Background and Rationale for the Development of a Guideline for the Control of Air Emissions from Small Wood-Fired Combustors with a Heat Input Capacity of Less Than 3 Megawatts (Guideline A-14)

Ontario Ministry of the Environment and Climate Change
Environmental Science and Standards Division
Standards Development Branch

June 2016
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1 Introduction

The Ontario Ministry of the Environment and Climate Change (the Ministry) has developed a new air quality guideline for the control of air emissions from small wood-fired combustors with a heat input capacity of less than 3 megawatts (Guideline A-14). The lower heating capacity limit for the applicability of Guideline A-14 is 50 kilowatts of energy output.

The purpose of this document is to present background information and the rationale for developing Guideline A-14, which has been designed to accompany Guideline A-13: Guideline for the Control of Air Emissions from Large Wood-Fired Combustors (with a heat input capacity of 3 megawatts or greater) published by the Ministry in 2015. Together, these two new air quality guidelines serve to replace the Interim Design and Review Guidelines for Wood Fired Combustors published by the Ministry in 1990.

1.1 Purpose for Developing Guideline A-14

The use of heat energy generated from wood fuel in small wood-fired combustors presents an opportunity to advance several government priorities, including: greenhouse gas (GHG) emission reduction targets as outlined in Ontario’s Climate Change Action Plan (2016) and Climate Change Strategy (2015); stimulating innovation, diversification and competitiveness; economic growth; community development, including First Nations communities; and successful implementation of the Growth Plan for Northern Ontario (2011) and Ontario’s Long-Term Energy Plan (2013). The primary beneficiaries of Guideline A-14 will be facilities that embrace a net-zero energy building concept that use renewable technology, in the form of wood fuel paired with a small wood-fired combustor, to produce the heat energy that they consume.

Small wood-fired combustors represent a source of air emissions and a number of jurisdictions are updating their regulatory requirements. The most significant regulatory developments are occurring in Europe, where governments have chosen to promote the use of wood fuel and small wood-fired combustors as one of a suite of renewable energy technologies (including wind, solar, etc.) that collectively achieve national greenhouse gas emission reduction objectives while limiting air emissions.

The improvements in thermal efficiency and reductions of air emissions, such as carbon monoxide (CO) from small wood-fired combustors over the past few decades, especially

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1 Organizations such as the United States Environmental Protection Agency (e.g., see Strategies for Reducing Residential Wood Smoke, March 2013); and the Northeast States for Coordinated Air Use Management, NESCAUM (e.g., see August 2012 letter to the administrator of the United States Environmental Protection Agency) have indicated that air emissions from older and/or poorly operated small wood combustors can result in health hazards in the vicinity of these units. These and other jurisdictions (e.g., City of Vancouver) are also in the process of updating their air emission requirements for small wood combustors where more stringent and less-polluting designs and experiences in Europe are forming the basis of these reviews.
in Europe where wood fuel quality and combustion equipment design standards have been developed, are significant as shown in Figure 1.

![Figure 1. Improvements in efficiency and reduction of air emissions for small wood-fired combustors](image)

1.2 Organization of Report

This document has been organized into the following chapters:

1. Introduction
2. Market Potential in Ontario for Small Wood-Fired Combustors
3. Overview of Wood Combustion
4. Wood Fuel Description and Specifications
5. Review of Selected Jurisdictions’ Regulatory Regimes
6. Modern Small Wood-Fired Combustion Equipment Design
7. Air Emissions from Small Wood-Fired Combustors
8. Air Emission Compliance Assessment Options

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2 Market Potential in Ontario for Small Wood-Fired Combustors

In Ontario, there is significant potential for the development of a larger domestic wood fuelled heating (bioheat) market. The first section of this chapter defines the current market in Ontario, as well as the rest of Canada. It also illustrates recent bioheat market developments. The second section highlights bioheat growth in other jurisdictions worldwide. The third section describes the potential for wood-based heat development by assessing Ontario’s Crown forest fibre supply and comparing costs of common fuel sources used for heating in the commercial/institutional and residential sectors.

2.1 Current Bioheat Market in Canada

The use of wood fibre for heating has been successfully implemented in many Canadian provinces and territories for decades. There are currently 230 bioheat projects identified in Canada at the commercial/institutional scale of 150 kilowatts (kW) to 5 megawatts (MW). A breakdown of the 230 projects by province/territory is presented in Figure 1. The two provinces with the largest forest industries, Quebec (64) and British Columbia (51), lead Canada in bioheat installations, followed by the Northwest Territories (30) and Ontario (24).

![Figure 1. Number of bioheat projects by province/territory in the 150 kW to 5 MW range](http://www.confederationc.on.ca/appliedresearch/BioHeatWorkshop)

In Canada, the majority of commercial/institutional bioheat applications are publicly funded institutions and community district energy projects, while in Ontario the current bioheat market largely consists of farms and greenhouses (Table 1).

Table 1. Distribution of bioheat projects by sector in the 150 kW to 5 MW range in Ontario versus the rest of Canada

<table>
<thead>
<tr>
<th>Sector</th>
<th>Number of Bioheat Installations in Ontario</th>
<th>Number of Bioheat Installations in Canada Excluding Ontario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Building</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Community District Energy</td>
<td>3</td>
<td>44</td>
</tr>
<tr>
<td>Farm or Greenhouse</td>
<td>10</td>
<td>33</td>
</tr>
<tr>
<td>Public Building</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Institutional Building</td>
<td>6</td>
<td>62</td>
</tr>
<tr>
<td>Residential Building</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Small Industrial</td>
<td>3</td>
<td>35</td>
</tr>
<tr>
<td>Unknown</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>206</td>
</tr>
</tbody>
</table>

The bioheat market in Canada has expanded steadily in recent years. Figure 2 illustrates the increasing growth in the number of bioheat installations in Canada within the 150 kW to 5 MW scale. Over 30 percent (%) of the bioheat projects identified in Canada were installed from 2010 to 2014. The vast majority of growth within this time period is attributed to developments in the public sector, including publicly-funded institutions and public buildings, as well as community district energy projects. However, Ontario and Nunavut are the only jurisdictions in Canada which have not realized increasing bioheat growth between 2005 to 2009 and 2010 to 2014.4

Figure 2. Installation date for bioheat projects in Canada in the 150kW to 5MW range

Wood burning appliances (i.e., less than 150 kW) were not included in the national survey and so data on the number of sites with devices in this size range is unavailable. As an example however, the Northwest Territories (NWT) has experienced rapid growth in this appliance size range for commercial/institutional applications. As of May 1, 2015, there were 88 wood pellet boilers installed in the five NWT Regions. Approximately 10% of commercial buildings and nearly most larger government buildings are using wood fuelled biomass boilers (Larson, J. 2015, Energy North, pers. comm.).

2.2 Bioheat Growth Worldwide

Jurisdictions worldwide have invested money into the development of various policies and programs as part of their larger climate change, energy security and renewable energy priorities, including direct support for biomass heat. As a result, these countries have experienced successful market growth in the biomass heating sector. Countries including Austria, Finland, Germany, Great Britain, Italy, Scotland, Sweden, and the United States all exhibit such growth, and accordingly also have favourable bioheat-related policies in place.

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Finland experienced rapid market growth of wood chip fuelled heating and combined heat and power (CHP) plants from 2000 to 2008 as shown in Figure 3 and this market continues to grow. CHP facilities in Finland play a substantial role; however, the heat-only facilities are much more numerous throughout the country.

Figure 3. Comparison of wood chip fuelled combined heat and power (black dots) and heat (green dots) production facilities in Finland in the years 2000-2008.

Upper Austria also experienced increasing growth in bioheat capacity from 1990 to 2013 as shown in Figure 4 due to the creation of a series of regulatory and financial measures. The United States is experiencing substantial growth within its bioheat

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industry as well. The Biomass Thermal Energy Council estimates that from 2010 to 2020 the bioheat industry (including solid biomass fuels as well as liquid biofuels) is expected to grow by 7.4% annually in terms of British thermal units (Btu) of energy and heat produced. Of this growth, over 84% is expected from solid biomass fuels such as wood and agricultural pellets and chips.\(^8\)

\[\text{Figure 4: Bioheat capacity in Upper Austria from 1990 to 2013}\]^7

### 2.3 Ontario’s Bioheat Potential

In Ontario, the current bioheat market primarily consists of forest industry, greenhouse and residential applications; however, a great opportunity exists within the commercial and institutional sectors. In Ontario, approximately 54% of total commercial and institutional energy use and 85% of total residential energy use was attributed to a combination of space and water heating in 2011.\(^9,10\) Since heat is such a large


component of Ontario’s overall energy use, opportunities for bioheat to become a component of the province’s renewable energy mix are significant.

Solid biomass fuels such as wood offer a number of advantages that contribute to Ontario’s bioheat potential. Wood fuel is a renewable resource that can be sustainably harvested in Ontario. From an energy supply perspective, heat production is the most efficient and cost effective use of forest-derived biomass.\textsuperscript{11} Wood fuels have stable pricing and at the commercial and institutional scale can be competitive with fluctuating natural gas prices. These fuels are also a cheaper alternative to electricity, heating oil, diesel and propane, and will likely continue to be so into the future. In addition, bioheat systems can be affordably installed to replace or supplement existing fossil fuel heating.\textsuperscript{12} The use of small wood-fired combustors can create new jobs in a region, assist with economic development, and allow community funds spent on energy consumption to be reinvested locally. Two of the key factors: Crown wood fibre supply and fuel pricing, are described below in greater detail.

2.3.1 Wood Fuel Supply

Using renewable and sustainable forest-derived wood fibre from Crown land can support increased opportunities for bioheat. Ontario has one of the most comprehensive forest management planning regimes in the world. The Crown Forest Sustainability Act (1994)\textsuperscript{13} and the Environmental Assessment Act (1990)\textsuperscript{14} provide the legislative framework for forest management to ensure sustainable harvesting and successful forest regeneration.

A substantial volume of wood fibre is available from Ontario’s sustainably managed Crown forests. The annual sustainable harvest level in Ontario is 29 million cubic metres, whereas the actual harvest level for 2014-2015 was only 14 million cubic metres. Figure 5 illustrates the annual provincial utilization of Crown forest wood fibre over the last 10 years, compared to the approved available volume. The economic downturn in 2008 was a large contributing factor to the decrease in the demand for Crown forest wood fibre over the last several years. The volume of wood fibre available from Ontario’s Crown forests can support expansion of the existing forest products industry, and provide wood fibre for emerging markets, including the development of domestic bioheat applications.


Figure 5. Available harvest volume versus actual harvest volume of wood fibre from Ontario’s Crown forests\textsuperscript{15,16}

2.3.2 Heating Fuel Costs

When comparing different heating fuel sources, the key factors include the historical stability of the fuel price and the likelihood of price fluctuations in the future. Fossil fuels are subject to potential unknowns, such as seasonality (winter duration and temperature) and stock market fluctuations\textsuperscript{17}, which have the ability to cause spikes in prices, thus posing a financial risk to fuel purchasers. Canada’s unusually persistent and frigid 2013-2014 winter season dramatically increased demand for both propane

\textsuperscript{15} Historical wood utilization data was derived from MNRF provincial scaling data using the Timber Resource Evaluation System (TREES). TREES is Ontario’s current wood measurement accounting system.

\textsuperscript{16} Information on available harvest does not reflect the conventionally termed unmerchantable volume that is also available to be harvested; therefore, actual available volume is higher than what is shown in this figure.

and natural gas, resulting in significant rate hikes. For instance, the average price of propane experienced a spike in price of approximately 31% (from 0.849 dollars ($)/litre (L) to $1.113/L) over a period of only one month. This susceptibility to price fluctuations imposes a financial burden on communities dependent on fossil fuels for energy generation. Wood fuels produced in Ontario provide a much more stable heating fuel price as they are sourced locally and not influenced significantly by world events.

The relatively low price, convenience, high efficiency and lower emission levels of natural gas compared to other fossil fuels make it an important part of Ontario’s Long-Term Energy Plan (2013). However, it is also a fuel that requires a pipeline distribution system and to date, distribution has been focused on higher density areas. As a consequence, significant areas of the province, primarily rural and northern regions, do not have access to natural gas. Figure 6 compares the fuel prices for small-scale heating systems from 2006 to 2015. Wood chips are the most cost effective fuel, followed by firewood and natural gas. Wood pellets are becoming more cost competitive to natural gas, and are significantly more affordable than electric, heating oil or propane. Heating with wood fuels is an attractive alternative in places where natural gas is unavailable.

Figure 6. Price ranges for heating fuel types from 2006 to 2015 for small-scale heating systems\textsuperscript{21,22}

\begin{itemize}
\item\textsuperscript{22} Natural gas prices calculated using Union Gas (current and historical) effective price, with additional costs factored in. All prices factored for average equipment efficiencies.
\end{itemize}
3 Overview of Wood Combustion

This chapter provides an overview of wood combustion and the types of air emissions emitted from wood combustion. In this chapter, two different types of chemical reactions will be described, endothermic and exothermic. Endothermic reactions must absorb heat in order to proceed, such as the melting of ice. Exothermic reactions release heat as a result of proceeding such as the burning of fuels.

3.1 Combustion Fundamentals

Combustion is a multi-step chemical reaction process, but is generally described as an exothermic chemical reaction that combines oxygen gas (O₂) with a fuel in the presence of an ignition source. The ignition source can be intermittent, such as a spark plug in a gasoline engine (where the reaction is not self-sustaining), but more typically the ignition source is the high temperature thermal reservoir within the combustion device that serves to auto-ignite incoming fuel on a continuous basis, such as a wood-fired combustor. Combustion (on a continuous, self-sustaining basis) requires a combination of: (i) sufficient temperature to initiate auto-ignition and provide the required activation energy to complete the oxidation reactions, (ii) effective mixing of the O₂ with the fuel in a turbulent environment, and (iii) sufficient residence time to allow the reactions to be completed.

The primary reactants of combustion are carbon (C), hydrogen gas (H₂) and O₂, while the products of complete combustion include carbon dioxide (CO₂), water (H₂O) vapour, and heat. The heat released during the formation of CO₂ is 94.1 kilocalories per mole (kcal/mole) and for H₂O vapour it is 57.8 kcal/mole (standardized to 25 degrees Celsius (°C)). The following chemical formula provides a theoretical example of complete combustion for a carbon-hydrogen based fuel:

\[ 2C + 2H₂ + 3O₂ \rightarrow 2CO₂ + 2H₂O + Heat \ (100\%) \]

The exact amount of O₂ required for complete combustion is known as the stoichiometric amount of O₂. Generally, ambient air (approximately 21 per cent (%) O₂ and 79% nitrogen gas (N₂) by volume) is used to provide the combustion air and by extension the required O₂. The N₂ in the combustion air “passes through” the combustion process with relatively small amounts of the N₂ being oxidized along with the carbon.

If insufficient, or sub-stoichiometric, O₂ is provided to the combustion reaction then incomplete combustion will occur and carbon monoxide (CO) with an associated lower amount of heat will be produced (as compared to full oxidation to CO₂). The heat released during the formation of CO is 26.4 kcal/mole (standardized to 25°C) which is only 28% of the heat released by the formation of CO₂. The following chemical formula provides a theoretical example of incomplete combustion for a carbon-hydrogen based fuel:

\[ 2C + 2H₂ + 2O₂ \rightarrow 2CO + 2H₂O + Heat \ (28\%) \]
In practice, excess O₂ is always provided to assist with ensuring complete combustion because stoichiometric mixing of carbon and O₂ is very difficult to achieve (and to capture the 72% energy available by oxidizing CO to CO₂). The amount of excess O₂ required is a function of the fuel type and a balance between providing sufficient O₂ while ensuring that the excess air does not lower the combustion temperature. This is important because excess air is drawn from the atmosphere and primarily contains N₂ which may contribute to incomplete combustion as a result of insufficient temperature, as too much excess air provides a cooling effect on the combustion reaction. However, providing turbulence to the combustion reaction assists with ensuring that the fuel mixes well with the excess O₂ thereby limiting the amount of excess air required.

3.2 Wood Fuel Components

Wood fuel can be divided into combustible and incombustible components as shown in Figure 7. Combustible components are carbon-based and can be either solid or gaseous, whereas incombustible components include water and solid substances that are typically described as ash. Since the water content (or moisture content) of a wood fuel can vary, it is common practice for wood fuel to be described on either a "dry basis" that excludes the water or on a "wet basis" that includes the water.

![Figure 7. Components of wood fuel](image)

3.3 Wood Fuel Chemical Constituents

Wood fuel (as described on a dry basis) is a heterogeneous material comprised of three main constituents: cellulose, hemicellulose and lignin along with other trace elements and impurities. The three main constituents are comprised of complex molecular structures containing primarily carbon (approximately 49-51% by weight on a dry basis),

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oxygen (O embedded within solid wood, approximately 42-45% by weight on a dry basis) and hydrogen (H embedded within solid wood, approximately 6% by weight on a dry basis) and are determined using a test for ultimate analysis. Trace elements include nitrogen (N in solid form), sulphur (S), calcium (Ca), potassium (K), silicon (Si), sodium (Na), phosphorus (P), chlorine (Cl) and naturally occurring heavy metals from the soil.

The carbon in wood fuel exists in two different phases: (i) the carbon component of volatile matter (which also includes O and H) and (ii) the fixed carbon (also referred to as charcoal) which are determined using a test for proximate analysis. In order to combust wood fuel completely, the two phases of carbon must be understood as a fuel characteristic and the combustion device designed and operated accordingly.

Volatile matter typically represents 80 to 85% of the dry mass of wood fuel but only 65 to 70% of the energy. This carbon exists as either a gas or tar and is contained within the solid wood fibre matrix. Fixed carbon typically represents 14 to 17% of the dry mass of wood fuel but 30 to 35% of the energy. The ash content comprises the balance of the dry mass, typically 0.5 to 5% depending on the amount of bark in the wood fuel, according to the proximate analysis, and has almost no energy content.

### 3.4 Stages of Wood Combustion

Wood combustion is a complex multi-step process that is best described by dividing into six individual stages as shown in Figure 8. The first three stages are endothermic reactions that absorb heat and do not require any O₂. This is because wood fuel is not flammable at ambient conditions and contains water (the flash point for auto-ignition begins above 230°C after the wood fuel is fully dry). The second three stages are exothermic reactions that release heat and require O₂. A fraction of the exothermic heat released by stages 4-6 is used to supply the endothermic heat required by stages 1-3 and the rest of the heat can be used for heating.

Figure 8. Stages of wood combustion

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Stage 1: Warming the wood fuel up to 100°C so that water can begin to evaporate. The amount of endothermic energy required for stage 1 will vary greatly depending on the moisture content of the wood fuel.

Stage 2: Drying the wood fuel up to 150°C so that the water fraction is completely evaporated from liquid to water vapour. The amount of endothermic energy required for stage 2 will vary greatly depending on the moisture content of the wood fuel.

Stage 3: Pyrolytic decomposition of the dry wood components from long-chain to short-chain molecules, in the presence of H₂O, up to 230°C. The products of decomposition are unburned charcoal, liquid tars and combustible gases such as CO, H₂ and gaseous hydrocarbons. The endothermic chemical reaction for transforming solid C and H₂O vapour into CO and H₂ is shown below:

\[ 2C \text{ (solid)} + 2H_2O \text{ (gas)} + \text{Heat} \rightarrow 2CO \text{ (gas)} + 2H_2 \text{ (gas)} \]

Since wood fuel contains some degree of water, this is not typically considered a problem. Any water in the wood fuel that is not needed for this reaction will pass through the combustion process chemically unchanged from a liquid to a vapour phase.

Stage 4: Gasification of volatile matter (referred to as devolatilized) up to 500°C in the presence of sub-stoichiometric oxygen to release combustible gases such as CO and gaseous hydrocarbons as well as heat.

Stage 5: Gasification of fixed carbon (devolatilized charcoal) up to 700°C in the presence of sub-stoichiometric O₂ to release combustible gases such as CO and H₂ as well as heat.

Stage 6: Oxidation of combustible gases, such as CO and H₂, above 700°C (typically up to 1,100°C) in the presence of excess O₂ to release CO₂, H₂O vapour and heat as shown in the chemical reaction below:

\[ 2CO + 2H_2 + 2O_2 \rightarrow 2CO_2 + 2H_2O + \text{Heat} \]

An effective multi-step wood combustion reaction is shown in Figure 9 where the dry wood components are being devolatilized at the bottom and the combustible gases are being oxidized at the top in a turbulent environment.
3.5 Types of Air Emissions Emitted by Wood Combustion

The types of air emissions released by wood combustion can be divided into three major groups: (i) emissions from complete combustion, (ii) emissions from incomplete combustion, and (iii) emissions from both complete and incomplete combustion. Although water vapour is emitted from this process it is not considered an air emission.

3.5.1 Emissions from Complete Combustion

CO₂ is the primary product of combustion from wood fuel and is only emitted once the carbon has been completely oxidized and all of the available heat has been released. Nitrogen oxides (NOₓ) are mainly the result of oxidation of N bound in the fuel, although some of the N₂ in the combustion air can be oxidized if the temperature is at least 1,300°C (this can occur in “hot zones” of the combustion chamber). The main form emitted is nitric oxide which is converted to nitrogen dioxide in the atmosphere.

Sulphur oxides are the result of oxidation of sulphur bound in the fuel and it is mainly sulphur dioxide that is formed, but the emissions are typically very low as the sulphur content of wood is very low.

Hydrogen chloride is emitted as a function of the amount of chlorine bound in the fuel but the emissions are typically very low as the chlorine content of wood is very low.

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3.5.2 Emissions from Incomplete Combustion

CO is the primary product of incomplete combustion and is widely recognized as the best indicator of combustion quality because it can be minimized with optimum excess air levels as shown in Figure 10 and because it is simple to measure on a continuous basis in conjunction with oxygen levels. Also, CO is often used as a surrogate indicator to indicate the presence of other products of incomplete combustion.

![Figure 10. Carbon monoxide emissions versus excess air ratio for selected small wood-fired combustors](image)

Hydrocarbons, often referred to as non-methane volatile organic compounds, are associated with CO emissions because they are also intermediate steps in the oxidation reaction of carbon and hydrogen in the wood fuel to CO₂ and H₂O vapour. Figure 11 illustrates the correlation between hydrocarbon and CO emissions for selected small wood-fired combustors.

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Polycyclic aromatic hydrocarbons (PAH) are considered separately from non-methane volatile organic compound hydrocarbons due to their carcinogenic health effects. PAHs are however, also intermediate steps in the oxidation reaction of C and H in the wood fuel to CO₂ and H₂O. PAHs can similarly be correlated to CO emissions as shown in Figure 12 as a function of combustion temperature, where both emissions are reduced by orders of magnitude as the combustion temperature approaches 1,000°C.

Polychlorinated dioxins and furans are a group of highly toxic compounds comprised of carbon, chlorine and O₂ that can be formed in very small amounts at temperatures between 200 and 500°C in the presence of a catalyst such as copper (Cu). Emission formation is highly dependent on combustion conditions and subsequent flue gas cooling. The presence of salts tends to minimize emission formation as the Cl is bound to K or Na and not available to create dioxins and furans.

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3.5.3 Emissions from both Complete and Incomplete Combustion

Particulate matter (PM) is generated by several processes occurring simultaneously within a combustion system and, depending on the completeness of the combustion reaction, can be comprised of several of the following constituents: organic carbon (i.e., unburned fuel particles or charcoal), soot, tars, inorganic salts (non-volatile and volatile), condensable organic compounds (COC), volatile organic compounds (VOC) and/or PAHs. Inorganic salts can be formed by: (i) non-volatile compounds such as Si or Ca that generally form large coarse fly ash particles, or by (ii) volatile compounds such as K or Na that generally form sub-micron fine fly ash (aerosol) particles.

The two types of PM are therefore distinguished by size, including coarse fly ash and fine fly ash/aerosols. Coarse fly ash particles are the result of entrainment of non-volatile inorganic salts and organic carbon/soot in the flue gas from within the combustion chamber fuel bed. Coarse fly ash typically has a diameter from 1 micrometre (µm) to 100 µm. Aerosols are formed by either the (i) nucleation (formation of submicron particle) or (ii) condensation (reaction with the surface of an existing particle) of VOCs or COCs after the combustion chamber fuel bed and have a diameter less than 1 µm. The pathways to PM formation are shown in Figure 13 (note: the colours in this figure do not have any significance for this discussion and are only for illustration purposes as copied from the source reference document).

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When combustion is effective the PM tends to be primarily comprised of multiple types of non-volatile and volatile inorganic salts (such as potassium sulphate, potassium carbonate, potassium chloride, calcium sulphate), small amounts of organic carbon, and soot as well as trace amounts of other constituents. When the combustion reaction is poor the PM tends to be primarily comprised of organic carbon, soot and tars, with small amounts of inorganic salts as well as trace levels of other constituents.

An example of a wood chip combustion fly ash particle laboratory characterization using a scanning electron microscope (equipped with an x-ray microanalysis system to determine elemental composition and approximate size of the particles) is provided in Figure 14. Significant amounts of Ca and K are shown, indicating good combustion as inorganic salts are primarily present but very little unburned carbon.

Figure 13. Pathways to particulate matter formation

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Trace amounts of naturally occurring heavy metals contained within the wood fibre (especially the bark), such as zinc, Cu, lead, cadmium and mercury can be released during the combustion process and attach to PM (particularly aerosols) that is generated concurrently. Trace amounts of heavy metals analyzed from fly ash particles derived from the combustion of wood chips are shown in Figure 14.

3.6 Additional References


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4 Wood Fuel Description and Specifications

In this chapter, the major types of wood fuels, key fuel properties, and associated fuel specifications (such as standards), including classifications and grading for wood fuels, are described. These items have significant impacts on fuel storage and handling characteristics, combustion performance, and air emissions. In writing this chapter, attention is given to ensure the terms and definitions described are consistent with those established by the International Organization for Standardization (ISO) and adopted by the Canadian Standards Association (CSA) for the CAN/CSA-ISO Solid Biofuel Standards.

Wood fuels are defined as solid biofuels that use “woody biomass” as raw material. The origins and sources of woody biomass come from forestry and arboricultural activities and include: (i) virgin wood (such as whole tree, stem wood and logging residue) and (ii) by-products and residues generated in the wood products industry (such as sawmills, lumber mills, furniture makers, etc.). Wood fuels are manufactured by incorporating one or more processing steps such as chopping, drying, chipping, grinding, and densifying (pelletizing or briquetting). The most commonly traded forms of wood fuels include: firewood, wood chips, wood pellets and briquettes. It is common to find ungraded mill residues, known as “hog fuel”, being used as fuel in Ontario as well as in many other jurisdictions in Canada. A brief description of hog fuel is therefore included to illustrate the degree of enhancements that are achievable in fuel quality and consistency from hog fuel to wood chips to wood pellets and wood briquettes.

In the later part of the chapter, recently developed and published fuel standards and key fuel properties that are used in classifying and grading major wood fuels within the CAN/CSA-ISO Solid Biofuel Standards are introduced. A series of Solid Biofuel Bulletins published by Natural Resources Canada to summarize these standards are provided in Appendix II.

4.1 Wood Fuels

As shown in Figure 15, wood fuels can come in various shapes and sizes originating from a range of sources, such as white wood (stem wood), logging residue and/or mill by-products and residues. In changing the form of the fuel during its manufacture, physical properties such as bulk density and moisture content are also altered. As a result, it is important that the appropriate fuel type is used for a given piece of combustion equipment; not only to ensure effective fuel handling, but also for efficient combustion.

4.1.1 Hog Fuel

Hog fuel is a woody biomass residue generated by the wood processing industry. This mill residue is typically a mixture of slabs, trimmings, bark, sawdust and shavings in varying amounts and has a wide range of particle sizes and shapes. Hog fuel is of a lesser quality when compared to other wood fuels; it has a high moisture content and
subsequently low energy content and bulk density. The inconsistency of the particle sizes and shapes may lead to fuel handling and/or combustion issues.

Hog fuel is typically only used in large industrial scale wood-fired combustors, where the combustion chamber and fuel handling system designs accommodate varying fuel particle sizes and properties, and there are more advanced air emission controls. As a result, hog fuel is excluded from Guideline A-14, but is provided for in Guideline A-13: Control of Air Emissions from Large Wood-Fired Combustors (with heat input capacities of 3 megawatts or greater).

![Figure 15. Various forms of wood fuels](image)

**4.1.2 Firewood**

Firewood or cordwood is split and seasoned tree stems, with a uniform length in the range of 15-100 centimetres (cm). The length and diameter should be specified to match the combustion system; specifically the fire box size. Seasoning refers to the drying of firewood using wind and sunlight. Drying and covered storage are necessary to achieve an appropriate moisture content for combustion. Firewood generally has a relatively high moisture content, relatively low energy content and low bulk density, all of which must be taken into account during the combustion system design. Firewood is

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conventionally used in combustion systems that are fed manually in batches, such as stoves and outdoor boilers, and is therefore not a focus in this guideline.

4.1.3 Wood Chips

Wood chips are typically characterized as chipped woody biomass of a defined particle size range. The typical length of a wood chip can range from 5 to 50 millimetres (mm), with a comparatively low thickness. Wood chips are produced by mechanical treatment with sharp tools, such as knives, creating more uniform particles\(^{36}\). When examining wood chips for their fuel quality, some key properties to be observed are the particle size range, the amount of the defined (main) particle size range, the amount of fine and coarse particles outside of the defined particle size range, the moisture content and the ash content. Wood chips can be used in automatically fed combustion systems. Care should be given so that the majority of the wood chips are within the defined particle size range. The amount of fine and coarse particles that are below and above the defined particle size range can have a significant impact on the operation of the fuel handling and combustion systems.

Wood chips typically have relatively high moisture content, but higher energy content and bulk density when compared to firewood. Like firewood, covered storage is extremely important to maintain appropriate moisture content.

4.1.4 Wood Pellets

Wood pellets are densified woody biomass particles that are cylindrical in shape with a diameter of up to 25 mm and a length of 5 to 40 mm. Pellets are manufactured through a series of five production steps. Drying and milling occur first, and then the ground woody biomass is conditioned with steam to improve adhesion of the lignin during the pelletizing process. Flat die or ring die pelletizers are used for the densification of the woody biomass and shaping of the individual pellets to the desired dimensions, which are then cooled to room temperature\(^{37}\).

Pelletization results in one of the highest wood fuel qualities. Wood pellets have: (i) low moisture content, (ii) high bulk and energy densities, and (iii) homogenous size and shape. These fuel properties allow them the ability to overcome the usual problems associated with the use of woody biomass as fuel over conventional fossil fuel sources. The consistency and homogeneity of the fuel characteristics also make them an ideal candidate for automatically fed combustion systems. Properties used to determine the quality of wood pellets include particle size distribution, mechanical durability, bulk density, calorific value and moisture content.


4.1.5 Wood Briquettes

Like wood pellets, briquettes are a densified wood fuel. They come in cubic or cylindrical forms with a diameter of more than 25 mm. They are manufactured in a similar fashion as wood pellets, but utilizing different densification technologies.

Briquettes have moisture content and bulk density values typically between those of the wood chips and wood pellets but have high energy content comparable to wood pellets. Briquettes may also be used in automatically fed combustion systems. Attention should be given to match the sizing of the fuel feed system and combustion chamber with the sizes of briquettes being burned.

Important properties related to the quality of wood briquettes include the particle size, calorific value and moisture content.

4.2 Physical and Chemical Properties of Wood Fuels

Wood fuels primarily contain carbon (C), hydrogen (H) and oxygen (O) as described in chapter 3. Compared to conventional fossil fuels, such as heating oil, the C content of wood fuels is lower while O content is higher. Nitrogen (N) and sulphur (S) contents of the wood fuel are low. The chlorine (Cl) content of wood fuel is typically very low, unless the woody biomass comes from salt laden sources (such as logs barged in ocean as it is practiced in British Columbia). All raw woody biomass sources contain naturally occurring heavy metals to some degree (such as copper, lead, cadmium, mercury). The concentration of these heavy metals would vary depending on the growing conditions such as soil composition.

The source of a wood fuel greatly influences its physical characteristics and chemical composition. These properties have an impact on the solid biofuel handling, storage, and combustion performance, as detailed in Table 2, Table 3 and Table 4.38

Table 2. Fuel characteristics and their key effects – physical properties

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content</td>
<td>Storage, durability, energy content, combustor design and operation</td>
</tr>
<tr>
<td>Particle Size</td>
<td>Fuel handling, combustor design and operation, dust formation</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>Fuel storage, transport, handling</td>
</tr>
<tr>
<td>Energy Content</td>
<td>Fuel utilization, combustor design and operation</td>
</tr>
<tr>
<td>Ash Content</td>
<td>Combustor design and operation, particle matter emissions, ash utilization</td>
</tr>
</tbody>
</table>

Table 3. Fuel characteristics and their key effects – chemical properties: Elemental composition

<table>
<thead>
<tr>
<th>Chemical Properties – Elemental Composition</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon / Hydrogen / Oxygen</td>
<td>Fuel energy content</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Air emissions</td>
</tr>
<tr>
<td>Sulphur</td>
<td>Corrosion, air emissions</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Corrosion, air emissions</td>
</tr>
</tbody>
</table>

Table 4. Fuel characteristics and their key effects – chemical properties: Ash Composition

<table>
<thead>
<tr>
<th>Chemical Properties – Ash Composition</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium / Sodium</td>
<td>Corrosion, lowered ash melting temperature, air emissions</td>
</tr>
<tr>
<td>Magnesium / Calcium</td>
<td>Ash utilisation, increased ash melting temperature</td>
</tr>
<tr>
<td>Heavy Metals</td>
<td>Air emissions, ash utilization</td>
</tr>
</tbody>
</table>

In the following sections, further details on key fuel properties are discussed. Note that the nomenclature that is used in the section below primarily follows that established by the CAN/CSA-ISO Solid Biofuel Standards.

4.2.1 Moisture Content

Moisture content refers to the quantity of water contained in a solid wood fuel. Moisture content can be abbreviated as MC or M. It is most commonly expressed on a wet basis, where it is defined as the fraction of water as a percentage of the total wet mass of the fuel sample (including moisture). Expressed on a dry basis, the moisture content refers to the mass of water as a percentage of the mass of the dry sample (with no moisture).

High moisture content has several adverse effects on fuel quality. Most importantly, it lowers the amount of useful energy captured from combustion as energy is consumed in the evaporation of water. Additionally, high moisture content can increase transportation costs per unit of energy and lead to degradation through fungal and bacterial activities during storage. Too low of a moisture content can pose the problem of excessive fines and dust.

Moisture content varies substantially within the major traded forms of wood fuels, but in general, to ensure a self-sustaining combustion reaction the maximum moisture content is typically limited to 50 percent (%) on a wet basis.
4.2.2 Particle Size

Particle size refers to the range of dimensions of wood fuel pieces. Particle size can be abbreviated as P or PS. It may be defined in various ways, depending on the shape of the traded form. Length, width, height, and/or diameter may be taken into consideration during this analysis. The particle size also indicates the weight distribution of a given particle size range. Typically, the majority of fuel pieces in wood fuels conform to a range of particle size; but there exists fuel particles that are outside of the given particle size range, i.e. oversized particles and fines.

Particle size is most relevant to the fuel handling and combustion chamber of the heating system. Oversized particles, often referred to as coarse particles, can create jams in the fuel feed system and are often discharged through the ash system without being completely burned. Very small particles, often referred to as fines, create handling and storage issues related to dust generation, and typically exit the boiler in the flue gas without burning.

Figure 16 shows wood chips being screened using a series of sieves and the resultant three fractions – main, coarse and fines - of wood chips obtained at the end of the sieve analysis. In this example, the fraction on the top sieve is the coarse fraction, the chips collected in the middle screens are the main fraction, which forms the majority of the wood chips, and the fraction collected in the bottom pan is the fines fraction.

Figure 16. Sieve analysis of wood chips (picture taken while analysis is in progress) and three screened fractions of wood chips. Photographs courtesy of Confederation College, Thunder Bay, Ontario.
It is important to have information both on the particle size range of the main fraction of the wood fuel and the weight percentages of coarse and fine particles. For example, the main fraction could have a minimum weight percentage requirement in order to achieve a quality standard by limiting the amount of coarse and fine particles within the fuel. Wood pellets have very low percentage of coarse and fine particles; whereas wood chips will often have more coarse and fine particles depending on how well the fuel is screened during its manufacture before its use as a fuel.

4.2.3 Bulk Density

Bulk density is defined as a mass per unit volume and is abbreviated as BD. It is beneficial for a fuel to be dense as it will contain more energy per unit volume. This in turn, makes it more economical to transport and store as it takes up less space for the same amount of energy that can be produced.

One of the major perceived drawbacks of using wood fuels in comparison to conventional fossil fuels is the low bulk density. As a result, densification may be used to improve the quality of a wood fuel.

4.2.4 Energy Content

Energy content refers to a measurement of the energy contained within a fuel per unit of mass in units such as megajoules per kilogram (MJ/kg) or British Thermal Unit per pound (Btu/lb). Energy content is abbreviated as Q. It is often measured by the calorific value; the amount of heat released from the complete combustion of a specific amount of fuel. Terminologies of energy content, calorific value or heating value are used interchangeably.

The energy content can be expressed in two ways: the gross calorific value (GCV) and the net calorific value (NCV). The GCV, referred to as the High Heating Value (HHV), is most often used in North America. It describes the total energy produced, including the energy contained in water vapour. This energy is released through the condensation of the vapour. The NCV, more commonly used in Europe, is also called the Low Heating Value (LHV). This term describes the amount of energy produced, not including the energy released from the condensation of the water vapour. For biofuels, there is approximately a 5 to 8% difference between the values recorded for the HHV and LHV, where the HHV is always larger.

Energy content is largely impacted by moisture content and can be reported on a wet basis (w.b.) or on a dry basis (d.b.). As shown in Figure 17, the heating value decreases as the moisture content increases. It should be noted that when compared on dry weight basis, at 0% moisture content, the GCVs of all the traded forms of woody solid biofuels fit to a narrow range and vary between 20 to 21 MJ/kg. There is little practicable difference between softwoods and hardwoods, but softwoods have a slightly higher heating value than that of hardwoods. The ash content may also impact the heating value, but to a lesser degree.
4.2.5 Ash Content

Ash is the inorganic residue remaining after the combustion of a fuel. It can be abbreviated as A. The ash content in a fuel is generally expressed as a mass percentage of the sample on a dry basis.

Ash in wood fuel comes from two main sources: (i) naturally occurring minerals and (ii) dirt and debris entrained from soil during harvesting and handling. As described in chapter 3, ash from wood combustion is primarily comprised of inorganic salts, bound in the C structure of the fuel. It is mainly composed of alkali minerals—such as calcium, potassium and sodium—along with magnesium and silica. Entrained ash is present as a result of activities throughout the supply chain. This includes the addition of mineral particles from dirt or clay from the harvest or transportation of the woody biomass.

Ash content depends on tree type, the part of the tree used, the growth conditions and soil type. Bark has higher ash content than white wood.

The presence of alkali minerals lowers the softening and melting temperature of ash (from 1700°C for pure silica to less than 800°C). This could cause ash to form clinkers and/or slag (i.e., fused ash in glassy form) and lead to premature boiler shut down.

![Figure 17. Calorific value of wood fuel as a function of moisture content](image)

Figure 17. Calorific value of wood fuel as a function of moisture content
4.3 Wood Fuel Quality Standards

There is a wide range of wood fuels potentially suitable for energy use, and the properties of one wood fuel can vary significantly from another as shown in Table 5. Combustion equipment is designed with a known set of fuel specifications and manufacturer’s operational performance can be met if the fuel specifications stay within the designed range. If the wood fuel quality changes from one fuel delivery to the next, for example it becomes wetter or drier or it becomes coarser or finer, then the equipment performance would be impacted (i.e., lower efficiency, increased emissions, and operational problems).

Table 5. Comparison of key properties for major traded forms of wood fuels

<table>
<thead>
<tr>
<th>Key Properties</th>
<th>Hog Fuel</th>
<th>Firewood</th>
<th>Wood Chips</th>
<th>Briquettes</th>
<th>Wood Pellets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content (Weight %)</td>
<td>High</td>
<td>High-Medium</td>
<td>High-Medium</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Bulk Density (kg/m³)</td>
<td>Low</td>
<td>Low</td>
<td>Low-Medium</td>
<td>Medium-High</td>
<td>High</td>
</tr>
<tr>
<td>Energy Content (MJ/kg)</td>
<td>Low</td>
<td>Low-Medium</td>
<td>Medium</td>
<td>Medium-High</td>
<td>Medium-High</td>
</tr>
</tbody>
</table>

To accurately describe fuel quality, standards specifically designed for fuel from biomass origins, including woody biomass, have been developed. With standardization the consumers, suppliers, and regulators can have confidence in the consistency and performance of solid biofuels and the equipment manufacturers can design and engineer their systems to match the fuel specifications.

Standards can be either voluntary or mandatory. Voluntary standards are typically developed through the cooperation of all parties who have an interest in participating in the development and/or use of the standards. Mandatory standards are standards that require compliance. A voluntary standard may become mandatory as a result of its use, reference, or adoption by a regulatory authority, or when invoked in contracts, purchase orders, or other commercial instruments. A product can be certified by a recognized third party authority which means that the product is inspected, evaluated, tested, or otherwise determined to be in conformance or compliance with referenced standards. Certified products imply a guarantee or warranty of product conformance and that the product is under the test and surveillance procedures of a specified certification system. In the section below, a brief description is presented on the standards and certification

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systems that are currently available and applicable to wood fuels, particularly wood pellets.

4.3.1 CAN/CSA-ISO Solid Biofuel Standards 17225 Part 1 - 8

ISO, with the assistance of a technical committee comprised of 24 participating countries and 14 observing countries, has developed voluntary standards for solid biofuels. These standards mirror the EN 14961 series, developed by the European Committee for Standardization from 2010 to 2012. The ISO standards are being adopted for use in Canada by the CSA Group and the first series of the CAN/CSA-ISO 17225 standards Part 1 to 7 were published in March of 2015 and Part 8 is under development as of the writing of this document. The CAN/CSA-ISO Solid Biofuels Standards are voluntary standards.

The CAN/CSA-ISO 17225 series provides classifications for solid biofuels originating from forestry and arboriculture, agriculture and horticulture, and aquaculture. The standards provide details on fuel quality classes and specifications based on major traded forms and applications of solid biofuels, as shown in Table 6.

Table 6. CAN/CSA-ISO standards under the general title: Solid biofuels – Fuel specifications and classes

<table>
<thead>
<tr>
<th>Standard Number</th>
<th>Standard Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAN/CSA-ISO 17225-1</td>
<td>Part 1: General requirements</td>
</tr>
<tr>
<td>CAN/CSA-ISO 17225-2</td>
<td>Part 2: Graded wood pellets</td>
</tr>
<tr>
<td>CAN/CSA-ISO 17225-3</td>
<td>Part 3: Graded wood briquettes</td>
</tr>
<tr>
<td>CAN/CSA-ISO 17225-4</td>
<td>Part 4: Graded wood chips</td>
</tr>
<tr>
<td>CAN/CSA-ISO 17225-5</td>
<td>Part 5: Graded firewood</td>
</tr>
<tr>
<td>CAN/CSA-ISO 17225-6</td>
<td>Part 6: Graded non-woody pellets</td>
</tr>
<tr>
<td>CAN/CSA-ISO 17225-7</td>
<td>Part 7: Graded non-woody briquettes</td>
</tr>
<tr>
<td>CAN/CSA-ISO 17225-8</td>
<td>Part 8: Thermally treated and densified biomass fuels (in development as of the writing of this document)</td>
</tr>
</tbody>
</table>

Within the CAN/CSA-ISO 17225 standards, the term “graded” means that solid biofuel is used either in commercial applications (households, small commercial and public sector buildings) or industrial applications. The type of application demands the use of fuels with specified quality (properties) expressed by quality classes (such as A1, A2 or B). The CAN/CSA-ISO 17225 Solid biofuels – Fuel specifications and classes Part 1: General requirements assigns classification following a hierarchical system for sources and origins, followed by major traded forms of solid biofuels (such as firewood, wood pellets, bales etc.), followed by specifications for physical and chemical properties.

The CAN/CSA-ISO 17225 Solid biofuel standards group properties into (i) normative properties, which are prescriptive and are a requirement indicating how to comply and (ii) informative properties, which are descriptive indicating supplemental information and are not a requirement for compliance. For wood chips the normative properties are
particle size, moisture and ash contents. For wood pellets, the normative properties include the mechanical durability, the amount of fines and bulk density in addition to particle size, moisture content and ash content. Threshold values of elements such as N, S and Cl, can also be defined as normative properties and contribute to the grading process. When necessary, restrictions are placed on the weight fractions of other minor elements such as heavy metals. Chemically treated woods, defined as those undergoing any treatment with chemicals other than air, water or heat, are restricted such that the amounts of heavy metals or halogenated organic compounds must not be more than typical virgin material values or typical values for the country of origin.

Grade values for residential, commercial, and industrial applications are denoted by the letters A, B and I, respectively, with additional subdivisions indicated by numbers. Wood pellets are graded as A1, A2 and B for residential and commercial applications; A1 being the highest quality wood pellet as shown in Table 7. Wood pellets graded as I1, I2 and I3 are for industrial applications as shown in Table 8. Wood chips are graded as A1, A2, B1 or B2 as shown in Table 9. Grade A1 wood chips represent low moisture content, indicating the chips were subjected to drying process, and low ash content, indicating the absence of extraneous substances (e.g., foreign materials such as dirt and grit). Table 10 summarizes particle size ranges for wood chips under CANCSA-ISO 17225:4.

In addition to the fuel grading standards, other new standards for sampling and testing methodologies for verification purposes and for the safe handling and storage of pellets are also being developed by ISO and adopted by CSA Group.
Table 7. Key fuel parameters for graded wood pellets for residential and commercial applications under CAN/CSA-ISO: 17225-2\(^{41}\)

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Grade A1</th>
<th>Grade A2</th>
<th>Grade B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin and source, CAN/CSA-ISO 17225-1(^{42})</td>
<td>N/A</td>
<td>• Stemwood</td>
<td>• Same as A1, plus</td>
<td>• Forest, plantation and other virgin wood</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Chemically untreated wood residues from wood processing industry(^{43})</td>
<td>• Whole trees without roots</td>
<td>• By-products and residues from wood processing industry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Logging residues(^{44},45)</td>
<td>• Chemically untreated used woods(^{46})</td>
</tr>
<tr>
<td>Diameter (D)</td>
<td>mm</td>
<td>6 ± 1 or 8 ± 1</td>
<td>Same as A1</td>
<td>Same as A1</td>
</tr>
<tr>
<td>Length (L)</td>
<td>mm</td>
<td>3.15 &gt; L ≤ 40</td>
<td>Same as A1</td>
<td>Same as A1</td>
</tr>
<tr>
<td>Bulk density (BD)</td>
<td>kg/m(^3) as received</td>
<td>600 ≥ BD ≤ 750</td>
<td>Same as A1</td>
<td>Same as A1</td>
</tr>
<tr>
<td>Mechanical Durability (DU)</td>
<td>w-%</td>
<td>≥ 97.5</td>
<td>Same as A1</td>
<td>≥ 96.5</td>
</tr>
<tr>
<td>Fines (F)</td>
<td>w-%</td>
<td>&lt; 1</td>
<td>Same as A1</td>
<td>Same as A1</td>
</tr>
<tr>
<td>Moisture (M)</td>
<td>w-% as received</td>
<td>≤ 10</td>
<td>Same as A1</td>
<td>Same as A1</td>
</tr>
<tr>
<td>Ash (A)</td>
<td>w-% dry</td>
<td>≤ 0.7</td>
<td>≤ 1.2</td>
<td>≤ 2.0</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>w-% dry</td>
<td>≤ 0.3</td>
<td>≤ 0.5</td>
<td>≤ 1.0</td>
</tr>
<tr>
<td>Net calorific value (Q)</td>
<td>MJ/kg</td>
<td>≥ 16.5</td>
<td>Same as A1</td>
<td>Same as A1</td>
</tr>
</tbody>
</table>


\(^{43}\) Mill residues from the production of lumber, sawdust shavings and cut-offs from dimension lumber production.

\(^{44}\) Portions of trees harvested in logging operations that are not utilized, such as the side branches, bark and other wood and tree waste.


\(^{46}\) Post-consumer recycled wood, and, construction and demolition wood.
Table 8. Key fuel parameters for graded wood pellets for industrial use under CAN/CSA-ISO 17225-2\textsuperscript{47}

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Grade I1</th>
<th>Grade I2</th>
<th>Grade I3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin and source, ISO 17225-1</td>
<td>N/A</td>
<td>Forest, plantation and other virgin wood</td>
<td>Same as I1</td>
<td>Forest, plantation and other virgin wood</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chemically untreated wood residues from wood</td>
<td></td>
<td>By-products and residues from wood processing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>processing industry</td>
<td></td>
<td>industry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Chemically</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>untreated used woods</td>
</tr>
<tr>
<td>Diameter (D)</td>
<td>mm</td>
<td>6 ± 1 or 8 ± 1</td>
<td>6 ± 1 or 8 ± 1</td>
<td>6 ± 1 or 8 ± 1 or 10 ± 1 or 12 ± 1</td>
</tr>
<tr>
<td>Length (L)</td>
<td>mm</td>
<td>3.15 &gt; L ≤ 40</td>
<td>Same as I1</td>
<td>Same as I1</td>
</tr>
<tr>
<td>Bulk density (BD)</td>
<td>kg/m\textsuperscript{3} as received</td>
<td>600 ≥ BD ≤ 750</td>
<td>Same as I1</td>
<td>Same as I1</td>
</tr>
<tr>
<td>Mechanical Durability (DU)</td>
<td>w-%</td>
<td>97.5 ≥ DU ≤ 99.0</td>
<td>97.0 ≥ DU ≤ 99.0</td>
<td>96.5 ≥ DU ≤ 99.0</td>
</tr>
<tr>
<td>Fines (F)</td>
<td>w-%</td>
<td>&lt; 4.0</td>
<td>&lt; 5.0</td>
<td>&lt; 6.0</td>
</tr>
<tr>
<td>Moisture (M)</td>
<td>w-% as received</td>
<td>≤ 10</td>
<td>Same as I1</td>
<td>Same as I1</td>
</tr>
<tr>
<td>Ash (A)</td>
<td>w-% dry</td>
<td>≤ 1.0</td>
<td>≤ 1.5</td>
<td>≤ 3.0</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>w-% dry</td>
<td>≤ 0.3</td>
<td>Same as I1</td>
<td>≤ 0.6</td>
</tr>
<tr>
<td>Net calorific value (Q)</td>
<td>MJ/kg</td>
<td>≥ 16.5</td>
<td>Same as I1</td>
<td>Same as I1</td>
</tr>
</tbody>
</table>

Table 9. Key fuel parameters for graded wood chips under CAN/CSA-ISO 17225-4

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Grade A1</th>
<th>Grade A2</th>
<th>Grade B1</th>
<th>Grade B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin and source, CAN/CSA-ISO 17225-1</td>
<td>N/A</td>
<td>• Whole trees without roots</td>
<td>• Same as A1</td>
<td>• Forest, plantation and other virgin wood</td>
<td>• Forest, plantation and other virgin wood</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Stemwood</td>
<td></td>
<td>• Chemically untreated wood residues</td>
<td>• By-products and residues from wood processing industry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Logging residues</td>
<td></td>
<td></td>
<td>• Chemically untreated used wood</td>
</tr>
<tr>
<td>Moisture (M)</td>
<td>w-%, wet</td>
<td>≤ 10 or ≤ 25</td>
<td>≤ 35</td>
<td>Maximum value to be stated</td>
<td>Same as B1</td>
</tr>
<tr>
<td>Ash (A)</td>
<td>w-% dry</td>
<td>≤ 1.0</td>
<td>≤ 1.5</td>
<td>≤ 3.0</td>
<td>Same as B1</td>
</tr>
<tr>
<td>Bulk density (BD)</td>
<td>kg/loose m³</td>
<td>≥ 150 or ≥ 200 or ≥ 250</td>
<td>≥ 150 or ≥ 200 or ≥ 250</td>
<td>Minimum value to be stated</td>
<td>Same as B1</td>
</tr>
</tbody>
</table>

Table 10. Particle size of graded wood chips under CAN/CSA-ISO 17225-4

<table>
<thead>
<tr>
<th>Particle Class</th>
<th>Main Fraction (mm)</th>
<th>Fines Fraction (mm)</th>
<th>Course Fraction (length in mm)</th>
<th>Maximum Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P16S</td>
<td>3.15 &lt; P ≤ 16 (≥60 % weight)</td>
<td>P ≤ 3.15 (≤ 15 % weight)</td>
<td>P &gt; 31.5 (≤ 6% weight)</td>
<td>P ≤ 45</td>
</tr>
<tr>
<td>P31S</td>
<td>3.15 &lt; P ≤ 31.5 (≥60 % weight)</td>
<td>P ≤ 3.15 (≤ 10 % weight)</td>
<td>P &gt; 45 (≤ 6% weight)</td>
<td>P ≤ 150</td>
</tr>
<tr>
<td>P45S</td>
<td>3.15 &lt; P ≤ 45 (≥60 % weight)</td>
<td>P ≤ 3.15 (≤ 10 % weight)</td>
<td>P &gt; 63 (≤ 10% weight)</td>
<td>P ≤ 200</td>
</tr>
</tbody>
</table>

51 Particle size defines size range as well as minimum weight percentage for the main fraction, fines and coarse particles.
52 “S” in the particle size (P16S or P31S or P45S) denotes for small-scale combustor use.
4.3.2 CANplus/ENplus Certifications of Wood Pellets

The European Biomass Association voluntary wood pellet certification program, ENplus, was launched in 2010 and adopted for use in Canada in 2013 under the brand CANplus (Figure 18). Managed by the Wood Pellet Association of Canada, CANplus currently employs an identical set of parameters as the ENplus certification and corresponds to the fuel specifications and grading system of the ISO 17225 series. The certification also covers other aspects of the supply chain, including chain of custody and quality management certifications. Pellet producers, traders and service providers can all be certified under ENplus and CANplus. Sustainability criteria stipulated by the Forest Stewardship Council or the Programme for the Endorsement of Forest Certification are also covered under the certifications in order to confirm that environmental, socioeconomic and cultural accountabilities are met.

In the CANplus program, annual inspections are required during a three-year term, after which a company needs to renew their certification. Inspections include, but are not limited to, the testing of product, verification of origins, equipment inspections, checks of quality management and complaint management systems, and validation of self-inspections. Additional information on the ENplus and CANplus programs can be found at: http://www.pellet.org.

Figure 18. CANplus certification seals

4.3.3 Pellet Fuel Institute Standards and Certification for Wood Pellets

Wood pellet standards and certifications have been developed within the United States that are separate from ISO standards and ENplus certification. In March 2015, the United States Environmental Protection Agency mandated through New Source Performance Standards that new, non-commercial wood-burning appliances are required to use graded fuels, certified under an authorized standards program, such as the Pellet Fuels Institute (PFI) Standards Program that was introduced in late 2011. As a result, most Canadian wood pellets are also certified under the PFI Standards Program and bear its Quality Mark, shown in Figure 19, on their packaging.

Figure 19. Pellet Fuels Institute quality mark and property specifications

The PFI program is a third party accreditation process for producers of pellets for residential and commercial applications. In examining similar chemical and physical properties as in the ISO standards, fuels are assigned a grade of Premium, Standard, or Utility, as shown in Table 11. The program differs from the ISO standards as it is not primarily based on the origin and sources of the woody biomass. There are, however, restrictions to the types of woody biomass that can be used; chemically treated materials are not accepted as raw material, and post-consumer recycled wood and construction waste debris must be verified as clean. Additional grading and certification information can be found at: http://www.pelletheat.org/joining-the-standards-program.

Table 11. Key fuel parameters for PFI graded wood pellets

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Premium Grade</th>
<th>Standard Grade</th>
<th>Utility Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>in</td>
<td>0.230-0.285</td>
<td>0.230-0.285</td>
<td>0.230-0.285</td>
</tr>
<tr>
<td>Diameter</td>
<td>mm</td>
<td>6-7.25</td>
<td>6-7.25</td>
<td>6-7.25</td>
</tr>
<tr>
<td>Fines</td>
<td>w-%</td>
<td>≤ 0.50</td>
<td>≤ 1.0</td>
<td>≤ 1.0</td>
</tr>
<tr>
<td>Moisture</td>
<td>w-%, wet</td>
<td>≤ 8.0</td>
<td>≤ 10.0</td>
<td>≤ 10.0</td>
</tr>
<tr>
<td>Inorganic ash</td>
<td>w-%</td>
<td>≤ 1.0</td>
<td>≤ 2.0</td>
<td>≤ 6.0</td>
</tr>
<tr>
<td>Durability index</td>
<td>N/A</td>
<td>≥ 96.5</td>
<td>≥ 95.0</td>
<td>≥ 95.0</td>
</tr>
<tr>
<td>Bulk density</td>
<td>lb/ft³</td>
<td>40.0-48.0</td>
<td>38.0-48.0</td>
<td>38.0-48.0</td>
</tr>
<tr>
<td>Bulk density</td>
<td>kg/m³</td>
<td>640-770</td>
<td>610-770</td>
<td>610-770</td>
</tr>
<tr>
<td>Heating value</td>
<td>Btu/lb</td>
<td>To be stated</td>
<td>To be stated</td>
<td>To be stated</td>
</tr>
</tbody>
</table>

4.3.4 Biomass Energy Resource Centre Specifications for Wood Chips

Certification of wood chips in the United States is not mandatory, though fuel specifications exist in the Northeastern states. Created by the Biomass Energy Resource Center, these specifications more closely follow the ISO 17225 series. Wood chips are given a Grade A, B, C, or D based primarily on their origins, while certain chemical and physical properties are also required to be within an accepted range of values. The complete specifications can be found at: [http://www.biomasscenter.org/images/stories/Woodchip_Heating_Fuel_Specs_electroni c.pdf](http://www.biomasscenter.org/images/stories/Woodchip_Heating_Fuel_Specs_electroni c.pdf). Accessed September 2015.

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5 Review of Selected Jurisdictions’ Regulatory Regimes

The purpose of this chapter is to describe the regulatory regimes in selected jurisdictions for small wood-fired combustors (SWFC) with a heat input capacity of less than three megawatts (<3 MW). Regulatory information for wood burning appliances with a heat output of less than 150 kilowatts (<150 kW) is only briefly described as they are excluded from Guideline A-14. The jurisdictions selected for review were chosen based on two criteria: (i) they had current and comprehensive information concerning air emission limits and/or air permitting regulations for SWFC, and (ii) they had a progressive and robust regulatory framework for SWFC that is consistent with current best-in-class manufacturer’s capabilities.

Due to the variety of reported air emission units of measure utilized by the selected jurisdictions, all of which are reported on a dry basis, the reported units are provided herein as stated in the cited reference document. Where possible, the equivalent units have been calculated according to Ontario’s reporting standard (at 25 degrees Celsius (°C) and 11 per cent (%) oxygen gas (O₂)) and Europe’s most common reporting standard (at 0°C and 10% O₂) using standard industry parameters. For example, the specific dry flue gas volume (SDFGV) per gigajoule (GJ) of heat input for wood was chosen to be 253 cubic metres per gigajoule (m³/GJ)56 for stoichiometric conditions of 0% O₂ referenced at 0°C and standard pressure of 101.3 kilopascals. For purposes of converting units, this SDFGV is equivalent to 483 m³/GJ at 10% O₂ and 531 m³/GJ at 11% O₂.

Also, many different air emissions are cited across the selected jurisdictions such as carbon monoxide (CO), particulate matter (PM), organic gaseous carbon (OGC) and oxides of nitrogen (NOx). However, CO and PM (frequently referred to as “dust” in European documents) were the most commonly cited air emissions and will therefore be the focus of this chapter so that the air emission limits can be compared across jurisdictions. The sampling and reporting methods amongst the jurisdictions can vary, especially for PM, so the stated equivalent units are therefore not always exactly representative, but are considered informative for discussion purposes within the context of this document.

5.1 Mandatory and Voluntary Performance Standards

To simplify the regulatory regime for manufacturers, owners, and regulators of SWFC and thereby reduce administrative burdens, jurisdictions in North America and Europe have initiated both mandatory and voluntary pre-qualification processes that allow manufacturers to demonstrate the performance of their SWFC to the regulators before

selling it to a customer and, where required, engaging with the regulator to obtain a permit.

5.1.1 Canadian Standards Association B415.1-10

The standard for SWFC in Canada has been developed by the Technical Committee for the Performance Testing of Solid Fuel Burning Heating Appliances under the auspices of the Canadian Standards Association (CSA) Group. This voluntary standard “Performance testing of solid-fuel-burning heating appliances”, referred to as CSA B415.1-10, describes performance testing methods. It is used by manufacturers, regulatory agencies and testing laboratories to determine heat energy outputs, thermal efficiency, PM emission levels and composition, and flue gas flow rates.\textsuperscript{57} The scope of CSA B415.1-10 is limited to wood burning appliances whose heat energy output is rated at less than 150 kW. It was written in 2010 and re-affirmed by CSA Group in 2015.

These wood burning appliances include manually and automatically fuelled stoves, fireplace inserts and factory-built fireplaces with minimum burn rates less than 5 kilograms per hour, as well as furnaces and hydronic heaters. As such, the standard is referenced in federal, provincial and municipal legislation relating to energy efficiency and the maximum PM emission rates. In particular, the CSA B415.1-10 sets PM emission limits of 4.5 grams per hour (g/hr) for non-catalytic wood stoves, and 2.5 g/hr for catalytic wood stoves. There are no emissions limits for carbon monoxide.

In Ontario, CSA B415.1-10 is referenced in the Ontario Building Code within Ontario Regulation 332/12.\textsuperscript{58} Other relevant CSA standards referenced within the Ontario Building Code pertaining to SWFC include:

- CSA B214-12 Installation code for hydronic heating systems
- CSA B365-10 Installation code for solid-fuel-burning appliances and equipment
- CSA B366.1-11 Solid-fuel-fired central heating appliances

5.1.2 United States Environmental Protection Agency Standards

The United States Environmental Protection Agency (USEPA) sets the mandatory standard for all wood burning stoves and fireplace inserts to be sold in the United States. Appliances are required to be tested by an accredited laboratory and meet the standards set by the USEPA \textit{Title 40 of the Code of Federal Regulations (CFR), Part 60 – Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces}, under the \textit{Clean Air Act}.\textsuperscript{59} These standards


were updated on March 16, 2015 and apply to NAICS codes for heating equipment that are primarily for residential use.

As part of this update, the USEPA implemented New Source Performance Standards (NSPS) for residential wood heaters under Section 111 of the Clean Air Act. As of May 15, 2015, new residential wood heaters will be required to meet the PM emission limit of 4.5 g/hr for catalytic and non-catalytic stoves. After a period of five years, the PM emission limit will be reduced to 2.0 g/hr for catalytic and non-catalytic stoves. Before the implementation of these new standards, Washington was the only state to have stricter standards for SWFC than the federal USEPA standard. With the NSPS, however, both the Washington State and USEPA standards are now congruent along with CSA B415.1-10.

5.1.3 European Standard EN 303-5 (2012)

The European Standard EN 303-5 (2012 edition) is currently the overarching quasi-mandatory standard for the European Union (EU) that deals specifically with solid fuel heating boilers, manually and automatically stoked, with a nominal heat output capacity of up to 500 kW. According to the standard, the national standard bodies of EU member countries are bound to implement this standard which then makes it mandatory within each jurisdiction. The standard outlines requirements for testing methods, combustion emissions, thermal efficiency, operating characteristics, as well as the manufacturing and maintenance of boilers. It also specifies design requirements, control, and safety requirements, and marking requirements. The standard distinguishes between biogenic fuels and fossil fuels. The biogenic fuels are most relevant for this document given that they denote the following types of fuel: log wood, chipped wood, compressed wood (pellets, briquettes), sawdust, and non-woody biomass.

The 2012 version replaced the original version of the standard that was published in 1999. The EN 303-5 (2012) standard defines three boiler classes (3, 4 and 5) with specific emission limits for each. This is an update to the three boiler classes (1, 2 and 3) defined in the 1999 version where class 3 is common to both versions and classes 1 and 2 were omitted from the 2012 update. In order for a boiler to meet the requirements of a specific class, it must meet all efficiency and emission limits required for that


Table 12 summarizes the EN 303-5 (2012) requirements for boiler classes 3, 4 and 5 regarding thermal efficiency and emission limit values for CO and PM (referred to as dust) for automatic stoked systems. For reference, the Ontario equivalent values are also shown on Table 12 (CO: parts per million by volume (ppmv) corrected to 11% O₂ and 25°C and PM: milligrams per cubic metre (mg/m³) corrected to 11% O₂ and 25°C).

<table>
<thead>
<tr>
<th>Nominal Heat Output (kW)</th>
<th>Boiler Class</th>
<th>Thermal Efficiency (%)</th>
<th>Carbon Monoxide (EU units, mg/Nm³ at 10% O₂ and 0°C)</th>
<th>Carbon Monoxide (ON units, ppmv at 11% O₂ and 25°C)</th>
<th>Particulate Matter (EU units, mg/Nm³ at 10% O₂ and 25°C)</th>
<th>Particulate Matter (ON units, mg/Rm³ at 11% O₂ and 25°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤50</td>
<td>3</td>
<td>82</td>
<td>3,000</td>
<td>2,179</td>
<td>150</td>
<td>125</td>
</tr>
<tr>
<td>&gt;50≤150</td>
<td>3</td>
<td>82</td>
<td>2,500</td>
<td>1,816</td>
<td>150</td>
<td>125</td>
</tr>
<tr>
<td>&gt;150≤500</td>
<td>3</td>
<td>82</td>
<td>1,200</td>
<td>872</td>
<td>150</td>
<td>125</td>
</tr>
<tr>
<td>≤500</td>
<td>4</td>
<td>84</td>
<td>1,000</td>
<td>726</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>≤500</td>
<td>5</td>
<td>89</td>
<td>500</td>
<td>363</td>
<td>40</td>
<td>33</td>
</tr>
</tbody>
</table>

A comparison of the CO and PM emission limits for automatic stoked systems between the 1999 and 2012 editions is provided in Figure 20. It is evident from this graph that the performance of the technology has increased significantly in order to achieve the significant reduction in air emissions. Of comparable significance is that these emission levels must be achieved not only at the nominal load (equal to the 100% firing rate) but also at the partial load (which cannot exceed 30% of the nominal load).

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62 EN 303-5, Heating Boilers – Part 5: Heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500kW- Terminology, requirements, testing and marking (EN 303-5:2012 (E)).
63 Ibid., 2012
5.1.4 Voluntary Pre-Qualification

In a few European jurisdictions, voluntary eco-labels exist for manufacturers of SWFC, including Nordic Swan, Der Blaue Engel, Umweltzeichen 37 and Flamme Verte. The voluntary eco-labels provide an opportunity for the manufacturer to design their products according to stricter emission requirements than the existing government regulations. Voluntary eco-labels are attractive for manufacturers due to the fact that they appeal to consumers. The purchaser can be assured that the product conforms to strict environmental requirements such as high efficiency and low emissions standards. In North America, the New York State Energy Research and Development Authority (NYSERDA) has initiated a call for qualified wood pellet boiler technologies up to 2 million British thermal units per hour (Btu/hr) (equivalent to 586 kW) through its

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Renewable Heat NY (RHNY) program to add to the current list of certified wood pellet boilers.

### 5.1.4.1 Nordic Swan

The Nordic Swan is a voluntary eco-label popular among Scandinavian countries. The eco-label evaluates the environmental impact of a product over its entire life cycle. The eco-label takes particular consideration on the impacts to the climate by examining carbon dioxide (CO₂) emissions in its evaluation. For boilers less than 300 kW, the Nordic Swan examines criteria related to high efficiency, and low emissions of PM, CO, and OGC. A summary of the Nordic Swan emission criteria for CO and PM are provided in Table 13 below showing the emission limits both under EU reporting standards (10% O₂ and 0°C) and Ontario reporting standards (11% O₂ and 25°C).

Table 13. Nordic Swan emission criteria for carbon monoxide and particulate matter in European Union (EU) units and converted to Ontario (ON) units.

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Carbon Monoxide</th>
<th>Particulate Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU units</td>
<td>400 mg/Nm³</td>
<td>40 mg/Nm³</td>
</tr>
<tr>
<td>ON units</td>
<td>291 ppmv</td>
<td>33 mg/Rm³</td>
</tr>
</tbody>
</table>

### 5.1.4.2 Der Blaue Engel

The Der Blaue Engel (Blue Angel) eco-label is an environmental label organized by the German federal government. Similar to the Nordic Swan, the eco-label evaluates the product over its entire life cycle. The eco-label assures consumers that the product meets the high standards of performance relating to the environment. Der Blaue Engel is for wood pellet boilers up to 50 kW or greater than 50 kW, and includes operating conditions for both nominal (full load at 100% firing rate) and partial load (30% firing rate) as per EN 303-5 (2012). A summary of the CO and PM emission limits are provided in Table 14.

Table 14. Summary of Der Blaue Engel carbon monoxide (CO) and particulate matter (PM) emission limits

<table>
<thead>
<tr>
<th>Air Emission</th>
<th>Boilers &lt;50 kW 100% Load</th>
<th>Boilers &lt;50 kW 30% Load</th>
<th>Boilers &gt;50 kW 100% Load</th>
<th>Boilers &gt;50 kW 30% Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>80 mg/Nm³</td>
<td>180 mg/Nm³</td>
<td>70 mg/Nm³</td>
<td>150 mg/Nm³</td>
</tr>
<tr>
<td>PM</td>
<td>20 mg/Nm³</td>
<td>40 mg/Nm³</td>
<td>20 mg/Nm³</td>
<td>40 mg/Nm³</td>
</tr>
</tbody>
</table>


5.1.4.3 Umweltzeichen 37

The Umweltzeichen 37 is an eco-label introduced by the Austrian government. The label is based on existing Austrian standards but has stricter emission limit values (ELV). The ELVs deal specifically with automatic and manual feed appliances. Similar to the other eco-labels mentioned, the Umweltzeichen 37 characteristics include life cycle assessment and supply chain stages, as social and environmental attributes. The eco-label has stricter standards than Austria’s ÖNORM EN 303-5. A manufacturer can achieve certification by meeting the specific requirements of the eco-label. There are different emission limits for wood pellets and wood chips at both nominal (full load at 100% firing rate) and partial load (30% firing rate) operation. A summary of the CO and PM emission limits are provided in Table 15 for automatic fed boilers; emission limits are reported using EU reporting standards of 10% O2 and 0°C and Ontario reporting standards of 11% O2 and 25°C.

Table 15. Summary of Umweltzeichen 37 (U37) carbon monoxide (CO) and particulate matter (PM) emission limits for automatic fed boilers including conversions to European Union (EU) and Ontario (ON) units

<table>
<thead>
<tr>
<th>Air Emission by Jurisdiction</th>
<th>Wood Pellets 100% Load</th>
<th>Wood Pellets 30% Load</th>
<th>Wood Chips 100% Load</th>
<th>Wood Chips 30 % Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO U37 units</td>
<td>60 mg/MJ</td>
<td>135 mg/MJ</td>
<td>150 mg/MJ</td>
<td>300 mg/MJ</td>
</tr>
<tr>
<td>CO EU units</td>
<td>124 mg/Nm³</td>
<td>279 mg/Nm³</td>
<td>311 mg/Nm³</td>
<td>621 mg/Nm³</td>
</tr>
<tr>
<td>CO ON units</td>
<td>90 ppmv</td>
<td>203 ppmv</td>
<td>225 ppmv</td>
<td>450 ppmv</td>
</tr>
<tr>
<td>PM U37 units</td>
<td>15 mg/MJ</td>
<td>15 mg/MJ</td>
<td>20 mg/MJ</td>
<td>20 mg/MJ</td>
</tr>
<tr>
<td>PM EU units</td>
<td>31 mg/Nm³</td>
<td>31 mg/Nm³</td>
<td>41 mg/Nm³</td>
<td>41 mg/Nm³</td>
</tr>
<tr>
<td>PM ON units</td>
<td>26 mg/Rm³</td>
<td>26 mg/Rm³</td>
<td>34 mg/Rm³</td>
<td>34 mg/Rm³</td>
</tr>
</tbody>
</table>

5.1.4.4 Flamme Verte

The Flamme Verte (Green Flame) is a voluntary eco-label created in 2000 by the French regulators and manufacturers of SWFC (closed fires, inserts, stoves, cookers and boilers). The purpose of the eco-label was to improve the performance of the SWFC appliances mentioned above. The performance criteria for the Flamme Verte label have been continuously improving over the years. According to a report by the

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European Commission, more than 50 companies sell appliances with the Flamme Verte label.  

5.1.4.5 State of New York

NYSERDA initiated a call for qualified wood pellet boiler technologies through its RHNY program\(^{70}\) to add to the current list of certified wood pellet boilers\(^{71}\). This list has been prepared in association with the list of qualified wood pellet boiler installers and contractors.

NYSERDA published the performance criteria for wood pellet boilers up to 2 million British thermal units per hour (MMBtu/hr) (equivalent to 586 kW). The thermal efficiency requirement, based on the high heating value of the wood fuel is 85%. The pellet boilers must be fully automatic for fuel feed and have sensors and controls to optimize combustion performance using a staged combustion design with lambda control. A summary of the NYSERDA CO and PM emission limits are provided in Table 16 as well as the EU and Ontario reporting standards (EU: 10% O\(_2\) and 0°C; ON: 11% O\(_2\) and 25°C).

Table 16. New York State Energy Research and Development Authority (NYSERDA) carbon monoxide (CO) and particulate matter (PM) emission limits for wood pellet small wood-fired combustors including conversions to European Union (EU) and Ontario (ON) standard units

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Carbon Monoxide</th>
<th>Particulate Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>NYSERDA units</td>
<td>270 ppmv at 7%O(_2)</td>
<td>0.08 lb/MMBtu</td>
</tr>
<tr>
<td>EU units</td>
<td>260 mg/Nm(^3)</td>
<td>71 mg/Nm(^3)</td>
</tr>
<tr>
<td>ON units</td>
<td>189 ppmv</td>
<td>59 mg/Rm(^3)</td>
</tr>
</tbody>
</table>

5.2 European Air Emission National Standards

As mentioned earlier, jurisdictions in the EU are intended to adopt the EN 303-5 standard for SWFC rated less than 300 kW (if using the 1999 version) or less than 500 kW (if using the 2012 version), but most have adopted the standard with modifications. Since the standard has not been harmonized across all EU member nations, individual national jurisdictions within the EU are able to establish emission standards that are either above or below the standards of EN 303-5. Examples of selected EU member nation air emission standards are provided below.

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\(^{69}\)Ibid., 2011.


5.2.1 Sweden

In Sweden, air emission limits are typically set for individual installations based on the Best Available Techniques (BAT). Permits and emission testing is updated if changes to the unit operation occur. The Swedish Environmental Protection Agency is the designated authority that would monitor performance and issue permits. Boiler testing follows the guidelines set out in the EN303-5 standard 1999 version. For boilers rated at less than 300 kW, emission limits are established following EN 303-5 with some slight modifications such as specific emission limits for CO among fireplaces and stoves. It should be noted that these standards do not apply to stoves that have been sold second hand.72

5.2.2 Denmark

Denmark follows Executive Order No. 1432 of November 12, 2007 which is the regulating instrument to control emissions from new stoves and boilers up to 300 kW installed after June 1st, 2008 that essentially follows the EN 303-5 standard, 1999 version.73 Existing stoves, however, are exempt from performance testing. Denmark is planning to introduce stricter standards in 2016 that will follow EN 303-5 (2012) Class 5 requirements; in particular, PM emissions are expected to be significantly reduced. Denmark has developed guidelines or the recommended emission limits for mass flows (measured in g/hr), emissions (measured in milligrams per normalized cubic metre, mg/Nm³) and carbon-values, which means “the total maximum approved contribution from an installation to the concentration of a pollutant in the air at ground level”.74 In particular, these emission limits are set for pollutants like NOx, CO, sulphur dioxide, and dust (PM).

5.2.3 Norway

Norway’s national standard is the NS 3058 which set the emission limits for stoves, fireplaces and boilers less than 50 kW. For units above 50 kW up to 300 kW the EN 303-5 standard, 1999 version class 3 requirements are used. Currently, the standard only regulates PM emissions. While most equipment must adhere to a maximum of 10

gPM/kg biofuel, if the stove or boiler is equipped with mechanisms for the catalytic cleaning of flue gas, this value is decreased to 5 gPM/kg biofuel.75

5.2.4 Germany

The DIN 4702 standard was published by Germany in 1990 and served as a precursor to the EN 303-5 standard 1999 version, with a primary focus on PM and CO emissions.76 The PM limits for SWFC are both stated at 150 mg/Nm³; however, DIN 4702 uses 13% O₂ whereas EN 303-5 uses 10% O₂ and as such the DIN 4702 PM emission level is actually higher on an equivalent basis. The CO emission limits varied from 500 to 4,000 mg/Nm³ depending on size because DIN 4702 established CO emission limits for the category size ranges 50 kW, 50-150 kW, 150-500 kW, 500 kW to 1 MW and 1-50 MW. The CO emission limits decreased as the size of the combustor increased.

In March 2010, the German Federal Environmental Agency enacted a new ordinance dealing specifically with emission limits for small heating appliances that utilize solid fuel with a specific emphasis on wood pellets. The “BlmSchv” or the German Federal Emissions Control Ordinance introduced lower CO and PM ELV for installations built as of March 2010 and served as a precursor to the updates to the 2012 version of EN 303-5, as the emission criteria are differentiated at above or below 500 kW. The PM levels are now 60-100 mg/Nm³ and the CO levels are 500-800 mg/Nm³. Stricter limits are proposed for installations starting operations in 2015, especially for PM.

5.2.5 Austria

Austria’s 1999 standard of ÖNORM EN 303-5 influenced the development of the 1999 version of European Standard EN 303-5 for solid-fuel boilers. However, the Austrian limits on CO and PM are below the limits set through the 1999 version of EN303-5.77 The country continues to follow this standard but has enacted regulations to improve boiler efficiency and emission controls. For instance, the PM emission limit is planned to be lowered from 60 down to 50 milligrams per megajoule (mg/MJ). A summary of the Austrian CO and PM emission limits for units less than 300 kW are provided in Table 17 as well as the EU and Ontario reporting standards (EU: 10% O₂ and 0°C; ON: 11% O₂ and 25°C).

77 Ibid., 2012.
Table 17. Austrian carbon monoxide and particulate matter emission limits for small wood-fired combustors less than 300 kW including conversions to European Union (EU) and Ontario (ON) units

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Carbon Monoxide</th>
<th>Particulate Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austrian units</td>
<td>500 mg/MJ</td>
<td>60 mg/MJ</td>
</tr>
<tr>
<td>EU units</td>
<td>1,035 mg/Nm³</td>
<td>124 mg/Nm³</td>
</tr>
<tr>
<td>ON units</td>
<td>751 ppmv</td>
<td>103 mg/Rm³</td>
</tr>
</tbody>
</table>

5.3 Environmental Permitting in Europe

Environmental permitting regulates the quantity of emissions that are released into the environment, primarily into the atmosphere. Depending on the jurisdiction and size of the project, meaning the unit’s heat input/output capacity, an environmental permit may or may not be required. However, for a project to be granted a permit, the project proponent typically submits an application document to the appropriate permitting authority which can include the municipal and/or sub-national governments. The permitting authority then reviews the application to determine if the application is complete or requires additional information. Once reviewed and approved, the application is typically given draft permit status which is then made available to the public for review through stakeholder engagement, public opinion, and consultations. The timeframe of this period is given a range of 30-45 days. After review, a final permit is granted but is still subject to appeal through a higher administrative body or court.

5.3.1 European Union

Currently, there is no overarching air emission permitting process for SWFC in Europe and the permits are issued independently within each jurisdiction according to the national regulatory regimes described in the preceding section of this document. However, environmental permitting in the EU may include an Environmental Impact Assessment (EIA) under the EIA Directive (85/337/EEC). EIAAs are required if a project is deemed to have a significant impact on the environment. To determine if a project requires an EIA, the national authorities determine the effects of a project on the basis of the jurisdiction’s particular thresholds. This process is defined as an “EIA screening”, which is a lengthy process performed by the relevant regulatory authorities. Generally, SWFC less than 3 MW do not require EIAs because they are below the size threshold for bioenergy projects. Some examples include: Belgium greater than 5 MW, France

greater than 4.5 MW, and Greece 2-50 MW. Denmark was the only jurisdiction found where an EIA is needed for units greater than 1 MW.79

The EN 303-5 air emission testing standards are utilized in the following countries with some national modifications as described earlier in this chapter: Finland, Sweden, Austria, Denmark and Germany. Boilers greater than 1 MW (or up to 4 MW in France) must be declared to the authorities and undergo mandatory air emission testing within the first year of use. Once testing has been completed, it is recommended that the operator or owner keep a copy of the test report. A re-test may be required should a complaint arise. Monitoring compliance is dependent on the regional or local requirements.

5.3.2 United Kingdom

The United Kingdom Department for Environment, Food and Rural Affairs has produced the Process Guidance Note 1/12(13), Statutory Guidance for Combustion of Waste Wood.80 The statutory note provides guidance on BATs detailing information concerning national regulations, compliance, emission limits, sampling, continuous monitoring, reporting, start up, shut down, training, maintenance, and other provisions. The statutory note also addresses combustion process control techniques based on programmable logic control of automated fuel feed, balanced primary and secondary air with a focus on O2 trim. The scope of the statutory note is directed towards the installation of SWFC with a net rated thermal input of 0.4 MW up to 3 MW, including where two or more appliances have a combined net rated thermal input in this range. The feedstock for these units is defined as “waste wood” and includes the introduction of off-cuts, briquettes, pellets, wood chips, sawdust and fine dust into the combustion chamber. Overall, the statutory note provides a strong framework for consistent and transparent regulation of installations regulated under the statutory Local Air Pollution Prevention and Control (LAPPC) regime in the United Kingdom (UK).

To ensure that a SWFC has been installed correctly, the SWFC requires an emission limit test for CO, PM, NOx and OGC to ensure compliance with the national standard. The LAPPC is the permitting authority and recognizes the statutory note when issuing permits for SWFC. Permits are issued once an application has been submitted and approved and the permit fee has been paid. After the LAPPC determines that the SWFC is compliant with the emission limit, records of the tests are recommended to be kept for at least two years along with the permit, and should be readily available to the examiner should a re-test be required. Although permits must be reviewed periodically,

the frequency is not specified by the LAPPC. Moreover, the document states that the frequency of re-testing depends on the local circumstances, and if complaints regarding a particular unit are being reported then annual testing could be imposed.

A summary of the UK emission limits for CO and PM for SWFC less than 3 MW as per the statutory note, differentiated according to new and existing units, is provided in Table 18 (reported at 11% O₂ and 0°C) as well as the EU and Ontario reporting standards (EU: 10% O₂ and 0°C; ON: 11% O₂ and 25°C). It is noted that all emission data is disregarded for the first 30 min following a cold start up.

Table 18. Summary of United Kingdom (UK) carbon monoxide (CO) and particulate matter (PM) emission limits for small wood-fired combustors less than 3 MW and converted to European Union (EU) and Ontario (ON) units

<table>
<thead>
<tr>
<th>Air emission by Jurisdiction</th>
<th>New Boilers 0.4-1 MW</th>
<th>Existing Boilers 0.4-1 MW</th>
<th>New Boilers 1-3 MW</th>
<th>Existing Boilers 1-3 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO UK units</td>
<td>250 mg/m³</td>
<td>250 mg/m³</td>
<td>150 mg/m³</td>
<td>150 mg/m³</td>
</tr>
<tr>
<td>CO EU units</td>
<td>275 mg/Nm³</td>
<td>275 mg/Nm³</td>
<td>165 mg/Nm³</td>
<td>165 mg/Nm³</td>
</tr>
<tr>
<td>CO ON units</td>
<td>200 ppmv</td>
<td>200 ppmv</td>
<td>120 ppmv</td>
<td>120 ppmv</td>
</tr>
<tr>
<td>PM UK units</td>
<td>60 mg/m³</td>
<td>200 mg/m³</td>
<td>60 mg/m³</td>
<td>200 mg/m³</td>
</tr>
<tr>
<td>PM EU units</td>
<td>66 mg/Nm³</td>
<td>220 mg/Nm³</td>
<td>66 mg/Nm³</td>
<td>220 mg/Nm³</td>
</tr>
<tr>
<td>PM ON units</td>
<td>55 mg/Rm³</td>
<td>183 mg/Rm³</td>
<td>55 mg/Rm³</td>
<td>183 mg/Rm³</td>
</tr>
</tbody>
</table>

The statutory note includes an innovative concept that identifies advanced combustion process control, such that “the requirement to continuously monitor carbon monoxide shall not apply providing the following conditions are met: (1) it can be demonstrated that there is consistency in fuel type and that fuel feed in continuous; and, (2) where automatic “oxygen trim” systems are in place such that the combustion air supply is dynamically regulated so as to maintain optimum oxygen (O₂) concentrations to ensure the efficient destruction of carbon monoxide.”

Where required, compliance monitoring of CO and O₂ is carried out by a continuous emissions monitor system (CEMS) and/or by a specific extractive test carried out at a frequency agreed with the regulator. The CEMS must be periodically calibrated in order to ensure accurate reporting of emissions, where a CEMS is required to be installed. If a unit does not have a CEMS, the regulator will perform an emission test and decide the frequency of testing required to ensure compliance. Depending on the margin gap between the emission level of the unit and the emission standards, and/or consistent emission compliance, the regulator may reduce or increase periodic testing. Changes to

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the unit that might affect the emission monitoring system would also trigger periodic emission testing.

In addition to the UK Guidance Note, the UK also provides a Renewable Heat Incentive (RHI) whereby the government provides financial support to both residential and commercial users of solid wood-fuel combustors. The purpose of the incentive is to replace fossil fuel use with renewable heating options in order to reduce greenhouse gas emissions and move toward a low carbon economy. In order to qualify for the RHI, operators must obtain an RHI emission certificate which states that the maximum permitted emissions are 30 grams per gigajoule (g/GJ) net heat input for PM and 150 g/GJ for NOx (expressed as NO2). It is noted that the 30 g/GJ emission criteria for PM is nearly identical to the 60 mg/m³ described above for new SWFC when corrected to equivalent units. The UK’s Gas and Electricity Market Authority are the administrators of the RHI which includes reviewing applications, issuing certificates, delivering incentive payments, and monitoring compliance based on the parameters set by the scheme.

5.4 Environmental Permitting in North America

5.4.1 Metro Vancouver, British Columbia

The local government of Metro Vancouver in British Columbia implemented the Greater Vancouver Regional District Boilers and Process Heaters Emission Regulation Amending Bylaw No. 1190 in 2013. This amending bylaw sets requirements for small and medium size biomass boilers rated less than 3 MW and between 3 MW and 50 MW, respectively. This amending bylaw was consolidated into the Greater Vancouver Regional District Boilers and Process Heaters Emission Regulation Bylaw No. 1087, 2008 that was originally adopted on October 24, 2008. A brief summary of the amended bylaw’s key points is provided in Table 19.

Table 19. Brief summary of key points for amending Bylaw No. 1190, 2013

<table>
<thead>
<tr>
<th>Title</th>
<th>Reference Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definitions</td>
<td>Biomass, good engineering practice, performance tune-up</td>
</tr>
<tr>
<td>General</td>
<td>SWFC to be maintained and operated as prescribed by the manufacturer; comply with a biomass fuel management plan</td>
</tr>
<tr>
<td>Emission Limits</td>
<td>&lt;3 MW: CO 250 ppm, PM 18 mg/m³ (corrected to 8% O₂ and 20°C)</td>
</tr>
<tr>
<td>Emission Stack</td>
<td>Minimum stack height 20 metres above ground level (unless</td>
</tr>
</tbody>
</table>

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otherwise approved by the district director) in accordance with methods set out by the American Society of Heating, Refrigerating and Air Conditioning Engineers

<table>
<thead>
<tr>
<th>Air Dispersion Modelling</th>
<th>Conduct according to the most recent version of the Guidelines for Air Quality Dispersion Modelling in British Columbia and assess for the following averaging times NOx (1-hour), PM10 and PM2.5 (24-hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission Testing</td>
<td>PM, CO, NOx, VOC within 3 months of commencing operation and subsequently once every calendar year if &gt;1 MW or as required by the district director if &lt;1 MW, at a firing rate 75% or greater</td>
</tr>
<tr>
<td>Record Keeping</td>
<td>For a minimum of 3 years, all inspections and maintenance, the type, source and amount of biomass fuel burned, emission testing results</td>
</tr>
<tr>
<td>CEMS</td>
<td>CO and O2 shall be installed, certified and operated in accordance with a quality assurance and/or quality control plan approved by the district director</td>
</tr>
<tr>
<td>Tune-ups</td>
<td>Biennial performance tune-up according to procedures recommended by the SWFC manufacturer and approved by the district director, not more than 26 months from the previous tune-up</td>
</tr>
</tbody>
</table>

A summary of the Metro Vancouver CO and PM emission limits (corrected to 8% O2 and 20°C) for units less than 3MW are provided in Table 20 as well as the EU and Ontario reporting standards (EU: 10% O2 and 0°C; ON: 11% O2 and 25°C).

Table 20. Metro Vancouver carbon monoxide (CO) and particulate matter (PM) emission limits for small wood-fired combustors less than 3 MW and converted to European Union (EU) and Ontario (ON) units.

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Carbon Monoxide</th>
<th>Particulate Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metro Vancouver units</td>
<td>250 ppmv</td>
<td>18 mg/m³</td>
</tr>
<tr>
<td>EU units</td>
<td>260 mg/Nm³</td>
<td>16 mg/Nm³</td>
</tr>
<tr>
<td>ON units</td>
<td>189 ppmv</td>
<td>14 mg/Rm³</td>
</tr>
</tbody>
</table>

The biomass fuel management plan is prepared by the project owner in accordance with the bylaw. The fuel management plan includes: (i) documenting fuel specifications such as acceptable fuel types, particle size range and moisture content, (ii) quality assurance plan including fuel testing, visual inspection and rejecting off-quality fuel, (iii) storage plan such as maximum storage times and storage of off-quality material, and (iv) record keeping requirements including fuel purchases, fuel use and reasons for rejecting off-quality material. The storage and handling of biomass must minimize fugitive particulate matter emissions.

Emission testing under the bylaw requires the measurement of PM, CO, NOx, and volatile organic compounds (VOC) at a firing rate of 75% or greater. Emission testing is required within three months of commencing operation, and is conducted once every
calendar year with a minimum of 300 days and a maximum of 430 days between each emission test where facility capacity exceeds 1 MW. For facility capacity under 1 MW, emission testing is conducted as may be required by the district director; thus the frequency of emission testing may vary.

All records and supporting documentation of inspections and maintenance, the date and time, and emission testing results, are recommended to be kept for a period of at least three years. Information pertaining to the type, source, and amount of fuels burned for biomass boilers should also be kept. Operators are required to have a CEMS installed near the biomass boiler exhaust. These are to be installed in accordance with the quality assurance/quality control plan approved by the district director. For facility capacity between 1 to 3 MW, the CEMS is required to measure CO and O2. For a facility capacity under 1 MW, the installation of CEMS near an exhaust is sufficient. As recommended by the manufacturer and approved by the district director, biomass boilers are required to conduct performance tune-ups every two years or no more than 26 months after previous tune-up.

5.4.2 Québec

In 2009, Québec adopted a regulation respecting wood-burning appliances, chapter Q-2, r.1 of the Environment Quality Act (chapter Q-2, ss. 31, 115.27, 115.34, 124.0.1 and 124.1), which states that all small wood-burning appliances manufactured, sold, offered for sale or distributed in Québec must meet the requirements set in the Act, except for boiler or furnaces with a heat output of more than 150 kW (outside the scope of CAN/CSA B415.1), maple syrup evaporators or wood burning appliances intended for export from Québec. This regulation is tailored specifically for small biomass heating systems.

Wood-burning appliances larger than 150 kW but less than 3 MW must meet the requirements set out in the Règlement sur l'assainissement de l'atmosphère, chapter Q-2, r.4.1 of the Loi sur la qualité de l'environnement, (chapter Q-2, a. 31, 53, 115.27, 115.34, 124.0.1 et 124.1). The PM emission criteria are 600 mg/Nm³ for existing SWFC and 150 mg/Nm³ for new SWFC, but there are no CO emission criteria.

5.4.3 American Federal Regulation: Clean Air Act

Currently, the United States of America does not have regulations that govern emission limits for SWFC less than 3 MW. The USEPA requirements that exist are only applicable to boilers whose thermal input size is greater than 10 MMBtu/hr (2.9 MW). As a result, the USEPA current regulation is out of scope for the purpose of this

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document. It should be noted, that all new or existing small biomass boilers that are below the 10 MMBtu/hr are still required to conduct tune-ups biennially starting no more than 25 months after initial start-up of the boiler as normally recommended by the boiler manufacturer.

Under the federal *Clean Air Act*, all states are required to have air operating permit programs for commercial, institutional, and industrial settings where there are “major sources” of air pollution. The operating programs are referred to as Title V Permits, or Part 70 Permits. These permitting programs outline specific requirements concerning standard operation and procedures, emission standards, monitoring, recordkeeping and reporting. This federal regulation evidently applies to boilers that meet the size threshold and the quantity of air pollutant emissions as defined in the *Clean Air Act*. As mentioned, SWFC less than 3 MW are outside the scope of the EPA’s regulation for commercial, institutional, and industrial permitting.

The implementation of air operating permit programs differs across states depending on the size and emission limit thresholds that have been established for boilers. For units not covered under the federal regulation (less than 2.9 MW), some states have introduced “minor new source permits” such as the state of Virginia. In most cases, for boilers below the 10 MMBtu/hr threshold, there is limited state regulation. Some states regulate boilers from 1 MMBtu/hr (293 kW) up to 10 MMBtu/hr (2.9 MW). In other states, regulation may be based on aggregate Btus, or thresholds on the amount in tons of emissions per year.

### 5.4.4 State Air Permitting Programs

A few of the Northeast States have specific air emission requirements for commercial boilers such as Massachusetts and New York where boilers that are above 1 MMBtu/hr (293 kW) or 2 MMBtu/hr (586 kW) for New Hampshire cannot emit PM at concentrations of more than 100-200 mg/m³, 600 mg/m³ and 300 mg/m³, respectively. Other states such as Connecticut, Maine, New Jersey, Rhode Island, and Vermont all require the implementation of a case-by-case Best Available Control Technology (BACT) determination.

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5.4.4.1 New Hampshire

The New Hampshire Department of Environmental Services (DES) is the air permitting body in the state of New Hampshire. The Administrative Rules Env-A 600 outlines the specific air permitting procedures and the sources that require permits for air emissions. New Hampshire defines the “sources” as stationary commercial and industrial facilities, or smaller stationary sources which include solid-fuel burning devices. The threshold set for solid wood fuel burning devices (e.g. biomass boilers) in New Hampshire is greater than 2 MMBtu/hr (586 kW).90

The state of New Hampshire air permitting process has two stages for SWFC. First, a temporary permit is issued before the installation of a unit for a period lasting no more than 18 months. The temporary permit is intended to establish the parameters of the device’s operation through an evaluation of certain criteria such as unit type, size, levels of production, and annual emission levels. The second stage is the issuance of a state permit to operate which is given for a period of five years once the unit has demonstrated compliance with all applicable air regulations.

Up until 2012, all units with an air permit were required to demonstrate compliance with the national ambient air quality standards (NAAQS), through the use of an USEPA approved dispersion modeling program. Currently, sources that are willing to accept certain emission limits would not be required to undergo modeling. Normally, where one unit is installed and is less than10 MMBtu/hr (2.9 MW), the operator would accept the permit limits and avoid modelling. New Hampshire’s air permitting sets emission limits on PM, sulphur dioxide (SO2), NOx, CO. State specific limits for biomass boilers less than 10 MMBtu/hr include a PM limit of 0.30 pounds per million British thermal units (lb/MMBtu) if installed after January 1985, and an opacity limit of 20% on a 6-minute average.91

New Hampshire’s air emission monitoring and compliance procedures include continuous and intermittent monitoring. CEMS are often installed on a stack or process ductwork to monitor emissions and pollutants such as NOx, CO2, SO2, etc. The CEMS records and archives air emissions data on a computer data acquisition system which is used to demonstrate compliance. Sources that have been issued a permit are normally required to report the air emissions report to the DES at least annually. If a CEMS is considered the tool for continuous monitoring by the state, New Hampshire requires that the CEMS undergo daily calibrations and quarterly audits as well as recertification at least once per year.

Overall, New Hampshire’s DES determines if it is necessary for a unit to demonstrate compliance with the applicable emission limits. According to the New Hampshire DES

91 Air Permit Programs Manager, NH Department of Environmental Services, personal communication, May 8, 2015.
“[d]epending on the situation or applicable regulations, the compliance emissions test may be required only once, or it may be required at regular intervals (e.g., once every 3-5 years) depending on the applicable rules or devices”.\textsuperscript{92} For units less than 3 MW, the state rarely requires a stack test, and CEMS do not need to be installed due to the size of the unit. A boiler may require a stack test if there is concern about the unit meeting an applicable PM limit.

5.4.4.2 Virginia

Virginia’s state regulation 9VAC Chapter 80 Permits for Stationary Sources provides thresholds to determine whether a unit requires an air emission permit.\textsuperscript{93} These thresholds include either a size/type exemption or based on emission levels. For SWFC such as boilers, units that are greater than 1 MMBtu/hr (293 kW) and higher require either a Minor New Source Review (NSR) Program permit, or a Biomass Pilot Test Facility General Permit. The NSR permit program is the more popular permitting program in the state of Virginia. It follows a similar permitting process whereby an application is filed along with an application fee. The application is reviewed within a specified timeframe and emission data is analysed by the state authority.

The Biomass Pilot Test Facility General Permit is strictly for a facility using biomass, but follows the same requirements as the NSR permit in terms of size, emission limits, and application process. For both permitting programs, there is no expiry date once a permit has been issued unless there are changes to the unit that would affect its air emissions, in which case the Virginia Department of Environmental Quality (DEQ) would re-issue a permit pending compliance verification with state standards.

If a unit is below the pollutant levels, they are exempt for either of the air permitting programs. Units that are above the exemption criteria, but emit less than 100 tons/year of PM, PM$_{10}$, PM$_{2.5}$, CO, NOx, SO$_2$, and VOC qualify for the two permits mentioned above. If a source is above the 100 tons/year threshold, it would require either a Major New Source Review permit or Title V permit. Virginia’s pollutant exemption levels for air permitting are provided below in Table 21.


\textsuperscript{93} Virginia Department of Environmental Quality. 2014. 9VAC5 Chapter 80 Permits for stationary sources – Part II Permit procedures, Article 6 Permits for new and modified stationary sources. Virginia Department of Environmental Quality. \texthtt{http://www.deq.virginia.gov/Portals/0/DEQ/Air/Regulations/806.pdf}. Accessed April 2015.
Table 21. Virginia criteria for permitting exemption

<table>
<thead>
<tr>
<th>Air Emission</th>
<th>New Source (tons/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>25</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>15</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>10</td>
</tr>
<tr>
<td>CO</td>
<td>100</td>
</tr>
<tr>
<td>NO$_{x}$</td>
<td>40</td>
</tr>
<tr>
<td>SO$_{2}$</td>
<td>40</td>
</tr>
<tr>
<td>VOC</td>
<td>25</td>
</tr>
</tbody>
</table>

Once a permit has been issued, the state of Virginia establishes certain monitoring and reporting requirements under their state regulations. Depending on the ruling of the Virginia DEQ, the monitoring requirements may include the installation, calibration, operation, and maintenance of equipment for continuously monitoring and recording emissions. The monitoring and reporting requirements are determined on a case-by-case basis. Any records regarding compliance and monitoring are recommended to be maintained and used for making emission reports to the Virginia DEQ (if required). The reports are intended to provide notifications, revisions, and results of emission tests as requested by the DEQ. These records are to be kept for a baseline period longer than three years.

5.4.4.3 Massachusetts

The Massachusetts Department of Environmental Protection (MassDEP) published a guidance report concerning air permitting and emission limits for solid-fuel biomass-fired boilers. Before the construction and installation of a unit, the MassDEP must provide a written approval of the Plan Application for the owner/applicant. For solid wood fuel combustors, a Comprehensive Plan Approval is required. Before a Plan Approval can be issued, the facility requires the utilization of the BACT.

The BACT are intended to follow the EPA’s NSPS or the National Emission Standards for Hazardous Air Pollutants. For wood furnaces or boilers, the BACT analysis often determines the emission limits for the particular facility on a case-by-case basis. The MassDEP does, however, provide guidance on emission limits for solid fuel biomass fired boilers. Operators seeking permits will also be required to undergo an air pollution control board regulations for the control and abatement of air pollution - 9VAC5 Chapter 80 – Permits for stationary sources, Part II permit procedures, Article 5. Virginia Department of Environmental Quality. <http://www.deq.virginia.gov/Portals/0/DEQ/Air/Regulations/805.pdf>. Accessed April 2015.

dispersion modeling to determine the air quality impact of a project and ensure it does not violate the NAAQS.

Given that BACT is determined on a case-by-case basis, it is difficult to assess the general monitoring and compliance procedures for SWFC in the entire state of Massachusetts.
6  Modern Small Wood-Fired Combustion Equipment Design

The purpose of this chapter is to describe modern small wood-fired combustion (SWFC) technology that is designed to achieve complete combustion and thereby minimize air emissions as described in chapter 3 using the quality controlled wood fuels described in chapter 4. The focus of this chapter is to present SWFC that use standardized wood fuels, including wood pellets, chips and briquettes as required by Guideline A-14. Fuel quality is a key consideration as modern SWFC technology is designed to be used with a narrow range of wood fuel properties. The moisture content (MC) of the wood fuel must be matched to the combustor design and for wood chips the MC should not exceed 50 percent (%), as fired, on a wet basis. An emphasis on the requirements of European Standard EN 303-5 (2012) is also included, particularly with regards to nominal and partial load heat output operating conditions as described in chapter 5.

Modern SWFC technologies that are typical for units less than 3 megawatts (MW) of heat input capacity as described in this chapter include:

(i) various types and combinations of fire bed grate configurations (e.g., inclined, step or horizontal with either moving or stationary grate);

(ii) continuous performance indicators used as inputs for real time process control, such as using a lambda sensor to measure the oxygen level in the flue gas;

(iii) multiple combustion zones (e.g., primary, secondary) with combustion air introduced in different areas of the combustion chamber;

(iv) automatic feed systems “overfed” onto the top of the grate or “underfed” from below;

(v) combustion air feed rate that is controlled by actuated dampers; and

(vi) combustion chamber static pressure that is controlled by an induced draft fan and dampers and maintained in a negative state while operational.

Fluidized beds and suspension burners are not included as they are more typical of large wood-fired combustors of heat input capacity greater than 3 MW that are accounted for in Guideline A-13. Likewise, manually batch fed and natural draft combustors are more typical of wood burning appliances rated at 50 kilowatts (kW) or less of heat output capacity and are omitted from Guideline A-14.

6.1 Multiple Combustion Zones

The most important feature used by the majority of modern small wood-fired combustion equipment designers is sub-dividing the combustion process into multiple zones to accomplish the six stages of wood combustion described in chapter 3. This is uniquely important for wood fuel (as compared to a solid fossil fuel such as coal) since wood fuel has such a large proportion of its carbon (C) energy contained in volatile matter as opposed to fixed carbon.
In practical terms, this means that the solid wood fuel must be warmed, dried and devolatilized before the oxidation reaction can begin in the gaseous phase. Since these represent different chemical reactions they are best achieved in distinct zones with appropriate temperature and oxygen gas (O\textsubscript{2}) levels, rather than trying to achieve all of the reactions simultaneously in one zone with one set of temperature and O\textsubscript{2} levels that are not suitable for all of the separate reactions.

The first three (endothermic) stages are generally completed on the upper end of the grate in the primary combustion zone (adjacent to the fuel feed entry point) while the wood fuel is still in the solid phase with the primary air providing sub-stoichiometric O\textsubscript{2} availability. The primary CO producing (exothermic) stages 4 and 5 are generally completed as the wood fuel transitions down to the lower end of the grate in the primary combustion zone. The wood fuel becomes devolatilized and gradually turned into ash, while the combustible gases are released with the primary air providing sub-stoichiometric O\textsubscript{2} availability. The carbon dioxide (CO\textsubscript{2}) producing (exothermic) stage 6 is generally completed in a secondary combustion zone above the grate as the combustible gases are oxidized in a highly turbulent environment with the secondary air providing excess O\textsubscript{2} availability. The stages of wood combustion described in chapter 3 are illustrated with a modified chemical reaction flow chart showing multiple combustion zones as shown in Figure 21.

### Figure 21. Stages of wood combustion\textsuperscript{96}

The primary combustion zone temperature is also designed to be less than approximately 800 degrees Celsius (°C) due to the low ash sintering, softening, and melting temperatures of the potassium and sodium based inorganic salts described in chapters 3 and 4. If the temperature exceeds approximately 800°C then these

components of the ash can fuse to the grate like cement and block the primary air from entering the combustion chamber. The combustion system would then have to be shut down while the cement-like fused ash is manually removed from the grate.

A side-sectional schematic for an overfed, inclined moving grate combustion chamber type design is provided in Figure 22 with the combustion zones, staged air inputs, and combustion stages identified. The primary combustion zone (I) area (1) represents the upper end of the grate where the fuel is fed onto the grate and transitions down to area (3) which represents the lower end of the grate. In the primary combustion zone (I), the wood fuel undergoes:

- combustion stages 1 to 3 in area (1) - warming, drying and pyrolytic decomposition;
- combustion stage 4 in area (2) - devolatilization of volatile matter; and
- combustion stage 5 in area (3) - devolatilization of fixed carbon.

In the secondary zone (II), the oxidation of combustible gases (stage 6) is completed. The combustion air flow rate is controlled by fans and dampers to ensure the correct amount of O\(_2\) is supplied to each zone.

![Side-sectional schematic for overfed, inclined moving grate combustor](image)

**Figure 22. Side-sectional schematic for overfed, inclined moving grate combustor**

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6.2 Automatic Fuel Feed, Start Up and Shut Down

To achieve optimum combustion efficiency and low emissions, wood fuel must be fed into the primary combustion zone and ignited in a controlled manner so it matches the primary air flow rate.

6.2.1 Fuel Feed Mechanism

There are several types of automatic wood fuel feed mechanisms currently available for small wood-fired combustors (SWFC), such as hydraulic rams and screw augers. These systems are typically designed to be either an “overfed” or “underfed” type mechanism. An overfed system can be either a hydraulic ram or screw auger and is generally designed to add wood fuel to the primary combustion zone at or above the level of the fire bed grate. An underfed system is usually a screw auger and is generally designed to add wood fuel to the primary combustion zone from below the level of the fire bed grate. An example of a screw auger for an underfed, stationary grate type SWFC is provided in Figure 23.

Figure 23. Screw feed auger for underfed stationary grate

6.2.2 Start Up Mechanism

In addition to automatically feeding the wood fuel into the primary combustion zone, the majority of modern systems are designed with an automatic start up mechanism that uses an electric hot air blower. This device injects air that is hot enough to warm, dry, devolatilize, and auto-ignite the wood fuel and then automatically shut off once the combustion becomes self-sustaining. An example of an electric hot air igniter is shown in Figure 24 and an example of an ignition pipe that blows hot air from an electronic igniter into a fixed (stationary), step grate combustion chamber (adjacent to the screw auger feed discharge) is shown in Figure 25.

![Image of electronic hot air ignition system](image.png)

**Figure 24. Electronic hot air ignition system**

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6.3 Multi-Zone Air Control

A multi-zone combustion process that introduces the wood fuel and combustion air into the distinct zones of the combustion chamber allows the wood fuel to be warmed, dried, devolatilized and oxidized more efficiently with the correct amount of O₂ in each zone. Modern SWFC are configured for a specific range of wood fuel properties and typically will not operate efficiently, and some won’t operate at all, if a different wood fuel is fed into the combustor. Consistent wood fuel properties are therefore essential to successful operation because a significant variation in wood fuel properties will not allow the primary air to warm, dry, and devolatilize the wood fuel properly without operational adjustments made to the fan(s) and dampers in real time to adjust the required amount of air. The most important fan in the multi-zone air control system is the induced draft (ID) fan, as it must modulate continuously in real time to assist in controlling the combustion process. The multi-zone air control system also allows the SWFC to operate efficiently over a range of load level firing rates, from nominal load at the full firing rate down to partial load at the minimum firing rate.

6.3.1 Combustion Air Inputs

An example of multi-zone combustion air inputs was shown in Figure 25 along with the electronic igniter hot air pipe for a single combustion chamber design. By contrast, Figure 22 shows a two combustion chamber design where the primary and secondary air inputs are in two different sections of the combustion chamber separated by a physical barrier wall. This type of sectional design is illustrated by the Froling TM500 units installed at Confederation College in Thunder Bay, Ontario in Figure 26 and Figure

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27, respectively, but with a refractory barrier wall between the secondary and tertiary combustion zones. Figure 27 also shows the tertiary zone air inputs as a set of two horizontally opposed rows of nozzles. A second refractory barrier wall is also shown; it lengthens the stage 6 oxidation reaction zone in order to oxidize the combustible gases more completely by preventing short-circuiting of the flue gases out of the combustion chamber prematurely. As a result, the distinct combustion zones are effectively linked together into a long S-shaped “tunnel” configuration.

All of the combustion air inputs are controlled by fans and dampers to ensure the correct amount of \( O_2 \) is supplied to each zone, regardless of the load level at which the SWFC is operating. This is important to achieve not only the complete oxidation of carbonaceous gas phase air pollutants, but also to minimize carry-over of fly ash from the primary zone. If too much combustion air is supplied to the primary zone, the resulting turbulence can entrain fly ash particles and cause them to be emitted to the exhaust stack (chimney) as particulate matter (PM). An effective SWFC design will therefore have very little turbulence and sub-stoichiometric air in the primary zone but higher turbulence and approximately 40-60% excess air in the secondary zone (and tertiary zone, where applicable). The desired amount of turbulence in each zone can be maintained across the various load levels with properly controlled combustion air inputs.

![Figure 26. Primary and secondary combustion zone air inputs for TM500 Froling combustor](image)

An image showing the combustion reaction, as viewed from the same location as Figure 26, but with wood fuel combusting, is provided in Figure 28. The refractory barrier wall is seen at the top of the secondary zone, ash is seen on the side walls and grate bottom and the gases are oxidizing brightly in the area of secondary combustion air as the combustible gases are transitioning from the primary to the secondary zone.

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102 TM500 Froling combustor [Photograph]. 2015. Courtesy of Confederation College, Thunder Bay, Ontario (annotation of photograph prepared by MOECC)
Another example of using tertiary air to sub-divide the combustion process into three zones is provided for an underfed grate combustor Hamont CATfire design as shown in Figure 29. In this design there is one large combustion chamber that has multi-zone air inputs but does not have a physical barrier wall to divide the combustion zones.

![Three Zone Combustor Design](image)

**Figure 29. Three zone combustor design**

### 6.3.2 Flue Gas Recirculation

An innovative technology that is now being used by many systems to enhance multi-zone air control and thereby improve combustion efficiency is flue gas recirculation (FGR), as shown in the side-sectional schematic in Figure 22. A portion of the flue gas is extracted from the outlet of the combustor or heat exchanger, typically on the pressure side of the induced draft fan, and sent back to mix with the combustion air for the primary and secondary combustion zones. An example of how this technology looks is provided in Figure 30, which shows the flue gas recirculation system for the Froling TX150 wood combustor installed at Confederation College.

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6.4 Oxygen Lambda Sensor

To make the multi-zone air control system work effectively across the various load level firing rates, the combustion air must be controlled so that the correct amount of primary and secondary air (and tertiary, where applicable) are forced into the associated combustion zones (with or without flue gas recirculation, where applicable). A lambda sensor is used to measure the amount of excess O\textsubscript{2} by volume in the flue gas at the outlet of the combustion chamber. This measurement is then used by the process control module in real time to continuously adjust the fan speeds and damper settings accordingly to achieve the desired performance. The most important fan is the induced draft (ID) fan, since it must modulate continuously in real time to assist with both combustion air levels and furnace draft static pressure. Since most SWFC will not typically operate at one load level continuously, the oxygen lambda sensor assists the multi-zone air control system to modulate up and down as necessary to match the variable heat output of the SWFC.

This measurement is typically made on a “wet basis” which means the water vapour in the flue gas is not removed and it therefore must be interpreted as such, especially if there is a high amount of MC in the wood fuel. The majority of small wood-fired combustor designers use a Bosch lambda probe for this purpose although other devices are available. An example of an O\textsubscript{2} lambda sensor is shown in Figure 31.

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The lambda sensor measurement is typically integrated with the combustion chamber induced draft fan setting in the process control module. The induced draft fan and dampers work in conjunction with the combustion air fan(s) and dampers to achieve the optimum O₂ level in the combustion chamber across all load levels.

6.5 Air Pollution Control

Depending on the type of wood fuel and combustion chamber design selected for a project, an air pollution control device may be required to meet regulatory emission requirements as described in chapter 5. The most common type of air pollution control requirement for SWFC is for PM since CO is usually minimized using an effective combustion process as described in Sections 6.1 to 6.4.

The ash content of the wood fuel has a significant impact on the amount of PM emitted. This is a key difference between wood pellets versus briquettes and chips. High quality wood pellets typically have an ash content of less than 1%, whereas wood briquettes and chips have ash contents of 1 to 3%. However, due to the variety of wood fuel specifications available as described in chapter 4, industrial/utility grade wood pellets can have an ash content of up to 3% and wood chip ash content can be up to 5% depending on the amount of bark in the wood chips.

The most commonly used type of device for control of PM is a cyclone, either as a single cyclone or multi-cyclone configuration. Both types of devices operate on the same principle, using a centrifugal force to mechanically separate the particle from the

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bulk gas flow. These devices typically last for a long time, have low pressure drop requirements, and have relatively low capital and operating costs.

The key difference between the two designs is that a multi-cyclone typically has higher rated removal efficiency for PM and can remove smaller diameter particles. In practice, SWFC less than 1,000 kW in size will typically have a single cyclone (due to cost considerations) whereas systems greater than 1,000 kW in size will often have either a single cyclone or a multi-cyclone.

Some SWFC manufacturers integrate a cyclone technology directly into the design (i.e., the cyclone is not optional equipment) while others provide an option to add a cyclone if needed to meet regulatory requirements.

Depending on the application and regulatory requirements, a higher degree of PM removal efficiency may be required beyond that provided by a cyclone. In such cases, a single (low cost) cyclone is often used as a “spark arrestor” pre-treatment step to remove larger diameter particles and any solid fuel particles that are still burning before using a high efficiency (and more expensive) fabric filter baghouse, electrostatic precipitator or venturi scrubber to remove smaller diameter particles. A graph illustrating the difference in removal efficiency as a function of fly ash particle diameter for selected air pollution control devices that could be used for a wood-fired combustor is provided in Figure 32.
6.6 Integrated Facility Design

As described in chapter 3, the air emissions from wood combustion are higher when there is an incorrect mixture of wood fuel and combustion air provided to the reaction. Since SWFC are generally used to supply variable heat load applications such as the comfort heating of buildings, the air emissions will likewise be variable, such as during start up, shut down and partial load operations. As described in chapter 5, European Standard EN 303-5 (2012) has air emission testing requirements for partial load, defined at 30% firing rate, because sophisticated combustion process controls are

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required to achieve low air emissions at partial load. Air emissions caused by incomplete combustion, such as CO and PAH, are generally lower at nominal load (i.e., 100% firing rate) because the wood-fired combustor is designed to operate at peak combustion efficiency at 100% firing rate.

6.6.1 Monthly Heat Demand Fluctuation

To minimize the amount of time that a SWFC operates at start up, shut down, and partial load conditions, there are several design concepts that could be integrated when designing the heating system at a facility. For example, the Natural Resources Canada RetScreen® software can be a useful tool when assessing heating system design. The basis of this analysis is to understand the monthly fluctuations in heat demand and is typically dependent on the number of degree days below 18°C (which is generally considered to be the ambient temperature below which heating is required for a building).

A degree day is defined as one degree Celsius for one day (24 hours), so if the ambient temperature for one day is 8°C then it represents 10 degree days (i.e., 18°C – 8°C) of heat load requirement. If the temperature were to stay the same for a month of 30 days then that month would have 300 degree days (i.e., 10 degree days x 30 days). In reality the number of monthly degree days below 18°C for a given location is derived from decades of climate data. Environment Canada compiles and publishes this information for cities across Canada as part of their “Climate Normals” data set. An example of the monthly degree days below 18°C for Ottawa and Sudbury, Ontario over the course of a year is provided in Figure 33.
As shown in Figure 35, the number of degree days in the colder months (i.e., November to March) range from approximately 500 to 1,000. In the spring and fall months (i.e., April, May, September, October) the number of degree days range from approximately 100 to 500. The summer months of June, July and August have a number of degree days within the range of approximately 5 to 75. This seasonal variation in heat demand represents a challenge for the efficient operation of a SWFC as it cannot operate continuously at 100% nominal load firing rate year round. This is in contrast to a natural gas fired heating system that can start up and shut down multiple times per day with no concern regarding increases to air emissions as compared with normal operation.

In order to minimize air emissions and maintain efficient operation as much of the time as possible, an integrated design philosophy is required. There are several technology options available for use with a SWFC, such as one or more of the following: (i) thermal heat storage, (ii) using auxiliary and/or peaking boilers, and (iii) dividing the heat load into multiple small wood-fired combustors.

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6.6.2 Thermal Storage

Thermal storage is a commonly used integration technology with SWFCs in Europe. This approach enables the combustor to operate at nominal load to heat the building and fill the storage tank. Once the storage tank is full the combustor will either modulate down to partial load or shut off. The building is then heated by the storage tank until the tank is depleted (which can be several hours or days depending on the size of the tank) and more heat is needed. The combustor then starts up and operates once again between nominal load and partial load to heat the building and refill the thermal storage tank, rather than starting up and shutting down multiple times per day as would be the case without thermal storage. An example process flow diagram of a biomass boiler integrated with a thermal storage tank showing the direction of the hot water flow path is provided in Figure 34.

Figure 34. Integration of thermal storage

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6.6.3 Auxiliary and/or Peaking Boilers

An auxiliary boiler (which could also be configured to be a peaking boiler) would generally be operated with a fossil fuel (such as natural gas or fuel oil) that can be start up and shut down quickly without significant air emissions. This is generally considered good practice since a wood combustion system will need to be shut down from time to time for inspection and maintenance and the auxiliary boiler can keep up with heat demand while the wood combustor is off-line. Also, if the biomass boiler is sized as a base load system to handle 50 to 60% of the peak load on a continuous basis, the fossil fuel boiler could operate intermittently as a peaking boiler to keep up with heat demand above the base load level up to the peak load level.

The auxiliary/peaking boiler can be either configured in parallel or in series with the SWFC. If configured in parallel, the hot water output from the SWFC would not flow through the auxiliary/peaking boiler on the way to heat the building but would instead by-pass it. If the auxiliary/peaking boiler is isolated from the hot water loop, it would be on “cold stand-by” waiting to start up. Otherwise, the auxiliary/peaking boiler could have the return water loop through it to maintain a “warm stand-by” setting while waiting to start up. Conversely, if configured in series, the hot water output from the SWFC would flow through the auxiliary/peaking boiler before going out to heat the building. This allows the auxiliary/peaking boiler to remain on “hot stand-by” while waiting to start up.

An example of a biomass boiler (without thermal storage) connected to a fossil fuel auxiliary/peaking boiler in parallel is provided in the hot water process flow diagram shown in Figure 35. In this configuration, the fossil fuelled boiler can be either isolated on cold stand-by when not in operation or the return water feed can circulate through the boiler to keep it on warm stand-by. Maintaining the fossil fuelled boiler on warm stand-by when shut down is preferred to minimize thermal stress and condensation in the heat exchanger.
Figure 35. Process flow diagram of a biomass boiler with auxiliary/peaking boiler configured in parallel\textsuperscript{110}

6.6.4 Dividing Heat Demand with Multiple Combustors

Confederation College in Thunder Bay, Ontario has three SWFC boilers connected in series to two fossil fuelled (natural gas) fired auxiliary/peaking boilers, separated with a “hydro separator” contact mix tank heat exchanger. Each SWFC boiler can be turned on and off (or modulated up and down between nominal and partial load firing rate) independently based on the required building heat demand. Likewise, the natural gas boilers can be turned on and off as needed to meet the required building heat demand. By having all of the boilers connected in series they remain on hot stand-by and can start up faster as compared with having the boilers arranged in parallel and having them either isolated on cold stand-by or connected to the return water feed on warm stand-by. This also serves to keep the heat exchangers hot to prevent thermal stress and condensation from periods of time when they are shut down. A hot water process flow diagram illustrating this design approach is shown in Figure 36.

6.7 Commissioning and Site Acceptance Testing

SWFCs are typically designed and tested by the manufacturer before going to mass production where they are subsequently built in a factory. They are then sold as off-the-shelf, factory assembled models and shipped to the customer’s site for installation. This is uniquely different from large wood-fired combustors that are field erected at the customer site and cannot be tested by the manufacturer prior to construction.

Nevertheless, due to the inherent complexity of storing, handling, and conveying wood fuel to a SWFC and achieving safe, effective operation it is important to commission the equipment and perform site acceptance testing before the SWFC is considered to be “in service”. All of the components must work together so that the thermal efficiency, O₂ and CO levels, draft static furnace pressure, temperatures and flows are operating within the manufacturer’s design set-points. A technician trained by the SWFC manufacturer would typically perform this task. However, this may represent only one aspect of the commissioning of the facility heating system, which may include other boilers, pumps and heat exchangers that could be commissioned by other technicians depending on the nature of the equipment procurement.

Most of the process control parameters are included in the scope of supply for monitors and sensors within the combustion system, but CO levels are typically measured with a separate device. During the equipment commissioning period and especially the site

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111 Process flow diagram prepared by Ministry of Environment and Climate Change.
acceptance test, a technician would typically measure the emissions levels of CO and O2 using a portable flue gas analyzer as shown in Figure 37.

![Portable flue gas analyzer](image)

**Figure 37. Portable flue gas analyzer**

It is considered good practice to perform the commissioning and site acceptance testing for the combustion system concurrently with any permanently installed continuous flue gas monitors, if required, such as CO and O2. The data from the combustor process control module and continuous flue gas monitoring systems should be aligned to the same time standard so that the measurements are recorded at the same time and with the same averaging period. This way a 5-minute average measurement, for example from 10:00 am to 10:05 am, can be compared for consistency between combustor operation (such as lambda O2 sensor, fan speeds, static pressure, etc.) and associated air emission levels (such as CO and O2).

### 6.8 Additional References

EN 303-5, Heating Boilers – Part 5: Heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500kW- Terminology, requirements, testing and marking (EN 303-5:2012 (E)).

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7 Air Emissions from Small Wood-Fired Combustors

The purpose of this chapter is to present a summary of air emission source testing data for small wood-fired combustors (SWFC) with an emphasis on particulate matter (PM) and carbon monoxide (CO). In general, air emission data from SWFC is difficult to obtain because it is either confidential or very limited in the available science literature. The confidential emission data from European manufacturers is mostly limited to PM and CO as these are the key regulated air pollutants as described in chapter 5. By contrast the United States Environmental Protection Agency (USEPA) has published a lengthy list of emission factors (EF) in their publicly accessible AP-42 database.113,114 These EFs were developed using large wood-fired combustors and last updated in 2003. Due to the limited availability of published air emission data, the AP-42 EFs are often referenced in environmental permit applications for SWFC.

To inform the development of new guidelines for SWFC, the Ministry of the Environment and Climate Change (MOECC) jointly funded a research testing program with the Ministry of Natural Resources and Forestry (MNRF) at Confederation College in Thunder Bay. The purpose was to gather air emission data during the 2014-2015 heating season using two of Confederation College’s Froling SWFCs with an emphasis on benzo[a]pyrene (BaP) and acrolein. These two air pollutants have been traditionally associated with wood combustion and the MOECC determined that more accurate data was required. Confederation College contributed their Environmental Compliance Approval (ECA) source testing report as an in-kind contribution to the project. Natural Resources Canada (NRCan) funded additional research testing for PM and CO immediately following the MOECC-MNRF joint research testing program using the same two Froling SWFCs.

There are four data sets presented in this chapter. The first data set was derived from confidential European SWFC manufacturer certification testing reports and is limited to PM and CO. These are summarized in aggregate by statistical parameters (average, minimum, and maximum) and all information pertaining to individual SWFC make and model or manufacturer has been removed. The second data set is a summary of USEPA AP-42 EFs for wood combustion and is limited to PM, CO, BaP, and acrolein. The third data set was prepared by the multi-agency partnership between the MOECC, MNRF, Confederation College and NRCan. This data set is likewise limited to PM, CO, BaP and acrolein. The fourth data set was prepared by Clarkson University as a

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research project funded by the New York State Energy Research and Development Authority (NYSERDA).

To provide a comparative analysis of the data, the PM emissions presented herein are compared with the Guideline A-14 limit value for PM of 75 milligrams per cubic metre at reference conditions (mg/Rm³). The emission results obtained in data set three are also compared with AP-42 emission factors from data set two. The CO emissions are compared with Guideline A-14 limit value (24-hr average) of 400 parts per million by volume (ppmv). In each case the comparative analysis is based on Ontario’s reference conditions of 25 degrees Celsius (°C) and 11 per cent residual oxygen (11% O₂).

7.1 European Certification Testing Data

As described in chapter 5, jurisdictions across Europe typically require some degree of testing to pre-qualify a SWFC prior to selling into the European market. The available testing data generally follows the requirements of European Standard EN 303-5 (2012) even for units above 500 kW in size. The MOECC was able to procure several confidential testing reports from European manufacturers who agreed to allow their data to be used as long as the data could not be connected to their individual make and model for business competition purposes. As such, the data has been rolled up into statistical averages, minimums, and maximums in this chapter. The test reports were prepared by independent third party organizations that fulfill the requirements of EN/ISO 17025. In each case, the testing was conducted by the third party at their laboratory facility.

The certification test reports include air emission data for the combustion of wood pellets or wood chips (or separately for both if it is a multi-fuel design) at both the 100% nominal load firing rate and the 30% partial load firing rate as required by EN 303-5 (2012). The data set also includes the moisture content of the wood fuel and thermal efficiency. The MOECC then estimated the net calorific value of the wood fuel (or net heating value) on a wet basis and the residual O₂ level of the flue gas as reported on a dry basis to make for a more informative data set for the purposes of this document.

The CO and PM emission data are presented in European standard units of milligrams per normalized cubic metre (mg/Nm³) corrected to 0°C and 10% O₂. As in chapter 5, the MOECC has converted these emissions to Ontario’s standard reference conditions of 25°C and 11% O₂ using standard industry parameters and also converted the CO emissions to ppmv.

The air emission data are presented in eight tables as follows; where each parameter is to be read separately. For example, the minimum net calorific value does not correlate with the minimum wood fuel moisture content or O₂ level in the flue gas:

- Table 22. Summary of net calorific value, moisture content, oxygen level in flue gas and carbon monoxide (CO) emission data (European (EU) and Ontario (ON) units) for wood pellets at 100% nominal load firing rate
• Table 23. Summary of net calorific value, moisture content, oxygen level in flue gas, and carbon monoxide (CO) emission data (European (EU) and Ontario (ON) units) for wood pellets at 30% partial load firing rate
• Table 24. Summary of net calorific value, moisture content, oxygen level in flue gas, and carbon monoxide (CO) emission data (European (EU) and Ontario (ON) units) for wood chips at 100% nominal load firing
• Table 25. Summary of net calorific value, moisture content, oxygen level in flue gas, and carbon monoxide (CO) emission data (European (EU) and Ontario (ON) units) for wood chips at 30% partial load firing rate
• Table 26. Summary of net calorific value, moisture content, oxygen level in flue gas, and particulate matter (PM) emission data (European (EU) and Ontario (ON) units) for wood pellets at 100% nominal load firing
• Table 27. Summary of net calorific value, moisture content, oxygen level in flue gas, and particulate matter (PM) emission data (European (EU) and Ontario (ON) units) for wood pellets at 30% partial load firing rate
• Table 28. Summary of net calorific value, moisture content, oxygen level in flue gas, and particulate matter (PM) emission data (European (EU) and Ontario (ON) units) for wood chips at 100% nominal load firing rate
• Table 29. Summary of net calorific value, moisture content, oxygen level in flue gas, and particulate matter (PM) emission data (European (EU) and Ontario (ON) units) for wood chips at 30% partial load firing rate

Table 22. Summary of net calorific value, moisture content, oxygen level in flue gas and carbon monoxide (CO) emission data (European (EU) and Ontario (ON) units) for wood pellets at 100% nominal load firing rate

<table>
<thead>
<tr>
<th>Statistical Parameter</th>
<th>Net Calorific Value (kJ/kg)</th>
<th>Wood Fuel Moisture Content (%)</th>
<th>Oxygen Level in Flue Gas (dry %)</th>
<th>CO (EU units: 0°C, 10% O2) (mg/Nm³)</th>
<th>CO (ON units: 25°C, 11% O2) (ppmv)</th>
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Table 23. Summary of net calorific value, moisture content, oxygen level in flue gas, and carbon monoxide (CO) emission data (European (EU) and Ontario (ON) units) for wood pellets at 30% partial load firing rate

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<thead>
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<th>Statistical Parameter</th>
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<th>Wood Fuel Moisture Content (%)</th>
<th>Oxygen Level in Flue Gas (dry %)</th>
<th>CO (EU units: 0°C, 10% O2) (mg/Nm³)</th>
<th>CO (ON units: 25°C, 11% O2) (ppmv)</th>
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<td>7.1</td>
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Table 24. Summary of net calorific value, moisture content, oxygen level in flue gas, and carbon monoxide (CO) emission data (European (EU) and Ontario (ON) units) for wood chips at 100% nominal load firing

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<thead>
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<th>Wood Fuel Moisture Content (%)</th>
<th>Oxygen Level in Flue Gas (dry %)</th>
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<th>CO (ON units: 25°C, 11% O₂) (ppmv)</th>
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<td>Minimum</td>
<td>9,893</td>
<td>20</td>
<td>5.3</td>
<td>8.0</td>
<td>5.6</td>
</tr>
<tr>
<td>Average</td>
<td>11,939</td>
<td>36</td>
<td>6.5</td>
<td>83</td>
<td>60</td>
</tr>
<tr>
<td>Maximum</td>
<td>14,905</td>
<td>47</td>
<td>7.6</td>
<td>214</td>
<td>156</td>
</tr>
</tbody>
</table>

Table 25. Summary of net calorific value, moisture content, oxygen level in flue gas, and carbon monoxide (CO) emission data (European (EU) and Ontario (ON) units) for wood chips at 30% partial load firing rate

<table>
<thead>
<tr>
<th>Statistical Parameter</th>
<th>Net Calorific Value (kJ/kg)</th>
<th>Wood Fuel Moisture Content (%)</th>
<th>Oxygen Level in Flue Gas (dry %)</th>
<th>CO (EU units: 0°C, 10% O₂) (mg/Nm³)</th>
<th>CO (ON units: 25°C, 11% O₂) (ppmv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>9,893</td>
<td>20</td>
<td>6.6</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Average</td>
<td>12,250</td>
<td>34</td>
<td>9.1</td>
<td>102</td>
<td>74</td>
</tr>
<tr>
<td>Maximum</td>
<td>14,905</td>
<td>47</td>
<td>11</td>
<td>311</td>
<td>226</td>
</tr>
</tbody>
</table>

Table 26. Summary of net calorific value, moisture content, oxygen level in flue gas, and particulate matter (PM) emission data (European (EU) and Ontario (ON) units) for wood pellets at 100% nominal load firing

<table>
<thead>
<tr>
<th>Statistical Parameter</th>
<th>Net Calorific Value (kJ/kg)</th>
<th>Wood Fuel Moisture Content (%)</th>
<th>Oxygen Level in Flue Gas (dry %)</th>
<th>PM (EU units: 0°C, 10% O₂) (mg/Nm³)</th>
<th>PM (ON units: 25°C, 11% O₂) (mg/Rm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>16,582</td>
<td>4.5</td>
<td>5.5</td>
<td>9.0</td>
<td>7.3</td>
</tr>
<tr>
<td>Average</td>
<td>17,472</td>
<td>6.2</td>
<td>6.1</td>
<td>31</td>
<td>26</td>
</tr>
<tr>
<td>Maximum</td>
<td>17,794</td>
<td>11</td>
<td>11</td>
<td>49</td>
<td>41</td>
</tr>
</tbody>
</table>
Background and Rationale for the Development of a Guideline for the Control of Air Emissions from Small Wood-Fired Combustors with a Heat Input Capacity of Less Than 3 Megawatts

Table 27. Summary of net calorific value, moisture content, oxygen level in flue gas, and particulate matter (PM) emission data (European (EU) and Ontario (ON) units) for wood pellets at 30% partial load firing rate

<table>
<thead>
<tr>
<th>Statistical Parameter</th>
<th>Net Calorific Value (kJ/kg)</th>
<th>Wood Fuel Moisture Content (%)</th>
<th>Oxygen Level in Flue Gas (dry %)</th>
<th>CO (EU units: 0°C, 10% O₂) (mg/Nm³)</th>
<th>CO (ON units: 25°C, 11% O₂) (mg/Rm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>16,955</td>
<td>4.5</td>
<td>7.1</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>Average</td>
<td>17,567</td>
<td>5.7</td>
<td>10</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Maximum</td>
<td>17,794</td>
<td>9.0</td>
<td>12</td>
<td>48</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 28. Summary of net calorific value, moisture content, oxygen level in flue gas, and particulate matter (PM) emission data (European (EU) and Ontario (ON) units) for wood chips at 100% nominal load firing rate

<table>
<thead>
<tr>
<th>Statistical Parameter</th>
<th>Net Calorific Value (kJ/kg)</th>
<th>Wood Fuel Moisture Content (%)</th>
<th>Oxygen Level in Flue Gas (dry %)</th>
<th>PM (EU units: 0°C, 10% O₂) (mg/Nm³)</th>
<th>PM (ON units: 25°C, 11% O₂) (mg/Rm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>9,893</td>
<td>20</td>
<td>5.3</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Average</td>
<td>11,939</td>
<td>36</td>
<td>6.5</td>
<td>50</td>
<td>41</td>
</tr>
<tr>
<td>Maximum</td>
<td>14,905</td>
<td>47</td>
<td>7.6</td>
<td>76</td>
<td>63</td>
</tr>
</tbody>
</table>

Table 29. Summary of net calorific value, moisture content, oxygen level in flue gas, and particulate matter (PM) emission data (European (EU) and Ontario (ON) units) for wood chips at 30% partial load firing rate

<table>
<thead>
<tr>
<th>Statistical Parameter</th>
<th>Net Calorific Value (kJ/kg)</th>
<th>Wood Fuel Moisture Content (%)</th>
<th>Oxygen Level in Flue Gas (dry %)</th>
<th>PM (EU units: 0°C, 10% O₂) (mg/Nm³)</th>
<th>PM (ON units: 25°C, 11% O₂) (mg/Rm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>9,893</td>
<td>20</td>
<td>6.6</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>Average</td>
<td>12,250</td>
<td>34</td>
<td>9.1</td>
<td>45</td>
<td>37</td>
</tr>
<tr>
<td>Maximum</td>
<td>14,905</td>
<td>47</td>
<td>11</td>
<td>64</td>
<td>53</td>
</tr>
</tbody>
</table>

It was observed that all of the data presented is rated equivalent to EN 303-5 (2012) Class 5 for thermal efficiency at greater than 89% and for CO at less than 500 mg/Nm³. By comparison, the CO data is also below 400 ppmv. However, only some of the PM data presented is equivalent to EN 303-5 (2012) Class 5 for PM while some is equivalent to Class 3 or Class 4. By comparison, all of the PM emission data is less than the Guideline A-14 emission limit value of 75 mg/Rm³. The PM data is challenging
to interpret because it is not evident as to whether or not a cyclone was used to control the PM or if the emissions were uncontrolled during testing.

One of the SWFC manufacturers provided some additional wood pellet boiler emission testing data from several units in operation at client sites that are all less than 1 megawatt (MW) in size. This data was intended to show the consistency in combustion performance with wood pellets (i.e., gas moisture, oxygen and carbon dioxide) and the difference in PM emissions depending on whether or not a cyclone was installed. Two of the sites did not have a cyclone installed, while at the third site a cyclone was installed to reduce PM emissions that indicated a reduction of approximately 50%. A summary of the emission testing results for the three sites is provided in Table 30, including a comparison with the Guideline A-14 emission limit value of 75 mg/Rm³ (PM data converted to Ontario reference conditions of 25°C and 11% O₂).

**Table 30. Summary of small wood-fired combustor testing data for wood pellet boilers**

<table>
<thead>
<tr>
<th>Test Parameter</th>
<th>Units</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Moisture %</td>
<td>%</td>
<td>10.3</td>
<td>11.3</td>
<td>10.1</td>
</tr>
<tr>
<td>Residual Oxygen dry %</td>
<td></td>
<td>7.0</td>
<td>6.6</td>
<td>6.0</td>
</tr>
<tr>
<td>Carbon Dioxide dry %</td>
<td></td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Particulate matter emissions</td>
<td>mg/Rm³</td>
<td>78.1</td>
<td>83.6</td>
<td>40.3</td>
</tr>
<tr>
<td>Below Guideline A-14 limit value of 75?</td>
<td>mg/Rm³</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Cyclone installed?</td>
<td>-</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

Despite the fact that these three sites are independent from one another and the wood combustors are not all the same make and model, the results are very similar as they all used wood pellets as the fuel and are EN 303-5 (2012) Class 5 compliant for thermal efficiency and CO. The effectiveness of a cyclone to control PM to approximately 50% from a SWFC is evident. The only site that would meet the Guideline A-14 PM emission limit of 75 mg/Rm³ is the one with a cyclone (Site 3). When compared with the certification data test results on Table 26 for wood pellets at 100% load, the only site that is close to those results is Site 3 (with a cyclone), whereas Sites 1 and 2 (without a cyclone) are much higher. Although not shown in Table 30, CO data was provided for Site 3 that indicated an emission level of less than 10 ppmv (corrected to Ontario reference conditions of 25°C and 11% O₂).

**7.2 United States Environmental Protection Agency AP-42 Emission Factors**

The wood combustion EF published by the USEPA in their AP-42 Chapter 1.6 are based on large wood-fired combustors but are often used for SWFC in the absence of better information. Although these EFs have not been updated for more than 10 years,
they are considered the benchmark in North America and are typically regarded by Canadian regulators as the best available information. Only pre-certification source testing for a SWFC, which is now common practice in Europe, can enhance the air emission data quality.

The AP-42 EFs are published in units of pounds per million British Thermal Units (lb/MMBtu) and some are designated for specific wood fuel types or combustion chamber designs. This is especially true for PM which has a large range of options to choose from. The authors of AP-42 use as little as one test to establish an EF or potentially over 100 tests where source testing data is available.

For the purposes of this rationale document, the MOECC has converted the EFs from lb/MMBtu to Ontario’s reference conditions of mg/Rm³ and corrected to 25°C and 11% O₂ using the same parameters described in chapter 5. For CO the EF was converted one extra step to parts ppmv. The PM EF was selected for the uncontrolled scenario with no cyclone using dry wood where dry wood is expressed at less than 20% moisture content. The PM and CO emission factors have extra data available for review in the AP-42 Chapter 1.6 background document 115 including the published value, minimum, and maximum; whereas the BaP and acrolein emission factors only have one single value. The PM EF was based on 15 tests while the CO emission factor was based on 128 tests.

The AP-42 EFs are summarized in the following tables:

- Table 31. AP-42 emission factor (EF) for particulate matter using dry wood, uncontrolled
- Table 32. AP-42 emission factor (EF) for carbon monoxide
- Table 33. AP-42 emission factors (EF) for benzo[a]pyrene and acrolein

The AP-42 published PM EF and other minimum and maximum test values are well above the Guideline A-14 emission limit of 75 mg/Rm³, shown as a percentage in Table 31. However, the published CO EF and minimum test value are below the Guideline A-14 emission limit (24-hour) of 400 ppmv, shown as a percentage in Table 32, while the maximum test value is well above.

Table 31. AP-42 emission factor (EF) for particulate matter using dry wood, uncontrolled and converted to Ontario units

<table>
<thead>
<tr>
<th>Statistical Parameter</th>
<th>AP-42 EF (lb/MMBtu)</th>
<th>Ontario Equivalent EF (mg/Rm³)</th>
<th>% Guideline A-14 75 mg/Rm³</th>
</tr>
</thead>
</table>

Table 32. AP-42 emission factor (EF) for carbon monoxide and converted to Ontario units

<table>
<thead>
<tr>
<th>Statistical Parameter</th>
<th>AP-42 EF (lb/MMBtu)</th>
<th>Ontario Equivalent EF (ppmv)</th>
<th>% Guideline A-14 400 ppmv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Published CO EF</td>
<td>0.60</td>
<td>387</td>
<td>97%</td>
</tr>
<tr>
<td>Minimum test value</td>
<td>0.028</td>
<td>18</td>
<td>5%</td>
</tr>
<tr>
<td>Maximum test value</td>
<td>2.578</td>
<td>1,664</td>
<td>416%</td>
</tr>
</tbody>
</table>

Table 33. AP-42 emission factors (EF) for benzo[a]pyrene and acrolein and converted to Ontario units

<table>
<thead>
<tr>
<th>Air Emission</th>
<th>AP-42 EF (lb/MMBtu)</th>
<th>Ontario Equivalent EF (mg/Rm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzo[a]pyrene</td>
<td>2.6E-06</td>
<td>1.9E-03</td>
</tr>
<tr>
<td>Acrolein</td>
<td>4.0E-03</td>
<td>3.0</td>
</tr>
</tbody>
</table>

As seen in Table 31 and Table 32, there is a significant range of potential results from emission testing for wood combustion systems. This is primarily due to the large variation in wood fuel quality and combustion chamber design used to gather the test data.

### 7.3 Testing and Research at Confederation College

The two SWFC tested at Confederation College consisted of: (i) Froling TM500, which is rated at 500 kilowatts (kW) of energy output and burns wood chips with a moisture content of up to 50%, and (ii) Froling TX150, which is rated at 150 kW of energy output and can burn either wood pellets or wood chips, where the wood chip moisture content is limited to approximately 25%. The TM500 unit was referred to as “Boiler 1” while the TX150 unit was referred to as “Boiler 3”. This is because a second TM500 unit exists at Confederation College which is referred to as “Boiler 2” which was not tested.

Boiler 1 was tested exclusively with wood chips as it is automatically fed from a wood chip fuel bunker and is not designed to receive wood pellets. Boiler 3 was tested with either wood pellets or wood chips since it is automatically fed from a small fuel bin that can be filled each day with the desired fuel using a 1-tonne sack and overhead crane.

Since both the TM500 and TX150 are EN 303-5 (2012) Class 5 compliant technologies with regards to thermal efficiency and CO, the MOECC decided to replicate the 100%
nominal load and 30% partial load firing rates and observe the results. Neither unit has a cyclone, so the emission data is considered uncontrolled and can therefore be compared directly with the AP-42 EF.

Lessons Learned: Although the test program was a success, there were some operational challenges during the first few days of emission testing because the site acceptance testing had not been fully completed before the start of testing. As such, there were a few instances where a boiler would automatically shut itself off when the cold water return temperature was above its set-point or the piping network pressure was too high and a safely relief valve would open. Once the programming of the boiler operating set-points was completed, then the boilers could operate continuously at either nominal load or partial load heat output capacity and the emission tests could be completed without interruption.

7.3.1 Wood Fuel Analysis

The project team performed a significant number of tests on the wood chips and wood pellets used during each day of emission testing. Analysis was performed on-site at Confederation College for a limited number of parameters, while large sample bags were sent to Lakehead University in Thunder Bay and the NRCan laboratory in Ottawa for more extensive analysis. A summary of the results is provided below for wood chips and wood pellets. All results are shown on a dry basis except for moisture content which is reported on a wet basis. Where results are not in close agreement, the name of the laboratory is noted for the low and high ends of the measured range. Also, the on-site analysis of moisture content at the College was considered to be the most representative of the “as-fired” condition since the external laboratory values were lower due to lost moisture during wood fuel sample storage and transit. As expected, the results from the analysis of wood chips were highly variable for many parameters whereas the analysis of wood pellets indicated consistent quality.

7.3.1.1 Wood Chips

- Moisture content (College):
  - Boiler 1 range from 20-55%, highly variable (by comparison, the Lakehead moisture content lab results for the same samples was 14-44%, demonstrating that wood chip moisture was lost during sample storage and transit)
  - Boiler 3 range from 15-25%, limited variability
- Ash content range from 0.8% (NRCan) to 1.5% (Lakehead)
- Volatile matter content range from 81% (NRCan) to 85% (Lakehead)
- Fixed carbon content range from 13% (Lakehead) to 18% (NRCan)
- High heating value range from 20 to 21 MJ/kg (megajoules per kilogram) on a dry basis (NRCan)
- High heating value on a wet basis (2 examples from Lakehead):
  - 17.5 MJ/kg at 16% moisture content
12.9 MJ/kg at 28% moisture content
- Carbon range from 49-52%
- Oxygen range from 41-43%
- Hydrogen range from 5.7-6.1%
- Nitrogen range from <0.1-0.16%
- Sulphur range from 0.01% (NRCan) to 0.45% (Lakehead)
- Bulk density range from 185 to 320 kilograms per metre cubed (kg/m³)
- Particle size distribution:
  - Less than 3 millimetres (mm): <1-5%
  - Above 3 mm: 5-19%
  - Above 5 mm: 12-26%
  - Above 10 mm: 40-65%
  - Above 30 mm: 1-10%
- Chlorine range from 75-170 microgram per gram (µg/g)

7.3.1.2 Wood Pellets
- Moisture content range from 3.7-4% (College)
- Ash content range from 0.6-0.8%
- Volatile matter content range from 82-83%
- Fixed carbon content range from 16-17%
- High heating value range from 20 to 21 MJ/kg on a dry basis (NRCan)
- High heating value on a wet basis 19.6 MJ/kg (2 examples from Lakehead at 3.3 and 3.4% moisture yielded identical results)
- Carbon range from 50-51%
- Oxygen range from 42-43%
- Hydrogen range from 5.9-6.3%
- Nitrogen <0.1%
- Sulphur range from 0.008% (NRCan) to 0.3% (Lakehead)
- Bulk density range from 675-735 kg/m³
- Single pellet density range from 1,230-1,300 kg/m³
- Pellet diameter range from 6.1-6.3 mm
- Pellet length range from 16-26 mm
- Mechanical durability range from 98-99%
- Fines amount range from 0.04-0.10%
- Chlorine range from 130-140 µg/g
7.3.2 Particulate Matter

During the February 2015 ECA testing program (referred to as ECA T1) Boiler 1 failed to pass the PM compliance test and the cause was determined to be variable wood chip moisture content (approximately 20-55%). A second ECA test was completed in June 2015 (referred to as ECA T2) with a consistent 40-45% wood chip moisture content and compliance with Ontario’s interim 1990 wood combustor guideline PM emission limit of 90 mg/Rm³ was achieved. The NRCan PM testing was below 90 mg/Rm³ despite some minor operational issues for the test on Boiler 3 with wood pellets at 30% partial load that led to slightly higher emissions when compared to the other tests.

A summary of the PM emission testing at Confederation College is provided in Table 34 including a comparison as a percentage of the AP-42 published EF of 0.40 lb/MMBTU (296 mg/Rm³) and the ECA limit value of 90 mg/Rm³ for PM (all PM emissions corrected to Ontario reference conditions of 25°C and 11% O₂). A comparison is also provided as a percentage of the Guideline A-14 emission limit value of 75 mg/Rm³. The SWFC firing rate, wood fuel type, and residual O₂ level (dry basis) are also shown for reference.

Table 34. Summary of particulate matter (PM) emission testing at Confederation College for wood chips and wood pellets

<table>
<thead>
<tr>
<th>Boiler No. (test)</th>
<th>Firing Rate (%)</th>
<th>Wood Fuel Type</th>
<th>Dry O₂ (%)</th>
<th>PM Emission (mg/Rm³)</th>
<th>% of AP-42 EF</th>
<th>% ECA 90 mg/Rm³</th>
<th>% A-14 75 mg/Rm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (ECA T1)</td>
<td>100</td>
<td>chips</td>
<td>8.6</td>
<td>138</td>
<td>47%</td>
<td>153%</td>
<td>184%</td>
</tr>
<tr>
<td>1 (ECA T2)</td>
<td>100</td>
<td>chips</td>
<td>7.7</td>
<td>66.9</td>
<td>23%</td>
<td>74%</td>
<td>89%</td>
</tr>
<tr>
<td>1 (NRCan)</td>
<td>30</td>
<td>chips</td>
<td>10.0</td>
<td>44.5</td>
<td>15%</td>
<td>49%</td>
<td>59%</td>
</tr>
<tr>
<td>3 (ECA T1)</td>
<td>100</td>
<td>pellets</td>
<td>9.9</td>
<td>16.6</td>
<td>5.6%</td>
<td>18%</td>
<td>22%</td>
</tr>
<tr>
<td>3 (NRCan)</td>
<td>100</td>
<td>pellets</td>
<td>9.8</td>
<td>17.7</td>
<td>6.0%</td>
<td>20%</td>
<td>24%</td>
</tr>
<tr>
<td>3 (NRCan)</td>
<td>30</td>
<td>pellets</td>
<td>9.7</td>
<td>84.4</td>
<td>29%</td>
<td>94%</td>
<td>113%</td>
</tr>
<tr>
<td>3 (NRCan)</td>
<td>100</td>
<td>chips</td>
<td>9.0</td>
<td>38.5</td>
<td>13%</td>
<td>43%</td>
<td>51%</td>
</tr>
<tr>
<td>3 (NRCan)</td>
<td>30</td>
<td>chips</td>
<td>9.1</td>
<td>27.6</td>
<td>9.3%</td>
<td>31%</td>
<td>37%</td>
</tr>
</tbody>
</table>

7.3.3 Benzo[a]pyrene and Acrolein

The BaP and acrolein emissions were below the laboratory detection threshold limit (DTL) for every test on Boiler 1 and Boiler 3, including for wood pellets and wood chips at both the 100% nominal load and 30% partial load firing rates. A summary of the BaP and acrolein emission testing at Confederation College is provided in Table 35 using the DTL as representative emission levels and includes a comparison as a percentage with the AP-42 emission factors (all emissions corrected to Ontario’s reference conditions of 25°C and 11% O₂). It is evident from the data that the BaP emissions were consistently less than 5% of the AP-42 EF while the acrolein emissions were more variable.
Table 35. Summary of benzo[a]pyrene and acrolein emission testing at Confederation College for wood chips and wood pellets

<table>
<thead>
<tr>
<th>Air Emission</th>
<th>Boiler No.</th>
<th>Firing Rate (%</th>
<th>Wood Fuel Type</th>
<th>Detection Threshold Limit (µg/Rm³)</th>
<th>% of AP-42 EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaP</td>
<td>1</td>
<td>100</td>
<td>chips</td>
<td>&lt;0.066</td>
<td>&lt;3.4</td>
</tr>
<tr>
<td>BaP</td>
<td>1</td>
<td>30</td>
<td>chips</td>
<td>&lt;0.04</td>
<td>&lt;2.1</td>
</tr>
<tr>
<td>BaP</td>
<td>3</td>
<td>100</td>
<td>pellets</td>
<td>&lt;0.048</td>
<td>&lt;2.5</td>
</tr>
<tr>
<td>BaP</td>
<td>3</td>
<td>30</td>
<td>pellets</td>
<td>&lt;0.04</td>
<td>&lt;2.1</td>
</tr>
<tr>
<td>BaP</td>
<td>3</td>
<td>100</td>
<td>chips</td>
<td>&lt;0.03</td>
<td>&lt;1.6</td>
</tr>
<tr>
<td>Acrolein</td>
<td>1</td>
<td>100</td>
<td>chips</td>
<td>&lt;55</td>
<td>&lt;1.9</td>
</tr>
<tr>
<td>Acrolein</td>
<td>1</td>
<td>30</td>
<td>chips</td>
<td>&lt;1,250</td>
<td>&lt;42</td>
</tr>
<tr>
<td>Acrolein</td>
<td>3</td>
<td>100</td>
<td>pellets</td>
<td>&lt;1,730</td>
<td>&lt;58</td>
</tr>
<tr>
<td>Acrolein</td>
<td>3</td>
<td>30</td>
<td>pellets</td>
<td>&lt;535</td>
<td>&lt;18</td>
</tr>
<tr>
<td>Acrolein</td>
<td>3</td>
<td>100</td>
<td>chips</td>
<td>&lt;10.7</td>
<td>&lt;0.4</td>
</tr>
</tbody>
</table>

7.3.4 Continuous Emission and Process Control Monitoring

CO and O₂ were recorded on a dry basis with a permanent continuous emission monitor system (CEMS) installed at Confederation College and the measurements were downloaded in 1-minute averages. Boiler 3 (TX150) also had a carbon dioxide (CO₂) CEMS. The steady state CO levels observed during the Relative Accuracy Test Audit (RATA) compliance testing were all below 10 ppmv for Boiler 1 (TM500) and below 60 ppmv for Boiler 3 (TX150). The MOECC took the opportunity to evaluate non-steady state operations such as start-up and shut down procedures. Low steady state CO emission levels were observed throughout the test program but higher levels were observed during non-steady state operations. The CO levels returned to steady state levels of well under 100 ppmv within 30-60 minutes of a non-steady state event which demonstrated the advanced process control capabilities of the Froling SWFC installed at Confederation College.

The Froling process controller data acquisition system was also configured to download 1 minute average data from the monitors and sensors to match the CEMS data. The MOECC analyzed the process control data together with the CEMS data to better understand what was happening in the combustor during its operation and thereby correctly interpret the emission data. The wet O₂ reading from the lambda sensor was compared with the dry O₂ reading from the CEM. The combustion air parameters were also analyzed, such as the damper (flap) position, fan settings, and “under-pressure” (which indicates the negative static pressure in the combustion chamber – although it is shown as a positive number for ease of data presentation).

Examples of the CEMS and process control data analyses are presented within the following nine figures in graphical format (CO emissions in ppmv corrected to 25°C and
11% O₂) where Figure 38 to Figure 43 represent Boiler 3 (TX150) and Figure 44 to Figure 46 represent Boiler 1 (TM500):

- Figure 38. Start-up carbon monoxide emissions for Boiler 3 (TX150) using wood pellets
- Figure 39. Start-up combustion air control for Boiler 3 (TX150) using wood pellets
- Figure 40. Steady state carbon monoxide emissions for Boiler 3 (TX150) using wood pellets
- Figure 41. Dry oxygen and wet oxygen for Boiler 3 (TX150) using wood pellets
- Figure 42. Steady state combustion air control for Boiler 3 (TX150) using wood pellets
- Figure 43. Carbon monoxide emissions for Boiler 3 (TX150) during shut down using wood pellets
- Figure 44. Steady state carbon monoxide emissions for Boiler 1 (TM500) using wood chips
- Figure 45. Dry oxygen and wet oxygen for Boiler 1 (TM500) using wood chips
- Figure 46. Steady state combustion air control for Boiler 1 (TM500) using wood chips

In Figure 38, the 400 ppmv CO emission limit (24-hour) from Guideline A-14 is shown for illustrative purposes. In this start-up scenario for wood pellets, the non-steady state CO emissions exceed the 400 ppmv emission limit for less than 20 minutes during a cold start in the morning but quickly drop below 100 ppmv once steady state conditions are achieved. This coincides with the activation of the secondary air system part way through the start-up procedure as shown in Figure 39 while the primary air system is constantly modulating throughout the start-up procedure.

In Figure 40, the steady state CO levels are shown to modulate within a range of approximately 10 to 50 ppmv while the O₂ levels modulate between 9 to 11% to maintain the desired set-point and good combustion of the wood pellets. The variation in CO and O₂ levels is quite limited mainly due to the consistent fuel properties of wood pellets as described in Section 7.3.1.2.

In Figure 41 it is observed that since the moisture content of the wood pellets is low, the moisture in the flue gas is also low, so that the dry and wet O₂ measurements are nearly identical. Again, the variation in both wet and dry O₂ levels is quite limited since the combustion characteristics of wood pellets are very good.

In Figure 42 it is observed that during steady state operation the primary air system does not modulate but remains steady while the secondary air system is constantly adjusting to keep the O₂ level at the desired set-point as shown in Figure 41.
In Figure 43 the emissions of CO are plotted during a shutdown procedure for Boiler 3 (TX150) using wood pellets. At 5:05 pm the shutdown procedure was initiated, which caused the wood fuel feed rate to decrease while the CO emissions increased. At 5:23 pm the wood fuel feed rate increased temporarily to empty the wood pellet feed auger for safety purposes. The CO emissions varied significantly for over an hour before stabilizing at a lower level during the second hour of the shutdown. The induced draft (ID) fan modulated while the residual wood pellets were burned then shut off at 6:23 pm which ended the CO emission occurrence. The remaining CO readings after 6:23 pm are a function of purge air in the boiler and do not represent an emission to the air.

In Figure 44, the steady state wood chip combustion CO levels are shown to be primarily below 10 ppmv except for two short duration spikes above 200 ppmv. The O\textsubscript{2} levels are likewise shown to be quite variable and range from 5 to 13%. These combustion performance observations are typical of wood chips that have inherently more variable fuel quality parameters as described in Section 7.3.1.1.

In Figure 45 it is observed that since the moisture content of the wood chips is higher than wood pellets, the moisture in the flue gas is also higher, so that the dry and wet O\textsubscript{2} measurements are offset from each other. Also, there is significant variation in O\textsubscript{2} levels since the fuel properties of wood chips are more variable as compared to wood pellets (refer to Section 7.3.1).

In Figure 46 it is observed that the ID flue gas fan, forced draft combustion air fan and flue gas recirculation (FGR) fan are all modulating automatically in real time to maintain the O\textsubscript{2} level at the desired set-point as shown in Figure 45. This process control scheme represents a very advanced degree of sophistication and is the key reason why CO levels are maintained below 10 ppmv for the majority of the time during steady state conditions while using wood chips as the fuel.
Background and Rationale for the Development of a Guideline for the Control of Air Emissions from Small Wood-Fired Combustors with a Heat Input Capacity of Less Than 3 Megawatts

Figure 38. Start-up carbon monoxide emissions for Boiler 3 (TX150) using wood pellets

Figure 39. Start-up combustion air control for Boiler 3 (TX150) using wood pellets
Background and Rationale for the Development of a Guideline for the Control of Air Emissions from Small Wood-Fired Combustors with a Heat Input Capacity of Less Than 3 Megawatts

Figure 40. Steady state carbon monoxide emissions for Boiler 3 (TX150) using wood pellets

Figure 41. Dry oxygen and wet oxygen for Boiler 3 (TX150) using wood pellets
Figure 42. Steady state combustion air control for Boiler 3 (TX150) using wood pellets

Figure 43. Carbon monoxide emissions for Boiler 3 (TX150) during shut down using wood pellets
Figure 44. Steady state carbon monoxide emissions for Boiler 1 (TM500) using wood chips

Figure 45. Dry oxygen and wet oxygen for Boiler 1 (TM500) using wood chips
7.4 Clarkson University – New York State Energy Research and Development Authority Research

In 2008, NYSERDA initiated a series of emission tests on two SWFC (150 kW and 500 kW in size) that were performed by investigators at Clarkson University.\textsuperscript{116,117} The results summarized herein are for the 150 kW Hamont CATfire technology imported from Austria that was tested at two sites (Site 1 – WAC, Site 2 – CNC). The 500 kW unit had operational problems and the data is not considered representative of normal operations and is therefore not presented in this chapter.

The two 150 kW units were identical and had an automatic bottom feed auger system, a cyclone to reduce PM emissions, and 3-stage combustion air input to provide for high thermal efficiency and low CO emissions. One of the units was tested with wood pellets, referred to as the WAC unit while the other was tested with wood chips, referred to as the CNC unit.

The WAC unit that used wood pellets as the fuel had very consistent CO emissions of approximately 260-300 mg/Nm³ (20°C, 7% O₂) while operating at 72% firing rate at steady state conditions. The CNC unit that used wood chips as the fuel had slightly more variable CO emissions of approximately 160-220 mg/Nm³ (20°C, 7% O₂) while operating between 60-75% firing rate at nearly steady state conditions. A 30-minute sample of CEM data recorded at each facility is presented within Figure 49 where the WAC CO data is in the middle of the graph (dashed blue line) and the CNC CO data is along the bottom (solid blue line). The CO emissions corrected to 7%O₂ are read against the far right axis.

Figure 47. Sample of continuous emission monitor data for 150 kW Hamont CATfire (dashed lines – wood pellets; solid lines – wood chips) during steady state operation

Since PM with an aerodynamic diameter of less than 2.5 microns (PM₂.₅) was tested but not PM the emission rates are not included in this chapter as the results cannot be compared with other PM data; however, an elemental analysis of the fly ash is included. The elemental analysis of the fly ash recovered from the PM₂.₅ testing was determined to be predominantly inorganic salts consisting of potassium and sulphate with small amounts of sodium, calcium, chloride and unburned C that indicated good combustion, consistent with the low CO levels at steady state conditions. Also, trace levels of naturally occurring metals such as iron, and heavy metals such as cadmium, lead,

titanium, and zinc were found in the PM$_{2.5}$ which is consistent with chapter 3. It is noted that the PM$_{2.5}$ emissions from wood chip testing was higher than that for wood pellets due to the higher ash content of the wood chips.

Polycyclic aromatic hydrocarbon emissions were reported to be low and BaP was reported as zero for the CNC unit. Of interest all 17 species of polychlorinated dibenzodioxins and polychlorinated dibenzofurans were reported to be below the detection limit.

8 Air Emission Management Strategies

In this chapter a suite of strategies are presented regarding the management of air emissions - based on the current jurisdictional, air emission and industry knowledge developed in the preceding chapters. The key aspects considered in this chapter are: (i) the ability of the small wood-fired combustor (SWFC) owner/operator to procure and store a wood fuel at the required level of quality, and (ii) the ability to demonstrate a consistently low air emission profile for a given wood fuel both before and after the installation.

Demonstrating an air emission profile before installation refers to the process of a SWFC manufacturer collecting source testing data prior to the sale to a customer. This can be accomplished through a third party independent certification process or validation of compliance testing results by a regulator in another jurisdiction. Demonstrating an emission profile after installation refers to the owner/operator conducting source testing and continuous performance monitoring (e.g., process control and possibly flue gas emission) to demonstrate compliance with emission criteria levels as prescribed by a regulatory agency.

The regulatory value of continuous performance monitoring is its ability to facilitate the long term monitoring of SWFC performance over a day, a month or a year and assess any complaints or problems with meeting regulatory emission limits. As with any combustion system, the device can lose its efficiency over time as component parts begin to degrade and wear out. This is less of a concern for SWFC certified to EN 303-5 (2012) Class 5 for thermal efficiency and CO due to their sophisticated process controls. For uncertified SWFCs that typically do not have a well-established air emission profile prior to installation, the risk of increased air emissions is higher.

As described in chapter 6, a SWFC would typically go through a commissioning period that includes a site acceptance test conducted by a manufacturer trained technician before beginning its “in service” commercial operation. As such, those activities are expected to be completed before any assessment of air emissions compliance and are not considered in this chapter.

8.1 Industry Trends

The industry trends for wood fuel is towards standardization as described in chapter 4 and for SWFC it is certification/pre-qualification of thermal efficiency and air emissions
as described in chapter 5. This trend is very intentional as jurisdictions around the world seek to use renewable energy in the form of wood fuel matched to a SWFC but regulators need instruments to reduce the risk of air emissions as described in chapters 3 and 7. Wood fuel producers and SWFC manufacturers, primarily in Europe, have responded by developing products that comply with applicable standards and air emission criteria levels. SWFC manufacturers have enhanced performance by designing specific models for a narrowly defined range of wood fuel properties, typically wood pellets, to achieve maximum efficiency and low emissions.

Regulators can make use of this industry trend by dividing their requirements along wood fuel quality and SWFC certification/pre-qualification lines. For example, as stated in chapter 7, the use of wood pellets typically results in lower particulate matter (PM) emission levels as compared with wood chips since they have uniform shape and size and contain lower and consistent moisture and ash contents. Likewise, a certified SWFC will have independently tested air emission data to characterize its emission profile in a way that an uncertified SWFC will not. However, field testing of PM at Confederation College was typically unable to repeat EN 303-5 (2012) Class 5 certification test levels as there was a high degree of variability depending on fuel type, fuel properties, firing rate load level, and whether or not a cyclone was installed. The PM data described in chapter 7 showed measured levels across Classes 3, 4, and 5 of EN 303-5 (2012). Carbon monoxide (CO) on the other hand was typically quite low during field testing and consistent with EN 303-5 (2012) Class 5 certification levels for all SWFC assessed regardless of fuel type or firing rate load level.

Not all SWFC manufacturers will have air emission source test data from certification/pre-qualification activities as those are primarily required in Europe. Any SWFC that does not have a reliable air emission data set for assessment during the permitting review phase presents a challenge for the regulator as to what the actual emission profile will be after its installation.

8.2 Standardization of the Wood Fuel Supply

In Ontario, the wood pellet industry has been developing for several years to serve the international export market but has recently begun to supply an emerging domestic market. Wood pellet producers are accustomed to working with quality standards as described in chapter 4 and a wood pellet consumer in Ontario typically has access to a supply of consistently good quality pellets. It is evident that this emerging industry is capable of supplying good quality wood pellets to SWFC projects.

In contrast, wood chips have historically represented a primarily unregulated fuel supply stream in Ontario and most producers are not accustomed to working with fuel quality standards since ungraded hog fuel is the industry norm. However there are wood chip suppliers that work to very high quality standards since their product is used as feedstock to the pulp and paper industry rather than fuel for combustion.
Regardless of the wood fuel type, an owner/operator of a SWFC must maintain the quality of the fuel while it is stored on-site until it is used. The requirement to develop and implement a wood fuel management plan has been included in Guideline A-14 and is included in several recently developed guidelines for SWFC such as those in Metro Vancouver, British Columbia and the United Kingdom. For example, Appendix 3 of Greater Vancouver Regional District Boilers and Process Heaters Emission Regulation Amending Bylaw No. 1190 (Metro Vancouver Bylaw No. 1190) includes the requirements of a fuel management plan listed in four parts: (i) documented fuel specifications, (ii) quality assurance plan, (iii) storage plan, and (iv) record keeping requirements.

8.3 Source Testing

Ontario has a long history of requiring source testing for wood fired combustors, large and small. This is primarily due to the fact that historically these units have been mostly large field erected units used for industrial or utility scale steam generation purposes and did not have any wood fuel quality standards. The air emissions could only be estimated prior to installation as the large units cannot be tested in a laboratory prior to their construction at the owner/operator site. Guideline A-13 includes a streamlined list of source testing parameters depending on combustor size and fuel characteristics. The source testing is required within the first 12 months of commencement of operations and thereafter every four years. This is consistent with other jurisdictions that require periodic air emission testing for large and small wood-fired combustion systems. For example, Metro Vancouver Bylaw No. 1190 requires annual emission testing for SWFC rated above 1 MW, but the regulator has discretion to decide the frequency of emission testing for units rated below 1 MW.

The source testing and associated research testing program conducted at Confederation College, as described in chapter 7, has yielded very valuable information for the purposes of developing Guideline A-14. For a certified SWFC, PM source testing is required where no air pollution control device is installed but the PM emissions could be easily reduced with a cyclone. Likewise, the need for CO source testing is also evident as it represents the key parameter to determine complete combustion. CO is a surrogate measure for toxic air pollutants (see chapter 3), and it is used by all jurisdictions without exception (see chapter 5).

In contrast, the results of the source testing demonstrated that emissions of benzo[a]pyrene (BaP) and acrolein were all shown to be non-detectable at Confederation College for each SWFC, wood fuel type and firing rate load level (see chapter 7). The New York State Energy Research and Development Authority (NYSERDA) funded testing at Clarkson University (see chapter 7) that showed consistently low or non-detectable results. In both cases, the emissions are much lower than the United States Environmental Protection Agency (USEPA) AP-42 emission factors that are based on 1990’s era combustion technology performance. The industry trend towards standardized wood fuel (see chapter 4) and certified combustor designs
(see chapter 5) has essentially removed these problematic air pollutants from consideration.

Since contaminated wood or waste materials are not permitted to be used as wood fuel according to the wood fuel standards described in chapter 4, there is no need to conduct emission testing for dioxins and furans. This is consistent with the other SWFC guidelines reviewed in chapter 5. This is also consistent with the approach in Guideline A-13 for large wood-fired combustors in Ontario where dioxin and furan testing is only required for units that propose to use waste materials as a portion of the fuel.

Guideline A-14 includes source testing requirements for PM and CO which is consistent with other jurisdictions and is well informed by the testing results from Confederation College. Including source testing requirements at both nominal load and partial load operating levels is an innovative approach for Ontario that is well informed by industry trends and developments in Europe according to EN 303-5 (2012).

8.4 Continuous Process Control Monitoring

A key component of the research testing program conducted at Confederation College was the assessment of process control data downloaded from the SWFC after each day of source testing. The data was extracted in 1-minute interval averages for research purposes. The default setting in the Froling software for process control monitoring is 5-minute interval averages. Several graphs of process control data were presented in chapter 7 to describe the oxygen (O₂) lambda sensor measurements (reported on a wet basis) and combustion air control parameters. These continuous process control measurements were valuable regarding the understanding of SWFC operation as the conditions change intermittently when wood fuel is added to the combustion chamber. These measurements enabled the correct interpretation of the steady state condition source testing results. These measurements were also valuable in the assessment of the non-steady state condition operations, including start-up and shut down procedures, for which source testing measurements were not collected.

The minimization of SWFC air emissions depends significantly on process control as the small combustion chambers do not have the large furnace volumes and long residence times typical of large wood-fired combustors. By using the advanced combustion chamber design and operating techniques described in chapter 6, a SWFC can achieve efficient combustion and maintain low air emissions by controlling the flow rate of combustion air, O₂ levels, furnace pressure and other parameters in real time. It is important that the process control system continues to function correctly over the life of the SWFC to maintain efficient combustion and low air emissions.

8.5 Continuous Emission Monitoring

Another key component of the research testing program conducted at Confederation College was the assessment of continuous emission monitoring system (CEMS) data downloaded from the CEMS after each day of source testing. The CEMS data set was extracted as 1-minute interval averages to match the process control data set. Several
graphs of CEMS data were presented in chapter 7 to describe the CO and O\textsubscript{2} measurements (reported on a dry basis). These CEMS measurements were valuable regarding the understanding of SWFC operation as the CEMS data could be compared with the process control data. They enabled the correct interpretation of the steady state condition source testing results and were valuable in assessing the non-steady state condition operations, including start-up and shut down procedures, for which source testing measurements were not collected.

The CEMS data for the certified SWFC tested at Confederation College showed that the CO emissions were very low. More importantly, the data showed that the sophisticated process controls returned the emissions to a very low level after an interruption to steady state operating conditions during which the emissions were higher, but only for a brief amount of time.

8.6 Data Acquisition System

The process control and CEMS data downloaded and reviewed each day as part of the research testing program at Confederation College was extracted as 1-minute interval averages. The facility was equipped with a data acquisition system to enable recordkeeping. The ability to assess real time data on a computer screen in graphical format and store data in spreadsheet format was immensely beneficial to the project team and was instrumental to the success of the project.

After analyzing the data in the months following the research testing program, it was observed that 1-minute averages yielded very fine resolution data that resulted in very large data sets. Under normal operating circumstances, it would not likely be required to characterize the SWFC performance and emission data with such high resolution. The default 5-minute average interval specified by Froling is adequate to observe the SWFC performance. However, there was enough variation of combustor performance over a 30 or 60 minute time frame that an average time interval of greater than 5 minutes would not be a fine enough data resolution to correctly understand the combustor performance. This is evident in the process control and CEM graphs shown in chapter 7, especially for the TM500 unit operating with wood chips.

8.7 Performance Tune-Up and Inspection

Another strategy for monitoring combustion performance is the use of a periodic performance tune-up and inspection to ensure the SWFC is being maintained and operated as per the original manufacturers design. For example, in Metro Vancouver Bylaw No. 1190 “performance tune-up means the process of inspection, testing and maintenance procedures used to restore a boiler to its efficient state, given its age and other parameters”. A performance tune-up must be conducted on a biennial basis according to procedures recommended by the manufacturer and approved by the regulator (no more than 26 months from the last performance tune-up).

Guideline A-13 likewise requires a performance tune-up every two years and a description of the tune-up requirements are listed in Table B-4 of Appendix B in
Guideline A-13. This is considered reasonable for large units that typically have full time technical staff on-site to operate and maintain the combustor on a daily basis.

However, for SWFC that will typically be located at facilities without full time technical staff on-site and are operated automatically, more frequent performance tune-ups and inspections conducted by a properly trained and equipped technician that is familiar with heating, ventilation and air conditioning (HVAC) equipment will be required. This provides reasonable regulatory oversight for certified SWFC for which continuous flue gas emission monitors are not required.

8.8 References


Appendix I: Acronyms and Units of Measure

This Appendix presents the acronyms and abbreviations referenced in this document in Table 36 and the units of measure referenced in this document in Table 37. The meaning of each item is provided to assist with interpretation of the document.

Table 36. Summary of acronyms and abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>BACT</td>
<td>Best available control techniques</td>
</tr>
<tr>
<td>BAT</td>
<td>Best Available techniques</td>
</tr>
<tr>
<td>BaP</td>
<td>benzo[a]pyrene</td>
</tr>
<tr>
<td>CEM</td>
<td>Continuous emission monitoring</td>
</tr>
<tr>
<td>CEMS</td>
<td>Continuous emission monitoring system</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined heat and power</td>
</tr>
<tr>
<td>C</td>
<td>Carbon</td>
</tr>
<tr>
<td>Ca</td>
<td>Calcium</td>
</tr>
<tr>
<td>Cl</td>
<td>Chlorine</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide</td>
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<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
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<tr>
<td>COC</td>
<td>Condensable organic compounds</td>
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<td>CSA</td>
<td>Canadian Standards Association</td>
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<tr>
<td>Cu</td>
<td>Copper</td>
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<tr>
<td>d.b.</td>
<td>Dry basis</td>
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<tr>
<td>DEQ</td>
<td>Virginia Department of Environmental Quality</td>
</tr>
<tr>
<td>DES</td>
<td>Department of Environmental Services</td>
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<tr>
<td>DTL</td>
<td>Detection threshold limit</td>
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<tr>
<td>EF</td>
<td>Emission factors</td>
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<tr>
<td>ECA</td>
<td>Environmental compliance approval</td>
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<tr>
<td>Dust</td>
<td>European Union term often used for particulate matter (see also, PM)</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
</tr>
<tr>
<td>ELV</td>
<td>Emission Limit Values</td>
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<tr>
<td>ESP</td>
<td>Electrostatic precipitator</td>
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<tr>
<td>EU</td>
<td>European Union</td>
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<tr>
<td>FGR</td>
<td>Flue gas recirculation</td>
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<tr>
<td>GCV</td>
<td>Gross calorific value</td>
</tr>
<tr>
<td>H</td>
<td>Hydrogen (solid)</td>
</tr>
<tr>
<td>H₂</td>
<td>Hydrogen (gas)</td>
</tr>
<tr>
<td>H₂O</td>
<td>Water</td>
</tr>
<tr>
<td>HHV</td>
<td>High heating value</td>
</tr>
<tr>
<td>ID</td>
<td>Induced draft</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>K</td>
<td>Potassium</td>
</tr>
<tr>
<td>LAPPC</td>
<td>Local air pollution prevention control</td>
</tr>
<tr>
<td>Acronym</td>
<td>Meaning</td>
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<tr>
<td>-----------</td>
<td>----------------------------------------------</td>
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<tr>
<td>LHV</td>
<td>Low heating value</td>
</tr>
<tr>
<td>MassDEP</td>
<td>Massachusetts Department of Environmental Protection</td>
</tr>
<tr>
<td>MC</td>
<td>Moisture content</td>
</tr>
<tr>
<td>MNRF</td>
<td>Ontario Ministry of Natural Resources and Forestry</td>
</tr>
<tr>
<td>MOECC</td>
<td>Ontario Ministry of Environment and Climate Change</td>
</tr>
<tr>
<td>NAAQS</td>
<td>National Ambient Air Quality Standards</td>
</tr>
<tr>
<td>NYSERDA</td>
<td>New York State Energy Research and Development Authority</td>
</tr>
<tr>
<td>N</td>
<td>Nitrogen (solid)</td>
</tr>
<tr>
<td>N₂</td>
<td>Nitrogen (gas)</td>
</tr>
<tr>
<td>Na</td>
<td>Sodium</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Nitrous oxides (also referred to as oxides of nitrogen)</td>
</tr>
<tr>
<td>NRCan</td>
<td>Natural Resources Canada (Federal Government)</td>
</tr>
<tr>
<td>NSPS</td>
<td>New source performance standard</td>
</tr>
<tr>
<td>NSR</td>
<td>New source review</td>
</tr>
<tr>
<td>NVC</td>
<td>Net calorific value</td>
</tr>
<tr>
<td>NWT</td>
<td>Northwest Territories</td>
</tr>
<tr>
<td>ON</td>
<td>Ontario</td>
</tr>
<tr>
<td>O</td>
<td>Oxygen (solid)</td>
</tr>
<tr>
<td>O₂</td>
<td>Oxygen (gas)</td>
</tr>
<tr>
<td>%O₂</td>
<td>Per cent oxygen by volume</td>
</tr>
<tr>
<td>OGC</td>
<td>Organic gaseous carbon</td>
</tr>
<tr>
<td>P</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>PAH</td>
<td>Polycyclic aromatic hydrocarbons</td>
</tr>
<tr>
<td>PFI</td>
<td>Pellet Fuels Institute</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate matter (also referred to as “dust” in the EU)</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>Particulate matter with an aerodynamic diameter less than 2.5 microns</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>Particulate matter with an aerodynamic diameter less than 10 microns</td>
</tr>
<tr>
<td>ppmv</td>
<td>Parts per million by volume</td>
</tr>
<tr>
<td>QA/QC</td>
<td>Quality assurance/quality control</td>
</tr>
<tr>
<td>RHI</td>
<td>Renewable heat incentive</td>
</tr>
<tr>
<td>RHNY</td>
<td>Renewable Heat NY (New York)</td>
</tr>
<tr>
<td>S</td>
<td>Sulphur</td>
</tr>
<tr>
<td>SDFGV</td>
<td>Specific dry flue gas volume (cubic metres per gigajoule)</td>
</tr>
<tr>
<td>Si</td>
<td>Silicon</td>
</tr>
<tr>
<td>SO₂</td>
<td>Sulphur dioxide</td>
</tr>
<tr>
<td>SWFC</td>
<td>Small wood-fired combustor(s)</td>
</tr>
<tr>
<td>UK</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>USEPA</td>
<td>United States Environmental Protection Agency</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile organic compounds</td>
</tr>
<tr>
<td>w.b.</td>
<td>Wet basis</td>
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Table 37. Summary of measurement units

<table>
<thead>
<tr>
<th>Unit of Measure</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Btu</td>
<td>British Thermal unit</td>
</tr>
<tr>
<td>Btu/hr</td>
<td>British Thermal unit per hour</td>
</tr>
<tr>
<td>Btu/lb</td>
<td>British Thermal unit per pound</td>
</tr>
<tr>
<td>°C</td>
<td>Degrees Celsius</td>
</tr>
<tr>
<td>cm</td>
<td>Centimetre</td>
</tr>
<tr>
<td>m³/GJ</td>
<td>Cubic metre per gigajoule</td>
</tr>
<tr>
<td>GJ</td>
<td>Gigajoule</td>
</tr>
<tr>
<td>g/hr</td>
<td>Grams per hour</td>
</tr>
<tr>
<td>g/GJ</td>
<td>Grams per gigajoule</td>
</tr>
<tr>
<td>gPM/kg biofuel</td>
<td>Grams of particulate matter per kilogram of biofuel burned</td>
</tr>
<tr>
<td>kg/m³</td>
<td>Kilograms per cubic metre</td>
</tr>
<tr>
<td>Kcal/mole</td>
<td>Kilocalories per mole</td>
</tr>
<tr>
<td>kW</td>
<td>Kilowatt</td>
</tr>
<tr>
<td>lb/MMBtu</td>
<td>Pound per million British Thermal unit</td>
</tr>
<tr>
<td>m³/GJ</td>
<td>Cubic metres per gigajoule</td>
</tr>
<tr>
<td>mg/MJ</td>
<td>Milligram per megajoule</td>
</tr>
<tr>
<td>MJ/kg</td>
<td>Megajoules per kilogram</td>
</tr>
<tr>
<td>mg/m³</td>
<td>Milligrams per cubic metre</td>
</tr>
<tr>
<td>mg/Nm³</td>
<td>Milligrams per normalized cubic metre (normalized units as specified)</td>
</tr>
<tr>
<td>mg/Rm³</td>
<td>Milligrams per reference cubic metre (reference units as specified)</td>
</tr>
<tr>
<td>mm</td>
<td>Millimetre</td>
</tr>
<tr>
<td>MMBtu/hr</td>
<td>Million British Thermal units per hour</td>
</tr>
<tr>
<td>MW</td>
<td>Megawatt</td>
</tr>
<tr>
<td>Tons/year</td>
<td>Tons per year</td>
</tr>
<tr>
<td>%</td>
<td>Per cent</td>
</tr>
<tr>
<td>$</td>
<td>Dollar</td>
</tr>
<tr>
<td>L</td>
<td>Litres</td>
</tr>
<tr>
<td>&lt;</td>
<td>Less than</td>
</tr>
<tr>
<td>≤</td>
<td>Less than or equal to</td>
</tr>
<tr>
<td>&gt;</td>
<td>Greater than</td>
</tr>
<tr>
<td>≥</td>
<td>Greater than or equal to</td>
</tr>
<tr>
<td>µm</td>
<td>Micrometre</td>
</tr>
<tr>
<td>µg/g</td>
<td>Microgram per gram</td>
</tr>
</tbody>
</table>
Appendix II: Natural Resources Canada – Solid Biofuels Bulletins

This Appendix presents the following solid biofuels bulletins published by Natural Resources Canada to summarize and describe the ISO wood fuel standards as adopted by CSA:

1. Solid Biomass Fuels
2. Primer for Solid Biofuels: Definitions, Classes/Grades and Fuel Properties
3. CAN/CSA-ISO Solid Biofuels Standards
4. Graded Wood Pellets
5. Graded Wood Briquettes
6. Graded Wood Chips
Solid Biofuels Bulletin No. 1

SOLID BIOMASS FUELS

This bulletin is the first in a series of bulletins related to solid woody biomass fuels (solid biofuels). The information captured in the series is based on a suite of Solid Biofuel Standards developed and published by the International Organisation for Standardization (ISO). The bulletins are aimed primarily at consumers who are using or considering solid biofuels for space heating. The intent is to provide easy-to-read introductory guides to the use of solid biofuels. The series may also be of interest to fuel suppliers, equipment manufacturers, testing laboratories and regulators.

This bulletin introduces sources of biomass, provides definitions for solid biofuels and their key characteristics.

What is Biomass?
The term ‘biomass’ encompasses all organic materials of biological origin and can be sourced from various operations including:

- forestry and arboriculture (the management of woody plants);
- agriculture and horticulture (the management of vegetable garden plants);
- aquaculture (the farming of aquatic organisms).

Woody biomass from forestry and arboriculture operations is by far the most common biomass available in Canada and worldwide. Forest biomass generated by the Canadian forest sector adheres to rigorous forest management practices, i.e. sustainable harvesting and replanting of harvested areas.

Sources of woody biomass include:

- forest, plantation and other virgin wood – such as stem wood, segregated wood from city forests, parks, gardens, roadside maintenance and logging residues;

<table>
<thead>
<tr>
<th>Wood Residue</th>
<th>Firewood</th>
<th>Wood Chips</th>
<th>Briquettes</th>
<th>Wood Pellets</th>
<th>Thermally treated fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Wood Residue" /></td>
<td><img src="image2" alt="Firewood" /></td>
<td><img src="image3" alt="Wood Chips" /></td>
<td><img src="image4" alt="Briquettes" /></td>
<td><img src="image5" alt="Wood Pellets" /></td>
<td><img src="image6" alt="Thermally treated fuels" /></td>
</tr>
</tbody>
</table>
by-products and residues from the wood processing industry – generated during the production of forest products and includes hog fuel (unrefined wood fibre), slabs, sawdust, shavings and bark;

used wood – post-consumer wood waste, such as construction and demolition wood, pallets and wood packages.

What are Solid Biofuels?

Solid biofuels are produced from biomass through processing steps such as chopping, drying, chipping, grinding and densifying (pelletizing or briquetting). This improves the physical and chemical properties: i.e. particle size, moisture content and energy content. Densification is usually required for efficient and economical long distance transportation, bulk handling and storage. Additional processes are under development (torrefaction, steam processing) to further improve fuel quality by increasing energy content, mechanical durability and reduce water absorption. Solid biofuels are available in various forms including:

- **Firewood**: cut and/or split logs, preferably dried and usually with uniform length.
- **Wood Chips**: chipped wood with a defined size, a typical length of 5 to 50 mm, and a low thickness compared to length; produced by mechanical processing with sharp tools.
- **Briquettes**: densified (compressed) biomass fuel in a cubic or cylindrical form with a diameter of more than 25 mm.
- **Wood Pellets**: densified biomass fuel in a cylindrical form with a diameter of up to 25 mm and length of 5 to 40 mm.

Advantages of Standardization

Since the early days of village markets an axiom has been that you should get what you pay for. From the development of hand-held scales to current exotic laser and microwave devices, the goal has been a uniform set of criteria or standards to facilitate commerce. These same criteria should be applied to solid biofuels in which what you are buying is really the energy in the fuel. Determination of this “energy quantity” requires more than simple measurement of weight and/or volume. Agreed-upon standardization criteria allow consumers, suppliers and regulators to have confidence in the consistency and performance of solid biofuels. Heating equipment manufacturers can then also design and engineer their systems to match the fuel specifications.

Industrial energy systems fueled with biomass fuels are custom designed with sophisticated controls and appropriate air emission control equipment. They can burn wood residue, such as hog fuel, efficiently and effectively. Space heating equipment, on the other hand, is typically factory built and may not have advanced controls or emission control equipment (mainly because of cost constraints). Furthermore, the equipment is not generally managed by professional engineers and facilities are typically located in populated areas. This makes fuel

Table 1. Comparison of key fuel property specifications of wood residue and solid biofuels

<table>
<thead>
<tr>
<th>Fuel Property</th>
<th>Wood Residue*</th>
<th>Firewood</th>
<th>Wood Chips</th>
<th>Briquettes</th>
<th>Wood Pellets</th>
<th>Thermally Treated Biofuels**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content</td>
<td>High</td>
<td>High-Medium</td>
<td>High-Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Energy Content</td>
<td>Low</td>
<td>Low-Medium</td>
<td>Medium</td>
<td>Medium-High</td>
<td>Medium-High</td>
<td>High</td>
</tr>
<tr>
<td>Bulk Density</td>
<td>Low</td>
<td>Low-Medium</td>
<td>Low-Medium</td>
<td>Medium-High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

* Often referred to as hogfuel
** Standards for classes and specifications of thermally treated biofuels are currently in development by ISO TC 238.
standardization a crucial requirement for safe, reliable and efficient operation.

Standards such as those published by ISO and CSA lay out the key properties affecting the energy content and performance of biofuels (Table 1). These properties include not only the form (size, shape and density) but also the energy and moisture contents and non-combustible portion (ash).

Standards for solid biofuels have been developed by the International Organisation of Standardization (ISO) within the 17225 series (8 parts), and, are adopted and available through the Canadian Standards Association Group (CSA) in Canada. Part 1 of the CAN/CSA-ISO 17225 includes comprehensive classifications and specifications for broad range of solid biofuels sourced from forestry, arboricultural, agricultural, horticultural and aquatic origins. Parts 2 to 8 of the CAN/CSA-ISO 17225 standards detail specifications for graded biofuels for applications in residential, commercial and industrial sectors.

In addition to the CAN/CSA-ISO 17225 series, standards for sampling and testing methodologies for verification purposes and for the safe handling and storage of pellets are slated for release by 2018.

Natural Resources Canada aims to make the new CAN/CSA-ISO 17225 solid biofuel standards widely known, understandable and user-friendly through a series of bulletins listed in Table 2. These bulletins are intended to provide the reader with a brief summary of the standards and highlight the most relevant information.

### Solid Biofuels and Carbon Impact

94% of the forest land in Canada is publicly owned. Management of this forest land involves integrating environmentally responsible and sustainable biomass harvest practices and forest management plans. Forestry in Canada upholds strong environmental values and has stringent requirements for forest regeneration, protection of species-at-risk and the integrity of ecosystems. Less than 1% of managed forest in Canada is harvested each year (Figure 1).

Forest harvesting and wood processing leave behind biomass as by-products and residues from logging and milling operations; biomass residues are also generated during thinning operations. These by-products and residues, resulting from sustainable forest practices and operations, are used as raw material for solid biofuel production. Other sources such as insect- or fire-killed trees and urban wood waste can also be valuable for solid biofuel production.

The use of solid biofuels is renewable, can replace energy generated from fossil fuels and help displace greenhouse gas (GHG) emissions from fossil fuels. It can also lower the risk of forest fires by managing the forest floor debris.

The net benefit of bioenergy to the environment is particularly significant when the sources of the woody biomass are by-products and residues and used wood. Other factors affecting the net environmental benefits of bioenergy over time include:

- alternative usage of the biomass (is the biomass left to decay, landfilled or manufactured into a consumer product?)

<table>
<thead>
<tr>
<th>Technical Bulletin</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.1 – Solid Biomass Fuels</td>
<td>Introduction to biomass and solid biofuels</td>
</tr>
<tr>
<td>No.2 – Primer for Solid Biofuels</td>
<td>Guide to definitions, classes/grades and fuel properties</td>
</tr>
<tr>
<td>No.4 – Graded Wood Pellets</td>
<td>Explains fuel specifications as defined in the CAN/CSA-ISO 17225 Part 2</td>
</tr>
<tr>
<td>No.5 – Graded Wood Briquettes</td>
<td>Explains fuel specifications as defined in the CAN/CSA-ISO 17225 Part 3</td>
</tr>
<tr>
<td>No.6 – Graded Wood Chips</td>
<td>Explains fuel specifications as defined in the CAN/CSA-ISO 17225 Part 4</td>
</tr>
<tr>
<td>No.7 – Graded Firewood</td>
<td>Explains fuel specifications as defined in the CAN/CSA-ISO 17225 Part 5</td>
</tr>
</tbody>
</table>
- type of fossil fuel being replaced (such as coal, fuel oil, propane, or natural gas),
- forest growth rates,
- furnace / boiler design and efficiency, air pollution controls, and operating conditions.

SUSTAINABLE FOREST MANAGEMENT

When will Canada harvest its last tree?

Never.

Canada’s forests are renewable resources that are carefully managed to ensure that their social, economic and environmental benefits are available for generations to come.

In fact, studies have confirmed that Canada has some of the most rigorous forest management policies in the world.

Figure 1. Allocation of Canada’s forest coverage

<table>
<thead>
<tr>
<th>Canada forest</th>
<th>348 million hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>161 million hectares</td>
<td>independently certified as sustainably managed (2014)</td>
</tr>
<tr>
<td>20.1 million hectares</td>
<td>damaged by insects (2013)</td>
</tr>
<tr>
<td>4.6 million hectares</td>
<td>burned in forest fires (2014)</td>
</tr>
<tr>
<td>0.74 million hectares</td>
<td>harvested (2013)</td>
</tr>
<tr>
<td>0.05 million hectares</td>
<td>deforested (2013)</td>
</tr>
</tbody>
</table>

Summary

- Solid biofuels can replace fossil fuels for heat and/or electricity production resulting in greenhouse gas emissions reductions and socio-economic benefits.
- There is increasing interest in the use of solid biofuels in commercial and institutional heating applications in Canada.
- Renewable, standardized solid biofuels offer consistent quality, leading to improved performance, lower maintenance costs and reduced emissions.
- Canada now has standards for solid biofuels under the CAN/CSA-ISO 17225 series.

References & Links


Acknowledgement

This bulletin was prepared in collaboration with Canadian Institute of Forestry, FPInnovations, Ontario Ministry of Natural Resources and Forestry, Pembina Institute, Wood Pellet Association of Canada, and Wood Waste to Rural Heat.

Acknowledgement

Canada has the world’s third-largest forest area. And 43% of the world’s certified forests. Certification provides third-party assurance that a forest company is operating within recognized standards of sustainable forest management.

Each year, fires and insects affect a lot of Canada’s forests. Fires, insects, diseases and other natural disturbances have occurred in Canada’s forests for millennia, shaping the diversity of plants and animals. In fact, most of Canada’s forests have regrown from seedlings in the last 200 years.

The impact of harvesting is much smaller. 100% of forests harvested on Canada’s public land must be successfully regenerated. And deforestation is even smaller. Deforestation is the clearing of forests to make way for new, non-forest land uses. Less than 0.02% of Canada’s forests are deforested each year.

Russia
Brazil
Canada
USA
China

Figure 1. Allocation of Canada’s forest coverage

Community Futures
Pembina Institute
FPInnovations
Wood Pellet Association of Canada
This bulletin, second in a series of bulletins, is based on the CAN/CSA-ISO 17225 Solid Biofuels – Fuel Specifications and Classes. This bulletin explains the most important terms and definitions used in the Standard, the basic principles of classification of solid biofuels and provides details on key fuel properties and their significance. Subsequent bulletins on the various grades of firewood, wood chips, briquettes and wood pellets elaborate on the information described in this bulletin. This primer will help end users and consumers ask appropriate questions and make informed decisions on solid biofuel purchases.

CAN/CSA-ISO 16559 and CAN/CSA-ISO 17225 – Part 1 to 8 Solid Biofuel Standards establish terms and definitions, classifications, traded forms, grades and specification of properties for solid biofuels. The principle for classification of solid biofuels under the CAN/CSA-ISO standards is based on:

- Origin and source
- Major traded forms
- Fuel Properties

**Classification by the Origin and Source:** The main origins of raw biomass materials, as classified in a hierarchical system under the CAN/CSA-ISO 17225 Part 1 standard include:

- Woody biomass
- Herbaceous biomass
- Fruit biomass
- Aquatic biomass
- Blends and mixtures
The above main grouping is further divided into second level of classification to differentiate the sources within the main groups (Table 1). The source-based classification makes distinction whether the woody biomass (classification 1) is virgin material from forest and plantation (classification 1.1), by-products/residues from the industry (classification 1.2), or used wood (classification 1.3). Groups in Table 1 are further divided into a third level sub-group.

In Canada, woody biomass comes most commonly from the following sources:

- Logging residues – generated during tree harvesting, and includes branches, tree tops and low-grade logs. All these biomass sources are identified under classification 1.1.4.

- By-products and residues from wood processing operations – such as slabs, sawdust, shavings and bark. Sawdust and shavings are primarily used for wood pellets and briquettes. “Chemically untreated” is a term that is used to describe residues from debarking, sawing or size reduction, shaping, and pressing processes (classification 1.2.1).

There are other woody biomass sources, which are available in limited amounts and currently have restricted use in Canada:

- Segregated wood collected from parks, gardens, roadside maintenance, vineyards, fruit orchards and driftwood from freshwater—is identified under classification 1.1.7.

**Table 1. Hierarchical classification and grading of Woody Biomass (classification 1) by origin and sources**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Grade A</th>
<th>Grade B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.1 Forest, plantation and other virgin wood</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1.1 Whole tree without roots</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>1.1.2 Whole trees with roots</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>1.1.3 Stem wood</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>1.1.4 Logging residues**</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>1.1.6 Bark (from forestry operations)</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>1.1.7 Segregated wood from gardens, parks, roadside maintenance, vineyards, fruit orchards, driftwood from fresh water</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

* The focus of this bulletin is solid biofuels for residential, commercial and institutional heating applications, i.e. Grades A and B; industrial grade solid biofuels, Grade (I), are excluded. Furthermore, the blends and mixtures as raw materials are excluded.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Grade A</th>
<th>Grade B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.2 By-products / residues from wood processing industries</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.2.1 Chemically untreated wood by-products, residues, wood constituents**</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>1.2.2 Chemically treated wood by-products, residues, wood constituents***</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

** Woody biomass sourced from classifications 1.1.4 and 1.2.1 is the main source for solid biofuel production in Canada

*** To qualify, chemically treated wood by-products and residues shall not contain heavy metals or halogenated organic compounds as a result of treatment with wood preservatives or coatings.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Grade A</th>
<th>Grade B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.3 Used wood</strong>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3.1 Chemically untreated used wood</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

***To qualify, used wood shall not contain heavy metals or halogenated organic compounds as a result of its usage and treatment with wood preservatives or coatings.
Used wood, or post-consumer wood waste—such as construction woods, pallets, and wood packages—is identified under classification 1.3.

**Commonly Traded Forms of Solid Biofuels:** The CAN/CSA-ISO 17225 Part 1 Standard establishes classification for solid biofuels based on shapes and sizes under which biomass fuels are traded. Storage, handling and combustion properties of the fuel are influenced by the shape and size of the fuel. Most commonly traded forms of woody solid biofuels that are most relevant to Canada are:

- firewood
- wood chips
- wood briquettes
- wood pellets

Physical and chemical properties of woody solid biofuels vary within each traded form. Some key property classes which are included in the specifications are:

- Ash
- Moisture content
- Bulk density
- Net calorific value
- Particle size (diameter/length)

**Classification by Properties:** The CAN/CSA-ISO 17225 Parts 2 to 5 Standards establish grades for common forms of woody solid biofuels based on (i) origin and source and (ii) specifications of properties (Tables 1 and 2). Grade designations make distinctions according to the types of application. Grades A and B are suitable for residential, commercial, and institutional heating applications; Grade I is suitable for industrial uses. The grade designations can be used both by buyers and sellers in contracts and specification sheets to eliminate confusion and clearly identify the required fuel specification.

From a fuel buyer or operator perspective, what is important and useful is whether the biomass fuel meets the appropriate standards, i.e. grading, classification and fuel specifications, not how it is produced. In the following sections, most significant fuel properties will be introduced. A buyer, operator, or producer should have the basic knowledge of these properties that are applicable to wide range of solid biofuels.

---

**Table 2. Comparison of key specifications of properties for selected woody solid biofuels and fossil fuels**

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Density* (kg/m³)</th>
<th>Density* (lb/ft³)</th>
<th>High Heating Value by Mass (MJ/kg)</th>
<th>High Heating Value by Mass (Btu/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood chips (about 45% Moisture, loosely packed)</td>
<td>300–400</td>
<td>19–25</td>
<td>10–11</td>
<td>4,300–4,700</td>
</tr>
<tr>
<td>Firewood (stacked; air dry to about 25% moisture)</td>
<td>300–500</td>
<td>19–31</td>
<td>14–15</td>
<td>6,200–6,500</td>
</tr>
<tr>
<td>Wood pellets** (≤10% moisture)</td>
<td>550–800</td>
<td>34–50</td>
<td>16–18</td>
<td>6,900–7,700</td>
</tr>
<tr>
<td>Heating Oil (No.2)</td>
<td>850</td>
<td>53</td>
<td>42</td>
<td>18,000</td>
</tr>
<tr>
<td>Propane (LPG)***</td>
<td>1.7</td>
<td>0.12</td>
<td>50</td>
<td>21,500</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>0.7–0.9</td>
<td>0.04–0.06</td>
<td>43</td>
<td>19,000</td>
</tr>
</tbody>
</table>

* Bulk density is typically used for solid biofuels (see Bulk Density section) while density is used for gaseous and liquid fossil fuel
** Typical bulk density for wood pellets is about 650–700 kg/m³
*** Liquid Petroleum Gas (LPG).
**Bulk Density (BD)**

Bulk density is defined as the mass of solid fuel particles divided by the total volume they occupy (i.e. kg/m³). The denser a solid biomass fuel is, the more energy it contains per volume (Table 2). Solid biofuels with greater bulk density are more economical to transport and take up less storage space.

**Moisture Content (M)**

Moisture content is defined as the quantity of water contained in a fuel. It is most commonly expressed on a wet basis, which gives the moisture content as a fraction of the total weight of a sample (e.g. a moisture content of 20% means that 20% of the weight of a solid biomass fuel is water).

The CAN/CSA-ISO 17225 Part 1 to 8 Standards define the range of moisture content for each type of graded solid biofuels. High moisture content has several disadvantages, such as increased transportation costs per unit of energy, risks of degradation through fungal and bacterial activities during storage (composting), self-heating and off-gassing. High moisture content also lowers the amount of useful energy captured from combustion as more energy is necessary to evaporate water. Extremely dry fuels can also cause problems, producing excessive fine particles and dust, and thereby creating an explosion hazard.

Most commercial heating equipment can only tolerate solid biofuels with a maximum of about 50% moisture (wet basis). Therefore, drying is important, as is keeping the solid biofuels dry during storage.

**Calorific Value (Q)**

The calorific value is a measure of energy content. It is defined as the amount of heat released from a specific amount of fuel during complete combustion, and is expressed in mega joules per kilogram (MJ/kg) or British thermal units per pound (BTU/lb) (Table 2). The term calorific value is synonymous with heating value.

The term high heating value (HHV), or gross calorific value (GCV), is typically used in North America and includes energy from condensation of water vapour from the combustion products. The term low heating value (LHV), or net calorific value (NCV), is more commonly used in Europe and does not include energy from condensation of water vapour. For biomass, there is about 5-8% more energy recorded in HHV as compared to LHV measures. This often leads to confusion when comparing the energy efficiencies of different systems.

Moisture content is the most important factor affecting calorific value. However, ash content, chemical composition and bulk density also influence calorific values to varying degrees. Wood species have a minimal effect on calorific value. When purchasing biomass fuels, payment should be based on calorific value.

**Ash (A)**

Ash is the inorganic residue remaining after the combustion of a fuel, typically expressed as a percentage of the mass of dry matter in the solid biofuel.

Woody solid biofuels typically have low ash content. Ash content increases mainly with bark content, contamination with soil and/or sand, and inorganic additives or chemical treatments such as paint or preservatives. The ash minerals are mainly composed of alkali metals (such as calcium, potassium and sodium), magnesium and silica.

Two types of ash are generated during combustion: bottom ash and fly ash. Bottom ash is collected from...
the furnace or boiler grates. Fly ash is the ash carried with the hot flue gas through the exhaust pipe and is very fine and mainly inorganic. Some of the fly ash accumulates on boiler surfaces (causing fouling); finer fly ash is emitted to the atmosphere as particulate matter. In a typical grate-type combustion system, about 98% of the ash is collected as bottom ash and 2% is collected as fly ash.

The presence of alkali minerals lowers the softening and melting temperature of ash (say from 1700°C for pure silica to <800°C). This could cause ash to form clinker and/or slag (fused ash in glassy form). It is therefore important to ensure that the temperature on the grate is kept below 750°C to prevent slag formation and premature shutdown of the boiler or furnace.

**Particle Size (P)**

Solid biofuels may be uniform in size, as in wood pellets and briquettes, or they may come in a range of sizes from a few centimeters to 50 cm or larger, as in the case of wood chips.

The CAN/CSA-ISO 17225 Part 1 to 8 Standards establish specific values for both acceptable particle size range and minimum allowable amounts of acceptable sized material for each traded form of solid biofuels and their grades. The standard describes the appropriate distribution of the majority of the fuel, termed main fraction, along with the fines (small) and coarse (large) fractions or portions. Fines, defined as particles less than 3.15 mm (less than 1/8 inch), pose issues related to combustion performance, as fines likely go through the boiler or furnace without burning. Very fine particles also pose a risk for dust generation, fires and even explosions (if subjected to an ignition source) during handling and storage. Coarse particles are defined as oversized material, which can cause issues in feeding systems (by jamming the augers) and will likely be discharged through the ash system without being completely burned.

The dimensions and size distribution of a fuel not only determine the appropriate fuel-feeding system, but also influence combustion. Pellets, for instance, are fed automatically, whereas firewood needs to be manually fed. A boiler designed to operate with wood chips may not operate with briquettes properly as the fuel handling system may not be able to handle larger briquettes and the combustion chamber of the furnace may not burn the denser and larger briquettes. It is therefore important to be aware of how particle size interacts with the feeding system and firebox of a boiler or furnace.

Particle size is measured by screening a known volume of fuel (typically 8 liters or 2 gallons) in a mechanical shaker. It is highly recommended to perform a visual inspection of the biomass fuel to confirm that the fuel does not have too many fines or coarse materials.

**Glossary**

**Biomass by-product:** A secondary product which is made incidentally during the production of wood products (such as sawdust and shavings).

**Biomass residue:** Biomass from well-defined side-streams of forestry and related industrial operations (such as logging residue including tops and branches).

**Binders and Additives:** Materials intentionally introduced in the production of wood pellets and briquettes to make production more efficient, improve durability, improve quality (i.e. combustion properties), and reduce emissions.

**Chemically untreated woody biomass:** Residues from debarking, sawing or size reduction, shaping and pressing processes.

**Chemically treated woody biomass:** Wood residues from production of panels and furniture (glued, painted, coated, lacquered) that contain no heavy metals or halogenated organic compounds at levels higher than those in typical virgin material values.

**Contaminants:** Impurities in a solid biomass fuel, such as a polluting substances (paint, rubber, plastics), and are most common within post-consumer derived fuels.

**Extraneous substances:** Foreign materials which enter the biomass or solid biomass fuel during harvest, logging, processing, transport and storage. Examples include, but are not limited to, stones, rocks, glass and metals. Presence of the extraneous substances increases the ash content of solid biofuels.

**Biomass heating equipment used in small commercial and institutional applications, such as public buildings, hospitals, schools and warehouses, requires higher quality solid biofuels to ensure reliable and clean operation.**
**Normative and informative properties:** Normative properties refer to mandatory specifications while informative properties are voluntary. Different traded forms of solid biofuels have different sets of normative and informative properties. The most significant normative properties include moisture content, particle size/dimensions and ash content. Informative properties include bulk density and energy content.

**Units and Conversions**

**Metric prefixes**

- MJ/kg* – MegaJoules per kilogram
- BTU/lb – British Thermal Units per pound
- kWh/kg – Kilowatt hour per kilogram
  
  * 1 MJ/kg = 1 Gigajoule/tonne (GJ/t)

Kilo (k) = Multiplier of 1,000
Mega (M) = Multiplier of 1,000,000
Giga (G) = Multiplier of 1,000,000,000

**Volume**

- 1 full cord = 128 ft³ (4x4x8 ft) = 3.6 m³ (stacked firewood)
- 1 cubic metre = 35.3 cubic feet
- 1,000 litre (lt) = 1 m³

**Weight**

- Metric ton (t) = tonne = 1000 kilograms = 2205 lb
- Imperial or Long ton (lt) = 1016 kilograms = 2240 lb
- Short (US) ton (st) = 907 kilograms = 2000 lb

From long ton to metric ton multiply by 1.016
From short ton to metric ton multiply by 0.9072

**Energy and Density**

From MJ/kg to kWh/kg multiply MJ/kg by 0.2778
From MJ/kg to BTU/lb multiply MJ/kg by 430
From BTU/lb to MJ/kg multiply Btu/lb by 0.002326
From MJ/m³ to BTU/ft³ multiply MJ/m³ by 26.84
From BTU/ft³ to MJ/m³ multiply Btu/ft³ by 0.0373

**Fuel Equivalents**

1000 litre (lt) heating oil equivalent (in energy basis)
- ~ 5–8 m³ dry stacked firewood (M 20%)
- 10–12 m³ wood chips (M 45%, loosely stored)
- ~2 metric tonne (or ~3 m³) wood pellet

**Example: Solid biofuels consumption for 500 kW (thermal output) furnace/boiler system:**

Assumptions:
- approximately 1800 operating hours @ full capacity per year.
- Wood Pellets – A2 Grade, Moisture 8%, wet basis; HHV = 16.5 MJ/kg (4.6 kWh/kg) as received.
- Wood Chips – A2 Grade, Moisture 35%, wet basis; HHV = 12 MJ/kg (3.3 kWh/kg) as received.
- Wood Chips – B1 Grade, Moisture 50%, wet basis; HHV = 9.3 MJ/kg (2.6 kWh/kg) as received.

**Table 3.** Comparison of annual fuel amounts as a function of solid biofuels, moisture content and boiler efficiency

<table>
<thead>
<tr>
<th>Solid Biofuels</th>
<th>Amount of Fuel (metric tonnes/year)</th>
<th>Amount of Fuel (metric tonnes/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler Efficiency</td>
<td>70 %</td>
<td>85%</td>
</tr>
<tr>
<td>Wood pellets (A2 – M10)</td>
<td>280</td>
<td>230</td>
</tr>
<tr>
<td>Wood chips (A2 – M35)</td>
<td>395</td>
<td>325</td>
</tr>
<tr>
<td>Wood chips (B1 – M50)</td>
<td>500</td>
<td>410</td>
</tr>
</tbody>
</table>

**References & Links**


**Acknowledgement**

This bulletin was prepared in collaboration with Canadian Institute of Forestry, FPInnovations, Ontario Ministry of Natural Resources and Forestry, Pembina Institute, Wood Pellet Association of Canada, and Wood Waste to Rural Heat.
This bulletin, third in a series of bulletins, introduces the CAN/CSA-ISO series of standards on solid biofuels adopted in Canada and summarizes details related to fuel classifications, specifications and test methods.

**CAN/CSA-ISO Solid Biofuels Standards at a Glance**

The CAN/CSA-ISO Solid Biofuels Standards are voluntary standards developed for residential, commercial and industrial energy applications. Intended stakeholders include:
- Solid biomass fuel producers
- End users and consumers
- Equipment manufacturers
- Testing laboratories
- Regulators

There are numerous benefits to adhering to these standards. Market adoption of the standards will:
- Facilitate domestic and international trade
- Enhance uptake of new technologies
- Promote public safety and contribute to a more sustainable industry
- Minimize emissions of pollutants
- Facilitate quality assessment of solid biomass resources.

The series of CAN/CSA-ISO Solid Biofuels Standards published in 2015 were developed to standardize the following: terminology; specifications and classes; and test methods for raw and processed biofuel materials originating from forestry, arboriculture, agriculture, horticulture and aquaculture.

Natural Resources Canada’s Solid Biofuels Bulletins uses the term “biomass fuels” interchangeably with “biofuels”. The CAN/CSA-ISO Standards use the term “biofuels” which is retained in these bulletins when referencing specific standards’ titles.

**Development of Solid Biofuels Standards**

The International Organisation for Standardization (ISO) established a Technical Committee (TC238) responsible for developing solid biofuels standards at the international level.
- ISO/TC238 is comprised of 24 voting countries and 14 observing countries. Canada is a voting member.
- ISO/TC238 plans to publish 55-60 standards on solid biofuels.
- CSA Group has been accredited by the Standards Council of Canada to manage a harmonized Standards Mirror Committee (SMC) on ISO/TC238 standards. This is to respond to market needs outlined by users (predominantly the biomass fuel industry and government agencies).
- The SMC is a balanced committee, comprised of different stakeholders from four main categories:
  - Producers, Users, Regulatory Authorities, and General Interest.
  - CSA Group has adopted several ISO Solid Biofuels Standards (see Table 1).
  - CSA Group is in the process of adopting more ISO/TC238 standards in the Canadian context.

Where to get Solid Biofuels Standards?
Purchase CAN/CSA-ISO Solid Biofuels Standards at: shop.csa.ca

Table 1. CSA Group has adopted and published Standards as the first series of solid biofuels standards, under the general title of Solid biofuels — Fuel specifications and classes

<table>
<thead>
<tr>
<th>Standard No.</th>
<th>Standard Title</th>
<th>Scope of the Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSA-ISO 16559</td>
<td>Terminology, definitions and descriptions</td>
<td>This Standard outlines the terminology and definitions for solid biomass fuels.</td>
</tr>
<tr>
<td>CSA-ISO 17225-1 Part 1: General requirements</td>
<td>The fuel quality classes and specifications for solid biomass fuels.</td>
<td></td>
</tr>
<tr>
<td>CSA-ISO 17225-2 Part 2: Graded wood pellets</td>
<td>The fuel quality classes and specifications of graded wood pellets for non-industrial and industrial use.</td>
<td></td>
</tr>
<tr>
<td>CSA-ISO 17225-3 Part 3: Graded wood briquettes</td>
<td>The fuel quality classes and specifications of graded wood briquettes.</td>
<td></td>
</tr>
<tr>
<td>CSA-ISO 17225-4 Part 4: Graded wood chips</td>
<td>The fuel quality classes and specifications of graded wood chips.</td>
<td></td>
</tr>
<tr>
<td>CSA-ISO 17225-5 Part 5: Graded firewood</td>
<td>The fuel quality classes and specifications of graded firewood.</td>
<td></td>
</tr>
<tr>
<td>CSA-ISO 17225-6 Part 6: Graded non-woody pellets</td>
<td>The fuel quality classes and specifications of graded non-woody pellets.</td>
<td></td>
</tr>
<tr>
<td>CSA-ISO 17225-7 Part 7: Graded non-woody briquettes</td>
<td>The fuel quality classes and specifications of graded non-woody briquettes.</td>
<td></td>
</tr>
<tr>
<td>CSA-ISO 18134-1 Determination of moisture content –</td>
<td>This document describes the method of determining the total moisture content of a test sample of solid biomass fuels by drying in an oven, and should be used when high precision of the determination of moisture content is necessary. The method described in this document is applicable to all solid biomass fuels.</td>
<td></td>
</tr>
<tr>
<td>Oven dry method – Part 1: Total moisture – Reference method</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSA-ISO 18134-2 Determination of moisture content –</td>
<td>This document describes the method of determining the total moisture content of a test sample of solid biomass fuels by drying in an oven and may be used when the highest precision is not needed such as for routine production control on site. The method described in this document is applicable to all solid biomass fuels.</td>
<td></td>
</tr>
<tr>
<td>Oven dry method – Part 2: Total moisture – Simplified method</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSA-ISO 18134-3 Determination of moisture content –</td>
<td>This part of ISO 18134 describes the method of determining the moisture in the analysis test sample by drying in an oven. It is intended to be used for general analysis samples in accordance with EN 14780. The method described in this part of ISO 18134 is applicable to all solid biofuels. The moisture content of solid biofuels (as received) is always reported based on the total mass of the test sample (wet basis).</td>
<td></td>
</tr>
<tr>
<td>Oven dry method – Part 3: Moisture in general analysis sample</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSA-ISO 16948 Determination of total content of carbon, hydrogen and nitrogen</td>
<td>This Standard describes a method for the determination of total carbon, hydrogen and nitrogen contents in solid biomass fuels.</td>
<td></td>
</tr>
<tr>
<td>CSA-ISO 16994 Determination of total content of sulfur and chlorine</td>
<td>This Standard describes methods for the determination of the total sulfur and total chlorine content in solid biomass fuels.</td>
<td></td>
</tr>
<tr>
<td>Standard No.</td>
<td>Standard Title</td>
<td>Scope of the Standard</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>CSA-ISO 16968</td>
<td>Determination of minor elements</td>
<td>This Standard describes methods for the determination of the content of minor elements arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, molybdenum, nickel, lead, antimony, vanadium, and zinc in all solid biomass fuels. Further, it describes methods for sample decomposition and suggests suitable instrumental methods for the determination of the elements of interest in the digests. The determination of other elements such as selenium, tin, and thallium is also possible with the methods described in this Standard.</td>
</tr>
<tr>
<td>CSA-ISO 16993</td>
<td>Conversion of analytical results from one basis to another</td>
<td>This Standard provides formulae which allow analytical data relating to solid biomass fuels to be expressed on the different bases in common use.</td>
</tr>
<tr>
<td>CSA-ISO 16995</td>
<td>Determination of the water soluble chloride, sodium and potassium content</td>
<td>This Standard describes a method for the determination of the water soluble chloride, sodium and potassium content in solid biomass fuels by extraction with water in a closed container, and their subsequent quantification by different analytical techniques.</td>
</tr>
<tr>
<td>CSA-ISO 16967</td>
<td>Solid biofuels—Determination of major elements—Al, Ca, Fe, Mg, P, K, Si, Na and Ti</td>
<td>This International Standard describes methods for the determination of major elements of solid biofuels respectively of their ashes, which are Al, Ca, Fe, Mg, P, K, Si, Na, Ti. The determination of other elements such as barium (Ba) and manganese (Mn) is also possible with the methods described in this International Standard. This International Standard includes two parts: Part A describes the direct determination on the fuel (this method is also applicable for sulfur and minor elements) Part B provides a method of determination on a prepared 550 °C ash.</td>
</tr>
</tbody>
</table>

**The complete list of standards under the direct responsibility of ISO/TC238:**

For the published standards visit:  

For the standards ‘under development’ visit:  

**References & Links**

2. ISO Technical Committee 238 Solid Biofuels  [www.iso.org/iso/iso_technical_committee%3Fcommid%3D554401](http://www.iso.org/iso/iso_technical_committee%3Fcommid%3D554401)
This bulletin, fourth in a series of bulletins, introduces the different grades of wood pellets, their appropriate use and the important parameters that can affect the fuel characteristics. It provides information on the graded wood pellets as specified in the CAN/CSA-ISO 17225 Part 2: Graded wood pellets.

Wood pellets are a highly consistent biomass fuel allowing for easy handling and storage, as well as efficient energy conversion.

As a globally traded commodity, wood pellets are used for space heating in residential appliances, boilers, district heating plants and for electricity generation in large coal-burning power plants.

Wood pellets are small densified cylindrical granules produced by compression of sawdust. As a result, wood pellets are a consistent fuel that can easily be transported and suited to automated fuel handling systems.

**Origins and Sources**

Wood pellets are mainly produced from the by-products of traditional forest operations such as sawmills and finished wood products manufacturing. Harvest residues are also used as raw material though to a much lesser extent. The highest quality sources tend to come from mill and manufacturing residues with little or no bark or ash content.

The CAN/CSA-ISO 17225 Part 2 Standard classifies several grades of wood pellets based on the origins and source of raw materials. Raw biomass used in the production of high grade wood pellets, Grades A1 and A2 (residential or commercial applications), primarily comes from mill residues including sawdust, shavings and cut-offs (classification 1.2.1) and stem wood (classification 1.1.3). In addition to the above sources, Grade A2 allows for the use of logging residues (classification 1.1.4) and whole trees without roots (classification 1.1.1).

Sources of the raw biomass impacts fuel specifications. For example, A1 grade wood pellets contain low ash and nitrogen contents, while Grade A2 wood pellets have slightly higher ash and nitrogen content.

Grade B wood pellets are manufactured from more diverse sources, over and above those used for Grade A wood pellets, and can include bark (classification 1.1.6), residues from thinning, pruning, and arboriculture operations in city parks (classification 1.1.7), and chemically untreated used wood (classification 1.3.1).
The CAN/CSA-ISO 17225 Part 2 Standard also specifies Industrial Grade (I1, I2, I3) wood pellets based on origins, sources and properties, but these are outside the scope for this bulletin.

Both softwood and hardwood tree species can be sourced for wood pellets. It is anticipated that purposely grown woody crops such as poplar and willow grown on marginally productive land may be sourced for wood pellet production in the future. For further details on the origins and sources, refer to Natural Resources Canada Solid Biofuels Bulletin No.2 – Primer for Solid Biofuels.

Key Properties

The production of pellets starts with size reduction (if necessary) of the raw biomass source followed by drying. The material is then extruded under high pressure in pellet machines coming out as small cylinders typically with a 6 or 8 mm diameter, and a length of up to 40 mm. Small amounts of additives and binders can be blended with biomass material to improve the quality of wood pellets, but this is not common in Canada.

A buyer or user of graded wood pellets should consider several quality characteristics:

- **Diameter and Length (D and L)** – tested in the lab or production site. Two alternative diameters are produced: 6 mm and 8 mm (± 1 mm). The length of the individual wood pellets should be larger than 3.15 mm, and less than or equal to 40 mm (3.15 ≤ L ≤ 40 mm) with the maximum length not exceeding 45 mm. The quantity of pellets longer than 40 mm can be 1% in weight. The quantity of pellets shorter than 10 mm (weight %) is stated by the producer.

- **Durability (DU) and Fines (F)** – determined in the lab by tumbling and screening the pellets. After tumbling, the quantity of pellets (in weight %) staying on the screen with the screen opening size greater than 3.15 mm determines the durability. The quantity of pellets passing through the screen with less than 3.15 mm opening size is defined as fines. Pellets handled in large quantities (bulk) experience some attrition, resulting in higher content of fines.

- **Bulk Density (BD)** – tested in the lab to provide guidance for sizing the storage space based on energy consumption needs. Minimum bulk density should be greater than or equal to 600 kg/m³. The actual bulk density of the pellets is often stated by the producer on the packaging. Rough estimates of bulk density can be made by weighing a known volume. When testing density, attempts should be made to minimize the void space between pellets by shaking and tapping pellets well.

- **Calorific value (Q) and Moisture Content (M)** – measured by lab testing. All grades of wood pellets must have moisture content less than 10% and a high calorific value greater than or equal to 18.6 MJ/kg (or low heating value of greater than or equal to 16.5 MJ/kg).

- **Ash Content (A)** – tested in the lab. For residential and commercial applications, ash content is low and increases from Grade A1 to A2 to B (Table 1). For residential stoves, furnaces and boilers, it is recommended to use wood pellets with low ash content.

**TABLE 1.** Key specifications of graded wood pellets based on the CAN/CSA-ISO 17225 Part 2 Standard

<table>
<thead>
<tr>
<th>Property Class</th>
<th>Unit</th>
<th>Grade A1*</th>
<th>Grade A2*</th>
<th>Grade B*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter, D</td>
<td>mm</td>
<td>6 ± 1 or 8 ± 1</td>
<td>6 ± 1 or 8 ± 1</td>
<td>6 ± 1 or 8 ± 1</td>
</tr>
<tr>
<td>Length**, L</td>
<td>mm</td>
<td>3.15 ≤ L ≤ 40</td>
<td>3.15 ≤ L ≤ 40</td>
<td>3.15 ≤ L ≤ 40</td>
</tr>
<tr>
<td>Moisture, M</td>
<td>% of weight</td>
<td>≤ 10</td>
<td>≤ 10</td>
<td>≤ 10</td>
</tr>
<tr>
<td>Ash, A</td>
<td>% of weight</td>
<td>≤ 0.7</td>
<td>≤ 1.2</td>
<td>≤ 2.0</td>
</tr>
<tr>
<td>Durability, DU</td>
<td>% of weight</td>
<td>≥ 97.5</td>
<td>≥ 97.5</td>
<td>≥ 96.5</td>
</tr>
<tr>
<td>Fines Content, F</td>
<td>% of weight</td>
<td>≤ 1</td>
<td>≤ 1</td>
<td>≤ 1</td>
</tr>
<tr>
<td>High Calorific Value, Q</td>
<td>MJ/kg</td>
<td>≥ 18.6</td>
<td>≥ 18.6</td>
<td>≥ 18.6</td>
</tr>
<tr>
<td>Bulk Density, BD</td>
<td>kg/m³</td>
<td>600 ≤ BD ≤ 750</td>
<td>600 ≤ BD ≤ 750</td>
<td>600 ≤ BD ≤ 750</td>
</tr>
</tbody>
</table>

* Suitable for residential and commercial applications.
**Maximum length of wood pellets shall be ≤ 45 mm. Amount of pellets longer than 40 mm can be 5% weight.
Further restrictions may be stipulated by the supplier of the combustion equipment regarding ash characteristics of the pellets, such as ash melting temperature, to minimize damage to equipment.

**Specifications of Properties for Graded Wood Pellets**

Graded wood pellets conform to specific feedstock sources as well as the quality requirements as stipulated in the CAN/CSA-ISO 17225 Part 2 Standard. Table 1 shows various properties and specifications for Graded wood pellets as detailed in the CAN/CSA-ISO 17225 Part 2: Graded wood pellets. A family of CAN/CSA-ISO testing standards is available to confirm compliance of the wood pellets with the grade, see Bulletin No.7 – CAN/CSA-ISO Solid Biofuels Standards.

**Certification of Wood Pellets**

The European certification ENplus for wood pellets was adopted in Canada in 2013 under the acronym CANplus. The ENplus and CANplus seals account for the whole wood pellet supply chain, from production to delivery to the final customer, to ensure high quality. Both ENplus and CANplus schemes define wood pellet quality classes following the ISO 17225 Part 2 Standard: A1, A2 and B. Examples of the two certification system logos are shown below:

![CANplus logo](image1)

![ENplus logo](image2)

Pellet Fuel Institute (PFI) in the USA has also developed standard specifications for residential and commercial grade wood pellets. The PFI wood pellet standard forms the basis of a third party accredited certification program. The certification under ENplus and CANplus are currently voluntary in Europe and Canada, while the PFI certification is mandatory in the USA.

**Safe Handling and Storage of Wood Pellets**

Wood pellets require closed storage, such as silos or storage tanks to keep them dry. During storage, chemical, physical and biological processes can take place including water absorption, off-gassing, oxygen depletion and self heating. Off-gassing can lead to production of toxic gases including carbon monoxide (CO) which is a poisonous, odorless, tasteless and non-irritating gas. As a result, bulk storage spaces need to be well ventilated with exhaust away from areas where people are present. As additional safety measure, CO detectors should be installed in and around the storage area. Personal protective equipment should be worn if entry into large storage areas is necessary.

Temperature measurements in large storage piles are recommended to monitor heat build up.

Dust can be generated while handling wood pellets. In large volumes dust may cause respiratory problems if inhaled, and constitutes a risk for fires and explosions. An extensive Safety Data Sheet (SDS) is available for wood pellets in bags and there is a separate SDS for wood pellets in bulk. SDS documents contain information on the potential hazards (health, fire reactivity and environmental) and how to work safely with wood pellets.

Standards and guidelines for safe handling and storage of wood pellets of all scales are currently under development by ISO/Technical Committee 238.

**References & Links**

5. Pellet Fuels Institute [http://www.pelletheat.org](http://www.pelletheat.org)
6. ISO Technical Committee 238 Solid Biofuels [http://www.iso.org/iso/iso_technical_committee%3Fcommid%3D554401](http://www.iso.org/iso/iso_technical_committee%3Fcommid%3D554401)

**Acknowledgement**

This bulletin was prepared in collaboration with Canadian Institute of Forestry, FPInnovations, Ontario Ministry of Natural Resources and Forestry, Pembina Institute, Wood Pellet Association of Canada, and Wood Waste to Rural Heat.
This bulletin, fifth in a series of bulletins, introduces different grades of wood briquettes, their appropriate use and the important parameters that can affect the fuel characteristics. The information on the graded wood briquettes is based on the CAN/CSA-ISO 17225 Part 3: Graded wood briquettes.

Wood briquettes for heat generation have been used in residential space heaters, boilers and in district heating for several decades.

Wood briquettes come in a variety of dimensions depending on the manufacturer. In general, they can be found in two sizes: larger, such as bricks or logs, and smaller, such as pucks (which fit in your hand) or cubes. As a densified fuel product, briquettes are a consistent solid biomass fuel similar to wood pellets. In comparison to wood pellets, briquettes are less dense, constituent particles are larger and typically require less drying leading to less power consumption in manufacturing and hence lower cost.

**Origins and Sources**

CAN/CSA-ISO 17225 Part 3 Standard\(^1\) classifies three grades of wood briquettes based on origins and sources: Grades A1 and A2 are intended for heating of residential and commercial buildings; Grade B briquettes are for larger-scale combustors, such as district heating and electricity production.

Raw biomass used to produce Grade A2 briquettes include sources used for Grade A1 and residues left behind from logging operations (tree tops, branches and low grade small dimension logs – classification 1.1.4) and whole trees without roots (classification 1.1.1)\(^2\). Raw biomass used to produce Grade A2 briquettes include sources used for Grade A1 and residues left behind from logging operations (such as tree tops and branches and low-grade small dimension logs—classification 1.1.4) and whole trees without roots (classification 1.1.1)\(^2\). Grade A1 briquettes contain low ash and nitrogen levels, while Grade A2 have slightly higher ash and nitrogen content.

Grade B further expands the briquette source material\(^2\) to include residues from tree thinnings, prunings and arboriculture operations in city parks (classification 1.1.7), bark (classification 1.1.6), and chemically untreated used wood (classification 1.3.1). Grade B also includes chemically treated wood by-products (classification 1.2.2), as long as they do not contain heavy metals or halogenated organic compounds from treatment with wood.
preservatives or coatings. Sources are expected to be free of contaminants such as stones, glass, metal, sand, plastics and rubber.

Both softwood and hardwood species can be sourced for wood briquettes. It is anticipated that purposely grown woody crops, such as poplar and willow, grown on marginally productive land will be sourced for wood briquettes production in the future. For further details on the origins and sources, refer to Natural Resources Canada Solid Biofuels No.2 – Primer for Solid Biofuels.

Key Properties

The production of briquettes starts with size reduction of the raw feedstock and drying. Next, the material is compressed or extruded under high pressure in briquette machines before coming out in a variety of shapes and sizes as logs, bricks, cylinders, nuts or pucks. In Canada, additives and binders blended with biomass material to improve the quality of wood briquettes are not common. Wood briquettes are distributed and transported in large plastic bags or stacked on pallets with plastic wrapping or cardboard packaging for distribution by truck or by shipping containers.

Wood briquettes, like wood pellets, are a highly consistent biomass fuel type which allows easy handling and storage, as well as efficient energy conversion.

A buyer of/user of wood briquettes should consider several quality characteristics, the most important of which are as follows (see Table 1):

- **Moisture content (M)** and **calorific value (Q)** – measured by lab testing.
- **Ash content (A)** – any restrictions regarding ash content and ash melting temperature as stipulated by the supplier of the combustion equipment need to be considered to minimize combustion equipment operational issues (clinker/slagging).
- **Particle density (DE)** – depending on the physical shape of the briquettes, particle density is used by some suppliers in lieu of bulk density to assist in estimating storage volume required.
- **Physical size of the briquettes** – recommended by the equipment supplier to avoid clogging the hoppers and augers that are used to feed the briquettes in automated systems.

### Specifications of Properties for Graded Wood Briquettes

The term “graded” means that the feedstock as well as the quality of the briquettes have to comply with certain requirements as stipulated in the CAN/CSA-ISO 17225-3 Standard. Table 1 is an excerpt from the CAN/CSA-ISO 17225 Part 3: Graded wood briquettes. It provides standards for three graded property classes: A1, A2 and B. The source materials as well as the briquettes are tested for compliance in accordance with a family of CAN/CSA-ISO testing standards, see NRCan Solid Biofuels Bulletin No.3 – CAN/CSA-ISO Solid Biofuels Standards.

For example, a label stating wood briquettes’ specifications of M9.0, A2.5 and Q17.0 indicates that the wood briquettes contain ≤ 9% moisture, ≤ 2.5 ash with a minimum calorific value of 17 MJ/kg. Based on these fuel property values, this wood briquettes is classified as Grade B.

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**TABLE 1.** Key specification of graded wood briquettes based on the CAN/CSA-ISO 17225 Part 3 Standard

<table>
<thead>
<tr>
<th>Property Class</th>
<th>Unit</th>
<th>Grade A1</th>
<th>Grade A2</th>
<th>Grade B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture, M</td>
<td>% of weight</td>
<td>≤ 12</td>
<td>≤ 15</td>
<td>≤ 15</td>
</tr>
<tr>
<td>High Calorific Value, Q</td>
<td>MJ/kg as received</td>
<td>≥ 17.5</td>
<td>≥ 17.3</td>
<td>≥ 16.8</td>
</tr>
<tr>
<td>Ash, A</td>
<td>% of weight</td>
<td>≤ 1.0</td>
<td>≤ 1.5</td>
<td>≤ 3.0</td>
</tr>
<tr>
<td>Particle Density, DE</td>
<td>g/cm³ as received</td>
<td>≥ 1.0</td>
<td>≥ 0.9</td>
<td>≥ 0.9</td>
</tr>
</tbody>
</table>
**Safe Handling and Storage of Wood Briquettes**

Wood briquettes need to be kept dry during storage to maintain their mechanical integrity and fuel quality.

Bulk storage spaces should be well ventilated and away from areas where people are present.

Dust can be created during handling of large volumes of briquettes, which may cause respiratory problems if inhaled, and increase risk of fires and explosions. Wood briquettes piles may self-heat, and temperature measurements in large storage spaces are therefore recommended to monitor heat build up.

A Safety Data Sheet (SDS) for wood briquettes is available with information on the potential hazards (health, fire, reactivity and environmental) and how to work safely with wood briquettes.

**References & Links**


**Acknowledgement**

This bulletin was prepared in collaboration with Canadian Institute of Forestry, FPInnovations, Ontario Ministry of Natural Resources and Forestry, Pembina Institute, Wood Pellet Association of Canada, Wood Waste to Rural Heat.
This bulletin, sixth in a series of bulletins, introduces the different grades of wood chips, their appropriate use and the important parameters that can affect the fuel characteristics. It provides information on graded wood chips as specified in the CAN/CSA-ISO 17225 Solid Biofuels—Fuel specifications and classes—Part 4 Graded Wood Chips.

Wood chips have been widely used as fuel for space heating in buildings for several decades. As a locally available fuel with minimal processing, wood chips offer a less costly fuel option compared to wood briquettes or pellets.

Wood chips are typically produced by grinding or chipping operations followed by screening and air drying of the chips. Screening is necessary to produce the desired wood chip quality (particle size, ash and fines content).

**Origins and Sources**

The major sources for wood chips are by-products and residues from wood processing operations in the forest sector (slabs, bark or shavings). The highest quality wood chip sources tend to be from milling and manufacturing operations. According to the CAN/CSA-ISO 17225 Part 4 Standard, classification is based on origins and sources and provides for four different grades of wood chips. Grade A (A1 and A2) are high quality wood chips that are sourced primarily from stem wood (classification 1.1.3) and by-products and residues from milling (classification 1.2.1) and logging operations (classification 1.1.4). A1 grade wood chips are dried and contain lower ash and no or little bark. A2 grade contains slightly higher ash and/or moisture content.

Sources for Grade B1 wood chips include materials from tree trimmings, prunings and arboriculture operations in city parks (classification 1.1.7).

In addition to the sources that are used for Grades A and B1, sources for Grade B2 wood chips include chemically treated by-products and residues from wood processing facilities (classification 1.2.2) and chemically untreated used wood (classification 1.3.1). B2 grade wood chips do not contain heavy metals or halogenated organic compounds from wood preservatives or coatings. For further details on classification by the origin and sources, refer to Natural Resources Canada Solid Biofuels Bulletin No.2 – Primer for Solid Biofuels.
Grade A classified wood chips are suitable for smaller bioenergy systems (assuming they meet the equipment’s specifications) used in schools, public and commercial buildings. Larger bioenergy systems typical of industrial operations (such as sawmills, pulp mills, commercial greenhouses and large district energy systems) are able to use the lower quality Grade B1 and B2 wood chips.

**Key Properties**

While a number of different parameters are important for small-scale bioenergy systems, the most critical properties to consider when buying and using wood chips are moisture content (M), particle size (P), and ash content (A) (Tables 1 and 2). Bark content, extraneous material (stones, sand, and dirt) and contamination (such as glass, metal, plastics) lead to an increase in ash content causing higher equipment maintenance costs. Particle size specifies both the acceptable size range for the diameter and length of wood chips and the minimum allowable amounts of acceptable sized material (main fraction in weight %). Each grade of wood chips also defines specific limits for the amounts of both undersize (fine fraction) and oversize materials (coarse fraction). Fines are defined as particles less than 3.15 mm (less than 1/8 inch). Increased amount of fine and/or coarse fractions can have a significant impact on the fuel handling and operation (efficiency and emissions) of the bioenergy system.

It is highly recommended that the moisture, size and ash properties be tested on a regular basis to confirm contractual requirements for wood chips quality are met. This will also ensure that the biomass fuel is appropriate for efficient and economical operation of the heat or energy system.

It is possible to determine particle size using a sieve test. A hand-held moisture meter can be used to quickly measure moisture; however, an oven-dry analysis gives more accurate measurement and is preferred.

The standard test methods for determining moisture content and particle size distribution are provided in the CAN/CSA-ISO 18134-1 or -2 and CAN/CSA-ISO 17827-1, respectively. The detailed list of testing protocols is available in Natural Resources Canada Solid Biofuels No.3 – CAN/CSA-ISO Standards for Solid Biofuels.

<table>
<thead>
<tr>
<th>Property Class</th>
<th>Unit</th>
<th>Grade A1</th>
<th>Grade A2</th>
<th>Grade B1</th>
<th>Grade B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (M)</td>
<td>weight %</td>
<td>M10</td>
<td>≤10</td>
<td>M35</td>
<td>≤35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M25</td>
<td>≤25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash (A)</td>
<td>weight %, dry</td>
<td>A1.0</td>
<td>≤1.0</td>
<td>A1.5</td>
<td>≤1.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Particle Size (P)</th>
<th>Main Fraction (min. 60 % weight)</th>
<th>Fine Fraction weight %, (≤ 3.15 mm)</th>
<th>Coarse Fraction weight % (length of particle)</th>
<th>Max. Length of Particle</th>
</tr>
</thead>
<tbody>
<tr>
<td>P16S</td>
<td>3.15 mm to 16 mm</td>
<td>≤ 15 %</td>
<td>≤ 6 % (&gt;31.5 mm)</td>
<td>≤ 45 mm</td>
</tr>
<tr>
<td>P31S</td>
<td>3.15 mm to 31.5 mm</td>
<td>≤ 10 %</td>
<td>≤ 6 % (&gt; 45 mm)</td>
<td>≤ 150 mm</td>
</tr>
<tr>
<td>P45S</td>
<td>3.15 mm to 45 mm</td>
<td>≤ 10 %</td>
<td>≤ 10 % (&gt; 63 mm)</td>
<td>≤ 200 mm</td>
</tr>
</tbody>
</table>

* Test method for determining particle size is ISO 17827-1 or -2
Figure 1. Wood Chip Classification Diagram, prepared by FPInnovations based on the CAN/CSA-ISO 177225 Part 4: Graded Wood Chips.
Specifications of Properties for Graded Wood Chips

The use of common names (such as hog fuel, shavings) is neither quantitative nor sufficiently specific, and should not be used when developing biomass fuel supply agreements. CAN/CSA-ISO 17225 Part 4 provides measurable parameters for the sale of wood chips (Tables 1 and 2).¹ Current forestry by-products and residues commonly sold as wood chips may not meet grade specifications without further processing and may not be appropriate for a specific bioenergy application. Variability of wood chips should be minimized to ensure proper bioenergy system operation.

When sourcing wood chips, the nomenclature should include at minimum source class, particle size (P), moisture content (M) and ash content (A). For example, wood chips specification label would show:

**Origin:** Logging residues (1.1.4).

**Properties:** Dimensions P45S, Moisture M40, Ash A1.5.

This label states that the minimum 60% weight of the wood chips is sized between 3.15 mm and 45 mm, has moisture content of less than 40% and contains less than 1.5 % ash. Figure 1 is a schematic diagram of specifications of properties for graded wood chips.

Safe Handling and Storage of Wood Chips

Protection of the wood chips pile from rain and snow with covered storage is critical to maintain fuel quality (Figure 2).

During storage of wood chips, chemical, physical and biological processes can occur. Microbial activities might be cultivated, dry fuel mass might degrade and the pile can heat up. In the worst case this can lead to self ignition. Particle size within a pile of wood chips affects rate of moisture absorption, heat build-up and heat dissipation. Large amounts of fines in a pile causes greater amounts of water to be absorbed, leading to faster heat up and even possibly spontaneous combustion. In contrast, large wood chunks heat up more slowly due to large void volumes between particles allowing more air flow. Microbial action also takes place at lower rates. To minimize the impact of these processes on the quality of the wood chips, it is highly recommended the storage period is kept to minimum.

The Ontario Office of the Fire Marshal has a technical guideline that recommends maximum sizes for outdoor piles of wet wood chips from storm debris⁴. For wood chips to be stored for more than three months, the recommended maximum height, width, and volume are 4 meters (13 feet), 8 meters (26 feet), and 1000 cubic meters (1,300 cubic yards), respectively. For periods less than three months, the recommended maximum height is 7.5 meters (25 feet).
Maintaining a low moisture and fines content in the wood chip pile will help minimize the risks of microbial activity, composting and self ignition. Storing low moisture pile under covered area is therefore a good practice.

To minimize the possibility of inadvertently transporting invasive species, care should also be taken when sourcing wood chips from other locations.

References & Links


Acknowledgement
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