is it's serotinous cones, which could have potentially high heating values due to their high resin and extractive contents.

3.1.2. Trembling Aspen *Populus tremuloides*

Trembling aspen is a medium to large-sized deciduous tree between 16-32 meters tall with a diameter of 30-60 cm (Barnes and Wagner 2004). It typically forms multi-stemmed clones that originate from suckering of killed parent trees by fire, harvest, or browse. The wood is light, soft, weak, close-grained, light brown with thin whitish sapwood, and it's main use is for pulpwood (Barnes and Wagner 2004). Trembling aspen is the most widely distributed native North American tree species and is abundant throughout the Boreal and Great Lakes region (Barnes and Wagner 2004). It is a fast-growing, and very shade-intolerant species, and its individual stems are short lived (Barnes and Wagner 2004). The maximum heating value of poplar wood is between 4120-5350 kcal/kg and for bark 4240-4670 kcal/kg (Tsoumis 1991). Trembling aspen was selected for this study because of the abundance in the region, it's fast growth rates, and it's adaptation to fires through root suckering.

3.1.3. Black Spruce *Picea mariana*

Black spruce is a wide-spread species found across Canada and Ontario. It is a slow-growing, shade-tolerant tree that ranges in size from 5-15 meters tall, reaching heights of up to 30 meters with a dbh of 60 cm on upland sites with rich soils. (Barnes and Wagner 2004). The wood is light and soft, with a yellowish white heartwood and pure white sapwood (USDA 2010). It is used mainly for pulpwood, poles, and for lumber. It is also a fire-adapted species with semi-

serotinous cones that open during fire, seeds are not destroyed by fire and germinate readily on seedbeds prepared by fire (Barnes and Wagner 2004). Frequently found in bogs and swamps with slow movement of water and low oxygen availability (Barnes and Wagner 2004).

3.2. AREA DESCRIPTION

The samples were collected in the Dog River-Matawin Forest management unit (DRMF) north-west of Thunder Bay in Northwestern Ontario. It is located between 48°:16' and 49°:28' latitude North and 89°:30' and 91°:50' longitude West. Figure 3.0. shows the location of the DRMF management unit.
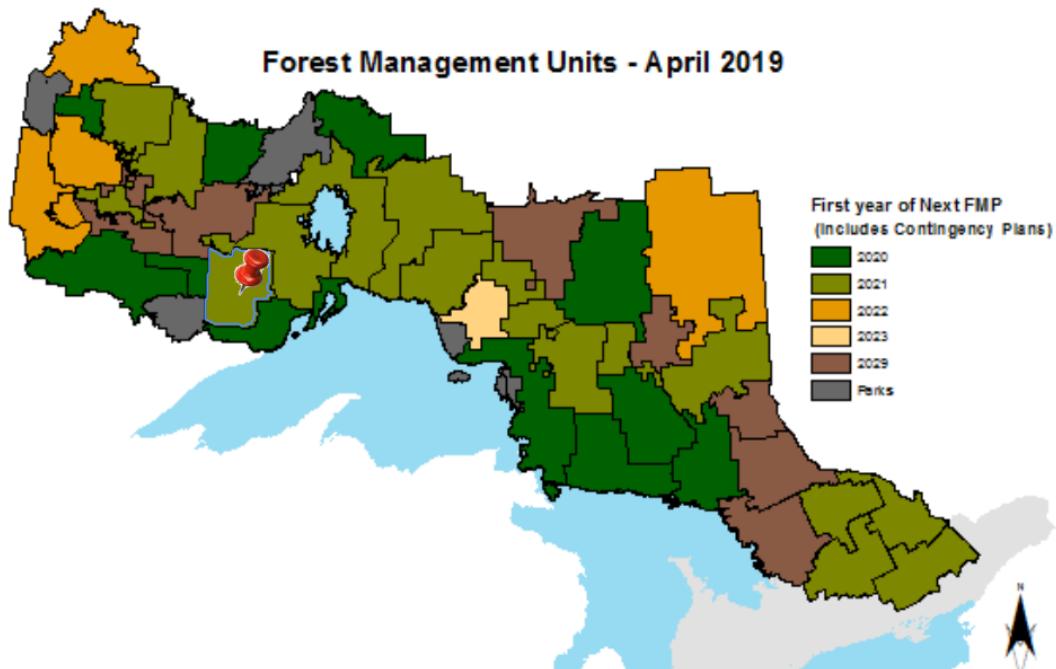
Figure 3.0. Location of Dog River- Matawin Forest Management Unit (MNRF, 2019).

The area has several different ecosites, with Hardwood-Fir-Spruce Mixedwoods and Fir-Spruce Mixedwoods being the main forest types. Other

ecosites include Spruce-Pine / Feathermoss, Spruce-Pine, Jack-Pine Conifer, and Pine-Spruce Mixedwood.

3.3. FIRE DESCRIPTION

The fire where samples were collected was identified with help from the Thunder Bay Fire Management Headquarters. The fire was selected due to its proximity to Thunder Bay and representative size. It occurred in 2016 in the Eastern corner of the DRMF, around 40 km up the Dog River rd. and was named THU 019. The location of the fire is at the coordinates 49°11'29.1"N 89°55'01.5"W.
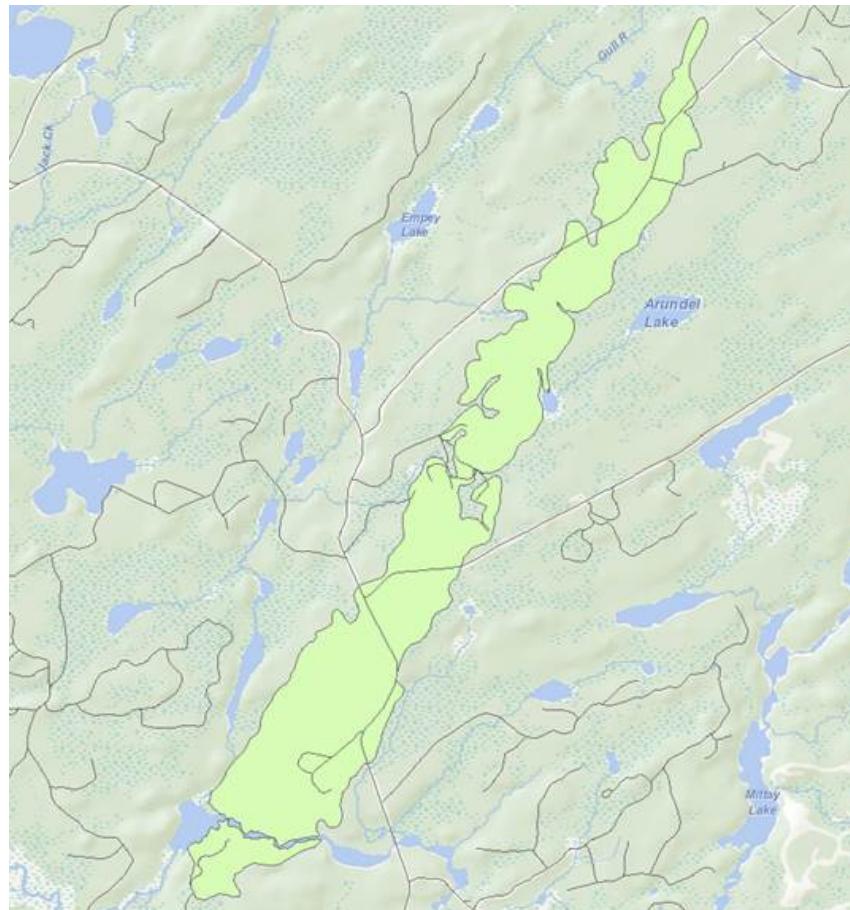
Figure 4.0. Location and area of 2016 Thunder Bay Fire 019. (Towell 2019).

3.4. SAMPLE COLLECTION

Samples were collected by cutting discs from jack pine, black spruce, and trembling aspen for determination of moisture content and calorific value. Sample trees were selected from downed trees that had mostly straight stems with little defect and varying levels of burn damage. Any defects or other factors that could affect the properties of wood were recorded. Discs with a width of 2 inches were cut using a chainsaw at intervals of 2 meters along the stems starting at 2 meters from the base of the tree. The discs were labeled with numbers using a permanent marker to identify the species and position on the stem where the sample was taken. The side of the tree that was more severely burnt (direction of the fire) was also labelled. Cones from jack pine were also collected from burnt and unburnt trees to test calorific value. Samples of twigs and branches were also collected for calorific testing. The discs and other samples were then brought back to the Lakehead University Wood Science and Testing Facility (LUWSTF) for sample preparation and testing.

3.5. SAMPLE PREPARATION

First, the bark and any charcoal was removed using a screw driver and other hand tools. The bark was placed in plastic containers and labelled with tree species and the letter "d" (i.e. Pj1d). The bark samples were placed in an oven at 103°C for 48 hours and weighed periodically to ensure a moisture content of 0% had been reached. Samples of completely charred wood were also collected from the disc by scraping away the charred outer layers of discs. These were then ground by hand using a mortar and pestle, as the charred

material was unsuitable to be used in the Wiley mill. Charred samples were labelled with the species ID and the letter "a" (i.e. Pj1a). Once the bark and charcoal was removed from the discs, a bandsaw was used to remove small enough pieces to be ground into shavings using a Wiley mill, these samples were labelled with species ID and the letter "b" for slightly burnt wood or "c" for unburnt. The shavings were placed in labelled containers and put into the drying oven at 103°C for 48 hours. Once all samples were dried in the oven, they were run through a Wiley mill to grind samples into small enough fragments to be used in the oxygen bomb calorimeter. Before samples were ran through the Wiley mill, it was first cleaned using compressed air and a shop vacuum to reduce cross contamination, this was also conducted between each sample ground in the mill. The samples were collected then placed in airtight containers and labelled to await calorific testing. Some sample IDs with descriptions are shown in Table 4.0. for clarification.

Table 4.0. Description of samples

Sample ID	Description	Sample ID	Description
Po1a	Charred wood	PoBrU	Branch wood unburnt
Po1b	Slightly burnt wood	PoBrB	Branch wood burnt
Po1c	Unburnt wood	PjCoU	Cones unburnt
Po1d	Bark	PjCoB	Cones burnt
PoKW	Knotwood		

Source: (Towell 2019).

Samples were prepared for determination of density and moisture content prior to drying the samples. A block from each disc of approximately 2.5 x 2.5 cm was cut from the juvenile wood (near the pith of the tree) of each disc as well as from the mature wood (outer portion of the stem) using a bandsaw. Each individual block was labelled using a permanent marker to identify species, juvenile/ mature, and from which disc it was sampled. Representative cones were also selected to determine moisture content / density.

3.6. DENSITY / SPECIFIC GRAVITY

The juvenile and mature wood samples were tested following ASTM standard D2395-07 to determine specific gravity. The green weight of each block was measured using a weight scale to 0.0001 mg accuracy. The volume of each sample was determined using the water-displacement method. First a glass beaker was placed on a weight scale with enough distilled water inside it so that the blocks could be submerged fully without spilling any water. The scale was reset to zero to account for the weight of both the water and glass beaker. The blocks were stuck with a long needle pointed instrument and then submerged in the glass beaker filled with water. The weight of the displaced water was measured by the weight scale to an accuracy of 0.01 mg, giving the volume of the sample because water has a density of 1 (1 g per cm^3). The blocks were then removed from the water and the scale was reset to zero again to account for any water soaked up from the wood. This process was repeated until all the green weights and volumes of samples were measured. The samples were then placed in an oven at around 103°C for 48 hours to reach an

assumed moisture content of 0%. The samples were then brought to room temperature before being weighed again as the heat released from a hot sample can heat the air above it, making the air lighter and affecting the weight given by the balance. The weights and volumes of the oven-dry samples were then measured using the same methods as explained above. From the weight in grams of the initial "green" mass of the sample and of the oven-dry sample, the moisture content was then determined on an oven-dry basis using the formula:

$$MC \% = \frac{Wet\ Weight - Dry\ Weight}{Dry\ Weight}\ x\ 100.$$

The oven-dry weight and weight of displaced water were used to determine the specific gravity based on the formula:

$$Specific\ Gravity = \frac{OD\ weight}{Weight\ of\ displaced\ volume\ of\ water}$$

Moisture content and specific gravity were recorded for each sample of juvenile and mature wood for each species and location obtained from on the stem.

3.7. CALORIFIC HEATING VALUE

Calorific values were determined using a Parr 6200 Oxygen bomb Calorimeter and Parr 6510 water handling system according to the Parr Operating Instruction Manual, following ASTM D5468. The shavings collected from the procedure explained in section 3.5. were used to test calorific content of fire-killed trees. An empty plastic container was placed on a weight scale and the scale was reset to zero so that the scale would automatically subtract the weight of the container. The samples in their plastic containers were then

weighed. For testing, the weight of the samples had to be close to 1 gram, which

was achieved by removing shavings from the container. The exact weight in

grams and milligrams was then measured before testing in the bomb

calorimeter. Each sample was placed in the "bomb", a metal vessel built to

withstand high pressures, a fuse wire was installed in the bomb and then sealed.

The bomb was then filled with pure Oxygen to 450 psi to ensure complete

combustion of the material. The bomb was then placed into a bucket filled with

2000 ml of distilled water that was 3-5°C below the jacket temperature of 30°C.

These temperatures were regulated by the Parr 6510 water handling system.

The submerged bomb in the bucket was then placed in the calorimeter and the

fuse wires connected. The lid was closed, and the calorimeter was then run

which combusted the contents of the bomb, increasing the temperature of the

water it is submerged in. The calorimeter detects and records the temperature

change until final equilibrium of the water was recorded. The calorimeter then

takes a final reading of temperature and calculates the gross heat of combustion

using the following equation:

$$H_c = \frac{(W \; x \; T) - e_1 - e_2 - \; e_3}{m}$$

Where,

H_c = Gross heat of combustion (MJ/kg)

T = Observed temperature rise (°C)

W = Energy equivalent of the calorimeter and bomb bucket combination being

used (MJ/°C).

e_1 = Heat produced by the burning the nitrogen portion of the air trapped in the

bomb to form nitric (MJ).

e_2 = Heat produced by the formation of sulphuric acid from the reaction of Sulphur dioxide, water and oxygen (MJ).

e_3 = Heat produced by the fuse wire and cotton thread (MJ).

m = The mass of the sample (kg).

3.8. STATISTICAL ANALYSIS

A one-way ANOVA was done on the oxygen bomb calorimeter data to look for a significant variance in one or more of the values. The values were grouped by species and tested with the ANOVA to test the null hypothesis that tree species affects heating values of fire-salvaged wood. Another ANOVA was done by grouping the data by component (burnt, unburnt, cones, etc.) to test the null hypothesis that level of burn in fire-salvaged wood does not significantly affect calorific value. The data for moisture content was not extensive enough to justify any testing using an ANOVA. If results of the ANOVA indicated a significant result and the null hypothesis was rejected, a Fisher's least significant difference test was used to identify where the statistically different means were.

4.0. RESULTS

This section will present the results of all data collected. This includes values for moisture content, specific gravity, and calorific values of samples. Tables and figures will show which species or tree component had the highest and lowest for each of these values / properties and the general variation and distribution of the data. ANOVA results will also be shown for the data that constituted this type of statistical analysis. Original data can be found in Appendix 1 and 2.

4.1. MOISTURE CONTENT / DENSITY

The results of specific gravity and moisture content are shown in Table 5.0. Jack pine cones were found to be much denser than the wood samples (0.82, 0.94, and 0.93) and had a much lower moisture content (about 5%). Of the wood samples, jack pine was also found to have the highest oven-dry specific gravity at 0.45 for mature wood and 0.43 for juvenile, which was about

Table 5.0. Density and Moisture Content Results

		Specific gravity (g/cm3)		MC%
		Green	Oven-Dry	
Jack Pine	Mature	0.49	0.45	17.83
	Juvenile	0.47	0.43	14.12
Poplar	Mature	0.44	0.40	16.06
	Juvenile	0.44	0.41	12.53
Black Spruce	Mature	0.41	0.39	13.73
	Juvenile	0.43	0.39	14.54
Pj Cones	1.00	0.82	0.82	5.47
	2.00	0.95	0.94	5.61
	3.00	0.90	0.93	4.46

Source: (Towell 2019).

the same as the published value of 0.45 (USDA 2010). Poplar mature wood had an oven-dry specific gravity of 0.40, and juvenile wood 0.41, slightly higher than the published value of 0.38 (Hoadley 1990). Black spruce had an oven-dry specific gravity of 0.39 for mature wood and 0.39 for juvenile wood, compared to the published value of 0.40 (Hoadley 1990). Moisture contents of wood samples were highest in jack pine mature wood (18%) followed by poplar mature wood (16%). Poplar juvenile wood had the lowest moisture content at 13% followed closely by black spruce mature wood at 14%.

4.2. CALORIFIC VALUE

The calorific values of all samples were generally between 19 and 21 MJ/Kg except for the char samples, which were much higher than the other samples tested. All calorific values by sample ID are illustrated in Figure 5.0.
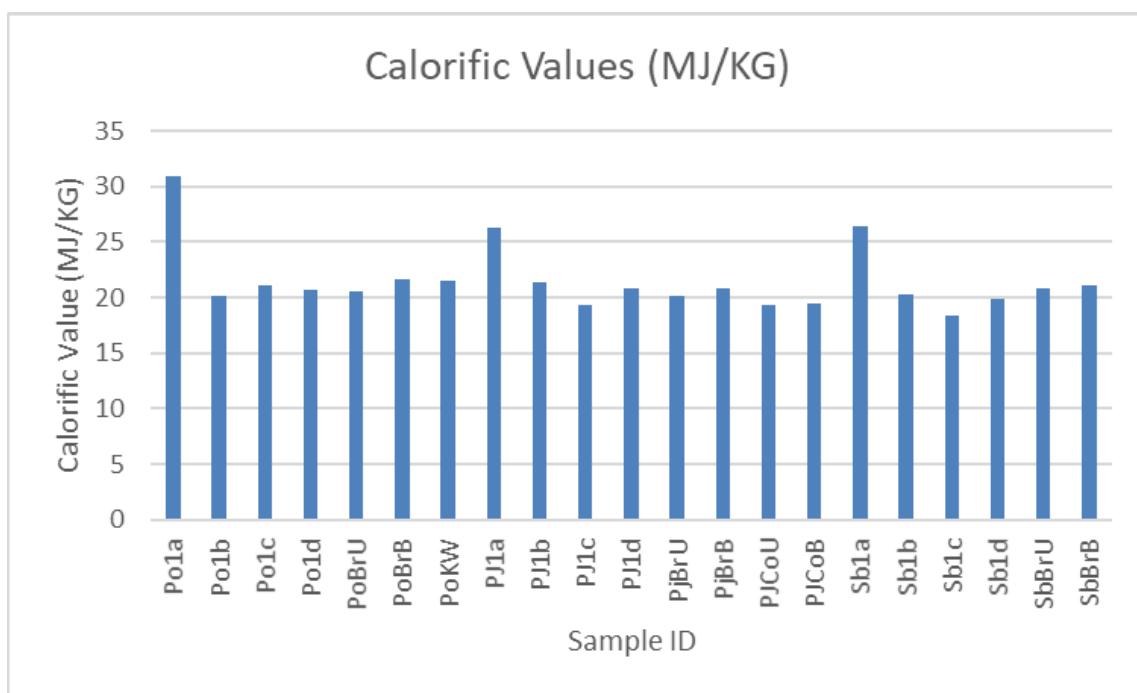

Figure 5.0. Calorific Values of all Samples (Towell 2019).

Poplar charred wood had the highest calorific value of 31 MJ/Kg followed by black spruce charred wood at 26.5 MJ/Kg and jack pine charred wood at 26.2 MJ/Kg. The lowest calorific content was found in black spruce unburnt wood at 18.4 MJ/Kg followed by unburnt jack pine cones at 19.3 MJ/Kg, jack pine unburnt wood at 19.4 MJ/Kg, and burnt jack pine cones at 19.5 MJ/Kg. The calorific value of all samples can be seen in Table 6.0.

Table 6.0. Oxygen Bomb Calorimeter Results

Bomb Calorimeter Results					
Poplar		Jack pine		Black spruce	
SampleID	Heat (MJ/Kg)	SampleID	Heat (MJ/Kg)	SampleID	Heat (MJ/Kg)
Po1a	30.8414	PJ1a	26.2158	Sb1a	26.4735
Po1b	20.1707	PJ1b	21.3661	Sb1b	20.2797
Po1c	21.135	PJ1c	19.3911	Sb1c	18.3772
Po1d	20.7348	PJ1d	20.8852	Sb1d	19.8634
PoBrU	20.6149	PjBrU	20.203	SbBrU	20.852
PoBrB	21.6303	PjBrB	20.843	SbBrB	21.095
PoKW	21.4954	PJCoU	19.3394		
		PJCoB	19.4967		

Source: (Towell 2019).

The results of the single-factor ANOVA on calorimeter results, grouped by species and using an alpha level of 0.05 show that the P-value is higher than 0.05, therefore this means no significant variance was found, accepting the null hypothesis that species does not affect calorific value of fire-salvaged wood. The ANOVA results also show that poplar had the highest variance in calorific values out of all groups, and jack pine the least. Another insight that can be made from the ANOVA is that variance was much higher within groups than between

groups. The table summarizing the results for the one-way ANOVA is shown in Table 7.0.

Table 7.0. Calorific ANOVA Results Grouped by Species.

SUMMARY

Groups	Count	Sum	Average	Variance
Po	6	135.1271	22.52118	16.85821
Pj	6	128.9042	21.48403	5.838893
Sb	6	126.9408	21.1568	7.706477

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6.088607	2	3.044304	0.300389	0.744882	3.68232
Within Groups	152.0179	15	10.13453			
Total	158.1065	17				

Source: (Towell 2019).

Another one-way ANOVA was done at alpha level 0.05, this time using the sample type (a, b, c, d, BrU, BrB) to group the results. These results are shown in Table 8.0.

Table 8.0. Calorimeter ANOVA Results Grouped by Sample Type.

Groups	Count	Sum	Average	Variance
a	3	83.5307	27.84357	6.756856
b	3	61.8165	20.6055	0.436855
c	3	58.9033	19.63443	1.945774
d	3	61.4834	20.49447	0.304339
bru	3	61.6699	20.55663	0.107847
brb	3	63.5683	21.18943	0.161649

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	138.68	5	27.73597	17.13275	4.27034E-05	3.105875
Within Groups	19.4266	12	1.618886			
Total	158.106	17				

Source: (Towell 2019).

Again, the null hypothesis was accepted, as the P-value is higher than 0.05, showing that sample type did not significantly affect calorific value. Group "a", the charred wood samples had the highest level of variance, while branch wood unburnt and burnt had the lowest variance. This time the variance between groups was higher than within as the data was grouped by sample type rather than species.

Descriptive statistics were determined for the data to determine how the data is distributed around the mean, and how confidently the data predicts the mean. Table 9.0. summarizes the descriptive statistics for the data. A mean of 21.5 MJ/Kg was given with a 95% confidence level that the actual mean is within 1.3 +/- MJ/Kg of the given mean.

Table 9.0. Descriptive Statistics of Calorific Values.

Column1	
Mean	21.49064762
Standard Error	0.631820149
Median	20.843
Mode	#N/A
Standard Deviation	2.895363656
Sample Variance	8.383130702
Kurtosis	5.071179653
Skewness	2.224471278
Range	12.4642
Minimum	18.3772
Maximum	30.8414
Sum	451.3036
Count	21
Confidence Level(95.0%)	1.317953735

Source: (Towell 2019).

5.0. DISCUSSION

The resulting moisture contents were lower than what would be expected for "green" wood. This could be due to the long time since fire, which allowed the dead trees to air-dry for three summers. One factor that could have affected these results however, is that the samples were inside for some time before blocks were cut for moisture content and density. Moisture content results suggested that jack pine cones had a lower moisture content than wood, which is not surprising considering the serotinous nature of the cones keeps them sealed, and the density leaves little room for moisture to get in. However, it should be noted that determining density and moisture content of cones was difficult using the traditional oven-dry method used for wood. This is because of the shape of the cones, and the fact that when cones were dried in the oven, this also led to the opening of the cones and removal of some of the seeds, which could have affected the results. Nevertheless, the high density and low moisture content of cones, along with the high resin content, suggests that they could be used as a hot burning solid fuel. The high moisture content and density found in jack pine mature wood could be attributed to the high resin content of pines, which was not considered in determination of density and moisture content using the oven-dry method. If the wood was tested using the distillation method an accurate measure of resin content could be taken and used to find a more accurate measure of moisture content and density. Overall, the density determined for each sample of juvenile and mature wood for each species, was close to the published values.

Although the statistical analysis did not show a significant result disproving the null hypothesis, this is most likely due to the small sample size that was used. Given a higher sample size with more repetitions the results may have suggested a different outcome. Despite the statistical analysis failing to disprove the null hypothesis, it can be seen from the data that the charred wood samples had higher calorific values than the rest of the samples tested, which is consistent with what the literature suggested, that is that carbonization of wood leads to a denser fuel, thus giving it a higher calorific heating value. Niu et al. (2019) describe a 30% increase in energy density from parent woody biomass to torrefied wood (wood that has undergone thermochemical reaction at a temperature of 200-300°C), which is similar to the increase in heating value seen between unburnt wood and charred wood. Some factors that could have affected the results of calorific testing include possible oil residue on the samples caused by the chainsaw used to cut the disks, and also the fact that samples were stored for some time at room temperature before testing possibly resulting in a lower moisture content. The drying of samples in the oven may have also removed some of the volatiles / extractives of wood or tree components, which have a high heating value, as jack pine cones were expected to have a high heating value but resulted in some of the lowest values out of all samples, despite the high density found in the cones. These findings suggest that calorific heating value is affected by a lot of different factors, and even within a single tree, the different components of the tree will have various heating values as was presented by Hosegood (2010).

CONCLUSION

The potential for salvaged wood from forest fires and other natural disturbances to be utilized as a biomass feedstock is mostly justified by the low moisture content of dead wood, and the fact that damage caused by the disturbance and subsequent degradation of wood from fungi and insects lowers the merchantability of the wood in other industries such as lumber and pulp (Araki 2002; Watson and Potter 2004). However ecological concerns of salvage logging and current policies have prevented the wide-spread utilization of this resource in Ontario, while other provinces such as Quebec and British Columbia have been more active in the implementation of salvage logging activities (Mansuy et al. 2015; Barrette et al. 2017). Major barriers to the wide-spread use of biomass for energy production include high transportation costs because of the low density of the fuel, lack of policies that would allow biomass to compete with cheap petroleum fuels (carbon pricing, etc.), and availability of sustainable biomass feedstocks. For these reasons it is important that biomass resources are utilized in the most efficient way possible. The literature and results of this study show the importance of technologies for densification of biomass, namely carbonization processes which remove moisture and volatile components of wood resulting in a high-carbon charcoal-like solid fuel. Gasification systems are likely the most promising of these technologies as they not only remove volatiles from wood, but turn these compounds into liquid fuels (bio-oil) and gasses (syngas) that can be utilized immediately or stored and transported for further use and/or refinement. Forestry operations could theoretically implement

gasification technologies on-site of operations to provide for the energy needs of

equipment, reducing fuel costs and reducing carbon emissions. If these

technologies were to become more portable and effective, they could potentially

be used by forest firefighters to power water pumps, reducing fuel costs and

environmental concerns. Although salvage logging has been a controversial

practice in some instances, it could potentially provide for a large amount of

biomass while rehabilitating stands if implemented with best management

practices and the following of guidelines. More research into the properties of

fire-salvaged woody biomass and technologies is needed to guide salvage

logging operations for optimum and efficient utilization of this resource.

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APPENDICES

APPENDIX I

CALORIFIC VALUES RAW DATA

Species	Component	MJ/Kg
Po	Charred Wood	30.8414
Po	Slightly Burnt Wood	20.1707
Po	Unburnt Wood	21.135
Po	Bark	20.7348
Po	Branch Wood Unburnt	20.6149
Po	Branch Wood Burnt	21.6303
Po	Knot Wood	21.4954
Pj	Charred Wood	26.2158
Pj	Slightly Burnt Wood	21.3661
Pj	Unburnt Wood	19.3911
Pj	Bark	20.8852
Pj	Branch Wood Unburnt	20.203
Pj	Branch Wood Burnt	20.843
Pj	Cone Unburnt	19.3394
Pj	Cone Burnt	19.4967
Sb	Charred Wood	26.4735
Sb	Slightly Burnt Wood	20.2797
Sb	Unburnt Wood	18.3772
Sb	Bark	19.8634
Sb	Branch Wood Unburnt	20.852
Sb	Branch Wood Burnt	21.095

APPENDIX II

DENSITY RAW DATA

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Species	Sample	Condition	Mass (g)	Volume (cm3)	Specific gravity (g/cm3)
Pj	Mature	Green	16.14	33.12	0.49
Pj	Juvenile	Green	17.42	37.06	0.47
Pj	Cone 1	Green	13.54	16.50	0.82
Pj	Cone 2	Green	7.62	8.03	0.95
Pj	Cone 3	Green	7.85	8.72	0.90
Po	Mature	Green	15.8285	36.29	0.44
Po	Juvenile	Green	19.3287	43.46	0.44
Sb	Mature	Green	11.5728	28.3	0.41
Sb	Juvenile	Green	17.4813	40.22	0.43
Pj	Mature	Oven-Dry	13.70	30.11	0.45
Pj	Juvenile	Oven-Dry	15.26	35.55	0.43
Pj	Cone 1	Oven-Dry	12.84	15.56	0.82
Pj	Cone 2	Oven-Dry	7.21	7.70	0.94
Pj	Cone 3	Oven-Dry	7.51	8.05	0.93
Po	Mature	Oven-Dry	13.638	34.32	0.40
Po	Juvenile	Oven-Dry	17.176	41.65	0.41
Sb	Mature	Oven-Dry	10.176	25.82	0.39
Sb	Juvenile	Oven-Dry	15.262	39.32	0.39