Emissions and Air Pollution Controls for the Biomass Pellet Manufacturing Industry

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TABLE OF CONTENTS

1.0 Introduction 1

1.1 Acknowledgements 2

2.0 Pellet Manufacturing Process 3

2.1 Process Overview 3

2.2 Raw Material Drying 5

2.3 Dryer Burners (Heat Source) 7

2.4 Post-Dryer Processes 8

2.5 Supporting Operations and Fugitive Emissions 8

3.0 Emissions from Pellet Manufacturing 9

3.1 PM Measurement Methods 9

3.2 Particulate matter Emission Factors 10

3.3 Permitted PM Emissions For The Pellet Industry 14

3.4 Volatile Organic Compound Emissions 23

3.4.1 Natual Forest VOC Emissions 23

3.4.2 Pellet Manufacturing VOC Emissions 24

3.5 Dryer Emissions From BC Pellet Mills 30

3.6 Non-Dryer Process Emissions From BC Pellet Mills 33

3.6.1 Pellet Coolers 33

4.0 PM/VOC Reduction Technologies and Best Practices 35

4.1 Pollution Prevention Planning and Strategies 35

4.2 Cyclones and Multiclones 36

4.3 Dry and Wet Electrostatic Precipitators (ESP and WESP) 38

4.4 Fabric Filters 41

4.5 Wet Scrubbers 42

4.6 Regenerative Thermal Oxidizers 43

4.7 Other Means to Clean PM/VOC From Gas Flows 44
4.8 Controlling Fugitive Emissions 44
4.9 Control Technology Comparison 46
5.0 Alternative Technologies and Products 52
5.1 Alternatives to Pellets 52
5.2 Mobile Pelletizers 53
6.0 Economic Analysis 55
6.1 Feed stocks 55
6.2 Capital and Personnel Cost of Pellet Plants 56
6.3 Economic Baseline of a Typical BC Pellet Plant 58
6.4 Cost of Additional PM Control Measures 61
6.5 Economic Impact of Additional Pollution Control Measures 62
7.0 Conclusions and Recommendations 65
7.1 pm emissions from pellet production 65
7.2 Observations on CPM Emissions 66
7.3 Observations on Economic Evaluations 67
7.4 Pollution Prevention Strategies 69
7.5 Achievable Emission Levels 70
7.6 Other Recommendations 73
Glossary: 74
References: 75

List of Figures

Figure 1: European Forecast for Renewables - 2020 ... 1
Figure 2: Emissions Diagram for a Typical Pellet Plant (Two Dryers) ... 4
Figure 3: Simplified Process Flow Diagram for a Pellet Plant ... 5
Figure 4: Comparison of Permitted PM Emissions (Total Pellet Plant) ... 20
Figure 5: Comparison of Permitted PM Emissions (Dryers only) ... 21
Figure 6: Pine Bark VOC Emissions as a Function of Temperature ... 25
Figure 7: VOC Emission Factors from a Particleboard Rotary Dryer ... 28
Figure 8: Composition of VOCs from a Particleboard Rotary Dryer ... 29
Figure 9: TPM Concentration versus Emission Factor in BC Dryer Exhaust Gases ... 32
Figure 10: Cyclone with Electrostatic Precipitation Features ... 37
Figure 11: WESP Collector Detail ... 39
Figure 12: Two Field WESP ... 39
Figure 13: WESP Complete Installed System ... 40
Figure 14: Extrapolated PM Control Efficiency ... 46
Figure 15: Particulate Removal Efficiency for WESP and Wet Scrubbers ... 47
Figure 16: Mobile Pelletizer Units ... 53
Figure 17: Capital Investment and Employment for Different Size Pellet Plants ... 57
Figure 18: CIF-ARA Prices as Reported by Different Pellet Actors in Europe ... 59
Figure 19: ROI Curves for Different Plant Outputs and Feed stock Costs ... 63

List of Tables

Table 1: PM Emission Factors for OSB Dryers - USEPA AP 42 11

Table 2: Estimated PM/PM10 Emissions for a 100,000 Tonne/yr Pellet Plant 13

Table 3: PM10 Emissions from Pellet Production for a 100,000 Tonne per Year Plant 14

Table 4: Permit Conditions for Wood Pellet Mills and Similar Facilities 16

Table 5: Summary of Table 4 (Permitted PM Emissions) 20

Table 6: Comparison of PM Emission Limits recommended for Wood Combustion with current Pellet Mill Emissions 22

Table 7: Biogenic Emission Estimates for Different Forest Types 23

Table 8: VOC Emissions from Uncontrolled Particleboard Dryers 27

Table 9: Emissions from Lumber Drying, in kg per dry tonne Processed 29

Table 10: Emissions From Pellet Dryers for BC Mills 31

Table 11: Non-dryer Process Emission Data for BC Mills 34

Table 12: Typical Control Equipment Efficiencies (%) 47

Table 13: Comparison of Main PM Control Technologies 48

Table 14: Data on PM Control Technologies 49

Table 15: Cost Estimates for WESP, Wet Scrubber, and Thermal Oxidizer in C$ 50

Table 16: Comparison of Pellet Plant Sizes and Announced Capital Investment 56

Table 17: FOB Pricing of Pellets at St. Petersburg Harbour 59

Table 18: Annual Cost Overview for a 200,000 Tonne Pellet Plant in BC 60

Table 19: Impact of Additional Pollution Control Measures on the ROI for Different Size Pellet Plants in BC 62

Table 20: Summary of Mill Permitted PM Emissions (kg/t) 65

Table 21: Summary of BC Measured Emissions from Dryers with Cyclones 66

Table 22: Summary of Achievable Mill TPM Emissions 72

List of Appendices

Appendix I: Properties of Torrefied Pellets versus Conventional Pellets

Appendix II: Permits

BC PERMITS

1. Canfor, PA-01543, April 16, 2007
2. Pacific BioEnergy, PA-18312, October 4, 2007
3. Pinnacle Pellet Meadowbank, Permit 100229, October 31, 2008
4. Pinnacle Pellet Quesnel, PA-13758 Amendment, November 27, 2001
5. Pinnacle Pellet Williams Lake, PA-17557, December 21, 2004
6. Princeton Co-Generation, PA-16509, June 12, 2003

NON-BC PERMITS

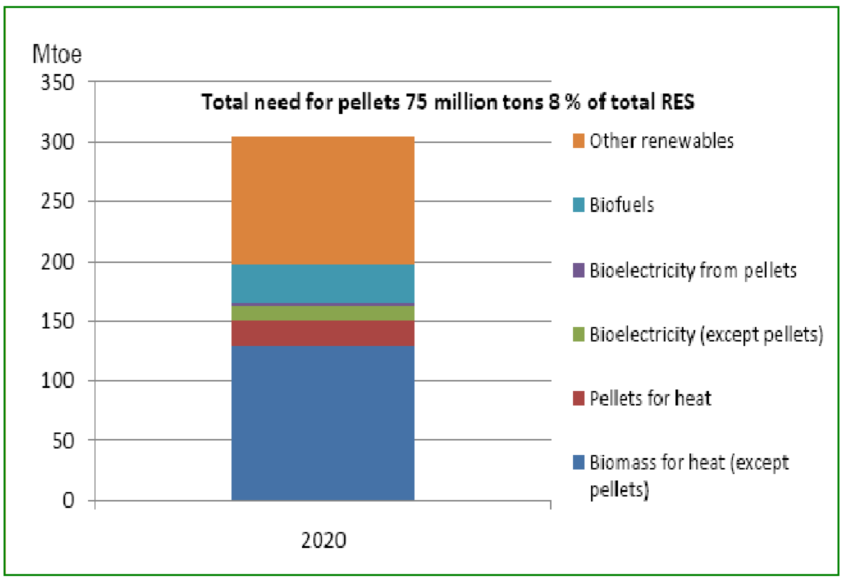
1. Ozark Hardwood Products, LLC, Marshfield, Missouri, Permit 032006-013, March 22, 2006
2. Greenova, LLC, Berlin, New Hampshire, Permit Application 08-0277, August 21, 2008
3. Tomorrows Energy LLC, dba Piney Wood Pellets, Wiggins, Mississippi, Draft Permit 25-40-00025 (undated)
4. Wayne Farms LLC, Laurel, Mississippi, Draft Permit 1360-0027 (undated)
5. Treasure Valley Forest Products, Mountain Home, Boise, Idaho, Permit P-2007.0165, January 8, 2008
6. Eureka Pellet Mills, Eureka, Montana, Permit 2554-04, December 19, 2006
7. PC Indiana Synthetic Fuels, #2, LLC, Lynville, Indiana, first amendment to Permit CP-173-10815-00041 (August 13, 1999), January, 2001
8. Future Fuel Chemical Company, Batesville, Arkansas, Permit 1085-AOP-R5, August 25, 2006
9. Comprehensive Report – RACT/BACT/LAER Clearinghouse, Virginia

1.0 Introduction

The world market for pellet fuels is rapidly growing. It is driven primarily by European demand for renewable (carbon neutral) fuels to replace fossil fuels in both power boilers and space heating. For example, renewable energy sources (RES) currently provide about 8.5% of the total energy produced in Europe; this is expected to rise to 20% by 2020, creating a potential market of 75 million metric tonnes per year (t/yr) (SM 2009); see **Figure 1**. This growth in the market for pellet in Europe and elsewhere will create manufacturing opportunities for BC where there is an ample supply of fibre (raw materials) and access to ocean terminals. The current export market for renewable fuels is primarily for electrical generation; however, there are potential domestic opportunities in Canada. For example, if Alberta or Ontario were to follow the European model and switch from coal-fired electrical generation to pellet fired electrical generation, the pellet industry could get a domestic market foothold.

BC is currently the world's biggest exporter of wood pellets, and according to the Wood Pellet Association, the BC industry is forecast to grow to ≥3,000,000 t/yr within the next few years. Producing about 2 million tonnes per year, British Columbia currently supplies about one-sixth of the world market [REW 2009].

Figure 1: European Forecast for Renewables - 2020



The growth in pellet manufacturing, along with other biomass related industries, is of interest to BC for a number of reasons, including:

- British Columbia has considerable biomass fuel reserves, particularly as a result of the recent mountain pine beetle infestation. This includes standing dead wood as well as additional wood residue from the milling of lower grade mountain pine beetle killed (PBK) logs. Since most of this reserve is not suitable for higher end uses, a local bioenergy industry may be the best option to provide domestic employment benefits.

- Pellet manufacturing can also help BC's goal of eliminating all remaining beehive burners.

- Global demand for wood pellets is growing as countries realize the benefits of using carbon neutral fuels, leading to GHG emission reductions and other benefits (e.g., when coal is replaced with biomass).

To allow this industrial growth without compromising air quality requires developing emission criteria or guidelines for new installations that are compatible with BC's environmental protection goals. This report is therefore embedded into the context of the BC Biomass Energy Strategy. It is meant to assist the province in sustainably developing its bioenergy resources to enhance both the environmental and economic benefits for the people who live in BC.

The BC Ministry of Environment (BCMOE) has committed to a target of achieving or maintaining Canada Wide Standards (CWS) for ambient air quality for $PM_{2.5}$ (particulate matter less than 2.5 microns in diameter) in all monitored communities by the end of 2010. Several airshed management plans are already in place throughout the province that are intended to provide a multi-stakeholder process for coordinating activities in an airshed –to identify and meet community supported air quality goals. In addition, at least two recently permitted plants have been granted permit conditions expiring at the end of 2010, requiring additional emission reductions after that date.

To provide background and supporting information for the government to develop emission standards that both safeguard the air quality as well as allowing the pellet industry to further expand, the BCMOE contracted Envirochem Services Inc., who was already working with the pellet industry in the areas of environmental management, air pollution control, and energy. BCMOE asked Envirochem prepare a study that would; provide an overview of the existing pellet industry, identify the best practices or technologies for emission reduction and the costs and benefits of these options. Although this study focuses primarily on particulate matter (PM) associated with pellet manufacture, it also considers other air contaminants and other wood fuel products, such as briquettes and pucks.

The report focuses on best achievable technologies (BAT) to control particulate emissions and does not look at facility siting considerations, such as existing airshed particulate loads, environmental sensitivity, or air quality. The results and recommendations are therefore to be understood as guidelines as to what current control technologies can economically achieve rather than actual values that may be set by the regulatory agencies for emission limits or permits, which may be more or less stringent than those outlined here, and may also incorporate other factors such as government priorities, air dispersion modelling results, or airshed sensitivity.

1.1 ACKNOWLEDGEMENTS

The authors would like to acknowledge the BC Ministry of Environment Victoria and Regional Office staff and the members of the Pellet Industry, who took the time to review the draft report, and provide valuable feedback that was incorporated into this report.

2.0 Pellet Manufacturing Process

2.1 PROCESS OVERVIEW

The manufacture of wood pellets is conceptually a simple process: wood (fibre) is dried to remove the excess water, and then compressed into pellets that have a high density and are amenable to bulk transport and bulk firing in conventional solid fuel burners. The process includes no other additives or chemical reactions. Although the process appears straightforward, the actual efficient and reliable operation of a pellet mill requires considerable operational skill in dryer and pelletizer operation and management skills in fibre selection and procurement.

The main processing steps are:

1. Receiving and storage of the raw wood.
2. Sizing the wood residue prior to feeding into a dryer.
3. Drying.
4. Additional size reduction of the dried wood and conveying to the pelletizers.
5. Pelletizing where the wood fines are compressed and formed into pellets. The natural resins in the wood act as the binder.
6. Cooling and screening of the finished product pellets.
7. Combustion, typically of waste wood from the process or other off-site wood residuals, to generate heat for the dryer.
8. Storage and shipping.

Figure 2: Emissions Diagram for a Typical Pellet Plant (Two Dryers)

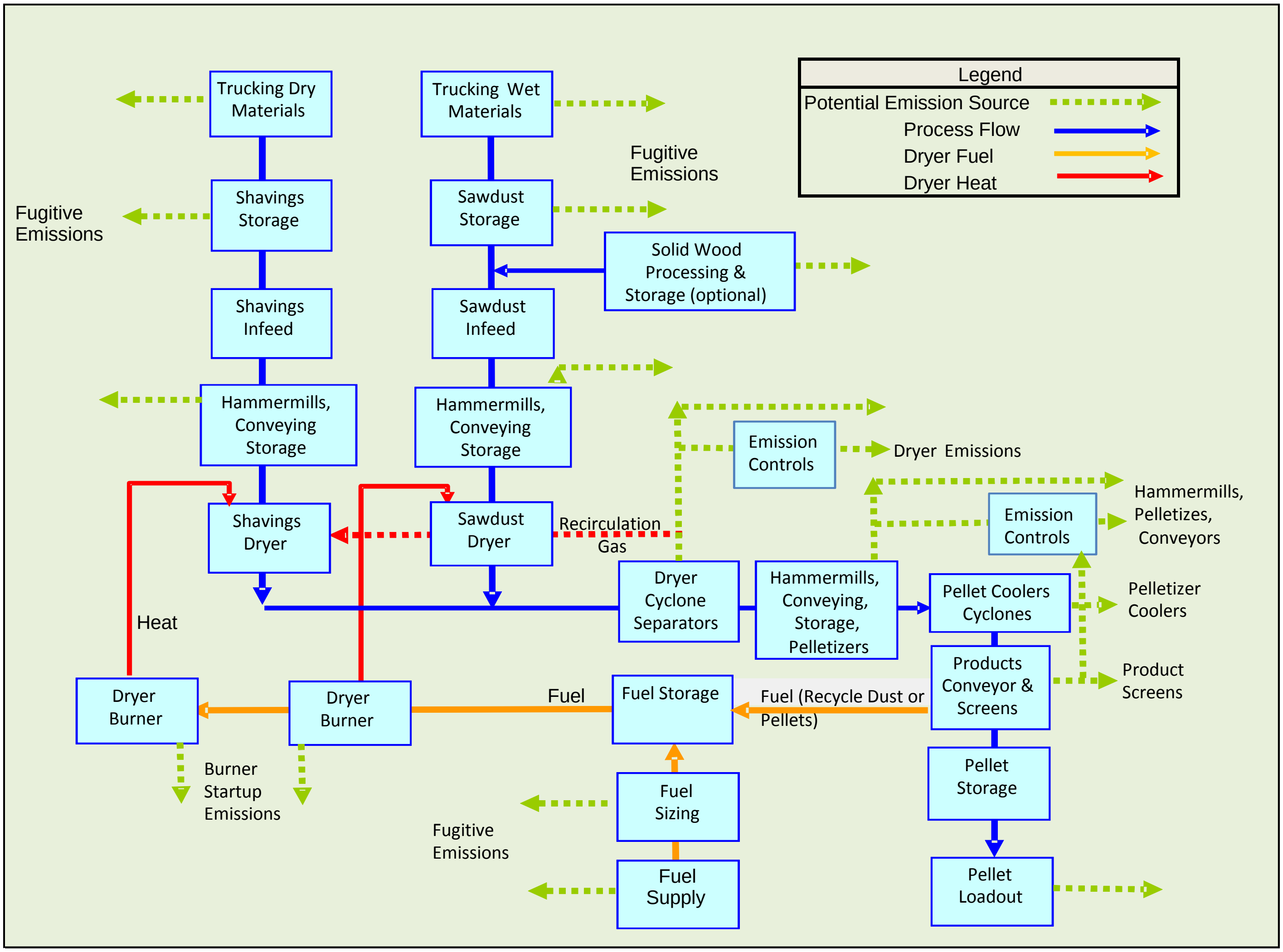


Figure 2 and **Figure 3** are both schematic flow diagrams for a typical pellet mills in BC. **Figure 2** highlights the potential sources of air emissions from a plant with two dryers, while **Figure 3** shows a schematic layout for a single dryer operation.

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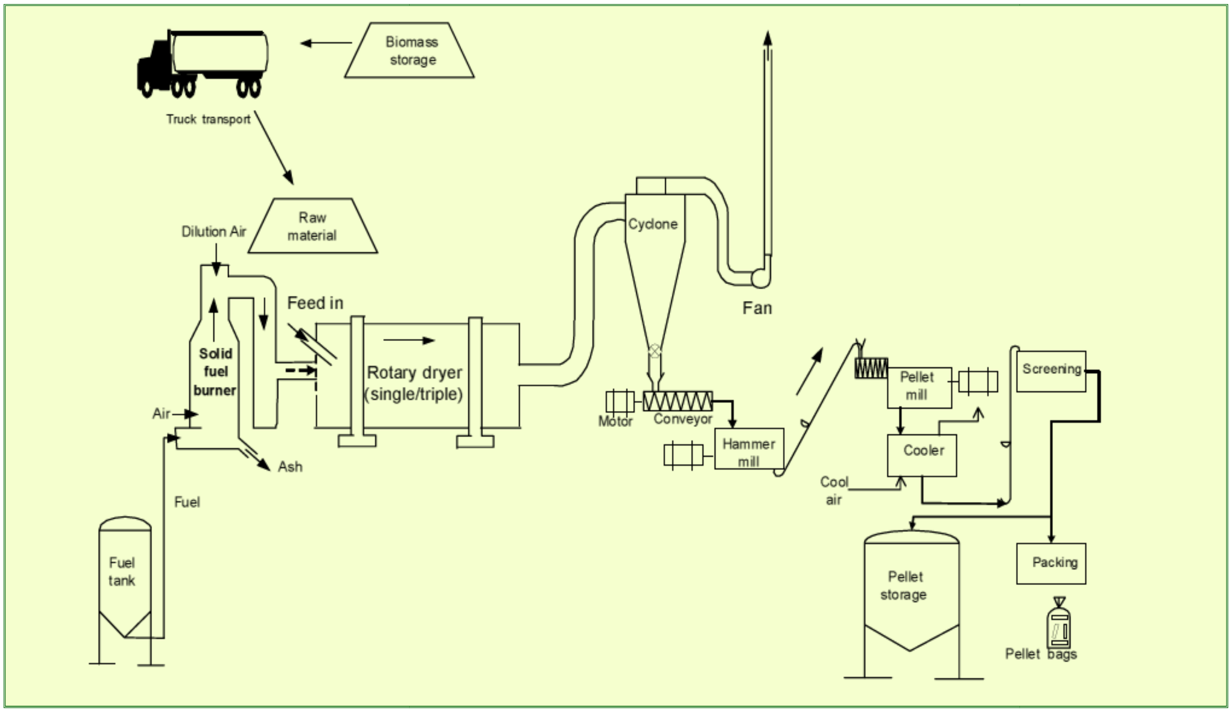
Figure 3: Simplified Process Flow Diagram for a Pellet Plant



2.2 RAW MATERIAL DRYING

The raw materials (typically shavings, sawdust, chips or other saw mill residue) are conveyed from stockpiles to a hammer mill and/or screen for sizing (if necessary) and then to a direct-fired dryer. The dryer feed hammer mill typically reduces the raw material size to about ¾ inch screen (pencil size 1½ to 2 inches long). The size of the wood particles entering (and leaving) the dryer is an important variable in determining the control efficiency of the dryer cyclone, since the finer the size, the less efficient the cyclone collection.

There are several types of dryers being used in the industry, with rotary dryers being typical. They may be either single-pass or multiple-pass. Most recent mills are favouring single-pass for a variety of reasons including; lower temperatures, lower susceptibility to plugging, the ability to allow the finer, dryer (lighter) material to more directly leave the dryer, and cost. Flat bed dryers have been tried, but are no longer typical. The drying technology and process depends on the characteristics of the raw material. Some pellet plants that accept only dry material (e.g. dry planer shavings) may not even have a dryer.

Dryer performance and emissions are dependent on the size and characteristics of the raw material components (sawdust, shavings or chips and wood species) and the amount of moisture in the raw material. Thus dryer operation is simplified if a consistent feed stock is available. If a mill has to accept a varied mix of feeds - for example, dry planer shavings and wetter sawdust or chips, the different feed stocks may be stored in separate areas and then dried in separate batches. Treating the different wood feed stocks separately allows for better control of the drying process, as the dry or finer materials do not get overheated while the wetter material is still in the drying phase.

Overheating the smaller or drier fractions of the fibre in a dryer due to poor size or moisture control on the infeed can increase the amount of volatile organics (VOC) and/or condensable particulate matter (CPM) generated. This has the combined effect of increasing dryer emissions and reducing production since the organics, if not released, would remain in –and add value to- the pellet product. Another approach to improving dryer control is to use separate dryers for the different feed streams, as shown in **Figure 2**. If separate dryers are not available, then the operator may choose to pre-mix wet and dry materials to allow them to equilibrate to common moisture content. Hammer mills and/or screens may be also used on the dryer inlet to make the feed more consistent and homogeneous, thereby resulting in a more uniform drying time.

Ambient and raw material temperatures also affect dryer load, with cold winter temperatures requiring maximum heating (burner firing). However, as the feed temperatures are also colder in the winter the VOC emissions may not increase with the increased burner firing. Although it is suspected that VOC and PM emissions may vary seasonally, there is little reliable information available.

The wood leaving the dryer is then separated from the drying air and combustion gases by one or more cyclones. The dryer may be designed to allow some of this “cleaned” dryer exhaust gas to be re-circulated back to the front of the dyer. Many pellet plants try to maximize this recirculation for energy saving purposes. It also gives another control point for the dryer operator. Recirculation rates can be up to 80% with 40 - 60% being more typical. The amount re-circulated depends on the moisture, carbon dioxide and PM content of the gas, and the system air pressure balance (e.g., increasing recirculation increases dryer air pressure, which can lead to back puffing the dryer system). Increasing recirculation decreases the amount of gas released to the atmosphere, consequently, the actual dryer stack flow rates will vary depending on the nature of the raw material, the fuel, the dryer operation, and the recirculation rate.

The exhaust gas leaving the dryer cyclone(s) contains PM, PM_{10}, and $PM_{2.5}$ from that originate from both the burner combustion process and from wood fines. The heated wood can also release VOC and/or CPM in the drying process with, higher drying temperatures generally resulting greater VOC emissions. Different options are available for the control of dryer emissions. Cyclones are the most common, but venturi scrubbers or wet electrostatic precipitators (WESP) are also used. Due to the CPM fraction, which may include sticky tars, dry electrostatic precipitators and fabric filters (i.e. baghouses) are not used since the tars may stick to the collecting surfaces creating both operational and fire issues.

2.3 DRYER BURNERS (HEAT SOURCE)

The heat for a pellet mill dryer is typically generated by burning wood waste from the process, pellets, or other mill residues. Small amounts of fossil fuels may also be used for startup preheating, pilot lighting or dryer temperature control. In some mills, diesel (e.g., fuel oil) may be used for startup, and if care is not taken, it is possible to have visible, but short-term (5 – 10 minute) emissions. Propane or natural gas are also used and typically create no visible emissions during startup. Various configurations are possible for dryer burners (suspension, grate, gasifier, etc.), depending on the fuel. Fuel types include: fine dust rejected from screenings usually burned in a suspension burner; pellets or broken pellets burned in a pellet burner; or sawdust, hog or other mill residue that may be burned in a grate or two-stage process, such as a gasifier. Although grate burners and gasifiers are much more expensive than suspension (dust) burners, they do accept a wider range of possible fuels and fuel moistures. As most dryers in this industry are direct fired –that is, the burner exhaust gases are exhausted directly through the dryer - there are typically no separate emissions from the burner other than during startup. Good skill and control is required to ensure that the wood is adequately dried while at the same time preventing potential dryer fires that could result from the hot burner flue gases overheating the raw wood material.

The combustion processes supplying dryer heat can be expected to produce oxides of nitrogen (NOx), carbon monoxides (CO), some unburned hydrocarbons, and particulates. However, as these combustion emissions are included in the dryer stack emission measurements, are typically much smaller than the PM and VOC emissions from the drying process itself, and have been discussed in other studies (EC2008) they are not covered in detail in this report. To provide insight into the emissions from wood dryers **Table 1** summarizes emissions from the Oriented Strandboard (OSB) drying process (the NOx level is lower than that of a natural gas power plant).

Table 1: Emission Factors for OSB Dryers, in kg/OD tonne (AP-42, Section 10.6.1)

Source	SO_2	NOx	CO
Rotary dryer, direct wood fired, softwood SCC 3-07-010-09	Not detectable	0.35 kg/ODT (153mg/DSm^{3*})	2.7 kg/ODT (1,175 mg/DSm^{3*})

Note: *All PM concentrations in this report are reported as mg per dry standard cubic metres at 20^{o}C (DSm^{3})
*Estimated from kg/oven dried (ODT) based on 2,300 m^{3} of flue gas per ODT of pellets

2.4 POST-DRYER PROCESSES

The material from the dryers is then typically conveyed to: hammer mills or other size reduction processes; in-process storage bins; to the pellet presses (pelletizers); pellet coolers; and then to product screens, storage bins and loadouts.

The bulk of the wood from the post dryer hammermills and pneumatic (or other) conveyance systems is separated from the air streams using cyclones. Since the remaining dust in the air stream leaving the cyclones now has a relatively low moisture content and is much finer than dryer exit dust, (as it has typically been through two hammermills) it is often fed into fabric filter (baghouse) collectors, especially in newer mills, before being exhausted. The separated, dried and sized wood is then usually stored in process storage bins prior to being fed to the pelletizers.

The pellets leave the pelletizers and enter the pellet coolers. Here the exhaust gases, which typically have lower PM loads than the air conveyance and screening systems, can be successfully treated with cyclones. Due in part to the energy input from the pelletizers, dust generated from the product screens is very dry. Therefore it is often recycled back to the pelletizers or recovered as fuel for the dyer suspension burners with any blow by from the cyclones typically being fed to a baghouse (if equipped). These gases from the various post dryer processes (coolers, screens, hammermills conveyors, product transfer points) may then be combined and vented through a common stack. The high moisture concentrations reported in pellet cooler gases limit can their ability to be treated with baghouses or be re-circulated for process heat recovery [PAB 2009, LOSS 2009].

2.5 SUPPORTING OPERATIONS AND FUGITIVE EMISSIONS

Other sources of fugitive emissions include haul road dust and engine exhaust from trucking, dusting during raw material handling, windblown dust from raw material storage piles, and releases from conveyor transfer points and yard dust if uncontrolled.

Typically, the raw material storage and handling emissions depend on the type of raw material being stored. The finer, dryer planer shavings and other feeds that are more susceptible to wind erosion (compared to wet sawdust or chips) and are normally stored under cover to prevent release of fugitive dust and to keep the material dry.

New pellet plants may also process both whole logs and landing debris which adds log handling, storage, debarking and chipping to the production process and therefore add the potential to generate fugitive dust. Raw material handling and storage and road dust emissions generally tend to be larger particles (>PM_{10}) and released at lower elevations than those in the dryer exhaust and other mill air pollution control systems, and therefore may not be transported far from the point of generation. Pellet and material conveyors, product bagging, and shipping can also be additional, but typically minor, sources of PM.

3.0 Emissions from Pellet Manufacturing

The contaminants emitted from pellet plants that are of primary environmental concern, as discussed earlier, are particulate matter and total organic compounds (TOC) which includes condensable particulate matter (CPM). Small amounts of carbon monoxide (CO), and nitrogen oxides (NO_x) are also emitted from the dryer burners,. The dryer burners also generate CO_2; however, emissions of CO_2 from the combustion of biomass are considered to be essentially carbon neutral, provided the wood is harvested sustainably.

The following sections provide a review of the available information on actual and permitted emissions from the various processes in a pellet manufacturing operation.

3.1 PM MEASUREMENT METHODS

The quantity of PM that will be reported in any given emission measurement (stack test) depends on the measurement method. The standard method is USEPA Method 5, which forms the basis for Canadian and BC stack test PM procedures and includes two main processes for capturing the sample. The first is a heated filter that catches material that is filterable at ~120°C, referred to as the front half catch or filterable particulate matter (FPM). The gases that pass through this filter then bubble through water filled and ice cooled impingers. The weight of sample (corrected for water) in the impingers is referred to as the back half catch and is called condensable particulate matter (CPM). Method 5 states that "*Particulate matter is... collected on a glass fiber filter maintained at a temperature of 120 ± 14^{o}C (248 ± 25^{o}F) .....*" and this is what is normally referred to as PM emissions in the reference literature i.e. for a typical Method 5 sample the PM is only the front half catch (FPM).

If there is condensable particulate matter (CPM) present, and it is to be measured, then Method 5 can be modified in two ways. In the first case, the filter temperature is held at 120°C –as for Method 5 and Oregon Method 7 - to determine filterable particulate matter (FPM) and the back half is then analyzed gravimetrically for CPM.

Alternatively, the filter may be cooled to the stack temperature (USEPA Methods 17-In stack and 202 - the BC Manual references Method 202). The amount that will collect (condense) on the filter and be reported as PM is now a function of stack (or filter) temperature – with more CPM (if present) condensing at lower temperatures. This lower filter temperature (e.g. 100^{o}C) will tend to increase the amount of PM that will be caught on the filter (if the stack temperature is below 120°C) and reported as FPM. Consequently, to interpret data, knowledge of the filter temperature when PM is sampled becomes important.

For purposes of this report it is assumed that the data are consistent with Oregon Method 7 (or Method 202 with a 120°C filter) where the FPM is equal to the front half or filter catch at 120°C and the CPM is the back-half catch collected in ice cooled impingers and Total PM is the sum of the two catches. It is important to note that in addition to condensable particulate matter, the total organic compounds (TOC) emissions from dryers also include volatile organic compounds (VOC) such as methane that do not condense in the iced impingers. Thus, TOC emissions are typically higher than the condensable (CPM) fraction. In the U.S., volatile organic compounds are now defined in both in terms of their photochemical reactivity (see CFR 2009) or sample method (e.g., US EPA Source Test Methods 18, 25, 25A, 25B…). Care must therefore be taken when comparing VOC data from different references and sources. As a consequence, this report focuses on condensable particulate matter (CPM) as measured in BC from data sources that were available for this work.

In summary, when referencing the emissions of both PM and organic compounds from stacks it is important to be clear on how they are measured and what was included (captured) in the measurement. Also, as CPM’s are temperature dependent, the emissions will depend on the dryer temperatures, the exit temperature of the control equipment and stack temperature.

3.2 PARTICULATE MATTER EMISSION FACTORS

Currently there are no specific US Environmental Protection Agency (USEPA) or Environment Canada emission factors for pellet production. To provide some insight into the type and magnitude of emissions from pellets plants, factors for wood drying were taken from USEPA AP-42, Section 10.6.1 (Oriented Strand Board) as being the closest approximation to pellet operations. Other AP-42 factors, such as for fugitive dust emissions, were also used.

The numbers in the following tables are based on measurements at different sources and therefore may not be directly comparable from one source to another since the efficiency of cyclones for PM control can vary from source to source depending on the cyclone design and the size of the particles in the flue gas. The data do however provide a good insight into the possible range of emissions from the drying process. A detailed discussion of these aspects can be found in **Section 4.**

Table 1 presents the USEPA AP-42 emission factors for oriented strand board (OSB) rotary dryers.

Table 1: PM Emission Factors for OSB Dryers - USEPA AP 42

Source	Emission control[c]	PM[a,b] kg/t	PM-10[a,b] kg/t	CPM kg/t
Rotary dryer, direct wood fired, softwood (SCC 3-07-010-09)	Uncontrolled	2.1	1.25	0.75
	MCLO[d]	1.15	ND	0.26
	EFB	0.28	ND	0.24
	WESP	0.215	ND	0.23
	RTO	0.15	ND	0.05
	WESP/RTO	0.026	ND	0.050
Rotary dryer/direct wood-fired, hardwood (SCC 3-07-010-10)	Uncontrolled	2.15	ND	0.95
	MCLO	2.6	ND	0.19
	EFB	0.47	0.5	0.23
	WESP	0.125	ND	0.19
	EFB/RTO	0.26	ND	ND
	WESP/RTO	0.025	ND	0.06
Rotary dryer, direct wood-fired, mixed species (40-60% softwood, 40-60% hardwood) (SCC3-07-010-15)	Uncontrolled	2.35	ND	0.55
	MCLO	1.65	ND	0.75(e)
	SCBR.	0.65	ND	ND
	EFB	0.21	ND	0.38
	WESP	0.33[a]	ND	0.18
Conveyor dryer, indirect-heated, heated zones, hardwood (SCC 3-07-010-40)	Uncontrolled	0.36[cc]	0.031[cc]	0.14

Notes:

From USAEPA AP 42 Table 10.6.1.1 See Table 10.6.1-8 for the hardwood and softwood species commonly used in the production of OSB and other composite wood products. Factors represent uncontrolled emissions unless otherwise noted.

SCC = Source Classification Code. ND = no data available. **Note:** emission factors in this table represent averages of data sets. The data spreadsheets, which may be more useful for specific applications, are available on EPA's Technology Transfer Network (TTN) website at: http://www.epa.gov/ttn/chief/.

a) Emission factor units are kg of pollutant per oven-dried metric ton (or tonne or Megagram Mg) of wood material out of the dryer in kg/oven-dried tonne (ODT).
For reference One lb/OD Imperial ton = 0.5 kg/metric tonne).
b) Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train. Filterable PM-10 is that PM collected on the filter or in the sample line between the cyclone and filter of an EPA Method 201 or 201A sampling train.
c) Emission control device: MCLO = multicyclone; EFB = electrified filter bed; WESP = wet electrostatic precipitator; RTO = regenerative thermal oxidizer; SCBR = wet scrubber; INCIN = exhaust vented through combustion unit emission control equipment. (This combustion unit is controlled with a multicyclone followed by a dry electrostatic precipitator). Cyclones (used in front of WESPS & EFB) are used as product recovery devices and are not considered to be emission control equipment (high efficiency cyclone performance is comparable to MCLO).
d) Multicyclones are used for PM; effects on PM-10 are considered negligible.
cc Emission factors apply only to the heated zones of the dryer; the cooling sections also have emissions but data were not available for cooling section emissions USEAP Reference 37.
e) This value appears to be from a different data set than the uncontrolled emissions just above.

Table 2 uses the emission factors from the literature (mainly AP-42 and related factors from the U.S.-EPA) to estimate the total particulate emissions for a 100,000 t/year plant. Including all the different pellet production process this is estimated at about 186 tonnes per year. Since AP42 emissions values are generally higher than current permitting practices and permit levels are also generally above actual measurements, the data may be more typical of worst case emissions rather than typical operations. For example in the table, the bulk of the emissions come from stockpiles (50 tonnes) and feed bins (75 tonnes). The emission factors assume a worst-case situation here, which does not occur in the BC context, i.e. very dry conditions, high wind, and uncovered storage. These fugitive emissions can be controlled fairly easily with simple measures, as described in **Chapter 4**. Once this is done, dryer emissions become the major concern and are therefore the main subject of this report. The following section summarizes allowable or permitted emissions in other jurisdictions and compares these to BC pellet operations.

Table 2: Estimated PM/PM10 Emissions for a 100,000 Tonne/yr Pellet Plant

Emission Points	Emission Factors uncontrolled	Emission Factors uncontrolled		Control Methods	Emission Factors (controlled)		Emissions (100 kt/yr Plant)		% of Total of Plant Emissions		PM10 Fraction
	PM/PM10	kg/t			kg/tonne		t/yr		%		%
	lb/ton	PM	PM10		PM	PM10	PM	PM10	PM	PM10	PM10
Log storage	Not available			None	0	0		0	0%	0%	
Log debarking	0.02/0.011 lb/ton (AP-42)	0.01	0.005 5	Water spray (50% eff.)	0.005	0.003	0.5	0.3	0%	1%	60
Log chipping	0.6/0.6 lb/hr [OK 2003]	0.3	0.3	None	0.024	0.024	2.4	2.4	1%	5%	100
Stock piles	(SCC 30700803, USEPA FIRE Now revoked)	.		Emissions controlled by moisture in sawdust (25-40%); watering unpaved areas	0.5	0.18	50	18	27%	35%	36
Load in							0	0	0%	0%	
Wind erosion	Front-end loaders (AP-42, Section 13.2.2, 12/03):						0	0	0%	0%	
Vehicular activity	5.48/4.60 lb/Vehicle mile traveled (VMT			(2.7/2.3 lb/VTM)	1.23 kg/ VTM	1.04 kg/ VTM			0%	0%	
Load out							0	0	0%	0%	
Feed bins	(3-07-008-03, FIRE page EF-77)			Multi-cyclone	0.75	0.27	75	27	40%	52%	36
Open conveyor belt							0	0	0%	0%	
Screen							0	0	0%	0%	
Hammer mill							0	0	0%	0%	
Enclosed drag belts							0	0	0%	0%	
Rotary dryer	3.4/0.69 lb/ODT (AP-42, Table 10.6.2-1)			Multi-cyclone	0.465		46.5	0	25%	0%	
Storage bin	0.33/- lb/ton of product (AP-42, 10.6.2)			Multi-cyclone	0.045		4.5	0	2%	0%	
Pellet mill	Cooler: (3-07-008-08, FIRE page EF-77)						0	0	0%	0%	
Pellet cooler					0.07	0.04	7	4	4%	8%	57

Emission Points	Emission Factors uncontrolled	Emission Factors uncontrolled		Control Methods	Emission Factors (controlled)		Emissions (100 kt/yr Plant)		% of Total of Plant Emissions		PM10 Fraction
	PM/PM10	kg/t			kg/tonne		t/yr		%		%
	lb/ton	PM	PM10		PM	PM10	PM	PM10	PM	PM10	PM10
Bagging									0%	0%	
Total 1	**Mill Total -Unadjusted**				**1.859**	**0.517**	**185.9**	**51.7**	**100**	**100**	
Total 2	**Total as above with the feed bin set the same as the storage bin**				**1.154**	**0.247**	**115.4**	**24.7**			
Total 3	**As above with Stockpile emission reduced by 50% (e.g. Shavings undercover)**				**0.904**	**0.157**	**90.4**	**15.7**			

Notes: 1) Based on year-round operation (8,000 hours) and plant size of 100,000 metric tonnes.
2) Emission factors in the USA are reported on lbs. emitted per ton (2000 lbs) of feed on input. Note that Lb/ton is equivalent to 0.5 kg/ton.

3.3 PERMITTED PM EMISSIONS FOR THE PELLET INDUSTRY

Table 3 was taken from a current U.S. permit [NH 2008] at an existing pellet mill. The data are based on both measurements and the permit limits. This mill includes baghouses for the pneumatic conveyance system and secondary hammer mill, whereas the former table only considered the use of multicyclones.

Table 3: PM10 Emissions from Pellet Production for a 100,000 Tonne per Year Plant

Emission point	Emission rate		Annual Emissions	
	(kg/hr)	(%) of Total	(t/yr)	kg/tonne
Rotary Dryer with baghouse	5.93	86.63%	51.23	.52
Pellet cooler with cyclone	0.02	0.30%	0.176	0.0018
Chip storage pneumatic convey system with baghouse	0.05	0.69%	0.41	0.0041
Pellet mill pneumatic convey system and secondary hammer mill with baghouse	0.39	5.66%	3.35	0.0335
Dryer fuel pneumatic convey system with baghouse	0.39	5.66%	3.35	0.0335
Pellet cooler and 3 pellet mills with cyclones	0.066	0.97%	0.57	0.0057
Pellet packaging with baghouse	0.005	0.07%	0.04	0.0004
Pellet mill storage silo with baghouse	0.0001	0.002%	0.0012	0.00001
2 pellet load-out silos with baghouse	0.002	0.03%	0.0163	0.0002
Total	**6.8**	**100.00%**	**59.14**	**0.59**

* Based on actual measurements at New England Wood Pellet prorated to 100kt and 360 day per yr.

Although the differences between the tables do highlight some of the uncertainties with respect to determining pellet plant PM emissions; they also provide a clear and consistent framework that will guide further analysis.

It is important to note that fugitive dust emissions from raw material handling (using heavy duty equipment) can be quite variable as they depend on weather and the type and characteristics of the feed stock. With the possible exception of stockpiles of dry planer shavings with unprotected the wind exposure, the fugitive emissions from material handling are generally a small part of total pellet production PM_{10} and $PM_{2.5}$ emissions. This is reflected in the following statement taken from a permit-related document:

> *"The bark conveyor systems are designed to minimize wind-blown emissions of fugitive dust. In general, bark consists of large fragments of materials that are relatively clean. This material is not prone to generate more fine particulates as it is handled, and usually is handled at a moisture content of approximately 50%. Thus, emissions from the bark (and chip) conveyor systems … are considered too small to be quantifiable." [OK 2003].*

In summary the high emissions listed in **Table 2** for the stock piles and feed bin open conveying systems seem out of line with the emission estimates in **Table 3** and the observed permit realities for pellet mills **(Table 4** below). The following conclusions can therefore be drawn from the measured data shown above:

- The main source of particulate matter is the dryer.
- Debarking and chipping are not large emission sources.
- Pelletizer and pellet coolers can have significant air flow volumes, however, plant design data suggests that emissions can be treated successfully with cyclones. As cooler emissions are sometimes combined with other sources actual emission data are limited and inconsistent.
- Hammermills and conveyor systems are also identified as significant in the US-EPA document AP42, however they do not appear to be major based on actual source measurements. Hammermills that precede dryers in the production line are typically processing wet wood. Wood particles from these hammermills are larger than those produced from hammermills that are placed after the dryers in the production line. Consequently, cyclone controls are effective controls for these upstream mills.
- Fugitive PM emissions from sawdust piles are a function of plant location, local winds, pile height, material size, moisture content, plant layout and the controls in place, such as wind barriers, containment, water sprays etc. Likewise, the use of logs or reduced amounts of dry feed stock (planer shavings) ─as can be expected for new pellet mills in BC─ can be anticipated to reduce the need to stockpile large quantities' of ground materials thus reducing the potential for windblown emissions.

- Unpaved and untreated road traffic can also contribute to particulate emissions, depending on weather conditions. Best practices assume dust suppression or watering on unpaved access roads and plant yards.

Although emission monitoring and reporting requirements are usually included as part of the pellet plant permitting process, the amount of emissions data available is limited since the wood pellet industry is an emerging industry in British Columbia. In addition, the data records available did not have detailed information on the pellet plant operating conditions (e.g., dryer, temperatures, throughputs and moisture contents). Therefore the variations in operating conditions that gave rise to the differences in emissions could not always be identified.

Table 4 provides a comparison of current permit restrictions/criteria in the US, Canada, and Germany. There is a tendency in the US to stipulate emissions per hour, or on a kilogram per unit of input (emission factor) or production basis, rather than concentration and volume of exhaust gas. To allow comparison between the different jurisdictions, where there was sufficient data, the total particulate emissions were converted to metric tonnes of PM per tonne of product.

Table 4: Permit Conditions for Wood Pellet Mills and Similar Facilities

Permit	Input material/ Annual output (dry tonnes)	Control Systems	Emission Limits	Max. Annual PM Emissions (metric tonnes)	Emission Factor (kg/t)
		USA			
International Biofuels, VA [RBLC 2007; permit year 2005]	Wood, wood paste, peanut hulls Wood: 430,000 t/yr Peanut hulls: 9,000 t/yr	2 heat energy systems (wood fired), 77.00 MMBTU/H: setting ducts or chambers (20% eff.), cyclones (90% eff.)	3.1/2.8 kg/hr (PM/PM_{10}) (x2)		*0.057/0.052*
		2 thermal oxidizers, 43.00 MMBTU/H: setting chambers, cyclones (99% eff.)	1.8/1.5 kg/hr (PM/PM10) (x2)		*0.033/0.028*
		Wood raw material unloading:	5.5 kg/h (PM)		*0.1*
		Peanut hull unloading:	0.3 kg/h (PM)		*0.06*
		3 primary grind hammer mills: setting chambers, cyclones, CEM system	6.6 kg/hr (PM) (x3)		*0.12*
		Rotary & fuel dryer: setting chambers, cyclones, CEM system	5.9 kg/hr (PM)		*0.11*
		Final grind hammer mills: baghouse	0.5 kg/hr (PM)		*0.009*
		Pellet mills	4.6/hr (PM)		*0.086*

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Permit	Input material/ Annual output (dry tonnes)	Control Systems	Emission Limits	Max. Annual PM Emissions (metric tonnes)	Emission Factor (kg/t)
		processing: cyclones			
		Total		*327 (PM)*	*0.75*
				314 (PM_{10})	*0.72*
FutureFuel Chemical Company, Batesville, AR (AR 2006)	Sawdust and wood shavings, bark 18,030 scfm (~100,000 t/yr) ~12.3 t/hr	Two baghouses/cyclones, only one of which will directly vent to the atmosphere	1.407 kg/hr PM		*0.115*
		Total		*12.2*	*0.12*
Ozark Hardwood Products Marshfield, MO (MO 2006)	Sawdust 18,000 t/yr ~2.2 t/hr	Hammer and pellet mill, drag belts, rotary drum dryer, pellet cooler: cyclones	Not specified	*13.6 (PM_{10})*	*0.75*
		Drum dryer (when fuelled by sawdust):	0.1924 kg/t		*0.1924*
Eureka Pellet Mills Eureka, MT (MT 2006)	Sawdust 8.2 t/hr 71,500 t/yr	Dryer: high efficiency cyclone Pellet mill &/ pelletizer: cyclone	6.95 kg/hr (PM)		*0.81*
		Pellet cooler: cyclone	1.82 kg/hr (PM_{10})		*0.21*
		Total		*>77*	*1.1*
Wayne Farms LLC Laurel, MS (MS 2007)	Grain, minerals 272,000 t/yr 33.3 t/hr	Grain receiving & grinding: baghouse	Not specified	*<90*	*0.33*
		Pellet cooler: cyclone			
Treasure Valley Forest Products Boise, ID (ID 2008)	~70,000 t/yr Sawdust, wood shavings	Drying kilns: only natural gas allowed	34 mg/m^3, 3% O2	Not specified	
		Rotary Drum Dryer	Not specified		
		Cyclone	90% eff. (only natural gas)		
		Pellet mill	cyclones		
			Opacity: 20%		
PC Indiana Synthetic Fuels Lynnville, IN (IN 2008)	Coal 2.4 Mt/yr (pelletization plant)	2 dryers: Wet scrubbers	0.2 kg/t (PM_{10}, x2)*	*960*	*0.4*
		Loading, stacking and conveying:	0.44 kg/t (PM_{10})	*1,056*	*0.44*
		Total		*2,016*	*0.84*
Greenova Pellet Mill Berlin, NH (NH 2008)	Wood logs 96,000 t/yr 11.7 t/hr	Cooler: cyclone	0.02 kg/hr	*0.17*	*0.002*
		Wood burner/dryer: baghouse	5.7 kg/hr	*49.9*	*0.52*
		Total		*50*	*0.52*

Permit	Input material/ Annual output (dry tonnes)	Control Systems	Emission Limits	Max. Annual PM Emissions (metric tonnes)	Emission Factor (kg/t)
Tomorrows Energy Wiggins, MS [MS 2009]	280,440 t/yr 34.2 t/hr	System dust collector: baghouse	0.07 kg/hr	*0.59*	*0.002*
		2 rotary dryers, hammermill: multicyclone	4.9 kg/hr (x2)	*84.6*	*0.30*
		Cooler: cyclone	0.33 kg/hr	*2.9*	*0.01*
		Total		*88.1*	*0.31*
DG Pellets I Jackson, AL (ADEM 2009)	600,000 t/yr 73.53 t/hr	2 hammer mills/storage: uncontrolled	1.59 kg/hr (2x)	*13.9*	*0.02*
		Dryer, hammer mill/storage: baghouses, venturi washer, RTO	10.1 kg/hr PM 8.7 kg/hr VOC	*88.5* *76.2*	*0.15* *0.12*
		2 pellet presses/ coolers: cyclones	4.7 kg/hr (2x)	*41.2*	*0.07*
		Pellet storage, loadout: bin vent filters, baghouse	0.79 kg/hr	*6.9*	*0.012*
		Total		*150.3 TPM*	*0.25*
Germany					
TA Luft, July 24, 2002	Wood fibre	Directly heated wood fibre dryers:	15mg/m^3(wet)TPM	n/a	
			300 mg/m^3 Org. C		
Quebec					
Granulés Combustibles Energex, Lac-Méganthic [MEF 1997]	35 t/hr (50% MC) 110,000 t/yr 13.48 t/hr	Dryer: Wet scrubber (71% eff.)	14.1 kg/h 1.05 kg/t		*1.05*
		Hammermill: Cyclone	50 mg/m^3		
		Cooler/conveyors: cyclones	50 mg/m^3		
		Total		*118*	*1.07*
Granulés LG, Saint-Felicien [MDDEP 2007]	90,000 t/yr 11.03 t/hr	Metal bag house (location not specified)	0.63 mg/m^3	*20*	*0.22*
		Total			*0.22*
British Columbia					
Pinnacle Pellet Quesnel [PP 2001a]	Sawdust, shavings 90,000 t/yr Cap 60,000 t/yr prod. 7.35 t/hr	Dryer: cyclone	115 mg/m^3	*18*	*0.3*
		Hammermill: cyclone	115 mg/m^3	*9*	*0.15*
		Air cooler cyclone	115 mg/m^3	*9*	*0.15*
		Total		***36***	***0.6***
Princeton Cogeneration [PCC 2003]	Sawdust, shavings 65,000 t/yr 7.97 t/hr	Dryer: cyclone	115 mg/m^3	*60*	*0.92*
		Pellet cooler: cyclone	115 mg/m^3	*10*	*0.17*
		Total		***70***	***1.08***
Pinnacle Pellet Williams	Sawdust/shavings 200,000 t/yr Cap 170,000 t/yr prod.	Hammermill/screen/ cooler: baghouse	50 mg/m^3 (PM& CPM), 25 m^3/s	*10.8*	*0.06 (PM)*
		Dryer: venturi	50 mg/m^3, 5 m^3/s	*7.2*	*0.04*

Permit	Input material/ Annual output (dry tonnes)	Control Systems	Emission Limits	Max. Annual PM Emissions (metric tonnes)	Emission Factor (kg/t)
Lake [PP 2004]	21 t/hr	scrubber	(PM&CPM)		
		Total		***18.0***	***0.1***
Westwood Fibre, Westbank [WWF 2006]	Shavings 50,000 t/yr 6.13 t/hr	Dryer (fuelled by wood gasifier): cyclone	50 mg/m^3	*15.7*	*0.31*
		Wood residue dust collection: baghouse	50 mg/m^3	*15*	*0.3*
		Pellet press: cyclone	50 mg/m^3	*2*	*0.04*
		Total		***32.7***	***0.65***
Canfor, Houston [BC 2007]	Sawdust, shavings Bark, 200,000 t/yr Cap 18.3 t/hr 100,000 t/yr prod.	Pellet plant furnish dryer: High-eff. cyclones	27.2 kg/hr	*238*	*1.3*
		Hammermill: High-eff. Cyclone	115 mg/m^3	*54*	*0.27*
		Pellet plant: High-eff. Cyclone	115 mg/m^3	*97*	*0.48*
		Total		***385***	***2.05***
Pacific Bioenergy, Prince George [PBC 2007]	Sawdust, shavings 231,000 t/yr Cap 28 t/hr 150,000 t/yr prod.	Sawdust dryer	390 mg/m^3	*103* **	*0.45*
		Shavings dryer	190 mg/m^3	*48*	*0.21*
		Baghouse & pellet cooler	45 mg/m^3	*37.5*	*0.16*
		Total		***188.5***	***0.82***
Pinnacle Pellet Meadow Bank [PP 2008]	Sawdust/shavings 200,000 t/yr 24.51 t/hr	2 dryers: high-eff. Cyclone	283 mg/m^3 7.85 m^3/s (x2)	*70* **	*0.32*
		Pellet plant: high-eff. Cyclone	77 mg/m^3 29 m^3/s	*70* **	*0.32*
		Total		***140***	***0.64***
Premium Pellet Vanderhoof [PGC 2007]	Sawdust/shavings 200,000 t/yr 24.51 t/hr	Dryer/cyclone	180 mg/m^3 32 m^3/s	*230*	*1.15*

Note: Calculated values in italics; gas flows used to calculate maximum annual emissions.
*incl. curing and pelletizing operations.
**to be reduced after 2010 Totals are as in permit unless in "bold", which is the sum of the available data for each process. CEM = Continuous Emissions Monitoring.

Table 5: Summary of Table 4 (Permitted PM Emissions)

Average Permitted PM Emissions (kg/tonne)					
Source	**All Mills**	**All Mills w/o Canfor**	**Non BC Mills**	**BC Mills**	**BC Mills w/o Canfor**
Dryers	0.55	0.50	0.45	0.64	0.55
Other Sources	0.17	0.22	0.25	0.09	0.19
Complete Plant	0.72	0.71	0.70	0.74	0.73

Figure 4: Comparison of Permitted PM Emissions (Total Pellet Plant)

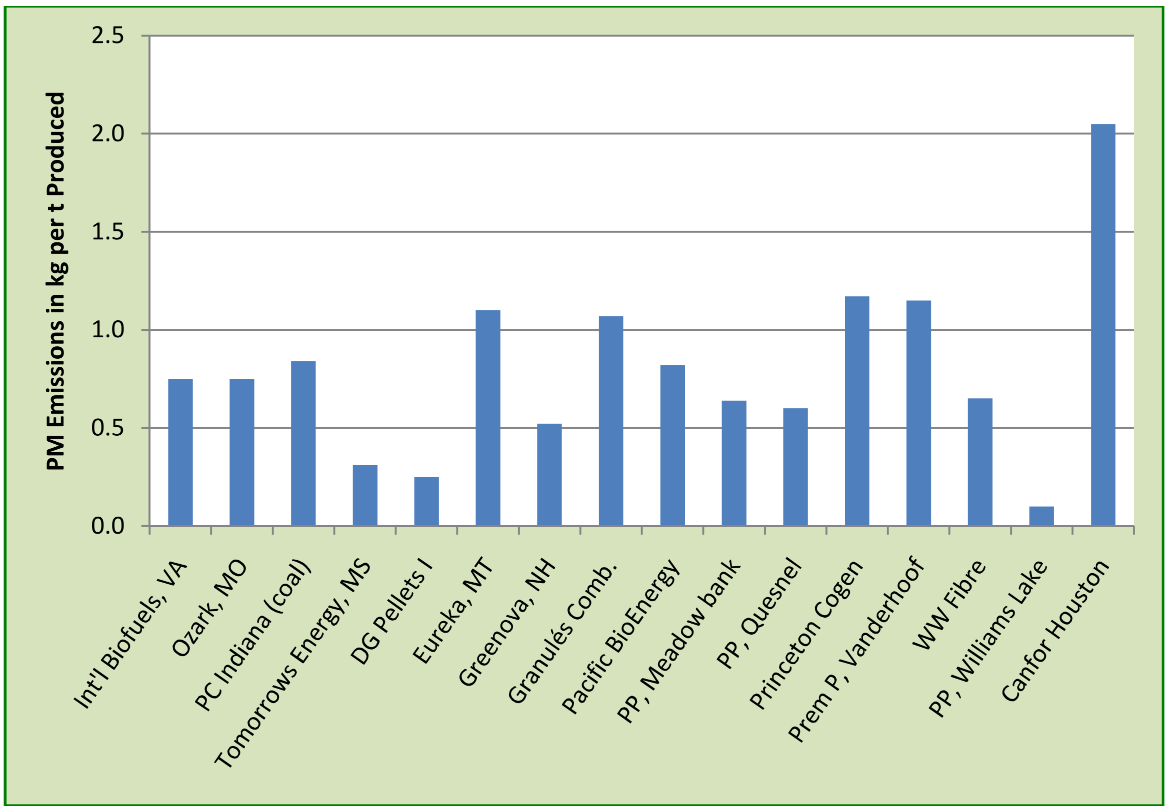

Figure 5: Comparison of Permitted PM Emissions (Dryers only)

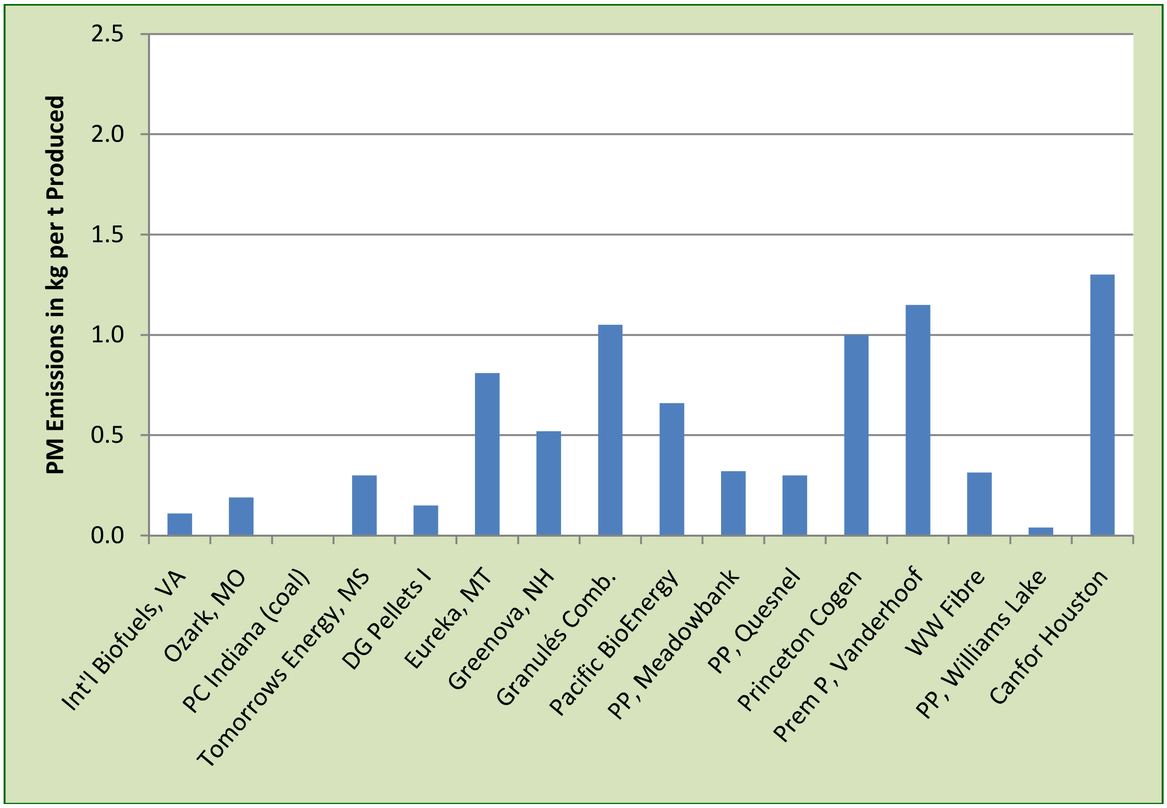

Table 5 above indicates that on average permitted PM emissions from BC pellet plants are similar to the permitted PM emission from other sites and jurisdictions. It must be appreciated that the design, operation, and emissions from a pellet plant are largely a function of the raw material available to that particular operation, For example, if the feed stock is sufficiently dry and fine, then the plant may not even have a dryer (e.g., Pinnacle Pellet in Armstrong). Thus the emissions per unit of input or production can and do vary from plant to plant, and over time as the feed stock changes. However, if the designs are similar to those shown on **Figure 2** or **Figure 3** and the raw material is similar, then similar emission factors (kg/tonne) should emerge.

In BC, the PM concentration in exhaust gas allowed in recent permits has varied between 50 and 390 mg/m^3, with some of higher permitted levels scheduled to be reduced over time e.g. 2010. Reaching the lower emission levels (e.g. ~50 mg/m^3) typically requires advanced controls beyond cyclones. Although there is one BC dryer equipped with a high-efficiency cyclone controlling emissions to < 70 mg/m^3; this level of performance is rare. In Europe, permits frequently stipulate that cyclones and baghouses be used and that PM concentrations generally should be under 100 mg/m^3 [KU 2009]. Baghouses are employed for dryers because condensable PM in the exhaust gas stream could cause operational or fire issues.[1]

[1] In the U.S., strict requirements to destroy VOCs have forced some recent very large pellet plants to install scrubbers or wet ESPs in connection with VOC destruction (see Section 4.6 on Thermal Oxidizers).

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Generally, high efficiency cyclones are part of permit requirements in BC for dryers, with some newer plants using cyclones followed by baghouses for processes downstream of the dyers (e.g. conveyor transfer points, hammermills etc).

BC permits frequently include general statements requiring the control of fugitive emissions, but only one permit among those examined stipulated that wood fibre storage must be housed. Control of fugitive dust through paving of the pellet plant operational areas is occasionally a permit requirement. In addition, as stated above, some BC permits expire by 2010 unless an acceptable plan is received by the Director to reduce particulate emissions further.

Table 6 was prepared to provide some insight as to how the emissions from pellet plants compare to biomass power plants. The table compares the PM limit values recommended in previous reports on wood combustion [EC 2008] to those currently permitted for pellet plants. Emissions are compared in terms of concentrations and emissions per tonne of fuel input.

Table 6: Comparison of PM Emission Limits recommended for Wood Combustion with current Pellet Mill Emissions

Installation Type	Fuel use, dry tonnes year	Concentration	Annual PM Emissions (tonnes)	Emissions per tonne of wood processed
Wood to electricity: (MW Electricity)				
50 MW	300,000	20 mg/m^3	50.0	0.17 kg/t
10 MW	100,000	50 mg/m^3	41.7	0.42 kg/t
2 MW	30,000	120 mg/m^3	30.0	1.00 kg/t
Wood boiler: (MW Thermal)				
40 MW_{th}	120,000	20 mg/m^3	20.0	0.17 kg/t
10 MW_{th}	33,000	35 mg/m^3	9.6	0.29 kg/t
2 MW_{th}	7,000	50 mg/m^3	2.9	0.41 kg/t
0.5 MW_{th}	2,000	120 mg/m^3	2.0	1.00 kg/t
Pellet Plant Total Emissions:				
Pacific Bioenergy	231,000	45-390 mg/m^3	188.5	0.82 kg/t
PP, Williams Lake	170,000	15-50 mg/m^3	18	0.10 kg/t
PP. Quesnel	90,000	115 mg/m^3	36	0.60 kg/t
Princeton Cogen	65,000	115 mg/m^3	70	1.08 kg/t

Note: Boiler fuel consumption estimated based on 100 tonnes per day for 10 MW. Annual emissions for combustion estimated using a factor of 417 m^3 of flue gas per GJ (20 GJ per dry tonne of wood). Fuel use for pellets means feed stock use for production, not fuel for the burner.

3.4 VOLATILE ORGANIC COMPOUND EMISSIONS

This section discusses the volatile organic compounds (VOCs) that can be given off by living forests as well as those generated by pellet plants. In this discussion, the term volatile organic compounds (or VOCs) includes all volatile organics and is not limited by excluding non-photochemically reactive species, as is the practice in the USA. VOCs are released from forests when the trees are heated by sunlight, decay (oxidize), or in forest fires. In pellet plants, VOCs are released when wood is heated in the manufacturing process. One of the reasons for discussing the natural forest emissions is to put the anthropogenic emissions in context.

3.4.1 NATUAL FOREST VOC EMISSIONS

Trees contain both non-volatile (fixed) and volatile organic compounds and emit the volatile compounds as part of the tree's natural life cycle. Examples of naturally occurring VOC emissions from forests are shown in **Table 7**. The most common volatile compounds originate from resin and are primarily terpenes; alpha-pinene, beta-pinene, delta-3 carene and sabinene, and the monocyclic terpenes limonene and terpinolene, that in part give forests their natural woodlands fragrance.

Table 7: Biogenic Emission Estimates for Different Forest Types

Forest type	Period	Emissions per ha	VOC species	Source
Deciduous (birch)	Year	150 kg	as monoterpenes	JAC 2006
Deciduous	Year	48 kg	Isoprene	EA 1999
Scots Pine	Aug/Sept	8.8 kg/month	monoterpenes	BER 2005
Swiss forest (Norway spruce, Scots pine)	Year	22.7 kg	Isoprene, terpenes	FMI 2008
Finnish boreal forest	July	2.1 kg	Isoprene, terpenes	FMI 2008
Western US	July	12 kg	Isoprene, terpenes	FMI 2008

Note: Monoterpenes ($C_{10}H_{16}$), molecular weight of 136 g; Isoprene (C_5H_8), molecular weight of 68g.

The 1997 United States estimate for biogenic VOCs emissions was 28,194,000 tons, while the estimate for man-made emissions of VOCs was 19,214,000 tons [EPA 1999]. Given that Canada has a large land mass with forest cover and less industry, the percentage of natural VOCs emissions should be even greater in Canada. Global annual biogenic VOCs emissions are estimated to be between 300 and 1,000 megatonnes of VOCs. This is about seven times the estimated anthropogenic emissions [FMI 2008].

As a consequence, it is worth investigating, or at least considering, the significance of the incremental contribution of VOC emissions from the forest industry relative to the natural background emissions prior to settling stringent VOC industrial emission standards, especially if the source is within a rural forested area rather than an urban airshed. On the other hand, emissions from forests are distributed over a wide, and frequently rural, area whereas pellet plant emissions are relatively concentrated and often located near urban areas. Consequently, different impacts result, and different control strategies are required for the management of these different source types.

3.4.2 PELLET MANUFACTURING VOC EMISSIONS

VOCs are released at several steps along the pellet lifecycle, including:

- Harvesting (cutting trees)
- Burning roadside slash (if not recovered for use in pellets or composts)
- Chipping or grinding of a tree
- Storing and handling of raw material (green wood, chips, & sawdust)
- Any heat treatment (i.e., drying and pelletizing)
- Transport (combustion engine emissions and off-gassing).

In BC, green wood can have moisture contents exceeding 50%,[2] although much of the beetle kill wood that has been standing for years can have a MC of 25% or less. In order to manufacture pellets from bug killed or green wood fibre, the moisture content must be reduced to levels between 3 and 10 %. Drying wood fibre in rotary dryers is the main process for lowering the moisture content, although the actual pelletizing process (compaction and extrusion) releases heat energy which further dries the wood fiber.

During the drying process, the water in the wood is driven off first, and then if heat is continued to be applied after the water is removed, the temperature of the wood increases and the volatile organics in the wood start to be driven off. The optimization of the dryer involves evaporating the moisture, while minimizing VOC releases.

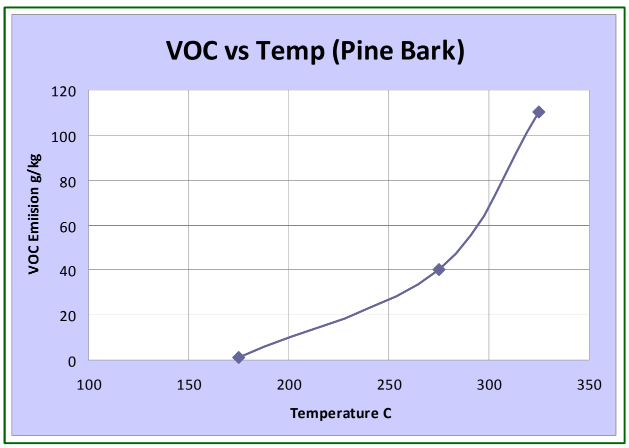
In a well controlled dryer, the heat capacity and heat of evaporation of the moisture in the wood tend to keep the wood temperatures around 100°C until the moisture content approaches 10%, after this point, the wood should be removed from the dryer. If the wood is not removed at this time, its temperature will start to rise above 100°C causing the VOC emissions to rapidly increase [FPJ 2003]. Thus the temperature of the dryer (both inlet and outlet), the wood moisture

[2] It is important to note that all moisture contents (MC) in this report are reported as wet (or original) wood basis (wb). Thus a 60% MCwb wood contains 60kg of water for every 100 kg of wet wood (e.g., the original as received wet wood would contain 60 kg of water and 40 kg of bone dry wood). MC is also often reported on a dry basis where the MC is calculated relative to the bone dry weight of wood, thus 60% MCwb would equal 60/40 or 150% MCdb. The general conversion is MCdb = MCwt/(1-MCwb)

content, and the homogeneity of the dryer feed are very important in controlling dryer VOC emissions.

Information on VOC emissions versus temperature in pellet dryers is limited. Information for pine bark is shown in **Figure 6** [HUT 2003]. This pine bark data, although illustrative of the effect of temperature on VOC, may not be representative of pellet dryers, which use mainly white wood. However as the amount of white wood residue available for pellet plants in BC decreases due to competing demands, some mills have been incorporating larger amounts of bark and roadside logging residue into the process stream. **Figure 6** does illustrate, that as the temperature rises from 175°C to 275°C, VOC emissions increase from less than 1 kg/tonne of wood to ~40 kg/tonne. Above about 275°C, VOC emissions increase rapidly (exponentially) until all of the VOCs are released.

Figure 6: Pine Bark VOC Emissions as a Function of Temperature



Pellet producers typically aim for a dryer exit moisture content of 8 to 10%. This is then further reduced to around 5% in the pelletizers. In multipass dryers, the finer and/or dryer wood particles may not be able to leave the dryer directly as they have to travel the multipass length; this could potentially result in some portion of the feed being overheated. In single pass dryers, it is easier for drier and/or finer particles to be more directly blown through the dryer without as much potential for overheating.

In summary, as the wood temperature rises above ~175°C, dryers can become an important source of VOC and CPM emissions.

In jurisdictions, other than BC, dryers are often the only VOC source considered in air permits (see e.g., ADEM 2009). In several BC permits, CPM's are also included for the emission limits for hammer mills, pelletizers and coolers.

Although it is possible to detect 25 or 30 compounds in the terpene family in dryer exhaust, only 5 to 10 are typically quantified. In some cases, reactions in the gas phase may occur and compounds are emitted from the dryer may not have been originally present in the wood. An example of this is the air oxidation of α-pinene to verbenol, verbenone, 3-pinene-2-ol, myrtenol, and myrtenal which are ringed compounds with aldehydes, ketones, and hydroxyl groups. Depending on the drying time and temperature, it is theoretically possible to release > 80% of terpenes in the wood during the drying process [HID 2006]; however measurements of condensable particulate matter (CPM) in BC do not support this high estimate.

Since no published data could be found for pellet dryer VOC emissions, or for the species and wood product mix used in the BC pellet industry, USEPA-AP-42 emission factors for particle board or oriented strand board (OSB) processing were used as a proxy. However, when viewing this AP-42 data it must be noted that particle board and OSB dryers typically dry to lower moisture contents (~2.5 to 3.5% MC versus 8-10% for pellet plants) and operate at higher dryer inlet temperatures than pellet dryers. As a result, the emissions of volatile (or condensable) organic compounds from pellet dryers would be expected to be lower than OSB and particle board dryers (PAB 2009); this observation appears to be supported BC CPM measurements.

The AP-42 emission factors from direct fired particle board dryers shown in **Table 1** above, ranged from 0.2 to 0.95 kg of CPM per tonne of wood. To provide information on the composition of these organics, **Table 8** (also based on AP42) was prepared. As the different organic compounds can have different environmental effects and toxicities, the estimated concentrations at the stack or source (based on the emission factors and an assumed dryer gas flow) were compared to the Ontario half-hour ambient air quality point of impingement (POI) guidelines.

This comparison provides insight into the potential for environmental and health concerns for each of the organic compounds. **Table 8** shows that formaldehyde, acetaldehyde, phenol, and acrolein (bolded values) have estimated uncontrolled source concentrations that are above the Ontario POI ambient guideline [e.g., these gases require some dispersion (dilution) from the stack before the plume reaches the ground] to be within the Ontario guideline. For the other contaminants, where POI values are available, the stack concentrations are already less than the Ontario ambient guidelines, and of these four gases, only acrolein requires a dispersion (reduction) of greater than 100 fold. Consequently, if acrolein emissions were determined to be comparable to the USEPA data, then dispersion modelling should be conducted to evaluate the need for additional controls. Acrolein, while not classified as a carcinogen, can cause respiratory problems and may aggravate problems with asthma. No measurement data on actual acroelin emissions was found during the research for this study.

However, as stated above, measurements from BC mills are generally much less than the emission factors in the literature. In addition, all dryers have at least a cyclone for controls, which, as shown on **Table 1,** can reduce CPM emissions by >60%.

Table 8: VOC Emissions from Uncontrolled Particleboard Dryers

Uncontrolled Emissions from Rotary Dyers Direct Fired Softwood (SCC3-07-006-07)		Emission Factor	Fraction of VOC	Est. Source Conc.	ON[2] Schedule 2 Values
CASRN	**Pollutant**	**kg/t**	**%**	**µg/m³**	**µg/m³**
80-56-8	Alpha-pinene	0.20	36.07%	80,000	n/a
64-82-8	Methane	0.13	24.04%	52,000	n/a
127-91-3	Beta-pinene	0.06	11.10%	24,000	n/a
67-64-1	Acetone	0.042	7.77%	16,800	35,640
13466-78-9	3-Carene	0.038	7.03%	15,200	n/a
138-86-3	Limonene	0.017	3.14%	6,800	n/a
50-00-0	**Formaldehyde** *	0.013	2.31%	**5,200**	65
66-25-1	Hexaldehyde	0.008	1.48%	3,200	n/a
74-84-0	Ethane	0.008	1.39%	3,200	n/a
67-56-1	Methanol *	0.007	1.29%	2,800	12,000
75-07-0	**Acetaldehyde** *	0.007	1.20%	**2,800**	500
108-95-2	**Phenol**	0.0033	0.61%	**1,320**	100
107-02-8	**Acrolein** *	0.0023	0.42%	**920**	0.24
78-93-3	Methyl ethyl ketone *	0.0020	0.37%	800	3,000
123-38-6	* Propionaldehyde	0.0016	0.30%	640	n/a
123-72-8	Butylaldehyde	0.0016	0.29%	640	n/a
100-52-7	Benzaldehyde	0.0013	0.24%	520	n/a
108-10-1	Methyl isobutyl ketone *	0.0012	0.22%	480	1,200
108-88-3	* Toluene	0.0011	0.19%	440	2,000
110-62-3	Valeraldehyde	0.0008	0.15%	320	n/a
71-43-2	Benzene *	0.00050	0.09%	200	n/a
75-09-2	Methylene chloride *	0.00032	0.06%	128	660
1330-20-7	m-, p-Xylene *	0.00028	0.05%	112	2,200
590-86-3	Isovaleraldehyde	0.00026	0.05%	104	n/a
620-23 -5	m-Tolualdehyde	0.00023	0.04%	92	n/a
117-81-7	Bis-(2-ethylhexyl phthalate)	0.00016	0.03%	64	100
100-42-5	Styrene	0.00006	0.01%	24	400
74-87-3	Chloromethane *	0.00006	0.01%	24	n/a
95-63-6	1,2,4-Trimethyl benzene	0.00005	0.01%	20	n/a
98-82-8	Cumene *	0.00003	0.01%	12	n/a
98-86-2	Acetophenone	0.00003	0.01%	12	n/a
123-31-9	Hydroquinone	0.00003	0.01%	12	n/a
92-52-4	Biphenyl *	0.00002	0.00%	8	n/a
5779-94-2	2,5-Dimethyl benzaldehyde	0.00002	0.00%	8	n/a
74-83-9	Bromomethane *	0.00001	0.00%	4	n/a
110-54-3	n-Hexane*	0.00001	0.00%	4	7,500
84-74-2	Di-N-butyl phthalate	0.00001	0.00%	4	n/a
75-15-0	Carbon disulfide *	0.00001	0.00%	4	330
85-68-7	Butylbenzyl phthalate	0.00001	0.00%	4	n/a
75-18-3	Dimethyl sulfide	0.00001	0.00%	4	30

Uncontrolled Emissions from Rotary Dyers Direct Fired Softwood (SCC3-07-006-07)		Emission Factor	Fraction of VOC	Est. Source Conc.	ON[2] Schedule 2 Values
CASRN	**Pollutant**	**kg/t**	**%**	**μg/m³**	**μg/m³**
95-47-6	o-Xylene *	0.00001	0.00%	4	2,200
71-55-6	1,1,1-Trichloroethane *	0.00001	0.00%	4	n/a
56-23-5	Carbon tetrachloride *	0.00001	0.00%	4	7.2
100-41-4	Ethyl benzene *	0.000002	0.00%	1	1,400
	1 ,2-Dichloroethane *	BDL			
	1 ,2,4-Trichlorobenzene *	BDL			
	Camphene	BDL			
	Chloroethane *	BDL			
	Chloroethene *	BDL			
	Cis-1 ,2-dichloroethylene	BDL			
	p-Cymene	BDL			
	p-Mentha-1,5-diene	BDL			
	TOTAL	**0.540655**	**100.00%**		
Totals	THC as carbon	0.50			
Totals	VOC as propane	0.45			

*= Hazardous Air Pollutant in USA Ref. USAEPA AP 42 Particle Board Dyers Table 10.6.2-3.
[1] Based on the an estimated dryer gas flow rate of 2,500 m³ per tonne.
[2] Ontario half-hour impingement guidelines. Schedule 2 values applicable to new plants as of 2010 [ON 2005].

The VOC data from **Table 8** is summarized graphically in **Figure 7** and **Figure 8**. Here it can be seen that alpha pinene, beta pinene and methane account for >70% of the total VOC emissions.

Figure 7: VOC Emission Factors from a Particleboard Rotary Dryer

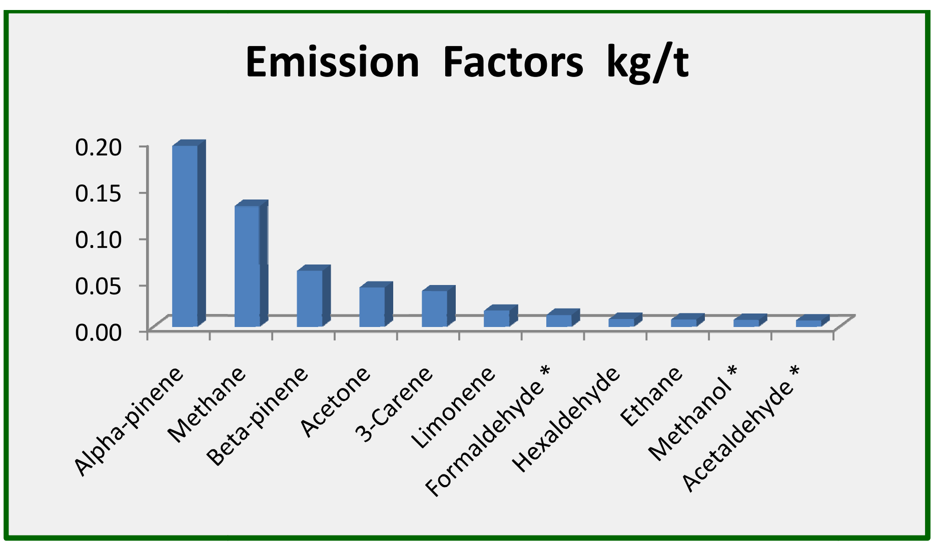
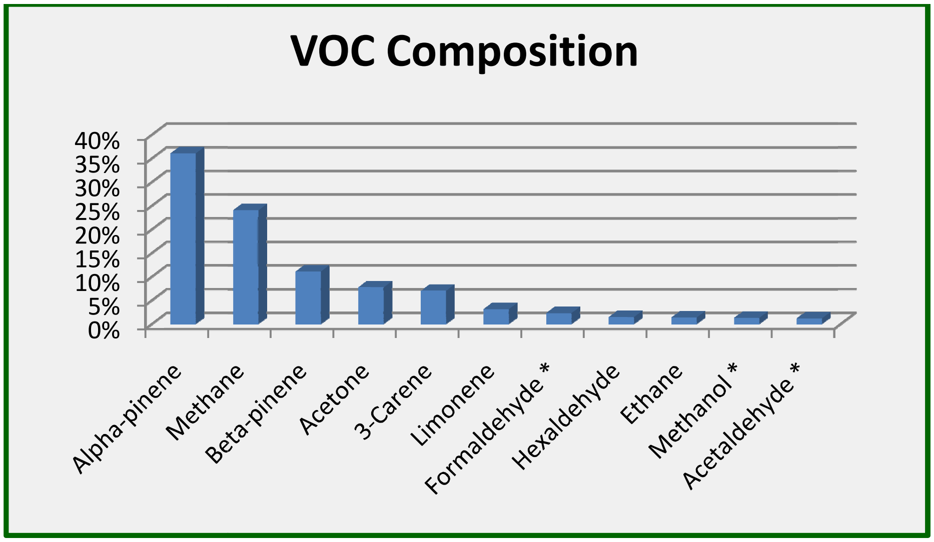


Figure 8: Composition of VOCs from a Particleboard Rotary Dryer



To provide insight into the emissions from different forest species, **Table 9** summarizes the emissions from different wood species that are dried in lumber drying kilns from green (high moisture content) to about 11% MCwb (the dry kiln data were used as no good comparable data were available for pellet rotary dryers). **Table 9** shows that organic emissions can vary by a factor of 10 between tree species; Lodgepole pine emissions at 0.20 kg/t are about 2/3 of that of Ponderosa Pine and Douglas Fir at 0.10 kg/t are about half of that from Lodgepole Pine.

Table 9: Emissions from Lumber Drying, in kg per dry tonne Processed

Species	Emissions From Drying Wood kg/tonne					
	Hydrocarbons		Methanol		Formaldehyde	
	Mean	Range	Mean	Range	Mean	Range
Ponderosa pine[2]	0.28	0.26 to 0.31	0.013	0.010 to 0.016	0.0006	0.0004 to 0.0007
Lodgepole pine[3]	0.20	0.17 to 0.23	0.012	0.011 to 0.013	0.0008	0.0008 to 0.0008
Douglas-fir[3]	0.10	0.09 to 0.11	0.005	0.004 to 0.005	0.0002	0.0002 to 0.0003
White fir[3]	0.05	0.04 to 0.05	0.024	0.019 to 0.030	0.0006	0.0004 to 0.0007
Southern pine[3]	0.55	0.39 to 0.67	0.021	0.012 to 0.024	0.0018	0.0014 to 0.0021

[1] Calculated from imperial values, using a density of 0.4 t/m^3; 1,000 scfm = 5.66 m^3.
[2] Green to 11 percent MC. [3] Green to 13 percent MC. [FPJ 2006, based on 30 samples each].

In separate studies it was also found that organic emissions from mixed chips (birch, spruce and pine) dried at 120°C were 0.5 kg/t, and that a more finely ground mixture of Nordic softwoods (spruce and pine) dried at 100°C emitted 2.1 kg/t [HUT 2003]. This data indicates that particle size may also have an effect on VOC emissions.

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3.5 DRYER EMISSIONS FROM BC PELLET MILLS

As discussed above, PM and VOC emissions from pellet dryers depend on the type of feed stock (tree species, age of the wood, moisture content, and particle size), and dryer technology and settings (e.g. temperature).

The following table summarizes particulate emission measurements taken at BC mills. The table presents the Total PM (TPM) which in BC includes both, the "front half" filter catch (FPM) and the "back half" condensable Particulate matter (CPM). Based on these measurements**,** the condensable PM fractions from BC pellet mills are very low, ranging from 2 to 75 mg/m^3 or about 16% of the total PM. This may be an indication that wood temperatures in the dryer are low relative to OSB and particle board dryers, and that mainly water is driven out, with the VOC component remaining in the wood. It may also result from use of dry beetle kill wood that has already lost much of its VOC content through natural in forest evaporation. More testing would be required to confirm actual VOC emissions from the BC pellet industry and to correlate emissions with operational and supply variables.

The data shown in **Table 10** for measured emissions from several pellet dryers at BC mills equipped with cyclones indicate that:

- The average TPM concentration is;
    - 174 mg/m^3, with a maximum of 432 and minimum of 47 mg/m^3.
- The average TPM emission factor is;
    - 0.40 kg/t, with a maximum of 1.12 and minimum of ~0.11 mg/m^3.
- On average TPM contains about 16% CPM.
- The average CPM concentration is;
    - 30 mg/m^3, with a maximum of 76 and minimum of 1 mg/m^3.
- The average CPM emission factor is;
    - 0.07 kg/t, with a maximum of 0.16 kg/t.

If these values are representative of BC pellet mills, then the total PM emissions for a typical BC pellet mill dryer equipped with cyclone controls and producing 120,000 tonnes per year would be about 6.2 kg/hr or 54 t/y of total particulates, of which about 16 % would be condensable particulate matter.

Comparing this information with the biogenic VOC emissions in **Table 7** above, such a plant would emit an amount of VOCs similar to about 1,000 hectares of pine forest, assuming natural emissions of 50 kg per hectare, per year. Note, that for these BC measurements there was only limited operational data available, to correlate against emissions. Consequently, if future measurements were taken at operating conditions that were different than the above tests, e.g. with a higher feed moisture content, then it is likely that the TPM and CPM emissions will also different, and may be higher, even with new and efficient control equipment.

Table 10: Emissions From Pellet Dryers for BC Mills

Location	Source Name	Controls	Gas Flow Rate	Part. Measurements			TPM Emission rate	PM Sizing % PM >		Gas flow / tonne	Emission Factor		
				TPM	FPM	CPM					TPM	Filtrable	CPM
			DSm3/s	mg/m3			kg/hr	PM2.5	PM10	m^3/tonne	kg/t	kg/t	kg/t
Pinnacle Pellet Meadowbank 110,000 t/yr	Dryer #1	Cyclones	5.8	306	255	51	6.35	83	91	1,549	0.47	0.39	0.08
			7.8	337	322	15	9.48	98.5	99.9	2,083	0.70	0.67	0.03
			5.1	133	124	9	2.45			1,362	0.18	0.17	0.01
			5.6	71	57	14	1.42	99	99.5	1,496	0.11	0.09	0.02
		Average	**6.1**	**212**	**189**	**22**	**4.93**	**93.5**	**96.8**	**1,622**	**0.37**	**0.33**	**0.04**
	Dryer #2	Cyclones	7.6	369	334	35	10.05			2,030	0.75	0.68	0.07
			7.5	269	247	22	7.23			2,003	0.54	0.49	0.04
			7.8	181	105	76	5.05	89.5	96	2,083	0.38	0.22	0.16
		Average	**7.6**	**273**	**228**	**44**	**7.44**	**89.5**	**96.0**	**2,039**	**0.55**	**0.46**	**0.09**
Pinnacle Pellet Williams Lake 200,000 t/yr	Dryer	Venturi Scrubber	14.3	70	8	62	3.6			2,100	0.15	0.02	0.13
		Average	**14.3**	**70**	**8**	**62**	**3.6**			**2,100**	**0.15**	**0.02**	**0.13**
Pinnacle Pellet Houston 100,000 t/yr	Dryer #1	Cyclones	10.8	164	144	20	6.36			3,173	0.52	0.46	0.06
			11.1	132	94	38	5.27			3,261	0.43	0.31	0.12
			7.8	429	382	47	12.09			2,291	0.98	0.88	0.11
			10.1	336	302	33	12.18			2,967	1.00	0.90	0.10
			8.8	432	419	13	13.7			2,585	1.12	1.08	0.03
		Average	**9.7**	**299**	**268**	**30**	**9.92**			**2,855**	**0.81**	**0.72**	**0.09**
Premium pellet Vanderhoof 150,000 t/yr	Dryer #1	Cyclones	11	100			4.0			2,154	0.22		
			12	76			3.3			2,350	0.18		
			13	73			3.4			2,546	0.19		
			13	47			2.2			2,546	0.12		
			12	90			3.9			2,350	0.21		
			17	85			5.2			3,329	0.28		
			13	52			2.4			2,546	0.13		
		Average	**13.0**	**75**			**3.5**			**2,546**	**0.19**		
Pacific Bioenergy Pr. George 100,000 t/yr	Dryer #1	Cyclones	8	242	205	38	7.0	67	68	2,350	0.57	0.48	0.09
			9	61	55	6	2.0	60	65	2,644	0.16	0.15	0.02
			8	249	230	20	7.2			2,350	0.59	0.54	0.05
			8	175	159	16	5.0	9	91	2,350	0.41	0.37	0.04
		Average	**8.3**	**182**	**162**	**20**	**5.3**	**45**	**75**	**2,424**	**0.43**	**0.39**	**0.05**
	Dryer #2	Cyclones	9.97	109	108	2	3.9	37	38	2,929		0.31	0.00
			9.4	186	182	4	6.3	37	60	2,761	0.51	0.50	0.01
			10.8	61	60	1	2.4			3,173	0.19	0.19	0.00
			10.6	85	84	1	3.2			3,114	0.26	0.26	0.00
		Average	**10.2**	**110**	**108**	**2**	**4.0**	**37**	**49**	**2,994**	**0.32**	**0.32**	**0.01**
Summary all Dryers Average Production 120,714 t/yr		**Overal Average**	**9.9**	**174**	**161**	**30**	**5.5**	**66**	**79**	**2,369**	**0.40**	**0.37**	**0.07**
		Maximum	**17.0**	**432**	**419**	**76**	**13.7**	**99**	**100**	**3,329**	**1.12**	**1.08**	**0.16**
		Minium	**5.1**	**47**	**8.0**	**0.8**	**1.4**	**9**	**38**	**1,362**	**0.11**	**0.02**	**0.00**
		Average %			**92%**	**17%**						**92%**	**16%**
		Maximum %			**97%**	**18%**						**97%**	**14%**
		Minium%			**17%**	**2%**						**16%**	**2%**
		Adjusted Average*	**9.9**	**174**	**145**	**30**	**6.2**	**66**	**79**	**2,369**	**0.40**	**0.34**	**0.07**
	Adjusted Average* % (* the quanity of FPM was adjusted to yield a TPM that was constent with the										**100%**	**84%**	**16%**

Note: Production figures shown are those that occurred during testing and may not reflect current levels.

Permitting practice in BC is to specify the TPM concentration and stack gas flow rate at dry standard conditions, rather than specify the PM mass emissions (kg/hr) or the emission factor (kg/tonne of production), as is frequently done in other jurisdictions. To determine if there was some way of correlating these two sets of units, the BC data were analyzed to determine if there was a repeatable value for the quantity of gas flowing out of a dyer stack per tonne of wood dried. If there is, then, it would be possible to not only compare PM concentration measurements in mg/m^3 with PM mass flow factors in kg/BD tonne, but to also estimate the actual PM mass emissions in kg/hr for a given dryer throughput.

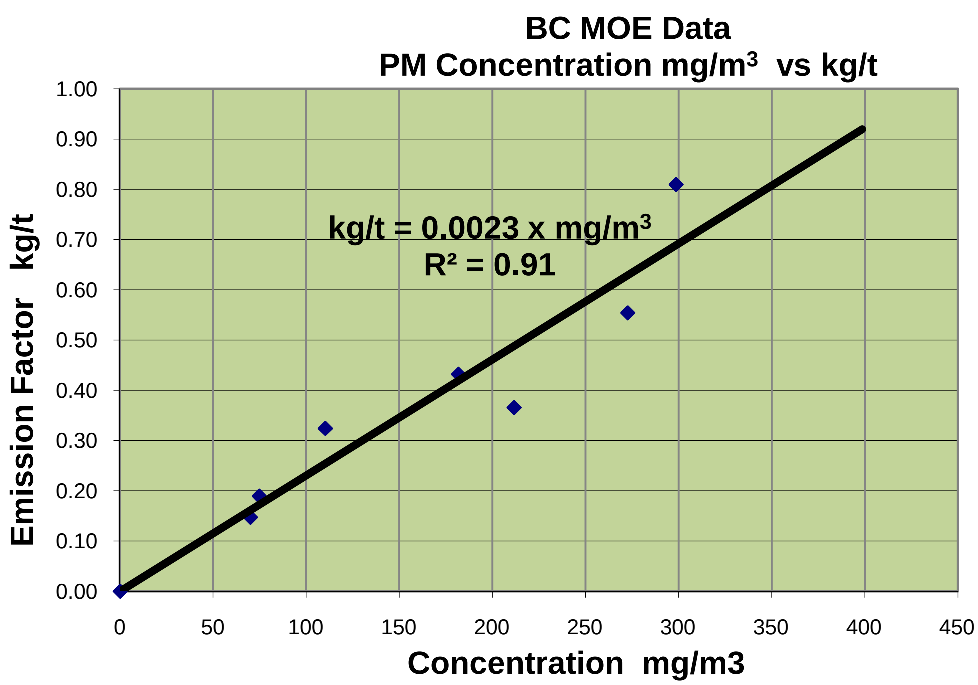
As shown in, **Table 10** there are on average about 2,369 m^3 of exhaust gases (dry STP) generated by the dryer per tonne of production. To determine how well this average factor correlated to the various BC mills, the actual measured emission concentrations in mg/m^3 were plotted against the emission factors in kg/t. The data shown on **Figure 9** yield an r^2 correlation coefficient of 0.91 with a straight line curve fit formula of 0.0023 or

TPM Emissions in kg/tonne = *0.0023 x (Stack concentration in mg/m^3)*
TPM Concentration in mg/m^3 = *435 x (mass emission factor kg/tonne))*

This is the same as saying 2300m3 of dryer stack gas per tonne of DB throughput.

The graph demonstrates the that the above formulae (or an average value of 2300 DSm^3 of dyer exhaust per tonne of production) is a reasonable first approximation to compare BC permits measured in mg/m^3 with other permits and emission factors measured in kg/t (bone dry).

Figure 9: TPM Concentration versus Emission Factor in BC Dryer Exhaust Gases



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3.6 NON-DRYER PROCESS EMISSIONS FROM BC PELLET MILLS

The measured emissions from the pelletizers, coolers, and screening systems for BC mills are shown in **Table 11**. The average PM emission from both the cyclone and the baghouse controlled systems of 0.03 -0.18 kg/t (11 – 30 mg/m^3) is, much less than from dryers. This confirms (based on this limited data) that the dyers at BC pellet mills are currently the major source of both filterable and condensable particulate matter. Also, even though CPM was about 40% of the total PM, for these non-dryer sources, the concentrations of total PM (3-5 mg/m^3) were sufficiently low that fouling of the bags does not appear to be an operational issue. However, since at least two of the mills did have baghouse fires, this could still be a potential issue that should be further investigated with the application of baghouses to these sources. Again, these operational issues (e.g., bag house fires) may result from the newness of this industry and the fact that there is not a long and developed history of pellet plant design and operational optimization.

Table 11 also shows that the average gas flow rate (dry STP) per tonne of production from these non-dryer sources of 5,087m^3/t (mg/m^3 = kg/t x 0.0051) is about double that for the dryers. It must be appreciated that these non-dryer air flows per tonne estimates are based on very limited data and that the emissions from one site may include processes that may not be directly comparable to another site. Consequently this value should be considered as a preliminary estimate only and requires further study. This ratio was calculated to outline an approach that could be used to compare different reporting and permitting variables (e.g. mg/m^3 and kg/t), as was done for the dryers.

3.6.1 PELLET COOLERS

Due to the relatively high moisture content and reported relatively low PM concentrations for pellet coolers gases, BAT is currently cyclone collectors [PAB 2009]. There are studies [LOSS 2009] that recommend that these cooler gases should not be recycled for heat. As these cooler gases are often combined with other emission sources (e.g.cyclone exhausts from pellet screens) and vented through a common stack, there are not a lot of actual measurement data to confirm emissions from these sources and more testing on these sources would be valuable.

Recent cooler emission tests at Pacific BioEnergy (not included in **Table 11**) indicated TPM concentrations of about 40 mg/m^3 of which about 20% (7.5 mg/m^3) were condensable PM. In this test the cooler accounted for about 33% of the total stack gas flow and 68% of the total PM mass emissions leaving the stack. The balance of the stack emissions came from the baghouse which controlled the remainder of the mill's non-dryer point sources. These baghouse emissions were calculated based on cooler and total stack emissions, and showed that the TPM concentration out of the baghouse were about 11mg/m^3, compared to 40 mg/m^3 out of the coolers cyclones.

Table 11: Non-dryer Process Emission Data for BC Mills

Pellet Mill	SOURCE NAME	Controls	GAS FLOW	PARTICULATE			TPM EMISSION	Production	GAS FLOW	Emission Factor		
				TPM	FPM	CPM				TPM	Filtrable	CPM
			DSm3/ sec	mg/m3			kg/hr	T/yr	m^3/ tonne	kg/t		
Pinnacle Pellet Meadow Bank 110,000 t/yr	Pelletizers , Screens and Coolers	Cyclones	24.3	16.1	14.3	1.9	1.41	110,000	6,489	0.10	0.09	0.01
			24.4	16.3	13.2	3.1	1.43	110,000	6,516	0.11	0.09	0.02
			22.4	56.5	54.3	2.2	4.55	110,000	5,982	0.34	0.32	0.01
		Average	**23.7**	**29.6**	**27.3**	**2.4**	**2.46**	110,000	**6,329**	**0.18**	**0.17**	**0.02**
Pinnacle Pellet Williams Lake 200,000 t/yr	Pelletizers , Screens and Coolers	Baghouse	22.9	9.3	2.2	7.1	0.77	200,000	3,364	0.03	0.01	0.02
			17.1	9.8				200,000	2,512	0.02	0.00	0.00
			21.1	12.8	10.6	2.2	0.97	200,000	3,099	0.04	0.03	0.01
		Average	**20.4**	**10.6**	**6.4**	**4.7**	**0.87**	200,000	**2,991**	**0.03**	**0.01**	**0.01**
Pacific Bioenergy 100,000 t/yr	Baghouse Stack - (Ham.mills, Conveyors, Screens & Coolers)	Cooler Cyclones and Baghouse	20.2	14	13	1	1.0	100,000	5,934	0.08	0.08	0.01
			19.7	15	10	5	1.1	100,000	5,787	0.09	0.06	0.03
			21	6	4	2	0.5	100,000	6,169	0.04	0.02	0.01
			20	5	2	3	0.4	100,000	5,875	0.03	0.01	0.02
		Average	**20.2**	**10.0**	**7.3**	**2.8**	**0.7**	**100,000**	**5,941**	**0.06**	**0.04**	**0.02**
Summary and Averages 137,000 t/yr	**Overall**	**Average**	**21.4**	**16.8**	**13.6**	**3.3**	**1.4**	136,667	**5,087**	**0.09**	**0.07**	**0.01**
	Cyclone	**Average**	**23.7**	**29.6**	**27.3**	**2.4**	**2.5**	110,000	**6,329**	**0.18**	**0.17**	**0.02**
	Baghouses	**Average**	**20.4**	**10.6**	**6.4**	**4.7**	**0.9**	200,000	**2,991**	**0.03**	**0.01**	**0.01**

*Calculated Gas flow m^3 (dry at STP) per tonne of pellet production.

4.0 PM/VOC Reduction Technologies and Best Practices

4.1 POLLUTION PREVENTION PLANNING AND STRATEGIES

The purpose of pellet manufacturing operations is to produce a renewable source of energy that can be used to offset fossil fuels thereby reducing the potential impacts of global climate change. Although this may be good (and even required) for the global environment, it is important to achieve this in a manner that is economically sustainable and yet does not degrade the local environment such that human health and enjoyment, or environmental/ecological health is negatively impacted or compromised. As there are impacts with any operation, the goal is to understand and minimize these impacts. Traditionally this could often be achieved by adding on pollution control equipment at the "back end" of a plant or process. However, within the context of sustainability and resource conservation as well as environmental protection a more holistic approach or strategy is preferred.

The pollution prevention approach looks at the whole process including both the physical operations (e.g. energy consumption, reductions in pollutant generation and so on), as well as the geographical location (e.g., is it; near the resource to minimize transport, near a community for local workers, in a sensitive airshed, in an area of good air dispersion.).

For this study six major pollution prevention opportunities were included that should be considered in the development of the project. These are summarized below.

1. Optimize the process design and operational variables to minimize the generation of any emissions prior to entering control systems. This may include
    a. Low emission (efficient) dryers that allow dry material to be removed without overheating.
    b. Dryers designed to operate with low inlet temperatures (e.g. less than ~400^{o}C)
    c. Dryer exhaust recirculation to reduce the emission (stack) flow rates and conserve fuel. Dryer exhaust gases could be re-circulated back to;
        i. The dryer inlet (recovers heat)
        ii. The burner inlet (recovers heat and combusts VOC and/or fine dust)
    d. Include piping and process insulation to conserve heat (reduce fuel consumption and combustion emissions)
    e. Efficient fibre –air separation (high efficiency cyclone pre-collectors)
    f. Efficient low emission combustion systems
    g. Investigation of other areas to optimize energy and fibre recovery, such as pellet cooler exhaust gas energy recovery and reuse
2. Select homogeneous and/or dry raw materials where possible. If low moisture content, consistent feed stocks are not available, then evaluate:
    a. Procedures/processes for pre-blending, or sizing
    b. Installing sizing equipment to ensure the dryer feeds are homogeneous
    c. Using different dryers for different feed or
    d. Batch-feeding the dryers with homogeneous batches of fibre.

3. Locate the operation near the timber supply and/or rail or ports as this will reduce transport emissions.
4. Once these factors have been examined and economically optimized then select air pollution control equipment designed for the specific operation and location. There are five main types of air pollution control systems applied to control the emissions from the pellet operations:
    a. Centrifugal collectors or Cyclones —used either alone or to pre-clean a gas stream that is subsequently passed through a WESP, scrubber or baghouse.
    b. Electrostatic precipitators (Wet ESPs–(WESP) rather than dry ESP are used for wood dyers or other processes that generate higher condensable organic emissions.
    c. Fabric filters or baghouses
    d. Scrubbers
    e. VOC combustors (e.g., regenerative thermal oxidizers –RTO) if the volatile components are of sufficient strength.

When dealing with emissions from wood pelletizing, the presence of condensable particulate matter (CPM) is a concern. Whereas grinding wood can produce dust and small particulates, the heating (drying, as opposed to combustion) of wood can lead to the release of volatile compounds some of which are condensable and form CPM. This CPM can cause problems with both the piping and exhaust gas treatment technologies especially, baghouses and dry ESPs due to fouling as the condensable components can be quite sticky and tarry –as well as flammable. Consequently, the different gas streams from various production processes will have different amounts of condensable matter, and will therefore require different treatment options. These control options are discussed below.

4.2 CYCLONES AND MULTICLONES

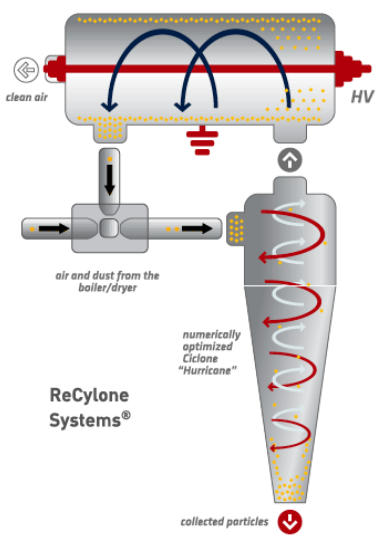
Cyclones and multicyclones are mechanical separators that use the centrifugal force in a rapidly rotating gas flow to separate particles. The larger or the denser the particle, the easier it is to separate them from the gas stream. Flue gases flow into these devices tangentially, causing the dirty gas to spin rapidly, forcing the PM to be thrown out to the walls where gas velocities are lower. It then flows down along the tapered walls to collection hoppers at the base of the cyclone.

A multicyclone is essentially a series of cyclones operating in parallel; this reduces the size of the cyclone required as the flow can be split between several cyclones ─multicyclones can also operate in series. Overall efficiency ranges from 70% to 90% (for large particles), with multicyclones being more efficient than single cyclones. The particle control efficiency of both devices decreases as the particle size decreases and cyclones therefore do not adequately control fine $PM_{2.5.}$

Typical emission concentrations from wood and hog fuel-fired grate systems equipped with cyclones are in the range of 100 to 400 mg/m^3. Cyclones are also used as a pre-cleaning stage before the flue gas passes a WESP, fabric filter, or scrubber. They continue to work effectively at flow rates slightly above their design; however, as the exhaust volume is reduced (such as during periods of reduced boiler load), the centrifugal forces in the cyclone decrease, resulting in lower control efficiencies.

Cyclones are the lowest-cost alternative to reduce particulate matter. They are very robust systems and used primarily to separate filterable particulates from gas streams. They also appear to be effective on condensable particulate matter, based on the USEPA emission factor information shown in **Table 1** where multicyclones reduce the CPM emissions from a softwood dryer by about 67% (from 0.75 to 0.26 kg/t). This is a substantial reduction and appears comparable to performance of a WESP (0.23 kg/t). A potential mechanism for this CPM removal in cyclones (if substantiated) could be impingement and possibly some condensation, provided there is a temperature-drop across the cyclone. In the author's opinion, however, a WESP would be expected to be significantly more efficient at CPM removal than a cyclone due to the scrubbing and cooling effects of the water. This apparent discrepancy may relate to the fact that the projected CPM emissions from a WESP are not rated as reliably as for cyclones (USEPA AP42 rating D for WESP versus rating B for cyclones). This highlights the importance of getting more actual data for BC operations.

Figure 10: Cyclone with Electrostatic Precipitation Features



High efficiency cyclones have longer cone sections and vortex breakers to prevent the collected particles from being re-entrained. Efficiency increases with increasing pressure drop across the cyclone which in turn consumes more energy.

Although Core Separators are identified by the USEPA as a control technology recent internet searches indicated no recent installations and it is possible that it may no longer be commercially available.

A new generation of cyclones combines features of electrostatic precipitation with mechanical PM removal in cyclones. Said to achieve a removal efficiency of over 90%, these devices recycle part of the gas stream coming from the top end of the cyclone through a second chamber where a central charged line causes small particulate matter to precipitate towards the vessel walls (see **Figure 10**). As with other cyclones, these systems can operate with glowing particles and high temperatures – however, it is not certain if they can operate safely with flammable/explosive materials such as wood dust. Since no data on these systems was found in

the literature, they appear to still be at the technology development or proving stage.
In summary, cyclones have been routinely and effectively applied as the final emission control on most processes within the pellet manufacturing industry, with TPM concentrations from BC dryers averaging 174 mg/m^3 and 30 mg/m^3 from the non-dryer processes. In applications that use control technologies such as WESPs or baghouses, the flue gas is always passed through cyclones as a pre-cleaning step, prior to being introduced into the WESP or baghouse. The collected dust may be reintroduced into the process to be pelletized or may be used as dryer fuel.

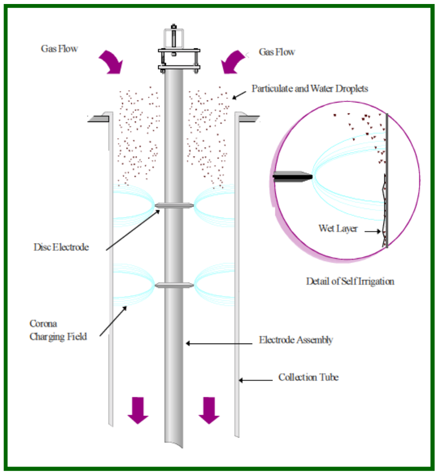
4.3 DRY AND WET ELECTROSTATIC PRECIPITATORS (ESP AND WESP)

Electrostatic precipitators (ESPs) are widely used for the control of particulates from a variety of sources. An ESP is a particle control device that employs electric fields to charge particles in the gas stream. The charged particles are then subjected to an electrostatic field (gradient) in which they are attracted to collector plates where they accumulate and form larger particles or slabs that can be removed through plate vibration. There are a number of different designs that can achieve very high overall control efficiencies, typically averaging over 95- 98%. Control efficiencies are almost as high for small particle sizes of 1 micrometer or less. Precipitator size (collection area and gas or space velocity) is a major variable affecting overall performance or collection efficiency. The larger the size (and cost) the more residence time is available for the particles to migrate across the gas flow to the collecting plates. Precipitator size also is typically defined in terms of the specific collection area (SCA), the ratio of the surface area of the collection electrodes to the gas flow. Higher SCA leads to higher removal efficiencies.

For gas streams with no CPM, ESPs perform almost as well as the best fabric filters. The RACT/BACT/LAER Clearinghouse (RBLC) database reports several large wood-fired boilers using ESP with PM_{10} emission rates in the range of 20 to 30 mg/m^3 (0.02 to 0.03 lb/MMBtu). ESPs require operator training due to high voltage electrode alignment issues; collection efficiencies will deteriorate if they are not properly maintained.

On a dry ESP system, the flow is normally horizontal through a series of parallel plates (collectors), with wire electrodes spaced between to charge particulates and cause migration toward collecting plates where they are deposited and released by rapping the plates. As the flow is horizontal, it is possible to add more fields in series, i.e., additional ESP collection systems can be added one after another. Three to four fields are typical, with collection efficiencies increasing as more fields are added. While adding to cost, more fields also provide greater control of final PM concentrations, which allows dry ESPs to reach very low emission concentrations consistently. The extra fields also reduce rapping losses. Rapping losses are an issue with dry ESPs, but not with wet ESPs (WESP), which use water washing to clean the plates.

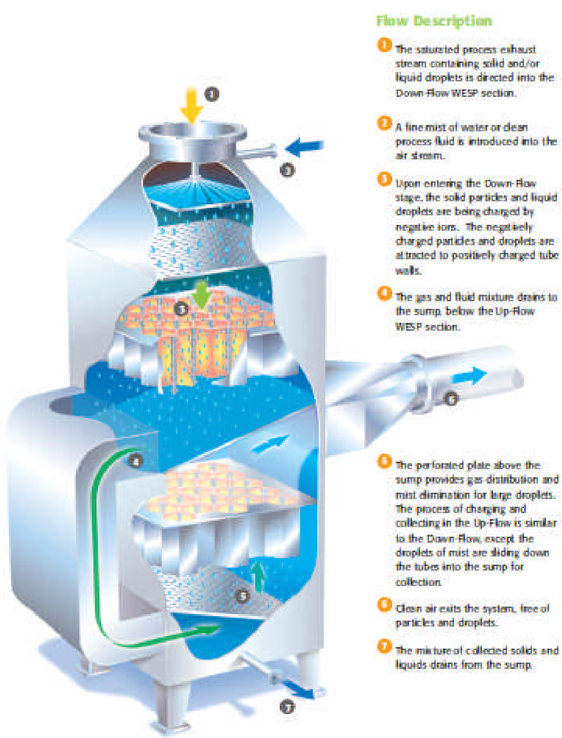
Figure 11: WESP Collector Detail



In a WESP, the gas flow is typically up or down through a series of parallel pipes, each of which is fitted with a single discharge electrode running down the centre (see **Figure 11).** Due to the up or down gas flow design of WESPs, they are typically only single field units with improvements gained by adding more collecting area (parallel pipes) to the single field.

Only one manufacturer, Eisenmann, is currently known to make a two field system as shown in **Figure 12.**

Figure 12: Two Field WESP



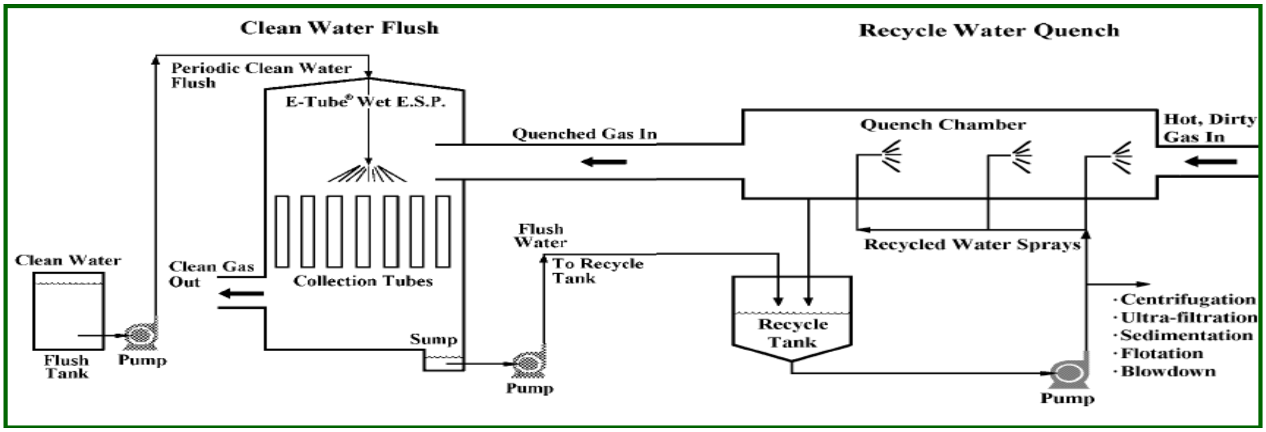
As there are only few of these installations available, it is difficult to confirm if the additional significant capital and operational costs are offset by the potential for increased performance. There is little relevant operational or performance data on such two-stage systems that would allow comparison with the traditional single-stage units.

Figure 13 presents a schematic for a complete WESP system including the water treatment system. The use of water has both:

a) advantages –it keeps the plates clean, can handle sticky tars (especially if water soluble), and minimizes the possibility of fire as electrode sparking can ignite the flammable PM if it is dry; and,
b) Disadvantages –requires a water treatment system with the ability to blow down in order to maintain suspended solids. This can present significant problems in northern winters where the system must be drained to avoid freezing in the event of a shutdown.

Consequently, where condensable or flammable PM is present, as in biomass dryers, WESPs are favoured over dry ESPs.

Figure 13: WESP Complete Installed System



The reduction in temperature due to the water spray is important in removing CPM as this leads to the condensation of the heavier and easier to condense molecules. By continually wetting the collection surface, the collecting walls never build up a layer of particulate matter (PM and CPM or tars). This means that there is little or no deterioration of the electrical field due to resistivity, and power levels within a WESP can therefore be higher than in a dry ESP. The ability to inject greater electrical power within the WESP and the elimination of secondary re-entrainment are the main reasons why a WESP can collect sub-micron particulate efficiently – one of their advantages over dry ESPs. On the other hand, this also means a wastewater stream is created that must subsequently be treated, and can cause potential corrosion problems with downstream equipment, if any. The water can be re-circulated and treatment sludge if dewatered may be able to be used as a fuel. Alternatively, as in the case of pellet dryers, the sludge may be recycled back to the process.

Due to the initial capital investment required in high voltage rectifier sets for ESPs and the water treatment system required for WESPs, these technologies are generally only used in larger systems. For example, in North America, ESPs are usually not used on combustors that have outputs of less than 3 MW. In the case of pellet dryers, WESP are generally not employed on pellet plants with an output of less than 100,000 t/yr [PAB 2009]. Although there is no direct correlation between a 3 MW combustor and a 100.000 t/yr pellet plant, the above statement serves to give an indication of the scale of operation where these technologies are employed. In the US, WESPs have been installed in new pellet plants to pre-clean dryer flue gas for subsequent VOC reduction in regenerative thermal oxidizers (RTO) [BM 2009].

In recent installations of WESPs on pellet mill dryers, the suppliers have guaranteed filterable PM concentrations of 19 to 20 mg/m^3. They have, however, avoided guaranteeing CPM/VOC emissions (at least in BC) as these are so dependent on the operation of the dryer and the raw material used. By itself (without a thermal oxidizer), WESPs can be expected to reduce VOC emissions somewhat, depending on the polarity of the compounds, and is estimated to achieve about a 50% reduction of organic (and odorous) substances, such as formaldehyde and terpenes [UBA 2006].

4.4 FABRIC FILTERS

Various types of fabric filters or baghouses have been successfully used for particulate control. With the correct design and choice of fabric, particulate control efficiencies of over 99% can be achieved even for very small particles (1 micrometer or less). The lowest emission rate for large wood-fired boilers controlled by fabric filters reported in the RBLC database is ~10 mg/m^3 (0.01 lb/MMBTU). This is consistent with expected control efficiencies of close to 98% and is supported by tests on BC units. Because of their design (large surface area of bags and longer residence times), fabric filters may capture a higher fraction of ultrafine particles than ESPs. Cleaning intensity and frequency are important because the build-up of a dust cake is significant in improving the ability of the fabric to capture fine particulate (i.e., cleaning and removal of the dust cake can temporarily reduce the gas cleaning efficiency).

Baghouses are not applicable to streams, such as dryer exhaust gases, since high moisture content and organic compounds can condense on and plug the bags. They are, however, applicable for the dryer dust from pellet mill screens, and post dryer hammermills, and as an add-on to the cyclone separators used on material air conveying systems transporting the finer dryer wood dust.

Operating experience with baghouses at pellet mills indicates that there is a fire risk, due to the presence of unburned wood dust or CPM. Such fires have already happened in the BC pellet industry. Additional measures are therefore sometimes required, such as using a cyclone or multicyclone to pre-treat the gas, or "*fire eyes*" (spark detectors) and water sprays. In pellet mills, the collected dust is often used as dryer fuel in suspension type burners.

Baghouses are often more suitable (economic) for low gas flow rates than ESPs, (EPSs become more economic when the treatment flow is sufficient to offset the capital costs of the high voltage systems). The operational costs for baghouses are higher due to the greater pressure drop. In addition special operator training may be required due to the fire risk. The larger the surface areas of the bags, and the greater the space requirement, the lower the pressure drop (and energy costs). Pressure drop increases with the thickness of cake on the bags, which results in increased collection efficiency (i.e., there is a compromise between keeping the pressure drop low and allowing for sufficient cake accumulation to achieve maximum removal efficiencies). A baghouse can reduce emissions by a factor of ten over the use of cyclones [FPAC 2007]. Cartridge collector systems (also known as mini-baghouses) are modular units that can be interconnected to the stack. These units operate with a variety of cartridge types. They use Teflon or ceramic bags to capture particles, and may have high collection efficiencies. This type of system has been used in conjunction with other control devices, and typically follows cyclone systems. Work is on-going in the development of efficient metal (usually stainless steel) bags that would allow higher operation temperatures. However, in the past, metal bags have not achieved the performance of cloth bags.

Baghouses as applied in BC to pellet mill processes (screens, hammermill and conveyors) have achieved emission levels of less than 10 mg/m^3 with ongoing routine performance limits in the 25 to 30 mg/m^3.

4.5 WET SCRUBBERS

Scrubbers work on the principle of rapid mixing and impingement of the particulate with the liquid droplets and subsequent PM removal with the scrubber water. Scrubbers, like WESPs, also require a waste water treatment system, though the majority of the water is recirulated.

For particulate controls the "Venturi scrubber" is an effective technology whose performance is directly related to the pressure drop across the Venturi section of the scrubber. To achieve higher collecting efficiencies and a wider range of particulate sizes, higher pressures are required. High-energy scrubbers refer to designs operating at pressure drops of 50 to 70 inches of water. Of course, higher pressure translates to higher energy consumption, and Venturi scrubbers are not commonly used as the primary PM collection device in pellet operations because of excessive pressure drop and associated energy penalties, corrosion and erosion, and the problems associated with water treatment and freezing. Due to the water cooling effect, solubility and impingement scrubbers can be expected to remove some CPM, although there is limited performance data available. Pinnacle Pellet Williams Lake, BC is equipped with a two-stage venturi scrubber; it had initial problems with significant erosion due to the high gas velocities at the throat and the abrasive nature of the wood particles. The system has since be upgraded to stainless steel and apparently is capable of producing emissions with TPM concentrations of less than 70 mg/m^3. As there is only limited data available it is not clear how effective and reliable these scrubbers will be in the long term when applied to the pellet industry. CPM and TPM emissions will depend on the water recycle and make-up rates. As there was no information on the water make-up rate or the TOC content of the scrubber water, it could not be determined if the measured emission level of 0.13 kg/tone CPM (**Table 10**) was representative of optimal conditions. A stack sampling from September 2009 showed also very low PM emissions [MOE 2009b].

Venturi and other wet scrubbers are more efficient than multicyclones, especially in size fractions below 1 micrometer. Performance of scrubbers varies significantly across particle size range with as little as 50 percent capture for small (<2 microns) sizes to 99 percent for larger (>5 microns) sizes, on a mass basis. A combined multicyclone followed by a Fischer Klosterman Spray Scrubber installed on a pair of wood-fired boilers with a combined capacity of ~14 MW (49 MMBTU/hr) had a design emission rate of ~10 mg/m^3 (0.01 lb/MMBTU). In pellet dryer applications in BC Venturi scrubbers have achieved emission levels of 50 mg/m^3.

Circulating gravel bed dry scrubbers have also been used but due to their higher operational and maintenance costs relative to performance they are not widely accepted for wood drying and were therefore not further evaluated in this study.

4.6 REGENERATIVE THERMAL OXIDIZERS

Regenerative thermal oxidizers are used to control VOC emissions, including CPM, and are currently being prescribed for some very large U.S. pellet plants (e.g., DG Pellets and also International Biofuels, see **Table 4**). Formaldehyde is one of the hazardous air pollutants emanating from wood dryers requiring control in the U.S. as a result of the "New Source Review" requirements for toxic air pollutants. The U.S. Federal maximum achievable control technology (MACT) applies when a source emits more than 25 tonnes of VOCs per year. Individual States can set more stringent limits. For example, in Washington State, facilities must reduce formaldehyde emissions if they emit more than 32 lb/year [WAC 2009]. Since the early 1990s, thermal oxidizers have been in use in the U.S. to control emissions from wood dryers in the panelboard industry.

In Regenerative Thermal Oxidizers (RTO), the VOC containing gas stream enters a heat recovery chamber filled with ceramic medium that has been previously preheated by the hot RTO exhaust gases. The flue gas steam is thus pre-heated close to the combustion temperature and then enters the combustion chamber, where a natural gas propane burner is used to reach a temperature of 815°C in order to oxidize the VOC contained in the gas stream. The high temperatures can cause increased NOx emissions, a disadvantage of oxidizer technology.

The gas then leaves the heat exchanger and is released to the stack. To recover up to 95% of the heat energy and minimize the use of natural gas, the direction of the gas flow is reversed every few minutes to preheat the ceramic medium. In order to reduce slagging and fouling to acceptable levels, the flue gas stream must be pre-cleaned and most particulate matter and tar removed. This is usually achieved using WESP technology. The combination of these two technologies at the Green Circle pellet plant in Florida reportedly reduces particulate emissions below 20 mg/m^3, and destroys 95% of VOCs [BM 2009].

RTOs work best if there are sufficient VOCs present to maintain combustion without additional or supplemental fuel. Where the gas stream does not have sufficient caloric value (e.g., sufficient VOC) to maintain combustion, additional/supplemental fuels must be added. This can significantly increase operational fuel and maintenance costs, and the GHG emissions. In BC, the data available indicate that VOC emissions are relatively low compared to other typical applications that use RTO technology. In addition, the pellet mill must have a readily available supply of natural gas for a RTO to be feasible. Thus the limited advantages gained in VOC reduction may be offset by increased NO_x & GHG emissions and cost.

4.7 OTHER MEANS TO CLEAN PM/VOC FROM GAS FLOWS

The Agenda 2020 program in Europe is already funding laboratory- and pilot-scale research into use of **low temperature plasma** technologies for treating VOCs and HAPs from facilities for wood products and pulp mills. The initial results suggest the possibility of significant cost and energy savings compared with current thermal oxidation technologies. **Biofilters** have also been tried in the forest products industry but are not used for pellet dryers due to the need to keep the substrate moist, at low temperatures, and avoid channeling or plugging [FPJ 2000a].

A novel milling and drying technology is First American Scientific Corp's. **KDS Micronex** (www.fasc.net). This technology grinds wood pieces (up to 6 inches) to around 1 mm in size while also drying it to about 7% moisture content by using a spinning rotor. The system does not add heat by burning a fuel but dries through the milling process itself and a strong air flow. This can be expected to lead to much lower VOC emissions due to the lower drying temperature, and the company also claims that PM emissions are so negligible and that no environmental permit is required for the system. The air coming from the mill is passed through a cyclone, and oversize material is recycled to the spinning rotor.

It is not certain that this technology is equivalent to the current use of rotary dryers. Concerns may arise over the expected higher VOC content of the resulting pellets, which may in turn present an increased explosion hazard from off-gassing VOCs during transport. The technology also uses a fair amount of electricity to drive the rotor, although this may be offset by dispensing with the hammer mills. According to the calculations in promotional material, it only becomes cheaper than a rotary kiln if the material to heat the kiln comes at a cost. This is not necessarily the case with pellet manufacturing where waste materials, including dust collected from cyclones is used as a fuel. Unless a demonstration can confirm its benefits and suitability for the industry, it is not possible to recommend this technology as a solution to controlling emissions from pellet plants at this point in time,

4.8 CONTROLLING FUGITIVE EMISSIONS

The potential for onsite emissions starts with the trucks entering the site to deliver the fibre. Controls here include paving or water spray or sealcoats, and then keeping the trucks from driving over and grinding the already delivered fibre, especially if it is in an outside uncontained pile.

The use of dust suppressants or paving the perimeter of plant operations is not specified in any of the air permits examined, but may be mentioned in building or other permits. Dust emissions from trucks accessing the plant over dirt roads, as well as front loaders moving within the pellet plant confines can contribute to fugitive emissions. Again, the use of dust suppressants or paving access roads and surfaces with high vehicle traffic would constitute best practices for pellet plants.

As the delivery of fibre to a pellet mill is usually by truck (typically equipped with walking floors for unloading) the reciept of the material is at ground level. Thus sawdust (and other fibre) storage piles at pellet mills are not subject to pile building emissions resulting from blow pipes or drop conveyors found at sawmills. If the pellet plant is receiving fibre from a neighbouring sawmill via direct blow pipe to an external pile, then emission controls such as lowering drop height or misting at the spout should be evaluated.

In determining the emissions from storage piles, the following variables should be considered:

a) Will the prevailing dry wind speed and direction carry the dust to sensitive downwind receptors? Or is offsite transport of PM observed?
b) Pile height; as wind speed increases with height, the taller the pile, the higher the potential emissions. Lower piles are exposed to lower wind speed and are also easier to protect with barriers.
c) The number of non-rainy or wet days. EPA data has shown that if the precipitation was >0.01 inch/day the emissions from storage piles would be essentially zero [WRA 2006]. In addition, in Northern BC, snow cover which quite often freezes into a crust on moist sawdust can be an effective cover for inactive piles.
d) The amount of time the wind speed at the pile face is above the threshold carrying velocity. For a rule of thumb, use >12 mph (~20kph) [WRA 2006].
e) Reduce wind exposure through the installation of upwind barriers or the location of the pile in the lee of buildings. As a barrier with a porosity of about 33% is optimal, and is more effective than solid wall, the planting or location of tree wind brakes can be effective [AARD 2002].
f) The height of the wind break should be sufficient to provide an effective wind shadow (typically at least as tall as the pile).
g) The dryness and amount of fines in the pile. Dry fine planer shaving will have a lower pickup velocity than wet sawdust or chips. So where feasible, planer shavings should be located in a three-sided building.
h) Typically, emissions derived from material handling and storage will consist of relatively coarse particulate matter (>PM10) and may be deposited locally once the wind drops below the carrying velocity.

Additional information can be found in the Western Regional Air Partnership Fugitive Dust Handbook 09/02/2006 http://www.wrapair.org/forums/dejf/fdh/.

Onsite log storage, debarking and chipping generally require no specific PM control measures as these processes cause only minor PM emissions due to the wet and large nature of the fibre. If the work is taking place on an unpaved area then dust suppression paving may be required.

Conveyors and transfer points should be enclosed to minimize fugitive dust generation due to outside wind exposure and from vibrations or movement inside the plant.

One permit document examined required that the Permittee ensure that wood residue stockpiled at the site is stored in enclosed containment [PP 2004]. **Table 2** and **Table 3** showed, however, that chip stockpile emissions are relatively small as the material is fairly coarse. For sawdust and planer shaving storage piles, emissions will mainly occur during dry, windy weather conditions.

4.9 CONTROL TECHNOLOGY COMPARISON

The range of emissions and efficiencies that can be achieved by various PM control systems are summarized in **Figure 14**. As can be seen, particle size is a very important parameter, with the efficiency decreasing as the particle size decreases.

Figure 14: Extrapolated PM Control Efficiency

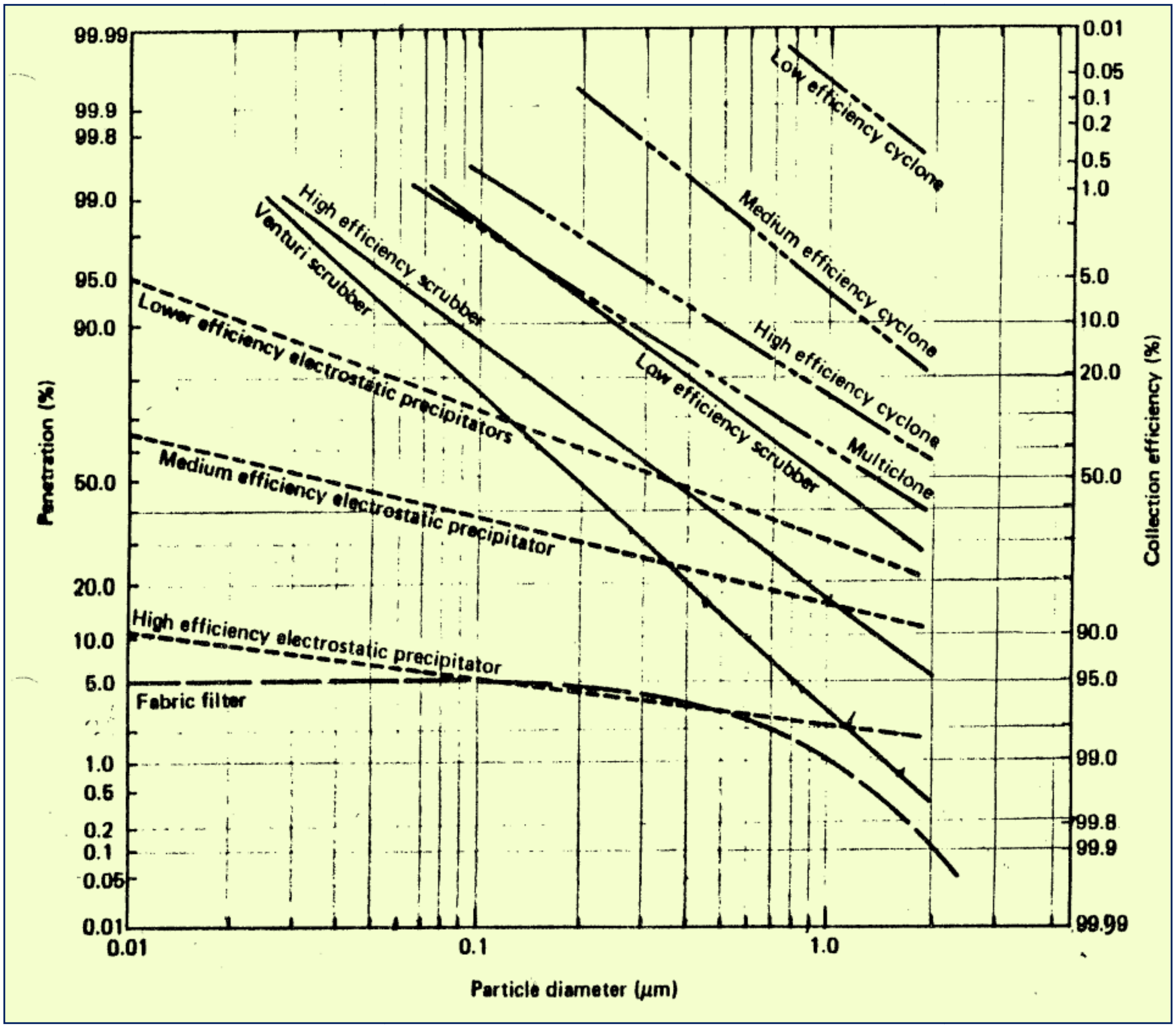


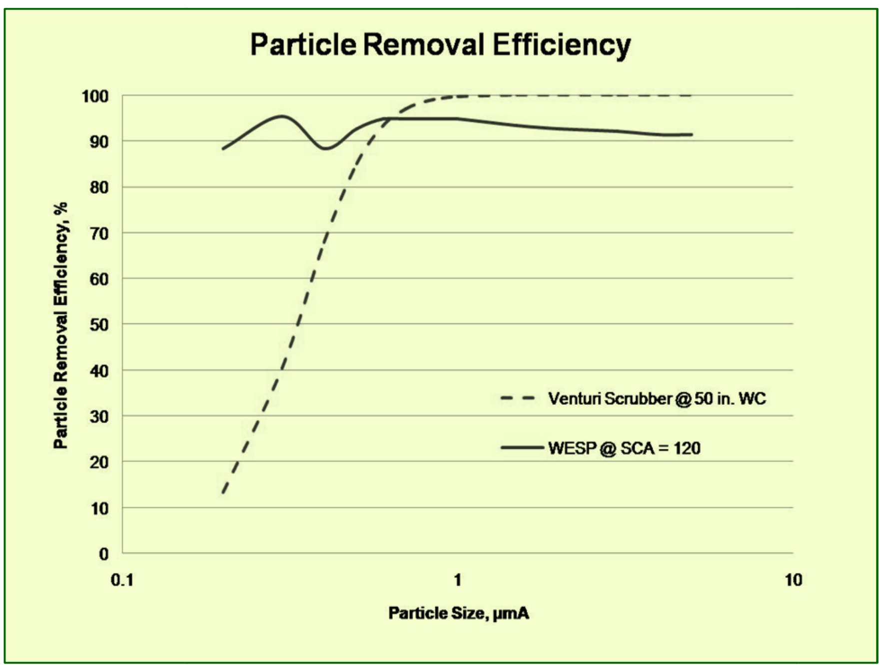
Table 12 summarizes the data from the above graph to show the impact of particle size on the performance of the various APC devices. The table also presents pressure drop data, which is directly related to the fan power requirements and consequently the long-term operating costs. For example, the cost of a Venturi scrubber may be much less (in some cases an order of magnitude) than an ESP but the high pressure drop and therefore ongoing operating costs can soon offset the original capital cost savings.

Table 12: Typical Control Equipment Efficiencies (%)

Control Technology	Efficiency at Different Particle Sizes					Press. Drop
	10 µm	2 µm	1 µm	0.5 µm	0.1 µm	H_20
High Eff. Cyclone	75	45	25	12	1	2-8
Multi-Cyclone	85	60	40	20	3	2-8
Fabric Filter	99.9	99.9	99	97	95	4-10
Dry ESP	99.0	98	97.5	97	95	0.5-4
WESP	91	93	95	96	90	~2
Venturi Scrubber	99.9	99.9	99	90	24	5-60

Ref: Stern Air Pollution Control Manual and Eisenmann Environmental and ET 2009

Figure 15: Particulate Removal Efficiency for WESP and Wet Scrubbers



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As **Figure 15** [ET 2009] shows, the particulate removal efficiency for wet scrubbers falls off steeply with particle sizes of less than 0.8 micron. Scrubber efficiency can be higher than WESP for large particulates over 1 micron, but the WESP shows better overall removal efficiency across all sizes. It is therefore the technology of choice when health concerns exist for plant locations near settlements.

Table 13: Comparison of Main PM Control Technologies

Control System	Removal Effectiveness	Cost (US$)*	Comments
Cyclone	PM10 - Moderate control efficiency ~50 percent PM2.5 – 0 to 10%	*7-10K* Maintenance *minimal*	• Inexpensive • Ineffective at removing fine PM • Little space required • Ineffective at removing gas phase PM (condensable PM)
Multicyclone	PM10 - Moderate control efficiency ~75 percent PM2.5 – 0 to 10%	*10-16K* Maintenance *minimal*	• Inexpensive • Ineffective at removing fine PM • Ineffective at removing gas phase PM (condensable PM)
Core Separator	PM10 – 90 percent and higher PM2.5 – 50 percent and higher	*83-130K* Maintenance *Unknown*	• Questions about availability • Questions regarding effectiveness
Baghouse / fabric filter	PM10 – 98 percent and higher PM2.5 – 98 percent and higher	*100K* Maintenance *10K*	• Higher cost • Large space requirement • Highly effective at removing fine PM • Unsuitable for high CPM concentrations • May be negatively affected by moisture in flue gas when applied in cold climates
*Electrostatic Precipitator (dry)***	PM10 – 98 percent and higher PM2.5 – 98 percent and higher	*1,000 -5,000K* Maintenance *1-2K (low energy cost)*	• Higher cost • Highly effective at removing fine PM • Ineffective at removing gas phase PM (condensable PM)
*Electrostatic Precipitator (wet**)*	PM10 – 96.5 percent and higher PM2.5 – 96.5 percent and higher	*1,000 5,000K* Maintenance *Est. 2-8 K*	• Make-up & Wastewater streams • Very efficient for PM10 and PM2.5 • Can handle sticky tars
Venturi scrubber (wet)	PM10 –97% PM2.5 – 97%	*93-788K* Maintenance *Unknown*	• Make-up & Wastewater streams Effectiveness directly related to pressure loss • High energy costs • Corrosion problems

Note: Table adapted from NESCAUM 2008, NESCAUM 2009, EPA 2003.
*For boiler sizes around 10 MMBtu/hr.
**Costs for ESP and WESP modified by author PAB.

Table 14 provides additional detail on the cost of PM control systems. While it is customary to indicate capital costs for emission control systems on a $/kW basis for power generation applications, this is not relevant for non-power applications. However, one of the main parameters dictating the "sizing" and hence, the costs of a PM control device is the quantity of flue gas it must handle. As a result, it is more appropriate to generalize capital costs in dollars per ACFM of gas flow. The values in **Table 14** represent typical costs for several of these technologies (these numbers reflect unit sizes ranging from utility-size units up to about 2,000,000 ACFM to smaller process down to about 10,000 ACFM [283 m^3/minute].

As stated earlier, a typical dryer stack flow for a 100,000 t/yr pellet plant is about 33,000 ACFM. O&M costs are difficult to generalize for such a variety of technologies and applications, as they are affected by many parameters that include type of fuel, type of process, local ash disposal options, local cost of power, etc. O&M costs include fixed and variable costs. The costs provided below are presented in $/year-ACFM and reflect costs for coal-based fuels but should reasonably apply to other sources as well.

Table 14: Data on PM Control Technologies

Technology	Capital Cost	Quotes*	Fixed O&M	Variable O&M
	in US$ per ACFM		in US$ per year-ACFM	
Cyclones	1 – 5	-	Not applicable	Not applicable
Dry ESP	15 – 40	-	0.25 - 0.65	0.45 - 0.60
Wet ESP	15 – 40	11-24	0.15- 0.50	0.25 - 0.50
Reverse Air Fabric Filter	17 – 40	-	0.35 - 0.75	0.70 - 0.80
Pulse Jet Fabric Filter	12 – 40	-	0.50 - 0.90	0.90 - 1.1
Venturi Scrubber	5 – 20	5-6	0.25 - 0.65	1.2 - 1.8

Sources: NESCAUM 2005; PAB 2009

Note: 1,000 ACFM at 340 F (171C) and 25% H2O= ~ 0.25 DSm^3/sec or 1 DSm^3/sec = ~ 4,000 ACFM from PAB 2009; included for comparison, converted from C$ using a rate of 1.13.

For example, a WESP to treat about 10m^3/sec (42,750 ACFM) of flue gas –a typical gas flow for a BC pellet dryer - was quoted at around $1.7 million, including the water treatment system [PAB 2009]. Adding 60% to account for installation and foundations, results in a total cost of about $2.7 million. **Table 14** above results in a maximum $3.4 million for the same amount of flue gas and therefore seems adequate, although O&M costs seem low at only 3% of capital cost, even taking the higher-end estimate (a different source suggests closer to 10%, EPA 1989). The discharge of a dryer is estimated at 2500 m^3 (dry STP) per tonne of wood dried (see **Figure 9**). Furthermore, applying a cost factor of 0.8 to account for the different plant sizes, the annual WESP costs for pellet plants were estimated in **Table 15** (capital costs were accounted for at a 14% interest rate).

Note that the wet scrubber results in lower costs than the WESP, although the operational costs are higher, due to the energy demand resulting from the required pressure drop. Although the costs are less than a WESP, the collection efficiency for small particles is also less (see **Table 12**), and therefore is not the best available technology. Scrubber costs may also be higher than anticipated due to the need to employ stainless steel components when used in pellet plants, due to erosion problems (see Section 4.5). Thermal oxidizer costs are also included in the table below, based on a theoretical quote obtained for a pellet plant [CPI 2009]. Operational costs only include natural gas ($10/GJ) and electricity costs for the RTO. If natural gas is not available and propane is used, cost would be proportionally higher .

Table 15: Cost Estimates for WESP, Wet Scrubber, and Thermal Oxidizer in C$

Production t/y	Flow		Cost of Capital at		14%*	Operating		Total Annual
	DN m^3/s	ACFM	$/ACFM	Cap$	$/yr	$/ACFM	$/yr	$/yr
WESP								
50,000	5.0	20,023	46	926,666	129,733	1	20,023	149,756
100,000	8.3	33,238	42	1,389,987	194,598	1	33,238	227,836
200,000	15.4	61,670	37	2,279,078	319,071	1	61,670	380,741
300,000	22.0	88,101	34	3,031,689	424,436	1	88,101	512,537
400,000	28.5	114,130	33	3,729,236	522,093	1	114,130	636,223
500,000	36.0	144,165	31	4,495,602	629,384	1	144,165	773,549
WET SCRUBBER								
100,000	8.3	33,238	10.4	344,599	48,244	2	66,476	114,720
300,000	22.0	88,101	9.4	829,873	116,182	2	176,201	292,383
THERMAL OXIDIZER								
100,000	8.3	33,238	21	713,302	99,862	4.16	138,270	238,132
200,000	15.4	61,670	19	1,169,565	163,739	4.16	256,549	420,288
300,000	22.0	88,101	18	1,555,768	217,808	4.16	366,499	584,307

See Section 6.2 for Cost of Capital methodology – Dry normal m^3/sec and Wet actual CFM (see earlier conversion).

Important considerations in the application or either wet scrubbers or WESP is the need for :

- a clean water supply, which depending on the system temperatures and recycle rates could be in the range of 100-300 Lpm;
- a waste water treatment system to treat the water sufficient to meet both recycle and discharge criteria; and
- the ability to dispose of the blow-down from the treatment system, which depending on the temperatures and recycle rates could be 5-50 Lpm (assuming the bulk of the makeup water is evaporated)

Also due to the cold climate, the entire system including recycle waste treatment needs to be well insulated and designed not to freeze up in the event of shut down. This may preclude the use of external settling ponds for the recirculation water. As a consequence the lack of a good water supply or disposal options or the treatment cost may limit the locations where of wet control technologies can be applied.

5.0 Alternative Technologies and Products

5.1 ALTERNATIVES TO PELLETS

For the moment, pellets are the predominant wood fuel product made in BC. While there is no reason to assume that this will change, there are other densified wood products that might be produced in the future:

1. **Torrefied pellets:** these are pellets that have gone through an additional heating process (i.e., they were heated to 200-300°C in the absence of oxygen) in order to reduce moisture content below that of conventional pellets and achieve better product properties, such as reduction of volatiles and a higher energy density.

2. **Densified firelogs:** these are usually cylindrical (other shapes do exist) logs of 1-3 kg and 8-12 inches length that can be used instead of firewood. The firelogs reduce the amount of wood required and produce less creosote and are free of dirt, insects, etc. Two producers are known in BC (Heatlog, Vancouver and Home Fire Presto Logs, Surrey), exporting around 13,000 tonnes per year [MRNF 2008].

3. **Briquettes or pucks:** used for e.g., barbeques in Europe, these are disks of similar diameter as firelogs, and replace charcoal.

The production process for these products is essentially identical for the first stages for conventional pellets (i.e., grinding, drying, and milling of wood), as well as compression into different shapes. Firelogs sometimes contain additives, such as paraffins, to bind the sawdust and facilitate lighting the logs. The BC Pellet Association has announced that a torrefied so-called ‘Super Pellet’ is under development. The exact process planned for BC has not been made public yet, but documents from the Dutch Energy Research Center show that torrefaction, while increasing the capital and operating cost of a plant, increases the energy density and hence reduces the cost to transport pellet’s energy (see **Appendix I**), resulting in overall cost neutrality or even a cost gain as compared to conventional pellets [ECN 2006]. Since the torrefaction process removes volatiles, condensable PM maybe found in the exhaust gas stream. If, however, the gas stream is combusted or recovered, as suggested by initial process diagrams, there should be no increase, but rather a decrease, in overall plant PM emissions when torrefaction is applied.

5.2 MOBILE PELLETIZERS

Figure 16 shows two prototypes of mobile pelletizers. These units are fairly small and do not include grinding or chipping, nor drying. Swedish Power Chippers AB offers somewhat larger units with capacities of up to 700 kg per hour, but additional grinding equipment would likewise be required. To produce wood pellets to international standards in the BC forest, additional equipment such as mobile grinders and dryers would therefore be required. IMG Pellet Systems appears to be offering low-priced Chinese-made complete mobile pelletizing systems to the Canadian market. No other commercial mobile wood pellet mills that could be used today in BC were identified for this study.

Figure 16: Mobile Pelletizer Units

Prototype Mobile Pelletizer by PelHeat (UK)

EQUIPMENT
1. Hammer Mill
2. Cyclone Separator
3. Hopper
4. Pellet Mill
5. Perkins Diesel Engine
6. Control Panel

Source: www.pelheat.com

BHS Slugger 1500 Demo Unit (US)

Producing half a tonne of round briquettes per hour, the BHS Slugger is powered by a tractor or electric motor. It has no dryer and requires material that is already ground.

Source: www.Bhsenergy.com

Previous work indicated that three-shift operation would be essential for this type of equipment to be cost-effective [Lev 2008]. Roadside residue can be piled up near the plant in one or two shifts, whereas processing would continue for 24 hours a day. These units could be installed on logging decks and operated for one or more weeks at a time at each location.

Mobile units are usually delivered with simple cyclones to control particulate emissions. In the forest, they are likely to operate on diesel fuel or possibly even wood gas. A detailed analysis of their emissions impact is not possible within the scope of this study, due to lack of published data and operating experience for such plants. It can, however, be assumed that unless their use becomes very widespread in BC, their emissions will be local and would not contribute to airshed emissions in a major way.

Nevertheless, their operation may have to be curtailed during poor dispersion weather conditions with already high PM concentrations in the ambient air. Due to their economies of scale and the ability to produce premium pellets that contain no bark and hence, have low ash content, larger-scale pellet plants may retain an economic advantage over small, decentralized plants in BC, despite the potential savings in transport costs due to on-site pelletizing in the forest. Mobile pelletizers producing pellets from roadside slash may be producing a pellet of lower market value because they cannot comply with current international pellet quality standards, due to higher bark (and hence, ash) content of the product.

6.0 Economic Analysis

This section provides an estimate of the economic impact of implementing additional air pollution control measures for new and existing BC pellet plants. First, it estimates revenues for three cases:

a) A pellet plant using only sawmill residue as a feed stock –given that this resource is almost entirely spoken for in BC [LEV 2008], this represents mainly existing pellet plants, and not those that are being built today.
b) A pellet plant using 50% sawmill residue and 50% roadside residue (trimmings). This is a more realistic scenario for new pellet plants.
c) A scenario where a pellet plant uses 100% standing dead pine. This scenario is shown not to work at this time in BC. Some companies, however, are buying forest licenses and intend to use some of the harvested wood for pellet making, with the higher-value stems be sold to pulp and sawmills, to improve the economics.

Based on the cost of residue and VOC controls, the impact both on profit reduction and in terms of extra costs per tonne of pellet produced is determined.

6.1 FEED STOCKS

The moisture content and the type of feed stock available, the security of long term supply, and the material cost, including transport, are major considerations in a pellet plant's economic viability. The moisture content of wood depends on the type of wood and the amount of drying (both forced and natural air) prior to entering the pellet process. Typical values for moisture content (MCwb) include:

- 60%+ for green wood;
- 55% for wet hog fuels;
- 30% for hogged scrap wood from sawmills;
- 35%+ for green sawdust
- 25% or less for beetle kill wood that has been standing for several years
- 10-15 % for planer shavings and sawdust from dried wood (wood is typically planed after some or complete drying); and,
- 4.5% for the final pellet product. Note, all moisture contents (MC) referenced in this report are on a wet or green basis (wb –calculated as the percentage of water in relation to the total mass of wood and water combined).

As sawmills close, BC pellet plants are moving from using sawdust and shavings to using bark (hog) and roadside residue [LSJ 2009], or standing dead pine in order to secure fibre. Some BC pellet producers envisage the use of standing trees as part of their feed stock. The Canadian

Wood Pellet Association proposes that future pellet plants may be integrated cogeneration facilities that produce power, heat, and pellets, as well as fibreboard and ethanol [WPA 2008].

6.2 CAPITAL AND PERSONNEL COST OF PELLET PLANTS

As **Table 16** shows, capital investment and the number of employees are both closely related to annual production of a given pellet plant. Three of the larger pellet plants (Dixie and New Gas Concepts, as well as Canadian BioPellet) show a disproportionate cost increase, whereas a fourth one (Green Circle, FL) appears to be within the expected margins. Wet ESPs and thermal oxidizers are used in the Green Circle plant. The cost of the exhaust gas treatment equipment for this plant is reportedly US$7 million [BM 2007]. Several factors may account for the higher cost of some of the larger plants. For example, the other large-scale U.S. plants are using gasifiers as a dryer heat source, which may be more flexible and produce less particulate matter, but is more expensive than conventional suspension wood burners. In addition, they also use Turbosonic Venturi scrubbers with a caustic wash to remove PM as well as regenerative thermal oxidizers [ADEM 2009]. Note that these are announced costs and employment mainly from prior press releases, rather than actual costs published after the construction of a facility, and may therefore over or underestimate these numbers.

Also included in the high cost of these plants are, it appears, are the trucks and barges for pellet transport [AL 2007]. Note that in this context, the location of these plants is on the East Coast and that they envisage export to Europe. This means their transport costs will be lower than for pellet plants on the West Coast, since their marine transport route is much shorter, avoiding the Panama Canal, leading to a cost advantage (about $10 per tonne of pellets) compared to BC producers.

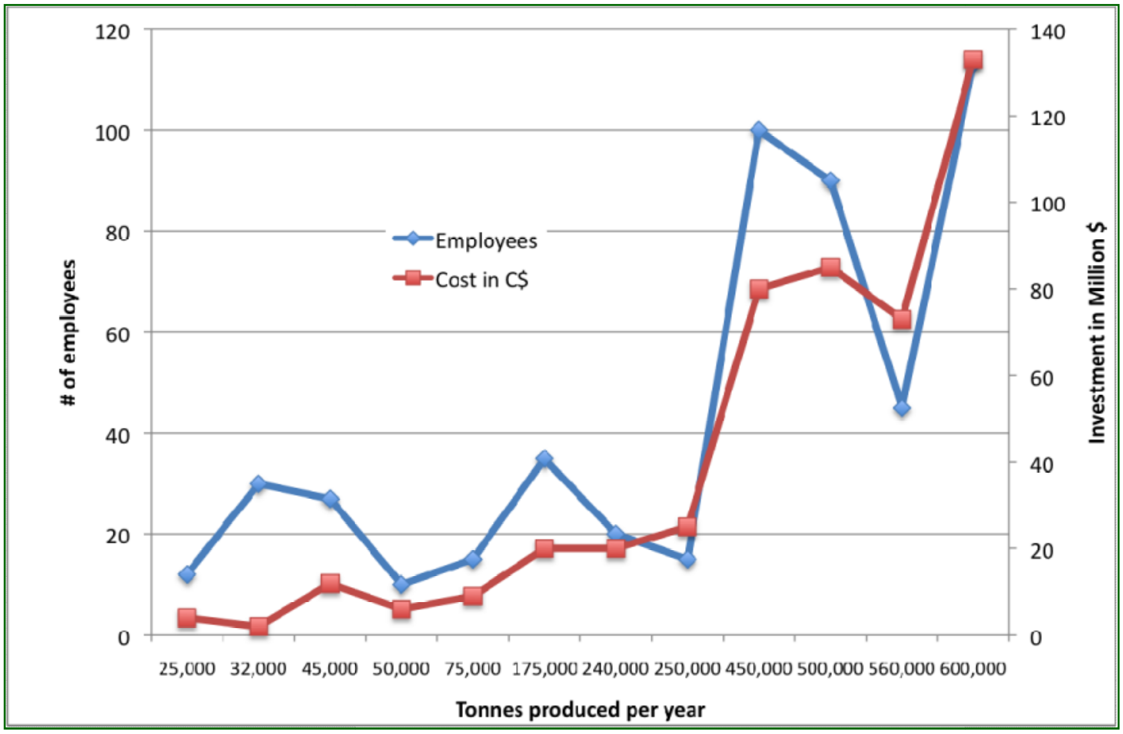
Table 16: Comparison of Pellet Plant Sizes and Announced Capital Investment

Facility	Annual Tonnes	Employees	Cost in C$	Source
Granulco, QC	25,000	12	$4.0 million	CP 2009
Fibre Brain, ON	32,000	30	$2+ million	SS 2009
Tomorrows Energy, MS	45,000	27	$11.9 million	SW 2009
Premium Pellet, Vanderhoof	50,000	10	$7 million*	PP 2001b
Shaw Resources, NS	75,000	15	$9 million	FIM 2008
Pelltiq't Energy Group, BC	175,000	35 (plant) 30 (forest)	$20 million	BCG 2009
Zilkha Biomass Energy	200,000	60-70	$20-40 million	TRN 2009
Pinnacle Pellet, Meadowbank	240,000	20	$20 million	LSJ 2009
Plantation Energy, AU	250,000	15	$25 million	BW 2009
Canadian Bio Pellet, ON	450,000	85-110	$80 million	LM 2009
Dixie Pellets, AL	500,000	80-100	$85 million	LM 2009
Green Circle, FL	560,000	45	$73 million	BM 2007
New Gas Concepts, AL	600,000	113	$133 million	LM 2009

Note: Conversion from U.S. to C$ at 1.13, * adjusted to 2009 costs for 2% inflation.

The number of employees generally increases with plant size, but tend to fluctuate between 15 and 30 full-time jobs for facilities producing < 175,000 tonnes per year. For the larger plants, differences may be due to plant characteristics; sometimes wood collection and pre-processing in the forest may or may not be counted. For example, the Pellit'q Energy Group reports they expect 35 jobs inside the plant (already a high number), plus another 30 for wood collection. They appear to envisage the use of standing dead pine. Another factor may be the sales model (i.e., more personnel would be needed for bagging facilities for local sale, whereas bulk shipping operations are mostly automated). There are not apparent economies of scale in terms of personnel requirements with increasing plant size.

Figure 17: Capital Investment and Employment for Different Size Pellet Plants



The data above is taken from press releases before a plant is built and is therefore based on estimates, it does reflect the common assumption that about $1 million must be invested for each 10,000 tonnes of annual production capacity [DRC 2005]. Looking at a plant with a capacity of 200,000 tonnes per year (a typical case for BC), the number of employees would be about 24 (based on the Pinnacle Pellet plant, with some extra personnel for grinding roadside residue, if any), and the investment around $20 million. This assumption would define the baseline as including cyclones for PM control equipment as found in current permits, but no ability to chip and mill whole trees. The graph does not suggest any economies of scale (i.e., when the plant size increases), capital costs also increase fairly linearly. This may be due in part to more sophisticated gas cleanup equipment usually applied for larger-size pellet plants.

Personnel costs are modeled as $50,000 per year on average [AS 2008], reflecting the need for several engineers and technicians, and shift work. For additional personnel, $50,000 is assumed for each regular employee.

6.3 ECONOMIC BASELINE OF A TYPICAL BC PELLET PLANT

The following parameters are used to determine the economic baseline for a BC pellet plant:

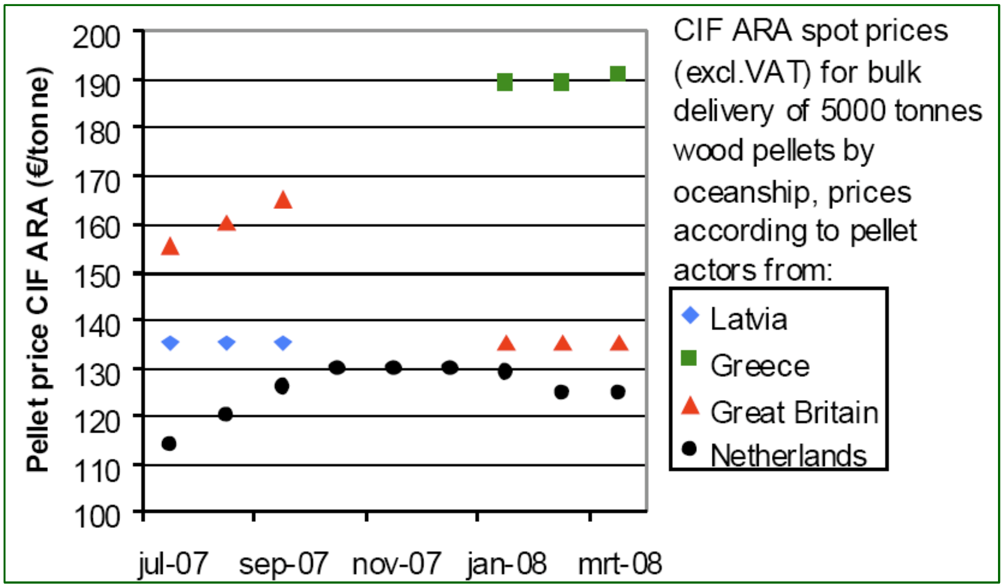
- Cost of capital for new plants is 14% (50% risk capital at 20% interest, 50% bank loan at 8%)
- Year-round, three-shift operation (350 days per year)
- Baghouse and cyclones used for PM control
- 100% of production exported to Europe
- Annual production is 200,000 metric tonnes of pellets (5% MC)
- 5% of feedstock burned for drying
- 24 full-time employees
- The per-kWh cost of electricity is 4.5 cents (incl. tax)
- The fuel consumption of the front loader is assumed to be 8 liters of diesel per hour, at a cost of $1.10 per liters
- Pellet sales price in Europe is $170 per tonne (5% moisture)
- Train transport to harbour costs $20 per tonne (average)
- Transfer train/ship costs $10 per tonne, including storage
- Marine transport cost to Europe is $50 per tonne (5% moisture)
- Base case uses sawmill residue at $35 per dry tonne[3]
- Modified case uses 50% roadside residue at $50 per dry tonne
- Third case uses 100% standing dead pine at $80 per dry tonne (see EC 2006, Table 6.1.2) and a 20% increase in capital cost to pay for debarking and chipping of whole logs

Pellet plant margins are mainly determined by sales price, feed stock price, exchange rates, and transport costs, which can all vary considerably over time. This report attempts to use realistic numbers for each parameter as reflected by recent market conditions. **Figure 18** shows estimates of bulk pellet pricing in Europe (spot price for delivery within two months to Amsterdam/ Rotterdam sea hubs). The reported prices indicate revenues around €130 per tonne, which corresponded to C$194 per tonne on March 1, 2008 and C$205 on November 26. Argus Media reports a drop to only €118 per tonne (C$189) by the end of November 2009, whereas long-term demand remains stable and is expected to increase further [Argus 2009].

[3] In the US Northwest, sawdust prices have gone up substantially the past five years. In 2004, average sawdust prices were US$28/odmt as reported by the North American Wood Fiber Review. These prices reached a peak of US$74/odmt in late 2008 and have since fallen, averaging US$64/odmt in the 3Q/09. The price increases that have occurred in Western US are likely to be seen in other regions experiencing rapid expansion of their pellet industries. [SWN 2009]

A more long-term conservative number of $170 per tonne is used in this report, also to reflect longer-term price agreements not operating in the spot market. As a comparison the FOB (freight on board, i.e., excluding marine transport to Rotterdam) prices of pellets in St. Petersburg Harbour are given in **Table 17**. The price trend is clearly upwards, but fluctuations occurred in recent years, also depending on the severity of European winters.

Figure 18: CIF-ARA Prices as Reported by Different Pellet Actors in Europe



CIF –ARA: cost, insurance and freight for pellets delivered to the Amsterdam/Rotterdam or Antwerp region
Source: PA 2008.

Table 17: FOB Pricing of Pellets at St. Petersburg Harbour

Year	2003	2004	2005	2006	2007	2008 (IX)	2009 (III)
€/tonne	85-90	90-95	95-105	110-125	90-100	95-105	105-120
C$/tonne*	136-144	144-152	152-168	176-200	144-160	152-168	168-192

*Conversion at C$1.6 per €. **Source:** BEI 2009.

Shipping costs also fluctuate wildly with the price of oil and ship demand. Marine shipping costs to Europe were close to $100 per tonne when oil prices were at their highest, and are now around $45. Given that economic activity is considered to pick up again after the crisis in 2008, an upward trend in transport costs can be reasonably expected, expressed here in the $50 cost assumption. Train transport is about $0.022 per tonne-km [EC 2006], $10 was added to account for transfer of the pellets at the harbour.

Table 18 compares the three cases, which represent different feed stock costs. Note that only parameters that change from the first case are shown again for the other cases; the remaining parameters remain unchanged. The production cost without transport coincides well with the base case of another pellet cost study [AEA 2006], but turns out higher because of the higher feed stock and transport cost parameters used here.

Table 18: Annual Cost Overview for a 200,000 Tonne Pellet Plant in BC

Base Case – 100% Sawmill Residue

	C$ per year	Comments
Capital Investment	*20,000,000*	*Total of all equipment*
Debt service	2,800,000	14% of investment
Salaries	1,200,000	24 employees
Maintenance	800,000	4% of capital cost
Fuels	147,840	On-site diesel fuel use
Electricity	513,000	Electricity use (60 kWh/bdt)
Feed stock cost	7,000,000	$35 per dry tonne, incl. dryer fuel
Transport to harbour	6,000,000	$30 per tonne
Transport to Europe	10,000,000	$50 per tonne, marine
Production Cost	**28,460,840**	**$144 per tonne of pellets**
Sales revenue	34,000,000	$170 per tonne of pellets
Profit	**5,539,160**	**Before tax**

Modified Case I – 50% Roadside Residue

Feed stock cost	8,500,000	$35 per dry tonne (sawmill residue) $50 per dry tonne (roadside or other residue)
Production Cost	**29,960,840**	**$152 per tonne of pellets**
Sales revenue	34,000,000	$170 per tonne of pellets
Profit	**4,039,160**	**Before tax**

Modified Case II – 100% Standing Dead Pine, incl. debarking/chipping

Debt service	3,640,000	30% increase
Salaries	1,300,000	26 employees
Maintenance	1,040,000	4% of capital cost
Electricity	842,175	98.5 kWh per bdt
Feed stock cost	16,000,000	$80 per dry tonne (dead pine)
Production Cost	**38,970,015**	**$195 per tonne of pellets**
Sales revenue	34,000,000	$170 per tonne of pellets
Profit	**-4,970.015**	

The above calculations indicate that conventional pellet plants may have some profit margin (28% ROI in the case of $35 per tonne feed stocks) to accommodate additional flue gas cleaning costs. However, pellet plants need some margin to safeguard against potential future increases in feed stock prices. BC feedstock providers usually only engage in short-term contracts, leaving users with considerable uncertainty in terms of future feed stock costs. Likewise, transport costs to Europe have been fluctuating heavily during past years depending on oil prices. A doubling of transport costs would easily use up the profits of a pellet plant. A plant using 50% roadside residue has an ROI of 20%, which would sink to 13% if 100% of the feedstock would cost $50 per tonne.

Using whole trees, on the other hand, increases feed stock costs to a point that no profit margin remains. Some companies plan to engage in whole tree logging, but will attempt to improve the bottom line by log merchandizing, with higher quality logs going to sawmills or pulp mills. Note that whole log chipping is complicated by the temporary availability of beetle kill wood, given that it is expected to be harvestable for between five and 15 years after the trees have died. Long-term harvesting rights will reduce the risk of further feed stock cost increases, but do not protect against possible price reductions for pellets in Europe. The emergence of very large pellet plants on the U.S. East Coast (see **Figure 18**) may affect European pricing negatively, due to a significantly increased amount of pellets on offer. In the long term, there is still a large market for new pellet production projected; European imports are expected to increase from one million tonnes in 2007 to three million in 2012 [NEF 2007], but given plans for several very large plants in the half a million tonne class in the coming years, this can be expected to impact noticeably on BC expansion plans.

6.4 COST OF ADDITIONAL PM CONTROL MEASURES

PM Emissions: WESP is currently considered as the best available technology to achieve better PM control for dust streams containing high amounts of condensable PM, and are therefore used here for economic modelling (wet scrubbers are cheaper but have somewhat lower PM removal performance) and have had mixed success in pellets application. No cost savings are applied when a WESP is installed to replace existing systems, since cyclones will still be applied to pre-clean the flue gas entering the WESP, such that the latter can be seen as an add-on to the previous plant layout. For the balance of plant emissions (from pelletizing, bagging, etc.), baghouses or high performance cyclones are already in use representing the best available technology.

Both dryer and to a lesser extent, pelletizer cooler gases, contain both PM and VOC. Both gas streams would therefore be best treated using WESP technology; however, as the total PM loadings in the back end of a pellet plant are typically lower than the dryer, the condensables also appear lower for BC mills. 1000 to 1,500 m^3/hr of flue gas from the cooler are produced for each tonne of pellets produced [MRNF 2008]. This is similar to the amount usually produced by pellet dryers (2,300 m^3/tonne), but BC's experience is not consistent with this source in all cases, i.e., cooler gas flows may be greater than those from dryers [MOE 2009c]. Although both flows could technically be treated together, the acceptable treatment of cooler gases with cyclones, as well as the very different flows and emission concentrations may result in the continued separate treatment of cooler and dryer flows, as is current practice in the pellet industry.

For a 200,000 tonne pellet plant, the annual additional cost to own and operate a WESP for the dryer gas stream would be $380,741. If emissions of 115 mg/m^3 (many current BC permits) can be achieved with high-efficiency cyclones and 25 mg/m^3 with a WESP, the resulting PM load would be 52.9 tonnes per year with cyclones and 11.5 tonnes per year with the WESP (assuming 2,300 m^3 of flue gas per tonne of pellets). The incremental PM abatement cost is then $8,461 per tonne, which is considered a reasonable cost by some jurisdictions (the BC government generally considers a cost of less than $20,000 per tonne acceptable). In addition, a WESP will also reduce VOC emissions somewhat, thus reducing the combined incremental abatement cost.

VOC emissions: Estimating dryer VOC emissions as 0.54 kg per tonne of wood processed (as per US EPA **Table 8**) would mean a flue gas concentration of 266 mg/m^3. This concentration is likely to be reduced by 50-70% when the gas is cleaned with WESP technology [EPA 1989]. Bringing VOC emissions down further would require thermal oxidizer technology. An EPA Factsheet lists Regenerative Thermal Oxidizer cost as $35-$140 per scfm, and operating costs as $4-$10 per scfm, per year [EPA 2003]. Values from a quote used in **Table 18** above are somewhat lower for capital cost and in the lower range of operational costs. In actual fact, the average measured CPM emissions of 0.07 kg/t (30 mg/m^3) from BC mills are much lower than even the non-methane portion of emissions based on USEPA estimates for Particle Board Dryers.

6.5 ECONOMIC IMPACT OF ADDITIONAL POLLUTION CONTROL MEASURES

Table 19 summarizes the impact of additional pollution control measures for three cases of BC pellet plants with capacities between 50,000 and 400,000 tonnes per year, expanding on data in **Table 17** and **Table 18** above. The ROI is calculated by dividing the net annual sales revenue (after subtracting all annual expenses, including the cost of capital) by the total investment made to set up a new pellet plant. Generally, each additional flue gas cleaning measures will reduce the profit margin by 1-4%, depending on plant size. The smallest plants are the most sensitive to increasing flue gas treatment costs.

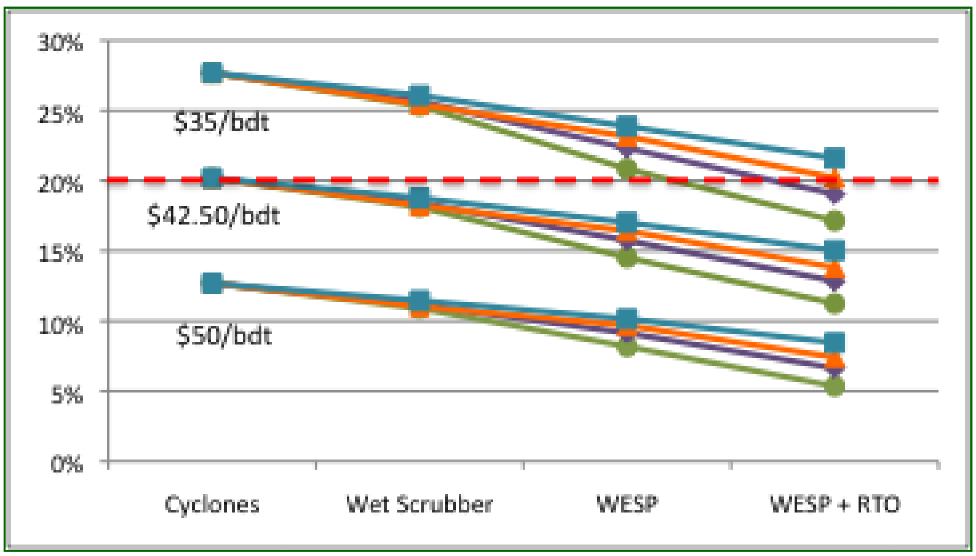
Table 19: Impact of Additional Pollution Control Measures on the ROI for Different Size Pellet Plants in BC

Annual Output	Feed stock Cost	With Cyclones	With WESP	With WESP, Thermal Oxidizer
50,000 t	$35.00/bdt	28%	25%	21%
	$42.50/bdt	20%	18%	15%
	$50.00/bdt	13%	11%	8%
100,000 t	$35.00/bdt	28%	26%	22%
	$42.50/bdt	20%	18%	16%

Annual Output	Feed stock Cost	With Cyclones	With WESP	With WESP, Thermal Oxidizer
	$50.00/bdt	13%	11%	9%
200,000 t	$35.00/bdt	28%	25%	23%
	$42.50/bdt	20%	18%	16%
	$50.00/bdt	13%	11%	10%
400,000 t	$35.00/bdt	28%	26%	24%
	$42.50/bdt	20%	19%	17%
	$50.00/bdt	13%	11%	10%

Figure 19 presents the results from **Table 18** graphically, showing ROI as a function of feed stock costs, plant size, and the type of flue gas cleaning equipment. These results are based on a simplified calculation that does assume some economies of scale for the flue gas treatment cost, but not for the pellet plant itself. 20% (red dotted line) is usually seen as the minimum return on investment to attract investors.

Figure 19: ROI Curves for Different Plant Outputs and Feed stock Costs



Blue squares: 400,000 t/yr; Orange triangles: 200,000 t/yr; Violet rhombi: 100,000 t/yr; Green dots: 50,000 t/yr.

Accounting for the WESP reduces the profit margin by three to seven percentage points, but it remains above 20% in the lower feed stock cost scenario. Note that the scrubber impacts less on the profit margin, especially with smaller-size plants (due to the lower cost of ownership). When the feed stock rises to $50 per tonne, the profit margin slips under 20% and is then reduced further as gas cleanup costs are accounted for. Even at a feed stock cost of $42,50 per tonne it becomes questionable whether such a project would go ahead if a WESP is mandated.

Note that this result will be somewhat better for existing plants since they can usually bank-finance additional measures at less than the 14% interest rate assumed here. If higher transport costs would accrue due to location or oil price increases, the ROI may drop under 20% even if feed stock costs are low.

Installing both WESP and a thermal oxidizer reduces the profit margin further such that a desirable margin only remains for low feed stock costs and the largest plant sizes. Given that a slight increase in transport or fuel costs can easily reduce the ROI by 4% or more, it is probably safe to say that no new pellet plants would be built in BC if both technologies were mandated.

An alternative to wet WESP would be either wet scrubbers or advanced cyclone systems with electrostatic precipitator features (see Section 4.2). The latter are suggested by the manufacturer to be more efficient on $PM_{2.5}$ than scrubbers, but no applications in the pellet industry have been demonstrated so far. The lower cost of these systems comes at the expense of lower collection efficiencies when compared to wet ESP, but both technologies can be expected to yield considerably better results than high-efficiency cyclones.

BC pellet plants may have a cost advantage (CA$5 per tonne) over some large Eastern U.S. pellet plants that are obliged to install thermal oxidizers in combination with either scrubbers or WESP. This advantage, however, is balanced by higher ocean freight costs for BC plants selling to European customers (cost difference of currently about $10 per tonne). Very large plants might still be able to operate with a 20% profit margin due to economies of scale, but mandating thermal oxidizers in BC would exacerbate the cost disadvantage for BC plants, and further complicate economics for businesses trying to use standing dead pine for part or all of their feed stock.

Given that BC stack emission measurements suggest very low condensable PM emissions, which are close to what can be achieved with thermal oxidizers, requiring the use of such equipment does currently not seem justifiable and would provide little, if any environmental benefit. In addition, low VOC emissions from a pellet plant would not add considerably to natural emissions of the same kind (a 200,000 tonne pellet plant would emit a similar amount as 18 km^2 of BC forest), which are present in BC forests and the communities located within them.

7.0 Conclusions and Recommendations

The purpose of manufacturing pellets is in part is to produce a consistent, renewable, and easily transportable source of energy that can be used to offset fossil fuels, thereby reducing the potential impacts of global climate change. In BC, it is also part of a shift in the use of forest fibre towards energy purposes, as part of a restructuring and diversification of the forest products industry. While these are positive developments, it is important to achieve this in a manner that is economically sustainable and does not degrade the local environment such that human health and enjoyment, or environmental/ecological health is negatively impacted or compromised.

To provide supporting information for the government to develop emission criteria that both safeguard the air quality as well as allowing the pellet industry to further expand, the BCMOE commissioned Envirochem Services Inc. to prepare a report evaluating the current state of pollution prevention and control technologies for the pellet manufacturing industry. The following sections present the conclusions and recommendations of this study.

CONCLUSIONS

7.1 PM EMISSIONS FROM PELLET PRODUCTION

The permitted emissions from BC Mills are comparable to the emissions permitted in other jurisdictions as shown in **Table 20.**

Table 20: Summary of Mill Permitted PM Emissions (kg/t)

Average Total PM Emissions kg/tonne		
Source	**Non BC Mills**	**BC Mills w/o Canfor**
Dryers	0.45 (~196 mg/m^3)*	0.55 (~240 mg/m^3)*
Other Sources	0.25	0.19
Complete Plant Non Fugitive)	>0.70	>0.73

*Concentration calculated based on 2300m^3 of dryer air flow/ton

The average measured emissions of total (TPM), filterable (FPM), and condensable particulate matter (CPM) from BC Mills are summarized in **Table 21** below.

Table 21: Summary of BC Measured Emissions from Dryers with Cyclones

Statistic	Particulate Measurements			Emission Factor		
	TPM	FPM	CPM	TPM	FPM	CPM
	mg/m^3			kg/t	kg/t	kg/t
Overall Average	174	161	30	0.40	0.37	0.07
Maximum	432	419	76	1.12	1.08	0.16
Minimum	47	8.0	0.8	0.11	0.02	0.00
Adjusted Average*	**174**	**145**	**30**	**0.40**	**0.34**	**0.07**
			Fraction	**100%**	**84%**	**16%**

*The amount of FPM was adjusted slightly to yield a Total PM that equaled the sum of Filterable and Condensable fractions

The data show considerable variability in TPM emissions between mills with cyclone discharges ranging from ~432 to less than 47 mg/m^3, with an average of 174 mg/m^3. Due to the relatively fine composition of particulate matter from BC Mills (e.g.~ 79% PM10 and 66% PM2.5), the relatively good performance of cyclones is somewhat surprising. The presence of CPM and combustible PM make the application of dry ESPs or baghouse filters unreliable or unsafe for dryer exhaust gases.

7.2 OBSERVATIONS ON CPM EMISSIONS

Experience from the particle board and OSB industry suggests that VOC emissions are between 0.5 and 1.0 kg per tonne of wood processed, which is confirmed by measurement data obtained from European sources on wood dryers. Actual stack emission measurements at BC pellet plants indicate much lower CPM concentrations (0.07 to 0.17 kg/t). This is likely due to lower drying temperatures and higher residual moisture in pellet dryers compared to OSB plats; although differences in feed or even differences in measurement methods may also be contributing factors.

If the acrolein (an aldehyde) emissions from BC pellet plants are similar to the USEPA AP42 data on OSB dryers, it is the only volatile organic that –depending on the atmospheric dispersion- could exceed Ontario Point of Impingement Guidelines. Currently there are no data available on actual acrolein emissions from pellet facilities in BC, however, based on the lower CPM/VOC emissions for BC sources relative to other studies, as discussed above, it is likely that the acrolein emissions are also proportionately lower.

Emission concentrations of filterable particulate matter (FPM) can be reduced from current average levels of about 145 mg/m^3 –with cyclones- to near 25 mg/m^3 with a WESP or 70 mg/m^3 with a scrubber. (Note that the scrubber is based on a single data point from a BC plant (i.e., it is insufficient to establish whether this level can be achieved consistently with scrubbers). As there are currently no WESPs operating on BC pellet mills, it is difficult to reliably estimate the condensable PM emissions as WESP suppliers currently tend to only guarantee filterable PM and not CPM control efficiencies. This is due in part to the fact that CPM emissions depend on the wood species, the wood moisture content, the dryer inlet, outlet, and wood temperatures, and the WESP discharge temperature, all of which are variables subject to some change.

If it can be assumed that current operational parameters (e.g., dryer throughputs and temperatures) and raw material feed stocks do not change, and that WESP or Venturi scrubber discharge temperatures will be lower than current cyclone temperatures, then it could be anticipated that a WESP or a scrubber should reduce CPM emissions about 30 – 60% from current levels. This would reduce CPM from the current maximum of 76 mg/m^3 (and average 30 mg/m^3) to about 35 to 15 mg/m^3. However, due to the changing raw material supply (e.g., the move to roadside slash –with more bark- in the feed stock, resulting from sawmill closures and the lock-in of most sawmill residue for internal purposes or existing pellet mills), it is difficult to reliably predict future CPM emissions for the industry when equipped with advanced control equipment.

It is interesting to note that USEPA AP42 data indicate that cyclones appear quite effective at reducing not only TPM but also CPM. More research is needed in this area of CPM emission and controls.

7.3 OBSERVATIONS ON ECONOMIC EVALUATIONS

The economic analysis assumes that cyclones are used for emission control for dryers and coolers, with baghouses being used to control balance of plant point source emissions. The financial burden imposed by the mandated use of BAT (WESP technology) on dryers would impact the industry to a degree that higher cost wood sources, such as round wood or roadside slash, could not be used for pellet production (or only to a lesser degree). Given that wood residues under $50 per tonne are dwindling in BC, this means requiring additional PM control equipment over cyclones for dryers and/or coolers may prevent investment in new pellet plant operations in certain cases. This complicates permitting decisions as the benefits of new economic activity must be weighed against air quality concerns.

Installing additional gas cleanup equipment is usually possible with a lower economic impact for existing plants than for new plants, since the former can retrofit such equipment with lower-interest bank loan financing. This allows for lower annual costs than financing for new plants, which usually contains some high-interest risk capital. For smaller plants of 100,000 tonnes annual production or less, the more cost-effective wet scrubber or other emerging technologies, such as an advanced cyclone system with electrostatic precipitation (if proven applicable), could be used to reduce PM emissions over multicyclones. These may offer somewhat less efficient control than a WESP for PM under 1 µm, but also place a lower financial burden on those plants.

The economic analysis showed that it is unlikely that new pellet plants would be built in BC if thermal oxidizers (RTO) would be mandated since the profit margin would be reduced to around or below 20%, especially in smaller plants of 100,000 tonnes or less annual production. In addition, the relatively low CPM emissions measured from the BC industry would not support self-sustaining combustion and therefore require additional fuel (natural gas), which would increase greenhouse gas emissions and resource consumption, possibly offsetting any potential environmental benefit of the RTO.

In addition the application of a wet scrubber or a WESP requires a good water supply, a waste water treatment system, and a location or facility where the blow-down waste water can be discharged. These water requirements must be considered in the design of a pellet mill and if not readily available, may place limitations on its location.

RECOMMENDATIONS

7.4 POLLUTION PREVENTION STRATEGIES

In the development of any large scale pellet manufacturing project, the selection of the pollution control equipment is just one of the elements in a sustainable pollution prevention strategy. The key elements in this strategy include evaluating the following elements.

1. Optimizing the process design and operational variables to minimize the generation of any emissions prior to entering the control system. This may include
    a. Low emission (efficient) dryers or drying processes that allow dry material to be processed without overheating.
    b. Dryers designed to operate with low inlet temperatures (e.g., less than ~400^{o}C)
    c. Dryer exhaust recirculation to reduce the emission (stack) flow rates and conserve fuel. Dryer exhaust gases could be re-circulated back to;
        i. The dryer inlet (recovers heat)
        ii. The burner inlet (recovers heat and combusts VOC and/or fine dust).
    d. Piping and process insulation to conserve heat (reduce fuel consumption and combustion emissions).
    e. Efficient fibre –air separation (high efficiency cyclone pre-collectors)
    f. Efficient low emission combustion systems.
    g. Investigation of other areas to optimize energy and fibre recovery, such as pellet cooler exhaust gas energy recovery and reuse.
2. Selecting homogeneous and/or dry raw materials where possible. If low moisture content, consistent feed stocks are not available, then evaluating:
    a. Procedures/processes for raw material pre-blending, or sizing;
    b. Installing sizing equipment to ensure the dyer feeds are homogeneous;
    c. Using different dryers for different feeds; or
    d. Batch-feeding the dryers with homogeneous batches of fibre.
3. Locating the operation near the timber supply and/or rail or to reduce transport emissions.
4. Utilizing non-stem or other "*waste*" woods (e.g., urban or roadside slash) that might otherwise be open burned in the woodlands. This will replace the open burning emissions with low emission efficient utilization of the biomass.

Once these factors have been examined and economically optimized, then focus on selecting air pollution control equipment designed for the specific operation and location. There are five main options or types of air pollution control systems applied to control emissions from pellet manufacturing. These include:

1. Centrifugal collectors or Cyclones —used either alone or to pre-clean a gas stream that is subsequently passed through a WESP, scrubber, or baghouse.
2. Electrostatic precipitators (Wet ESPs–(WESP), rather than dry ESPs, are used for wood dyers or other processes that generate higher condensable organic (tarry) emissions.
3. Fabric filters or baghouses .
4. Venturi scrubbers.
5. VOC combustors (e.g., regenerative thermal oxidizers –RTO) if the volatile components are of sufficient strength.

The following sections provide an overview of the emissions from pellet mills from BC and internationally and provide recommendations on the control options.

7.5 ACHIEVABLE EMISSION LEVELS

Based on the findings in this report, **Table 22** summarizes the values for Total PM (i.e., both filterable and condensable PM combined) that, based on currently available data, is economically achievable for pellet plants in order to reduce emissions without unduly impacting the financial viability of the BC pellet industry. The table addresses the four main emission sources;

1. Dryers;
2. Coolers;
3. Other [point source] process emissions (hammermills, screens, conveyors and transfer points, etc.); and
4. Fugitive emissions, (primarily related to raw material handling.)

Emission limits are shown for several plant sizes. Large plants are shown as being able to meet more stringent emission standards. This is due to the economies of scale of flue gas treatment equipment associated with larger plants. Note that the mg/m^3 to kg/t conversion used in this report is based on current data which indicates an average dryer air flow of 2,300 m^3/tonne of pellets. This air flow (m^3 of dryer air/tonne) conversion may have to be modified as more information becomes available or as technology changes.

Care must be taken in using PM concentration as the main permit compliance measure since there are no set oxygen, or carbon dioxide levels to normalize the measurements to, as in the case of combustion sources. Consequently, consideration should be given to regulating the kg/t or the actual emissions in kg/hr (or per second, day or year), rather than, (or in addition to) the concentration, as these values better reflect the actual impact of the operation on the receiving environment, and are also the main input to dispersion models. This approach also offers the plant operations more flexibility with their operational controls (e.g., the ability to vary dryer air and recirculation flows to maintain good operation without being unduly constrained about total air flow, as long as the mass emission stays within permit limits).

Generally, cyclones on dryers in BC may emitted between 100 and 400 mg/m^3 with an average 175 mg/m^3 of TPM (at least five dryers in BC have achieved TPM emissions below this level.) However, as little operational data relating to the measurements are available (e.g. dryer feed type, moisture contents, and dryer inlet temperatures) it is difficult to confirm if this value is achievable over a typical range of operating parameters. Since the actual concentration is a function of not only cyclone design and dryer operation, but also and feedstock qualities, it is not possible to provide specific guidance as to what emission limit a cyclone on a dryer can consistently achieve.

Table 22 below shows the achievable emission limits using best available technologies.

For pellet coolers, particulate emissions can be expected to be much lower than for dryers (based on discussions with pellet plant design engineers) consequently, the use of scrubbers or WESP does not seem warranted for these sources at this time. Only one data point was available for this study, which indicated a cooler exhaust TPM concentration of 40 mg/m^3. Given the lower particulate loads to start with, concentrations of 70 to 115 mg/m^3 are considered achievable (cyclones are generally not known to reduce emissions lower than ~ 70 mg/m^3). The recommended criteria 115 mg/m^3 for cooler cyclones is therefore considered achievable; however it should be further confirmed by additional field measurements. Since there is no combustion process, and consequently no CO_2 or O_2 concentration available for normalization, kg/time or kg/tonne should be considered as alternatives to concentration limits.

For other plant processes, emission levels of around 115 mg/m^3 may be achieved with cyclones, but a baghouse is considered as BAT which would reduce emission concentrations to between 10 and 20 mg/m^3. A slightly higher permit level is proposed here to leave some room for operational irregularities. Since coolers and other plant processes are often discharged through a common stack, care should be taken when permitting, that a good understanding of the contributions from the various processes to the stack are available before setting emission standards.

Table 22: Summary of Achievable Mill TPM Emissions

	Control Technology	Annual Pellet Production in Tonnes: < 100,000	100,000 – 250,000	> 250,000	Assumptions & Comments
Dryer Exhaust					
TPM Emission Limit (mg/m^3) [1]	BAT	100[2]	55-70[1]	50 [1]	
TPM Emission Factor (kg/t)	BAT	0.23	0.13-0.16	0.12	Assumes dryer air flow 2,300 m^3/t
Annual Dryer Emissions t/yr	BAT	<23	23 – 40	>30	Estimated
BAT is: (2, 3)		Scrubber	Scrubber or WESP[2]	WESP	
Pellet Cooler Exhaust					
TPM Emission Limit (mg/m^3) [1]	Cyclone	115 mg/m^3	115 mg/m^3	115 mg/m^3	Cyclone opacity 10% at full load
Estimated TPM Emission. Factor (kg/t)	Cyclone	0.08	0.08	0.08	[4]Based on air flow of 1,000 m^3/t
Est. Annual Cooler Emissions Tonnes/yr	Cyclone	<8	8 – 20	> 20	
Note: Due to the relatively high moisture content and reported relatively low PM concentrations for pellet coolers gases, BAT is currently cyclones. As these cooler gases are often combined with other emission sources (e.g., pellet screens baghouse/cyclone exhausts) and vented through a common stack, there is only limited reliable actual measurements available.					
Other Plant Processes[3]					
TPM Emission Limit	Baghouse	20 mg/m^3	20 mg/m^3	20 mg/m^3	
TPM Emission Factor kg/t	Baghouse	0.10	0.10	0.10	[4]Assumes air flow 5100m^3/t
Estimated Annual Other Process Emissions t/yr	Baghouse	10	10 – 25	>25	
Estimated Total Mill Point Source Emissions kg/yr					
TOTAL Process Emissions in t/yr	Baghouse	<49	49 – 98	>88	
Fugitive Emissions Raw Material Storage Pile and Road Dust					
Sawdust and Wet Material	Visual monitoring with controls as required including: Limit pile heights; Limit exposed pile faces to high winds (e.g. wind breaks vegetative or screens) Include meteorological controls and planning.				No visible downwind carry over
Planer Shavings and Dry Material	As above plus three sided and covered containment Prevent vehicle traffic from grinding material finer				
Onsite Haul roads	Dust suppression in dry season or paving				

Notes to Table

1. 70 mg/m^3 of TPM were measured on the only scrubber currently being used in a pellet plant in BC (Williams Lake) new installation should be able to achieve this level. Concentrations of 19 to 25 mg/m^3 of filterable PM are currently achievable and guaranteed by WESP suppliers. Since no data is available on CPM emissions for a pellet plant fitted with a WESP, CPM emissions were assumed equal to an additional 25 mg/m^3 for large mills and 30 for medium sized mills. (Current dryer CPM emissions from BC mills average 30 mg/m^3). As additional data on CPM and TPM emissions from WESPs and scrubbers operating on BC mills becomes available, then it is anticipated that these values will be adjusted.
2. Or newer emerging technologies - for example, an electrostatic cyclone if proven applicable to pellet operations.
3. Other process emissions include pelletizers, hammermills, storage, screening, and conveyors.
4. These air flows per tonne data are based on very limited data from different processes that may not be comparable, consequently they should not be considered as reliable and require further study for validation.

7.6 OTHER RECOMMENDATIONS

1. Additional investigations or research should be conducted to confirm the emission levels that pellet plant dryer cyclones can continuously achieve. In some cases cyclones may be sufficient to control particulate emissions.
    a. Firstly the testing should characterize dryer emissions from various feedstocks such as fire killed and bug killed timber, logging slash, hog fuel and bark.
    b. Secondly testing should characterize emissions from processes with various feedstock pre-treatments and feedstock moisture contents.
    c. Thirdly emission from driers using various dryer fuels should be characterized.

2. More research is needed in the area of CPM emission and controls from dryers and other sources to better understand the relationship between drying temperature, wood species, controls and VOC and CPM emissions.

3. Likewise, cooler emission data is lacking and more measurements under different operating conditions need to be taken in order to confirm the low TPM emission level observed in one case coming from a cooler cyclone.

4. The emissions data should be incorporated in an easily accessible and updatable database that includes not only the emissions, but also operational data.

5. A measurement program should be initiated to measure and speciate VOC emissions in the BC pellet industry, and to determine how these relate to condensable particulate emissions.

6. Investigation should also be considered to evaluate the relative contribution that pellet plant CPM makes to background VOC emissions in northern BC, including odour.

7. The BC (or Canadian) pellet industry could consider preparing a best management guide for optimization of pellet manufacturing facilities that covers energy, resource conservation, emissions and impact reduction.

Glossary:

ACFM	Actual cubic feet per minute, independent of pressure.
AP-42	Collection of industrial emission factors maintained by the US-Environmental Protection Agency (EPA).
BAT	Best available technology.
CPM	Condensable particulate matter, as determined by the back half or impinger catch in USEPA Method 5.
DSCM	Dry standard cubic meters, measured at standard temperature and conditions.
FPM	Filterable particulate matter, front half or filter catch in USEPA Method 5.
HAP	Hazardous Air Pollutants as defined in the U.S. Clean Air Act. Typically carcinogens, mutagens, and reproductive toxins. For wood dryers, the main HAPs are methanol, formaldehyde, and acetaldehyde –all part of the VOC classification as well.
MC	Moisture content (dry basis throughout this study).
PM	Particulate matter.
PM2.5	PM of a size of 2.5 microns or less (material considered a particular health risk since it can easily enter the lungs.
PM10	PM of a size of ten microns or less.
ROI	Return on investment. Calculated by dividing annual returns before tax by the initial capital investment and expressed in %. For commercial project, usually an ROI of 20% is required to attract capital.
TPM	Total particulate matter (all PM, including condensable material).
VMT	Vehicle miles travelled.
VOC	Volatile organic compounds The quantity and species included in VOC are a function of the sample method (e.g. USEPA Methods 18, 25 A, B, C) or Regulation (e.g., photochemically reactive).

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Appendix I

Properties of Torrefied Pellets versus Conventional Pellets

Properties	unit	Wood	Torrefied biomass	Wood pellets		TOP pellets	
				low	high	low	high
Moisture content	% wt.	35%	3%	10%	7%	5%	1%
Calorific value (LHV)							
dry	MJ/kg	17.7	20.4	17.7	17.7	20.4	22.7
as received	MJ/kg	10.5	19.9	15.6	16.2	19.9	21.6
mass density (bulk)	kg/m3	550	230	500	650	750	850
energy density (bulk)	GJ/m3	5.8	4.6	7.8	10.5	14.9	18.4
Pellet strength		-	-	good		very good	
Dust formation		moderate	high		limited		limited
Hygroscopic nature		water uptake	hydrofobic	swelling / water uptake		poor swelling / hydrofobic	
Biological degradation		Possible	Impossible	Possible		Impossible	
Seasonal influences (noticable for end-user)		High	Poor	Moderate		Poor	
Handling properties		normal	normal	good		good	

Note: It appears that the 'high' and 'low' energy density may have been reversed in the original table.

Source: ECN 2006.

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