Composting Manufactured & Treated Woods

Prepared for Divert Nova Scotia &
Nova Scotia Environment

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Executive Summary

An evaluation of composted products using manufactured and treated woods as amendments has been completed to determine if manufactured woods have any residual impact on compost product quality. To date, there is little detailed documented evidence on the impact of using manufactured wood in the compost process; this study provides a comprehensive analysis of composted products from a mixture of source-separated organic waste and various manufactured wood wastes. Fifty-two samples over three years were prepared using various wood constituents as bulking agents. Although there are a number of different manufactured wood products, many of the non-natural constituents are similar and consistent from product to product.

As the compost process by its nature is a heterogeneous mix of organic constituents, the presence of any substance of concern will automatically be diluted by the presence of other organics. Although the unnatural constituents in manufactured wood (particularly various derivatives of formaldehyde) do create an early inhibitory effect and supress an immediate increase in temperature, the inhibition is only short-lived as the temperature does increase, albeit after approximately 120 h of operation. As the more volatile constituents are transferred to the exhaust air, more emphasis is placed on proper air ventilation for health and safety concerns.

Results indicate that while the presence of some of the original polymeric substances persists, manufactured woods using larger particles such as plywood and OSB should be considered for inclusion in the compost process. The persistence of melamine derivatives, excessive copper in pressure treated wood, and other high metal concentrations in mixed wood waste suggests that if manufactured woods are to be included in the compost process, melamine, pressure treated wood and C&D wood waste of a mixed and unknown origin be excluded at this point.

As the results indicate little concern for persistent contaminants in compost amended with manufactured wood, it is recommended that a pilot-scale operation of approximately 500 tonnes be initiated in which uncoated, manufactured (excluding melamine and pressure-treated) woods are chipped and amended with municipal source-separated organic waste and composted in parallel with the conventional process and ultimately compared in terms of metals and constituent chemicals to determine if there is a measureable difference in product quality. Composted products from manufactured wood should undergo additional chemical tests in the early stages to establish their presence/absence and confirm persistent chemicals.

Not only does the diversion of waste manufactured wood from C&D sites save landfill space, it provides a considerable inexpensive supply of much-needed amendment for compost facilities across the province. Effectively utilizing manufactured woods as an amendment to compost operations is more of a logistical challenge than an issue of negatively impacting compost quality and is best realized through incentives to supply C&D sites and compost facilities with clean manufactured wood,

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1. Introduction

Nova Scotia leads the country in waste diversion. Over the last 20 years, the province has introduced bans on various wastes such as paper products (1996), glass and tin and (as the first major region in North America) organics (1998). In addition, construction and demolition (C&D waste) has been banned from standard landfills in the Province since 2001. C&D waste is deposited in any of 24 C&D landfills throughout the Province because of their relatively benign nature. Concurrently, the Province reduced the number of landfills to six, which has further increased the importance of diversion to minimize the disposal of unnecessary standard wastes. As the costs of conventional and C&D landfills continue to rise, various waste products must continue to be re-evaluated to determine if there are alternative uses for some of these wastes that not only removes unnecessary capacity from the landfills, but also increases the worth of the material through a value-added process.

Currently, because of their more benign nature, C&D waste is separated from the common waste stream and buried in less costly landfills with less sophisticated containment practices where the organic constituents slowly decompose. A significant organic constituent of the C&D waste stream is wood waste, which consists of clean wood (untreated, and uncoated lumber), and manufactured and coated wood products. The clean wood is of little concern and can (and should) be separated and chipped on-site for utilization as a compost bulking agent or a potential fuel source. The manufactured and coated wood wastes, however, contain a number of unnatural constituents whose ultimate state is unknown as the products decompose and are currently not an acceptable compost feedstock. If the manufactured wood was separated from the general C&D waste stream, it could potentially be utilized in a productive way as a compost bulking amendment, diverting a amount of waste from landfills and helping Nova Scotia meet its goal of reducing waste production to 300 kg/person/year. Not only would the waste wood serve as to supplement to the clean, chipped wood (which is currently purchased by compost facilities), it is turned into a valuable product. Composting manufactured wood saves landfill space, saves compost operators money and contributes to a value-added product.

The purpose of the following study is to determine if manufactured wood can be utilized in a similar manner as clean wood in the compost process. The glues and adhesives in manufactured and treated woods could affect both the decomposition process and the quality of the product. The following report will look at the possible contaminants that may contribute to the composted product and quantify their fate through the compost process to ultimately determine their impact on product quality.

2. Manufactured and Treated Woods

Manufactured woods are wood products produced from a manufacturing process that uses glues and adhesives to blend, press and form wood scraps, flakes and dust into commercial products. Because the feedstock is often waste material from lumber processing, manufactured wood products are often more affordable and therefore readily used in construction where each product has a specific application that requires specific conditions to retain their integrity. Resins are often used to hold the pieces of wood together which may have chemical elements that slow or stop decomposition; with the exception of pressure treated lumber, manufactured wood is primarily found in a panel form and has yet to truly be sold commercially in post or plank form.

2.1 Types of Manufactured and Treated Wood

The type of manufactured and treated wood is determined by the nature of the wood waste and its application. Six of the most popular types of manufactured wood are listed below.

2.1.1 Plywood

Plywood is the most commonly used form of manufactured wood that is made from sheets of wood glued together. It has been made for thousands of years, dating back to Egyptian times. The simplicity and strength of layering and bonding plies of wood has allowed plywood to be a staple in many different applications such as floors, walls, and roofs in house construction as well as concrete shuttering panels, and container flooring. Plywood is popular because of its high degree of strength and it ages well; plywood is usually made from either Douglas fir or southern pine.

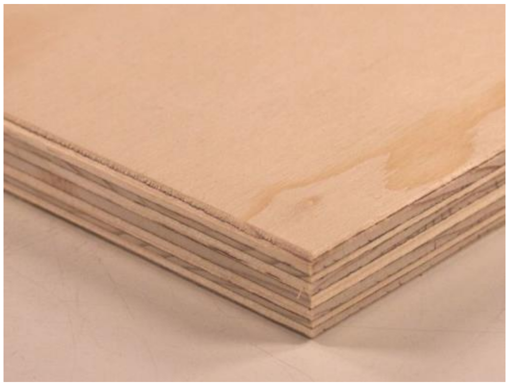


Figure 2.1 Plywood
http://en.wikipedia.org/wiki/Plywood

How it is Manufactured:

Plywood is manufactured through gluing together thin strips of wood in layers, called plies. The stripes are glued in such a way that the grains along the same ply are all in the same direction, and that the grains in adjacent plies are perpendicular to each other to increase the strength of the wood. After the plywood is glued together (usually using a formaldehyde-based resin) the plywood is then pressed together to the desired thickness under high pressure and temperature. After this, the plywood may be coated with preservatives or finishes.

Applications:

Plywood is used for general construction, as flooring, and in furniture.

Constituents:

Typical primary plywood constituents include urea-formaldehyde and phenol-formaldehyde; Table 2.1 lists particular manufacturers and the associated constituents.

Table 2.1 Plywood Manufacturers and Constituent Chemicals

Company	Wood	Ingredient	Percent
Potlatch	Softwood Plywood	Phenol-formaldehyde resin	<1 %
Ainsworth	Sheathing Plywood	Hydrotreated petroleum distillate	0.25 %
		Phenol-formaldehyde resin	1.5-3.5 %
		Free formaldehyde	<0.1 %
Plum Creek	Softwood Plywood	Phenol-formaldehyde	
Plum Creek	Overlay Plywood	Free formaldehyde	<0.4 %
		Phenol-formaldehyde	<0.7 %
		methanol	<0.04 %

Types of Wood:

Often Douglas fir, but panels are available in many hardwoods and softwoods.

2.1.2 Oriented Strand Board (OSB)

OSB is a relatively new type of manufactured wood. Due to higher strength and the ability to use a much higher percent of a log than most conventional woods, OSB is quickly becoming as popular, if not more popular, than plywood for general construction use. This type of manufactured wood does not have a single direction of grain and therefore has a consistent strength in all directions. Due to its growing popularity, it will be more available in the future as wood is recovered from the demolition of the current era of houses.

Figure 2.2 OSB
http://www.consmos.com/osb.html

How it is Manufactured:

Unlike plywood, which is made of wood strips directly from the log, OSB is constructed from wood strands and flakes. This provides a much more efficient use of the log (as flakes allow more of the tree to be used) and also allows for the use of recycled wood. OSB can also be made from smaller logs. To manufacture, the wood strands and flakes are made to a predetermined thickness and then arranged in crosses. The OSB mat is then covered in resin, and bound together under high heat and pressure. After this, the OSB may be coated with preservatives or finishes. The result is a board that gets much of its strength from the uninterrupted wood fibre across the mat.

Applications:

Oriented strand board is used for general construction including roof sheathing, subfloors, underlayment, single-layer floors, exterior siding and wall sheathing.

Constituents:

OSB uses similar resins as plywood, including formaldehyde-based compounds; a typical product is found in Table 2.2.

Table 2.2 A Typical OSB Product Constituent List

Company	Product	Ingredient	Percent
Ainsworth	OSB	Polymeric diphenylmethane diisocyanate	0-10 %
		Wax emulsion	0-5 %
		Phenol-formaldehyde	0-10 %
		Free formaldehyde	<1 %
		Zinc borate	0-3 %

Types of Wood:

Generally made from small fast-growing trees such as aspen and poplar.

2.1.3 Medium Density Fibreboard (MDF)

MDF is a popular form of particle board. It is characterised by its homogeneous surface (no grain), as well as being constructed from very small pieces of wood bonded together into panels by heat and pressure. The composite panels are thin, grainless, dense, uniformly textured, and strong, however, fibreboard may warp in humid conditions. The density of MDF makes it noticeably heavier than plywood and OSB.

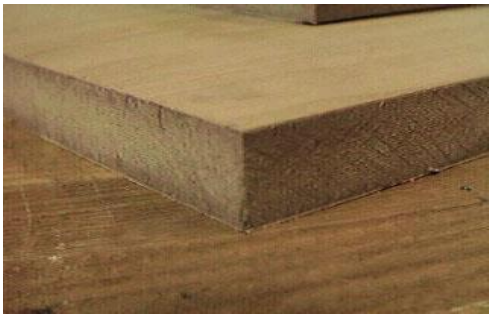


Figure 2.3 MDF
http://www.lungster.com/l/speakers/mdffaq/mdf.shtml

How it is Manufactured:

MDF is a subset of particle board, and refers to a medium density of the wood particles. In comparison, hardboard has a higher density, and particle board has a lower density. MDF is constructed from new and recycled wood chips, as well as sawdust. These small particles are then broken down further into pulp. It should be noted that the pulp is mostly homogeneous at this stage. The pulp is then formed into thick mats and glued together with the resin. These mats are then cut, pressed together under very high pressure and temperature to the desired thickness, and then cut to the final dimensions. After this, the MDF may be coated with preservatives or finishes.

Applications:

MDF is used in furniture, fixtures, millwork, and cabinetry. It has a high density and uniform consistency which makes it easy to mill.

Constituents:

Although urea-formaldehyde is a common constituent in addition to phenol-formaldehyde for moisture resistance in some MDF products, alternatives promoted with NAF (no added formaldehyde), and NAUF (no added urea formaldehyde) are also on the market. Three specific products are listed in Table 2.3.

Table 2.3 Example MDF Products

Company	Product	Ingredient	Process
Plum Creek	Glacier Green MDF	Urea formaldehyde	7-10%
		Ammonia	1%
		Wax (paraffin)	<1%
		Formaldehyde content	<1%
Plum Creek	Glacier Green NAF, NAUF (fibreboard)	Methylene-diphenyl-diisocyanate	5-10%
		Phenol-formaldehyde	7-10%
		Wax (paraffin)	1%
Plum Creek	Glacier Green MDF	Urea formaldehyde	7-10%
		Wax (paraffin)	<1%
		Melamine	>1%
		Ammonia	1%
		Free formaldehyde	<0.1%

Types of Wood:

Made from residual sawdust and chips (hardwood and softwood) from other manufacturing processes.

2.1.4 Melamine Board

Melamine board is a special type of particle board that has a paper coating, saturated by a melamine resin. The center of the board is usually either MDF or particleboard (low density). The outer coating can be a solid color (often white) or can be printed with the grain and appearance of a finished wood.

How it is Manufactured:

Melamine board starts with common MDF, or particle board. The board is sanded to create a clean surface. The particle board is then sandwiched with melamine-saturated paper. This is then hot-pressed, and the edges are trimmed.

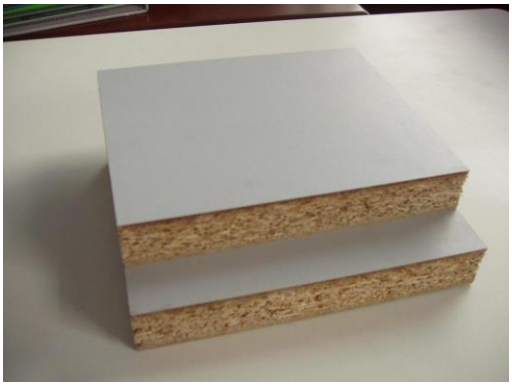


Figure 2.4 Melamine Board
http://cnshunhewood.en.made-in-china.com/product/HeWmPLUJsMRv/China-Melamine-Particle-Board-SHDQ-03-.html

Applications:

Melamine board can be found in cabinetry, desks, countertops, and furniture. Melamine-formaldehyde produces less formaldehyde emissions than urea-formaldehyde, produces a stronger bond than urea and is therefore endorsed by LEED (Leadership in Energy and Environmental Design).

Constituents:

Melamine-formaldehyde, urea-formaldehyde, phenol-formaldehyde are common constituents in melamine board.

Types of Wood:

The type of wood varies from the type of composite material the melamine is used in and can be a softwood or hardwood. The type of wood is generally indistinguishable as it is behind a surface layer.

2.1.5 Hardboard

Hardboard or high density fibreboard (HDF) is a particle board with a higher density than MDF. This creates a heavier, but stronger board. Hardboard was discovered by hot-pressing waste paper, and is often found in thin sheets.

Figure 2.5 Hardboard
http://www.woodbusinessportal.com/en/Messages/Hardboard-T-NT-from-manufacturer_id-168775.html

How it is Manufactured:

Hardboard refers to the highest particleboard density. Hardboard uses the smallest wood particle size and all the particles are very homogeneous. Hardboard can be manufactured using two processes. The wet process uses water to carry the wood fiber, creating slurry. The water is then drained from the slurry to make a mat of wood fiber which is held together with resin. It is then pressed at extreme temperatures and pressures to remove the excess water and bind the fibers together. The dry process instead uses air to convey the wood fibers. Once the board is pressed, the hardboard is humidified to increase its strength. After this, the hardboard may be coated with preservatives or finishes; the result is a very dense, heavy but strong board.

Applications:

Hard board is used in siding, retail shelves (perforated hardboard), furniture, and some construction.

Constituents:

Common constituents include combinations of formaldehyde, urea and phenol. Table 2.4 identifies the constituents in Plum Creek hardboard products.

Table 2.4 HDF Products from Plum Creek

Company	Product	Ingredient	Process
Plum Creek	Glacier Green HDF	Urea formaldehyde Formaldehyde content Wax (paraffin) Melamine	10-14% <0.1% <1% >1%
Plum Creek	Glacier Green HDF	Urea formaldehyde Ammonia Wax (paraffin) Formaldehyde content	7-10% 1% <1% <1%
Plum Creek	Glacier Green HDF	Urea formaldehyde Wax (paraffin) Melamine Ammonia Free formaldehyde	7-10% <1% >1% 1% <0.1%
Plum Creek	Ultra Core HDF	Phenol-formaldehyde Methylene-diphenyl-diisocyanate Wax (paraffin)	 5-10% 1%

Types of Wood:

Just the fibres of the wood are used and as such the origin of these fibers is often unimportant.

2.1.6 Particle Board

Particle board usually refers to the section of particle boards that have the lowest density. They are also called low density fibreboard (LDF). It has a sandy look since it is constructed with larger wood particles than both MDF and HDF. This product is the least resistant to water as the water easily penetrates and swells the product by way of the larger wood particles, quickly losing integrity and therefore not used for structural applications, however the product warps less than the fiberboards under humid conditions.

Figure 2.6 Particle Board
http://www.lowes.com/cd_OSB+MDF+&+Particleboard+Buying+Guide_42276845_

How it is Manufactured:

Particle board is similar to both MDF and hardboard in its construction, however it uses bigger particles (wood chips as opposed to sawdust or pulp); these particles are less uniform than the other types of particle board. The particle board may be coated with preservatives or finishes; this creates a much lighter looking, but weaker board.

Applications:

Particle board is rarely used in outdoor and moisture-prone conditions as it expands and deteriorates very quickly; it is used in cabinetry, furniture, and tabletops.

Constituents:

Polymerized urea-formaldehyde and phenol-formaldehyde are common constituents of particle board.

Types of Wood:

Made from residual sawdust and chips (hardwood and softwood) from other manufacturing processes.

2.1.7 Preservatives, Treated

Treated wood uses preservatives to prolong the life of wood products in outdoor conditions. Generally, preservatives can be grouped in terms of either residential or industrial application. Residential use includes most decks and exterior wooden housing supports, while industrial use includes preserved wood for telephone poles, piers and other large-scale aplications. Self-applied preservatives are applied to the surface of cut edges on preservative-treated wood to complete the preservative’s coverage. This is often done on decking and exterior lumber products. The high concentrations of preservatives inherent with treated wood may be exclude it from the composting process; it is also generally advised to keep wood treated with these products away from drinking water sources or food storage containers.

Figure 2.7 Wood with Preservative Applied
http://ovgrs.editme.com/Bellamy

In Canada, six types of wood preservatives are registered for application to residential wood products: alkaline copper quarternary (ACQ), copper azole (CA), Wolman AG, micronized copper azole (MCA), didecyl dimethyl ammonium carbonate (DDAC), and disodium octaborate tetrahydrate (DOT or SBX) - borates (Wood Preservation Canada); a brief summary of each preservative follows.

Alkaline Copper Quarternary:

These compounds are water-borne wood preservatives typically used for exterior residential use. Copper, a recognized wood biocide, is the active constituent in ACQ that is augmented with quaternary compounds that serve as co-biocides which are biodegradable in soil.

Copper Azole:

Used in exterior wood applications this water-borne preservative also has copper as the active biocide, with tebuconazole as the co-biocide for fungal control which is also used in the agricultural sector.

Wolman AG:

Perhaps the most recognizable name of the preservative products, Wolman AG was the first non-metallic preservative with three carbon-based pesticides: tebuconazole, propiconazole and imidacloprid. The preservative, introduced in 2006, is in a water solution and is applied to wood surfaces through pressure or non-pressure means.

Micronized Copper Azole (MCA):

MCA is another copper-based preservative used with applications above and below ground as well as in contact with freshwater. Micronized copper and tebuconazole provide deep penetration for longer term protection.

Didecyl Dimethyl Ammonium Carbonate (DDAC):

DDAC is another carbon-based preservative that is water-borne and used in light-duty applications. Didecyl dimethyl ammonium carbonate ($C_{45}H_{96}N_2O_3$) is the active chemical that provides wood protection from rot and decomposition.

Disodium Octaborate Tetrahydrate (DOT or SBX) - borates:

DOT borates are the oldest of the accepted preservatives, having been used for over 50 years. Once applied, water-borne borates (which consist of naturally occurring compounds of boron and oxygen) help protect wood from fungi and destructive insects and are often used for indoor wood protection, resisting decomposition provided prolonged periods of water exposure are avoided.

Preservatives for industrial applications includes creosote, pentachlorophenol and CCA; summary comments on these products follow.

Creosote:

Creosote is derived from tar at very high temperatures and is not water-soluble. It is currently used as a wood preservative on railway ties, marine piles and building pikes; as it is the oldest form of wood preservative, it is also present in older woods. Creosote treated wood is normally dark brown in color, weathering to light brown. Since creosote is a compound of over 150 different chemicals, it must be handled with care. Creosote will irritate the skin, but studies have not shown that it causes cancer. Another problem with creosote is that some of it will leak from the wood into the surrounding soil and have an effect on plants. Therefore, it seems logical that precautions must be taken when composting wood with creosote.

Figure 2.8 Creosote Treated Fence Posts
http://www.huetbois.be/vpage.php?id=69&lg=3

Pentachlorophenol:

Pentachlorophenol (PCP) is the preservative normally used in utility poles, cross arms and bridge timbers. PCP wood is normally more reddish in color and is oil-based (not water-soluble). In terms of human digestion, PCP is not stored in the body if inhaled or ingested, and quickly excreted. No long-term effects have been shown. However PCP has a negative effect on plants and it is recommended keep PCP wood away from areas where plants may grow. Therefore precautions must be taken when composting. Research on PCP and plants is presented below.

Figure 2.9 PCP Treated Playground
http://npic.orst.edu/ingred/ptype/treatwood/penta.html

Chromated Copper Arsenate:

Chromated copper arsenate (CCA) is the most common of the wood preservatives, used in many different applications such as guide rails, foundations and posts. One important fact about CCA is that of the big three wood preservatives, it is the only one that is water-soluble. CCA treated wood is normally green in color, but unlike PCP and creosote, is odor-free. It should be noted that the toxic part of arsenic is due to trivalent arsenic, which is not in CCA. CCA poses a low health risk to humans and because of its complex nature, does not leach out of the wood. The effect of composting on CCA treated wood is provided below.

Figure 2.10 CCA Treated Wood
http://www.ccaresearch.org/about_**cca.htm**

In general, manufactured wood products contain approximately 95% wood, and 5% resins/wax/and other additives. Formaldehyde resins in a solid state have proven to be stable and (relatively) harmless chemicals which have been noted as being environmentally neutral. Formaldehyde resins were used in manufactured wood products because once it set, it did not liquefy again which raises the question as to whether it will decompose. As a precaution, to reduce the risk of formaldehyde release in the past, it was often advised to buy products that were sealed on all sides and edges. Owners of manufactured wood products with exposed sides and edges were advised to cover the exposed surfaces with polyethylene and secured with aluminum foil tape. Multiple MSDS sheets state that if left in the environment over a period of time, the resins should break down and decompose.

Over the last 10 years, there has been a measureable move away from the inclusion of formaldehyde in manufactured wood products. Consequently, past research results do not usually reflect present conditions. For example, research by Myers (1983) found the free formaldehyde and the formaldehyde chemically formed and released in particleboard and plywood was both below and above product standards in mobile homes; today, much of the particleboard and plywood is formaldehyde-free. Alternatively, the use of exterior-grade pressed wood products have been known to have lower formaldehyde emissions because they contain phenol resins rather than urea resins (U.S. EPA, 2011).

2.2 Common Brands/Makes in NS

Since the goal is to compost the manufactured wood in Nova Scotia, it is important that wood products that are sold in Nova Scotia are identified. Table 2.5 lists wood product brands that are sold in the province by three of the major wood retailers in Nova Scotia (Kent, Rona and Home Depot).

Table 2.5 Common Manufactured Wood Product Brands

Plywood	Columbia, Plum Creek
OSB	Norbord Stabledge, D-Blaze
MDF	Uniboard, Flakeboard, Plum Creek
Melamine	Uniboard
Hardboard	Uniboard, Canexel
Particle Board	Flakeboard, Uniboard.
Pressure Treated Spruce	Stella Jones

2.3 Past Research on Composting Manufactured Woods

Wood, whether chipped, shredded or as sawdust, has been the preferred compost amendment due to its ubiquity, affordability, and desirable physical properties (Willson et al., 1980). It has the benefit of not containing hazardous compounds (such as heavy metals), provides excellent moisture regulation, and acts as a carbon source as it decomposes. There is approximately a 30% loss by volume per cycle (Higgins et al., 1986), thus, wood as a bulking agent implies a recurring cost to compost facilities in need of a plentiful and inexpensive supply of wood.

There are numerous cases of manufactured woods being composted and a sizable body of research exists on the feasibility of composting manufactured woods. However, the majority of activity has occurred on rural land, by untrained composters, with inadequate scientific scrutiny. For this reason, the majority of large-scale composting operations using manufactured woods have not contributed to the body of research on manufactured wood composting. Furthermore, the majority of research that had been done has been on a laboratory scale. In general, there is a need for more well-designed large scale composting studies that utilize manufactured wood. A number of detailed reviews of experimental work follow.

2.3.1 Recycled Organics Unit

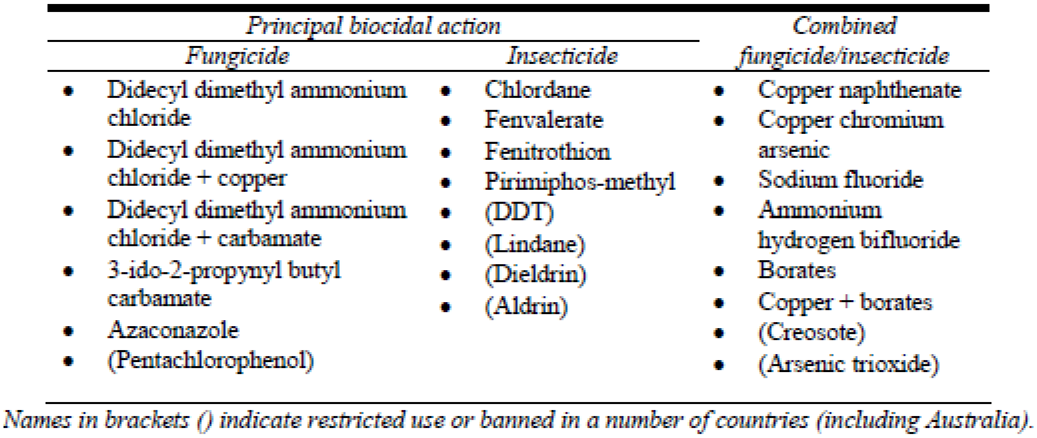
A review of the composting of composite wood products up to the year 2007 was conducted by the Recycled Organics Unit (2007). This is a very useful resource, as it discusses all the various aspects of composting wood including: size reductions, efficiencies, contaminations, dangers, and per cent inclusion. In terms of binding resins, a list of the common resins includes:

- urea-formaldehyde
- melamine-formaldehyde
- melamine-urea-formaldehyde
- phenol-formaldehyde, and
- isocyanates.

It should also be noted that preservatives are also commonly added to the resin as well as coating the manufactured wood to give it extra protection. However, according to the multiple sources found by the authors, the resin will readily degrade in the composting process. The bigger danger with the resin are the emissions released during composting. The formaldehyde is emitted as the wood composts, which could cause harm if the decomposition process occurs in a poorly ventilated area. In order to prevent this problem, it is recommended that the composting be done with proper ventilation.

Another relevant topic is the breakdown of chemicals that would be applied to the wood to preserve it; a list of common chemicals used to preserve wood is given in Table 2.6.

Table 2.6 A Partial List of Biocides (Recycled Organics Unit, 2007)



Principal biocidal action		*Combined*
Fungicide	*Insecticide*	*fungicide/insecticide*
Didecyl dimethyl ammonium chloride Didecyl dimethyl ammonium chloride + copper Didecyl dimethyl ammonium chloride + carbamate 3-ido-2-propynyl butyl carbamate Azaconazole (Pentachlorophenol)	Chlordane Fenvalerate Fenitrothion Pirimiphos-methyl (DDT) (Lindane) (Dieldrin) (Aldrin)	Copper naphthenate Copper chromium arsenic Sodium fluoride Ammonium hydrogen bifluoride Borates Copper + borates (Creosote) (Arsenic trioxide)

Names in brackets () indicate restricted use or banned in a number of countries (including Australia).

It was found that most of these chemicals were composted easily with no toxicity created from them. However some exceptions were found (like DDT) in older woods. The exceptions were resistant to degradation.

Size reduction and quality of wood being composted was also discussed. Making sure that non-toxic chemicals and lead-based paints did not enter the compost is important, especially with the demolition of older buildings. An efficient sorting process is needed to keep out these unwanted contaminants. The focus of the size reduction is the machinery used; it is stated that whatever machinery is used to shred or chip the wood must be able to handle many different sizes. This makes sense as C&D waste can range from a large structural pole to a small portion of a wooden wall.

As one would expect, the authors noted the need to add a large amount of nitrogen to the wood as it composts. This is because wood has a very high carbon:nitrogen (C:N) ratio, which slows the degradation process. A number of measures to address this issue include mixing the wood feedstock with a low C:N feedstock such as food waste to bring the ratio into better balance, or adding manure, which is also higher in nitrogen.

The review concludes that the products of the composite wood composting meet common composting standards, and a facility that composts composite woods should be able to create similar end-products to a facility that does not compost treated woods.

2.3.2 Wiltcher et al. (2000) and Borazjani et al. (2000)

In a six-month study conducted by Wiltcher et al. (2000), the feasibility of composting softwood plywood bonded with phenol-formaldehyde resin with 5 % chicken manure, 5 % cow manure, 5 % horse manure, 3 % cotton gin trash (residual from cleaning and ginning of cotton containing a mixture of cotton fibre, seeds, leaves, limbs and twigs), and one litre inorganic fertilizer (Miracle-Grow) was investigated. Manures were allowed to dry under a hood and were added on a dry-weight basis. One hundred grams of inorganic fertilizer was mixed with one litre of deionised water and stirred. Each inorganic fertilizer treatment received one litre of this solution. The plywood sawdust with the amendments were composted in 18, 75-litre, plastic containers. The compost was aerated once or twice per week and the moisture content was maintained at about 50 % through atmospheric precipitation and deionised water. The composts were analysed on 30-day intervals for toxicity and pH; on day 180 the compost cans were weighed to measure the decrease in dry weight.

Over the course of the study, all treatments showed a significant decrease in toxicity, maintained a neutral pH (with the exception of the horse manure treatment), and saw a decrease in dry weight. The decrease in dry weight of the amended treatments were nearly double that of the control sawdust treatment (Figure 2.11).

A greenhouse study was also conducted to evaluate the composted sawdust's effect on plant growth. Twenty-five percent by weight sawdust compost was mixed with potting soil in which corn, soybean, and cotton seeds were planted. The plants were allowed to grow for 55 days with daily watering. The chicken manure treatment performed the best in the plant growth trials, showing no significant difference in mean dry

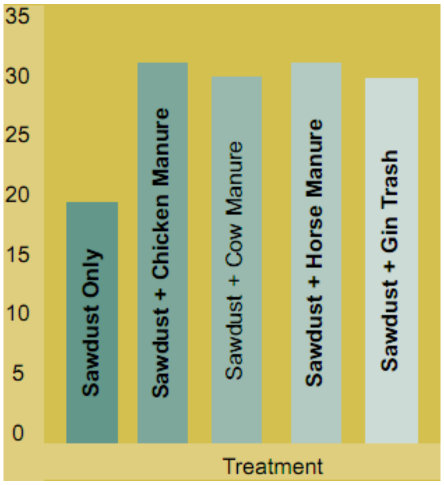


Figure 2.11. Average percent of total weight lost from the composted plywood sawdust at day 180 (Borazjani et al, 2000).

weight compared to the control plants grown in potting soil; the other treatments were comparable to chicken manure, except the gin trash treatment, which had a significantly lower mean dry weight compared to the control.

2.3.3 ADAS UK Ltd (2005) Chipboard

A large-scale study was conducted by ADAS UK Ltd (2005) and published by The Waste and Resources Action Plan (WRAP) in 2006. ADAS UK Ltd investigated the feasibility of composting chipboard in six composting trials. Prior to the trials the chipboard was analysed for heavy metals, organic contents, and formaldehyde as shown in Table 2.7.

Table 2.7. Chemical Concentrations in Chipboard

Chemical	Concentration
Cadmium (mg/kg)	0.18
Chromium (mg/kg)	3.76
Copper (mg/kg)	8.07
Mercury (mg/kg)	<0.01
Nickel (mg/kg)	<2.0
Lead (mg/kg)	17.2
Zinc (mg/kg)	21.5
Loss on ignition (g/100 g)	97.1
Nitrogen (g/kg)	32.7
Organic Carbon (% m/m)	41.9
Formaldehyde (mg/kg)	1100

The six trials consisted of three windrow trials and three in-vessel trials. In the windrow trials 10 % w/w shredded chipboard was mixed with garden waste and in the in-vessel trials 5 % w/w shredded chipboard was mixed with a combination of garden waste and kitchen waste. A summary of the trials is shown in Table 2.8.

Table 2.8 Summary of Chipboard Trials

Trial	Chipboard Percentage (%)
Garden Waste (Windrow)	
Control (Garden waste only)	0
Chipboard 1 (Garden waste and chipboard)	10
Chipboard 2 (Garden waste and chipboard)	10
Garden Waste and kitchen waste (In-tunnel)	
Control (Curbside collected garden, kitchen, and cardboard waste)	0
Tunnel Chipboard 1 (Chipboard and curbside collected garden, kitchen, and cardboard waste)	5
Tunnel Chipboard 2 (Chipboard and curbside collected garden, kitchen, and cardboard waste)	5

Prior to composting a chemical analysis of the six composts were performed for organic content and formaldehyde (Table 2.9).

Table 2.9 Chipboard Compost Chemical Analysis for Organic Content and Formaldehyde

Sample Type	**Windrow Control**	**Garden Waste Chipboard Average**
Dry matter (g/kg)	547	668
Bulk density	269	318
Total nitrogen (g/kg) DM	11.0	20.3
Nitrogen %	1.1	2.0
Organic carbon % m/m (Tinsley)	18.8	14.0
Formaldehyde (mg/kg)	<5.0	54.2
Sample Type	**Tunnel Control**	**Tunnel Chipboard Average**
Dry matter (g/kg)	382	391
Bulk density	271	324
Total nitrogen (g/kg) DM	11.1	13.6
Nitrogen %	1.11	1.36
Organic carbon %m/m (Tinsley)	30.3	20.2
Formaldehyde (mg/kg)	2.5	34.3

The report’s authors suggested three reasons for why the chipboard was difficult to process:

- the boards were very large,
- once shredded, the fine dust created blocked the radiators in plant equipment, and
- personal protective equipment was required due to the dust and formaldehyde present.

The six mixtures were composted for 10 weeks. The garden waste chipboard mixture was composted in windrows 2.5 meters high, three meters wide and four meters long, which were turned weekly. The ‘meat excluded’ curbside collected garden and kitchen waste and chipboard trials were composted for one week in-vessel, where the temperature and moisture content were carefully monitored and maintained, and the remaining nine weeks in windrows. During windrowing, composted temperature and moisture content observations were recorded. In general, when the compost was at its minimum temperature (37.7 °C–60.2 °C) it was described as near optimum moistness and when at its maximum temperature (66.7 °C–74.5 °C) it was described as too dry.

After composting, the mixtures were screened to 10 mm. At this point close examination of the screened product showed a large number of chipboard fines in the compost. The mass balances for the six trials were then calculated; they showed that, in comparison to the controls, little mass was lost in the composting process. On analysis of the mass results, the report concluded that the chipboard fines passed through the screen into the product and were not degraded to any major extent. The mass reduction varied considerably between the in-tunnel and the windrow trials: mass reductions of 58.9 % and 15.4 % respectively were recorded for the controls and an average of 54.6 % and 11.3 % were respectively recorded for the chipboard trials. The higher initial moisture content in the in-tunnel trials is likely a significant contributing factor to the larger mass reduction observed for the in-tunnel trials.

The product quality was then compared to the controls and the PAS 100 (British Standards Institution, Publically Available Specification 100) which is a set of compost standards in Britain which applies to compost products produced at centralised, on-farm and community composting facilities (WRAP, 2011). Contaminants not specifically referred to in PAS 100 were compared against levels in the controls only.

In general, the organic matter content of the chipboard trials was marginally higher than the controls and the nitrogen content was higher in the chipboard trials, compared to the controls. Visually, the chipboard compost looked lighter in colour than the controls and the chipboard fibres were clearly visible in the chipboard compost. A summary of the physical and chemical analysis is shown in Table 2.10. A list of all chemicals tested are included in Appendix A.

Table 2.10 General Characteristics of the MDF Compost Trials

Sample	**Windrow Control**	**Garden Waste and Chip Average (Windrow)**	**Tunnel Control**	**Curbside Collected and Chip Average (In-Tunnel)**
Dry Matter (g/kg)	660	747	630	582
Bulk Density (g/L)	450	418	379	400
Total Nitrogen (g/kg)	13.4	16.2	18.5	20.4
Nitrogen %	1.3	1.6	1.9	2.0
LOI	33	38	53	55
Organic Carbon (% m/m)	19	22	30	32
ph	8.4	9.0	9.0	8.7
Carbon Nitrogen Ratio (C:N)	14	14	16	16
Conductivity (µS/cm 20 °C)	1540	1265	1505	1340

The report analysed the six compost trials for 16 nutrients (Appendix A). The report concludes that levels of phosphorus, magnesium, iron and zinc were similar in all six compost trials and were satisfactory to support plant growth. This was confirmed in plant growth trials. Potassium levels were very good compared to organic fertilizers such as manures. Chloride levels were high; the report states that this could have damaging effects on the roots of sensitive plants if the compost application rate was high enough. Nitrate-N levels were higher in the chipboard trials than the control trials. Ammonium-N levels were unusually high in the chipboard trials which could cause plant damage if the compost was used at the recommended 20 to 33 % in a growing medium. CAT extraction was used to measure of phosphorus, magnesium, iron and zinc concentration and water extraction was used to measure potassium concentration.

When the six compost trials were compared to the PAS 100 compost standard, all but the tunnel control and the tunnel chipboard trial 2 passed. The two trials failed on the physical standards having elevated concentrations of glass, metal and plastics over two millimetres and stones over four millimetres respectively. In germination tests, although the plants performed well, there were abnormalities in the chipboard trial plants compared to the control plants. These abnormalities were plant purpling and inter-veinal chlorosis of the oldest leaves. The report did not conclusively determine the cause of these abnormalities but it suggested that the cause was either elevated concentrations of formaldehyde or ammonium-N.

The report identified the following chemical contaminants outside the scope of PAS 100 which would be expected in manufactured wood. The report tested for the first five explicitly and tested for the last implicitly. It was not possible to test for all the contaminants listed in the last bullet; however since these contaminants were likely volatile, a suit of analysis was conducted on volatile organic compounds and semi-volatile organic compounds which, the report predicted, may indicate the presence of other contaminants if they were present at elevated levels.

- fluoride (common preservative)
- arsenic (used in chromate copper arsenic)
- PAHs (preservative)
- polychlorinated bi-phenols (PCBs, used in paints)
- phenols (used in resins), and
- likely volatile contaminants probably associated with bond agents (hydrocarbons (napthalene, fluorene), quaternary ammonium compounds, organoiodines, carboxylic acid derivatives, cyclodienes, isocyanates, dicarboximides, organophosphates, pyrethroids, triazoles)

The analysis showed that levels of fluoride and arsenic were low in the chipboard compost compared to the controls, garden waste composts had higher levels of arsenic than garden and kitchen waste composts, and levels of PAHs, VOCs, SVOCs and phenols were all low in the chipboard trials compared to the controls. Furthermore, most PAHs, VOCs, SVOCs and phenols were below detectable levels in the chipboard trials. Only formaldehyde was found at a significantly higher level in the chipboard trials compared to the controls. The reduction of formaldehyde was much less than the report expected; the concentration of formaldehyde was reduced by 68 % in garden waste and 39 % in kerbside collected waste.

The report makes several conclusions regarding the feasibility of composting chipboard:

1. Collection: A clean source of chipboard is required for composting so intensive segregation is required. An additional segregation step would likely be required following segregation by the public.
2. Processing: Specialist equipment many be required to lift, break-up and shred the material. Chipboard fines caused difficulties with equipment operation; the fines clogged the shredder twice and routinely had to be removed from equipment radiators. During size reduction (where dust is generated) and during composting (where heat is generated) formaldehyde is released. Occupational exposure to formaldehyde must be

controlled and appropriate protective clothing must be worn. The observed temperatures indicated that the trials were composting adequately.

3. Maximum inclusion rate: Inclusion rates up to 5 % are possible in a 12 week process and possibly up to 10 % in a 30 week process. The presence of chipboard fines in the final product may be explained by a lack of degradation of the lignin. Wood is composed of three main components (cellulose, hemicelluloses and lignin) where lignin is the most difficult to break down.
4. Benefits and disadvantages: The benefits of adding chipboard to compost are a higher nitrogen concentration in the final product. However, chipboard if difficult to process and it was difficult to maintain moisture levels in the compost. Ensuring there is sufficient moisture at the start is essential. Urea formaldehyde is used as a slow release fertiliser and the data show that adding chipboard to compost increases the nitrogen concentration overtime as the urea formaldehyde decomposes. However, chipboard resins may also contain phenol and melamine formaldehyde. It is not clear from the trials if composting can completely degrade phenol or melamine formaldehyde. Literature suggests that composting can degrade phenol formaldehyde but there is less certainty regarding melamine formaldehyde. Therefore, the type of formaldehyde present in the feedstock should be identified prior to composting and a trial period should be done to validate the composting method.

The report suggests three areas for additional research: (1) using different methods of wetting such as sprinklers; (2) lignin degradation rates; and (3) biodegradation analysis of the phenol formaldehyde and melamine formaldehyde in the chipboard.

2.3.4 Furniture Industry Research Association

In a 2003 case study performed by the Furniture Industry Research Association (FIRA) at Blue Line Office Furniture sawdust (a by-product of the furniture manufacturers operations) was composted. Chipboard accounts for approximately 10 % of Blue Line Office Furniture’s wood waste; the other 90 % is made up of 47 % solid timber, 33 % veneer, and 10 % MDF. The results of this experiment are shown in Table 2.11. It is important to recognize that the characteristics outlined in Table 2.11 are for compost where only 20 % of the incorporated wood products fall under this literature review’s definition of manufactured wood.

2.3.5 ADAS UK Ltd (2005) MDF

In a large scale study conducted by ADAS UK Ltd in 2005 and published by The Waste and Resources Action Plan (WRAP) in 2006, ADAS UK Ltd investigated the feasibility of composting medium density fibreboard in 10 composting trials. Prior to the trials the MDF was analysed for heavy metals, organic contents, and formaldehyde as shown in Table 2.12.

Table 2.11 Blue Line Waste Compost

Parameter	Blue Line Waste Compost
Bulk density (g/L)	410
Humidity (%)	65
pH	6.4
Carbon content (%)	45
Nitrogen content (ppm)	34300
Phosphorus content (ppm)	8350
Potassium content (ppm)	320
Cadmium (mg/kg) DM	0.5
Chromium (mg/kg) DM	9.1
Copper (mg/kg) DM	12.8
Lead (mg/kg) DM	101.0
Mercury (mg/kg) DM	<0.1
Nickel (mg/kg) DM	<10.0
Zinc (mg/kg) DM	63.1
Germination (cress seeds)	>95 %

Table 2.12 Chemical Concentrations in MDF

Determinant	Concentration
Dry matter (%)	84
Total Nitrogen (%)	4.7
Ammonium nitrogen (mg/kg)	<0.1
Organic Carbon (% m/m)	58
Phosphorus (mg/kg)	55
Potassium (mg/kg)	455
Copper (mg/kg)	2.2
Zinc (mg/kg)	4.1
Lead (mg/kg)	0.6
Cadmium (mg/kg)	0.1
Mercury (mg/kg)	<0.05
Nickel (mg/kg)	0.2
Chromium (mg/kg)	0.7
Formaldehyde (mg/kg)	124

The 10 trials consisted of five windrow trials and five in-vessel trials. In the windrow trials 10 % w/w shredded MDF was mixed with garden waste and in the in-vessel trials 10 % w/w shredded MDF was mixed with a combination of garden waste and kitchen waste. A summary of the trials is shown in Table 2.13.

Table 2.13 Summary of MDF Trials

Trial
Garden Waste (Windrow)
Control (Garden waste only)
MDF 1 (Garden waste and chipboard)
MDF 2 (Garden waste and chipboard)
MDF 1 (Garden waste and chipboard; MDF wet)
MDF 2(Garden waste and chipboard; MDF wet)
Garden Waste and kitchen waste (In-tunnel)
Control (Curbside collected garden, kitchen, and cardboard waste)
Tunnel MDF 1 (Chipboard and curbside collected garden, kitchen, and cardboard waste)
Tunnel MDF 2 (Chipboard and curbside collected garden, kitchen, and cardboard waste)
Tunnel MDF 1 (Chipboard and curbside collected garden, kitchen, and cardboard waste; MDF wet)
Tunnel MDF 2 (Chipboard and curbside collected garden, kitchen, and cardboard waste; MDF wet)

The MDF was received pre-shredded so no pre-processing was required. Half of the MDF fines were soaked in water to determine if this would improve the composing process. This increased the compost moisture content from 15.6 % to 62.2 %. Prior to composting a chemical analysis of the 10 composts were performed for organic content and formaldehyde (Table 2.14).

Table 2.14 MDF Compost Chemical Analysis for Organic Content and Formaldehyde

Determinant	**Windrow Control**	**Windrow MDF Wet Average**	**Windrow MDF Dry Average**
Compacted bulk density (g/L)	547	297	286
Dry matter (g/kg)	269	465	480
Total nitrogen (g/kg)	11	13	14
Organic carbon (LOI) (%)	19 (Tinsley)	28	36
Carbon to nitrogen ratio	N/A	23	26
Formaldehyde (mg/kg)	<5	20	22
Determinant	**Tunnel Control**	**Tunnel MDF Wet Average**	**Tunnel MDF Dry Average**
Compacted bulk density (g/L)	382	292	322
Dry matter (g/kg)	271	381	286
Total nitrogen (g/kg)	11	12	14
Organic carbon (LOI) (%)	30 (Tinsley)	32	45
Carbon to nitrogen ratio	N/A	27	32
Formaldehyde (mg/kg)	2.5	20	17

The 10 mixtures were composted for 10 weeks. The garden waste MDF mixture was composted in windrows 2.5 meters high, three meters wide and four meters long, which were turned weekly. The ‘meat excluded’ curbside collected garden and kitchen waste and MDF trials were composted for one week in-vessel, where the temperature and moisture content were carefully monitored and maintained, and the remaining nine weeks in windrows. During windrow composted temperature and moisture content observations were recorded. In general, when the compost was at its minimum temperature (47.7 °C–63.1 °C) it was described as near optimum moistness and when at its maximum temperature (60.1 °C–79.2 °C) it was described as too dry. After composting the mixtures were screened to 10 mm. The data showed an approximate mass reduction of 40 % during composting. Pre-wetting the MDF appeared to be beneficial to green waste composting but not to green and kitchen waste composting. The report suggests this is because the green and kitchen waste had a high initial moisture content compared to the green waste only.

The product quality was then compared to the controls and the PAS 100, and contaminants not specifically referred to in PAS 100 were compared against levels in the controls only. In general, the product derived from 10 % MDF to garden waste was similar to compost produced from garden waste alone; the differences include a lower bulk density, higher nitrogen and carbon content and much lower conductivity of the MDF compost compared to the control. The differences between the test composts and the controls were less evident for the MDF, garden waste, and kitchen waste trials. A summary of the physical and chemical analysis is shown in Table 2.15; a list of all chemicals tested is included in Appendix A.

Table 2.15 General Characteristics of the MDF Compost Trials

Sample	**Windrow Control**	**Garden Waste and MDF Average (Windrow)**	**Tunnel Control**	**Curbside Collected and MDF Average (In-Tunnel)**
Dry Matter (g/kg)	660	537	630	515
Bulk Density (g/L)	450	320	379	287
Total Nitrogen (g/kg)	13	18	18.5	17
Nitrogen %	1.3	1.8	1.9	1.7
LOI	33	54	53	54
Organic Carbon (% m/m)	19	31	30	31
ph	8.4	9.3	9.0	9.6
Carbon Nitrogen Ratio (C:N)	14	18	16	20
Conductivity (µS/cm 20 °C)	1540	522	1505	464

The report analysed the six compost trials for 16 nutrients, which can be found in Appendix A. The report concludes the following regarding nutrient content:

- The levels of nitrogen, potassium, phosphorus and trace nutrients in the test composts were sufficient to support plant growth;
- The concentration of total nitrogen was elevated in the MDF and garden waste compost;
- The concentration of the average total nitrogen concentration was less in the MDF, garden waste, and kitchen waste compared to the control;
- The levels of ready available nitrogen (ammonium-N and nitrogen N) were low in all MDF composts;

- There were less available nutrients in the MDF compost compared to the controls due to a lower dry solids content;
- Chloride, potassium, magnesium and calcium were much less available in the MDF compost compared to the controls; and
- Sulphur and sodium concentrations were much lower in the MDF composts compared to the controls.

When the six compost trials were compared to the PAS 100 compost standard, five of the eight MDF composts met the standard's criteria. The three which failed the criteria, failed due to physical contaminants:

1. Windrow MDF Dry 1 failed because the level of plastic was above 0.25 %;
2. Tunnel MDF Dry 1 failed because the overall level of physical contaminants was above 0.5 %; and
3. Tunnel MDF Dry 2 failed because the overall level of physical contaminants was above 0.5 % and the lead content was higher than permitted. The report attributes the high lead concentration observed to the green and kitchen waste as it was three orders of magnitude lower in the MDF analysis.

The report identified the following chemical contaminants outside the scope of PAS 100 which would be expected in manufactured wood:

- arsenic (used in chromate copper arsenic)
- PAHs (preservative)
- polychlorinated bi-phenols (PCBs, used in paints)
- phenols (used in resins)
- volatile organic compounds (VOCs)
- semi-volatile organic compounds (SVOCs).

The levels of all the tested contaminants were low and were comparative to the control concentrations except formaldehyde. In the trials using collected kitchen and garden waste with 10 % MDF the formaldehyde concentration decreased as expected (approximately 50 % in the trials using wet MDF and marginally in the trials using dry MDF). However in the trials using garden waste with 10 % MDF the formaldehyde concentration increased in all four trials by as much as 100 %. This result is not consistent with literature predictions. The report offers two possibilities for this inconsistent result: sampling error and the majority of MDF fines passing through the screening process while many larger and uncontaminated green waste constituents not passing through leading to a higher end product formaldehyde concentration. As a final statement the report states that the screening theory cannot fully account for the increase in formaldehyde concentration observed and attributes the inconsistent result primarily to sampling error.

The report makes several conclusions regarding the feasibility of composting MDF:

1. Processing: Finely shredded MDF is “fluffy” and is therefore difficult to evenly incorporate into the composting process. It also has the potential to block machinery. The observed temperatures indicated that the trials were composting adequately.
2. Maximum inclusion rate: A Ten percent inclusion rate is appropriate; the data showed that this inclusion rate did not have any detrimental effect on compost quality or plant growth. The mass balance showed that degradation occurred at this incorporation rate and a similar percentage of products were recovered in the MDF trials compared to the controls.
3. Benefits and disadvantages: Incorporating MDF in the compost process has the potential benefit of increasing the nitrogen concentration in the final product; however, this result was only observed in half of the MDF trials. Disadvantages of incorporating MDF are its difficulty to process and the release of formaldehyde during processing and composting. The report states formaldehyde monitoring programme would be required.

2.3.6 Leungprasert and Otten (2000)

The main concern with composting manufactured woods is the formaldehyde resin that is often used. The concern is that the formaldehyde will not biodegrade and make the compost toxic. However, according to Leungprasert and Otten (2000), this is not the case.

At the University of Guelph, in a lab-scale reactor, Leungprasert and Otten conducted two experiments to determine the fate of formaldehyde in MDF sawdust during municipal solid waste (MSW) composting. The first experiment was under isothermal conditions with trials at temperatures 45 °C and 55 °C and MDF sawdust concentrations of 2.5 % and 5.0 %. The second was under adiabatic conditions with three trials, where MDF sawdust was included at 2.5 %.

The first (isothermal) experiment used simulated MSW composed of water, sand, rabbit chow and newspaper. The particle size was approximately 40 mm. The compost reactor was placed in a water bath to control the temperature. Formaldehyde concentrations were analysed using high performance liquid chromatography (HPLC) using the EPA method 8315A. The experiment ran for 10 days.

The second (adiabatic) experiment used simulated MSW composed of water, sand, rabbit chow and newspaper. The particle size was approximately 40 mm. The compost reactor was placed in a water bath with a temperature controller. The temperature of the water bath was controlled by the temperature of substrate in the reactor, thus minimizing the heat loss from the reactor to the environment. Formaldehyde emission was determined daily from exhausted gas using the Dräger tube technique. The experiment ran for ten days. According to the authors, an adiabatic process very closely simulates field composting.

In the first (isothermal) experiment a formaldehyde reduction between 91.94 % and 93.44% was observed. The results are summarized in Table 2.16. The gaseous emission of formaldehyde was also measured (using the Dräger tube technique); formaldehyde concentration in the exhausted air was nearly constant at 0.2 ppm indicating that experimentally significant formaldehyde reduction did not occur through vaporization. During the experiment biodegradation rates were also measured; biodegrading rates for 2.5 % MDF sawdust and 5.0 % MDF sawdust were -1.076 and -2.756 respectively.

Table 2.16 Formaldehyde Reduction Under Isothermal Conditions After 10 Days Composting

Temperature (°C)	**Formaldehyde Concentration (µg/g)**		**% Reduction**
	Initial	***Final***	
45	14.79	0.97	93.44
45	15.90	1.15	92.77
55	18.52	1.36	92.66
55	22.58	1.82	91.94

In the second (adiabatic) experiment a formaldehyde reduction between 50 % and 66 % was observed. During the ten days of composting the temperature in the adiabatic system varied approximately between 50 °C and 70 °C. The results are summarized in Table 2.17.

Table 2.17 Formaldehyde Reduction Under Adiabatic Conditions After 10 Days Composting

Formaldehyde Concentration (µg/g)		**% Reduction**
Initial	***Final***	
18.91	9.38	50
14.79	6.65	55
14.01	4.80	66

It was found that while the formaldehyde slightly slowed the rate of microbial growth to begin with, by the end of the 10 days 90 % of the formaldehyde had been decomposed; this was true no matter how much MDF was initially added to the compost.

2.3.7 Bonigut and Kearley (2005)

In a 2005 study for the Waste Management Action Programme, Bonigut and Kearley investigated the options for increasing the recovery of panelboard waste such as medium density fibreboard and particleboard. The objectives of the study were to determine how to increase the quality of the panelboard waste recovered from the waste stream and to produce an action plan to prioritize the activities that would accomplish this goal. The report considered a number of options, including composting, and performed ranking exercises to determine the comparative suitability of options to manage the waste based on nine criteria:

1. Status of the technology
2. Operational cost
3. Product, value of output
4. Development Cost
5. Regulatory issues
6. Process capacity
7. Intellectual Property Rights (IPR)
8. Technical capability
9. Environmental impact

Of the 15 options considered, composting was among the five options identified as having the potential to make the greatest impact in the short- to medium-term. As part of the action plan, the report recommends the following actions for pursuing composting as an option for panelboard waste recovery:

- investigate co-composting with other (green) wastes to speed up the process,
- test / demonstrate the compost quality, and
- explore use of the product.

Prior to discussing the processing options for panelboard waste, the report discusses pre-processing options. As part of this section, bonding resins are discussed which include urea formaldehyde resin (UF), melamine urea formaldehyde resin (MUF), phenol formaldehyde resin (PF), melamine urea phenol formaldehyde resin (MUPF), and diisocyanate resin (pMDI). Table 2.18 summarizes the report's discussion on resins. Sources include Zeppenfeld, 1999; TRADA, 2003; Dynea, 2005; and VDH, 2005.

Table 2.18 MCW Resins

Resin	Comments
UF	• Inexpensive to produce and purchase, fast drying, high dry bond strength, good water resistance, transparent bond joints, good compatibility with fillers and extruders • Most popular resin • Can be used as cold, warm, or hot setting adhesive • Suitable for interior use
MUF	• Thermosetting polymer that can be formulated to provide various degrees of water and weather resistance suitable for interior, humid, and outdoor climates • Wide application area due to variable viscosity and reactivity • Comes in liquid and powder form
PF	• Second most popular resin, high dry and wet bond strength, very good adhesion to wood. • Can be used as cold or hot setting adhesive • Primarily used to produce moisture-resistant particle and fibre boards, plywood, formwork and OSB • Suitable for humid or exterior climates
MUPF	• Hybrid-adhesives in the production of particleboards, MDF and OSB • Very similar adhesive properties to PF resins, but have a shorter setting time
pMDI	• Not an adhesive themselves but by hot-setting they react with moisture in wood to form string adhesive bonds • Used to produce weather-proof particleboards, fibreboards, and OSB • High reactivity means less resin compared to PF is required to make a weatherproof bond • No formaldehyde

In the report's evaluation of composting as an option for recovering panelboard waste, two companies were contacted. First, William Sinclair Hortculture Ltd. Of Lincoln, Lincolnshire does not compost itself but does procure between 6 300 and 12 600 tonnes per year from a supplier who produces compost uses only particleboard wastes. The particleboard is ground down and wetted; the compost reaches temperatures between 70 and 80 degrees Celsius. Second, Triesse Ltd. Of Tadcaster, North Yorkshire stopped composting in 2000; however, during operations they composted approximately 40 000 tonnes of panelboards including particle board, MDF, hardboard, OSB, plywood and softboard. The process consisted of collecting waste in a silo until it was full, loading the waste into lorries and wetting it, shipping it to another corner of the yard, and letting it compost for five years. During the five years the compost was only turned three times. Triesse mentioned that the British Society of Soil Science tested their compost and said it was good and that their compost is also very good as a fertiliser; no further details of the analysis were available.

The report states that the nitrogen-containing urea, in urea-based resins appears to act as a catalyst for the composting process. It suggests that Triesse's five year process is unnecessarily long and could be reduced with smaller particle sizes and process refinement. The report suggests investigating composting wood with green waste. The report also states that screening possibilities would have to be explored and developed if high quality compost is to be produced.

The report outlines the following opportunities/ strength and barriers associated with composting panelboard waste.
Opportunities / Strengths:

- The result of the composting process is a product that can be sold, if the quality is according to customers' demands, thus any operating organisation will be able to make revenue from it. If the product is of low quality then it could be "given away" for lower value uses as a means of waste disposal with income coming from the charge for disposal of the waste panels.
- Although fairly simple, mechanical technology is used, factors such as feedstock control, temperature, moisture, turning, analysis of the product and suitability of the product make the process overall somewhat complicated. However it is regarded as a low tech process with the potential to divert vast amounts of panelboard waste from landfill.
- Since it is predominantly organic compost, it is contributing to the fertility of the soil to some degree.

Barriers:

- Although the process can be very time consuming, there is potential for optimisation.
- There is a risk of running out of large-scale end users and / or end-users might not need huge quantities – however as well as horticultural uses, it could be used on farm and forestry land or as part of remediation work on brownfield or contaminated land.
- Risk that the compost may not meet PAS 100 (British compost standard) or may be of a lower quality and thus it may prove to be difficult to find a market for
- Neighbours of the processing facility may complain about dust being blown away from the processing yard.

The report compares the fifteen possibilities based on suitability for managing panelboard waste. It does this using a capability matrix with 'nearness to market' on the vertical axis and capability score on the horizontal axis. The capability matrix is separated into four areas, as shown in Figure 2.12. The options in the bottom right-hand corner of the matrix are projected to have the most immediate influence. Those in the top right-hand corner should have their development monitored for future applications. Those in the bottom left of the diagram are available, or will shortly be available and may be appropriate for limited applications whilst those in the top left of the diagram are less likely to make a short-term contribution, but should remain under observation for future developments.

Capability Score

Nearness to market

	low	high
low	Potentially less capable and further from market	Potentially capable but further from market
high	Less capable but available or near to market	Capable and available or near to market

Figure 2.12 Capability Matrix

The ‘nearness to market’ along the vertical axis was measured from high to low as follows:

1. **(LOW)** At basic research stage
2. Needing further development, proven at laboratory scale
3. Developed at pilot scale
4. Proven at an industrial scale’
5. Commercially available
6. In commercial operation **(HIGH)**

The capability score along the horizontal axis was calculated as a weighted average of the nine evaluating criteria. A summary of the capability score decision making criteria is shown in Table 2.19. The position of composting relative to other options is shown in Figure 2.13. The Action Plan developed by Bonigut and Kearley for composting panelboard waste can be found in Appendix B.

Table 2.19 Compost Capability Score Decision Making Criteria

	Criteria
Status (of technology)	The technology does not need developing since it is carried out commercially, however the time it takes to compost the panelboard needs to be speeded up.
Operational costs	Will largely be determined by the capability to chip and store the material.
Product (value of output)	Compost might be hard to sell, since it could be of low quality (low nutrients). It may not meet the quality specification PAS 100.
Environmental impact	Benefit to soil structure.
Development costs	The composting process needs to be improved by speeding it up and improving the quality and consistency of the compost.
Process capacity	It is thought that there are great opportunities to co-compost in existing facilities. However if composting takes place in windrows is the capacity is potentially huge, less so if in-vessel composted.
IPR	There could be issues if in-vessel composting is desired. No issues are expected with wind row composting.
Technical capability	All wood-based panel materials can be used, but quality issues might be created if mixed input and material will have to be screened at some point to remove (melamine) coatings and / or materials like e.g. metals or plastics.
Regulatory issues	Planning difficulties might arise with the issues of dust, smells, effluent run-off, required space and traffic.

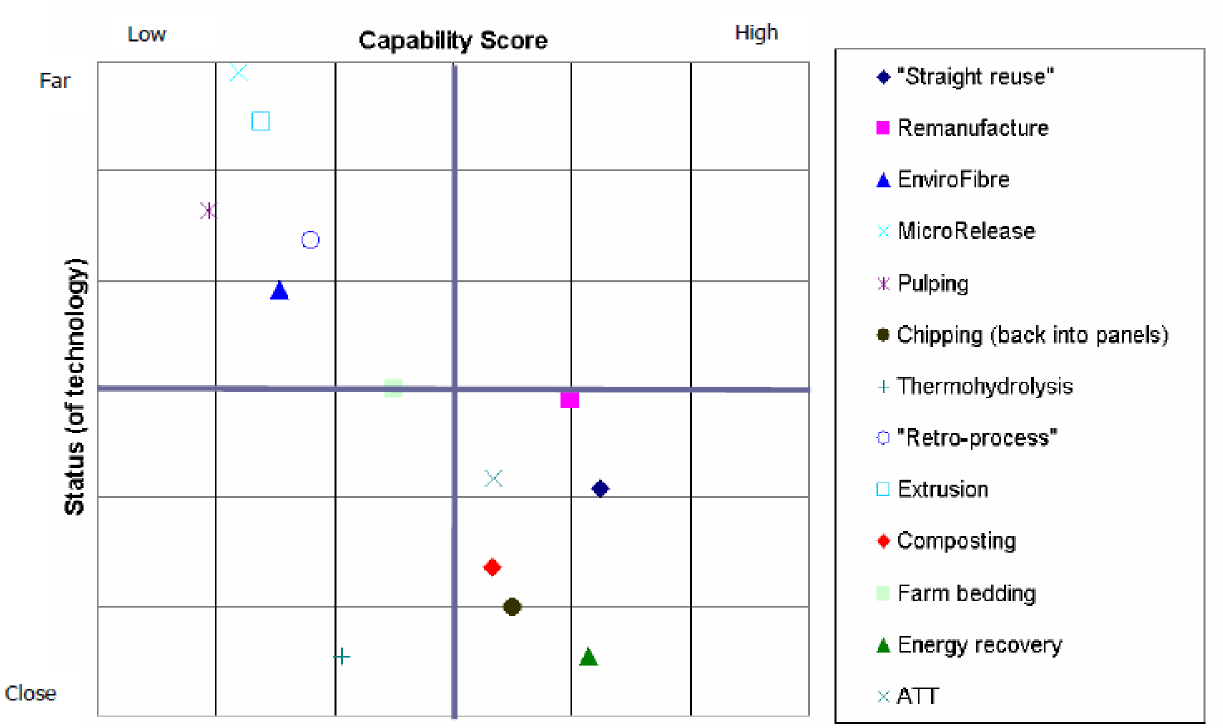


Figure 2.13 Capability Grid

2.3.8 Valzano (2007)

In a 2007 paper for the Recycled Organics Unit and the Western Sydney Waste Board, Valzano conducts a literature on composting composite wood. Although Valzano uses sources from various parts of the world, the review has a focus on Australia. The review focuses on four topics in composite wood composting: size reduction, composting, biodegradability of chemical constituents and general safety issues. In a general sense the purpose of the review was to identify problems and safety measures associated with the handing of these materials as compost feedstocks. In general, Valzano found that there are individuals in the composting industry who have serious concerns regarding the suitability of composite wood as a compost feedstock. This apprehension stems from the presence of potentially toxic substances and uncertainty regarding their fate during composting. These substances include adhesives and resins, preservatives, biocides, fire retardants, and coatings.

In terms of size reduction, Valzano found that the size reduction of composite wood products presents both technical and health problems. The size reduction process may expose machinery operators and nearby workers to airborne physical and chemical containments such as adhesives, resins, pesticides, preservatives, and wood dust that may cause detrimental health effects. Valzano recommends that size reduction machinery operators wear protective clothing including respirators and clothing that covers the entire body. He also recommends that workers near size reduction equipment be informed of the hazardous and be made to wear protective clothing and respirators where required.

In terms of composting, Valzano states that composting of composite wood products cannot occur in isolation. This is for two reasons. Firstly, the carbon to nitrogen ratio of these materials is generally too high for effective decomposition and secondly, the presence of persistent biocides may result in a compost product that has toxic effects on plants and animals. Valzano recommends that composite woods products are mixed with low-toxicity non-woody garden organics or food organics to optimize the carbon to nitrogen ratio and to mitigate possible contamination issues. Valzano states that compost products containing a high proportion of composite wood products are not suitable for use unless they are fully mature. Pasteurisation alone may not be sufficient to degrade all toxic chemical constituents found in composite wood products.

In terms of biodegradability of chemical constituents, Valzano concludes that generally modern chemicals used in the manufacturing of composite wood products readily degrade in the environment and even faster in a compost pile. However, some chemical used in older products, which as now banned from use, such as organochlorines (DDT, dieldrin), will not readily degrade in compost and may cause considerable health risks is they are present in high enough concentrations in a final product. Valzano recommends that operators of facilities minimise the use of older composite wood products in compost feedstocks. Table 2.20 summarizes the biocides which Valzano lists in the review.

Table 2.20 Some Biocides Used in Composite Woods

Fungicide	Insecticide	Combined Fungicide / Insecticide
Didecyl dimethyl ammonium chloride	Chlordane	Copper naphthenate
Didecyl dimethyl ammonium chloride + copper	Fenvalerate	Copper chromium arsenic
Didecyl dimethyl ammonium chloride + carbamate	Fenitrothion	Sodium fluoride
3-ido-2-propynyl butyl carbamate	Pirimiphos-methyl	Ammonium hydrogen bifluoride
Azaconazole	DDT*	Borates
Pentachlorophenol*	Lindane*	Copper + borates
	Dieldrin*	Creosote*
	Aldrin*	Arsenic trioxide*

*Indicates restricted use or banned in a number of countries

In terms of general safety issues, Valzano considers fire and formaldehyde. Valzano suggests a fire in a facility composting composite wood products would be considerably dangerous as constituent toxic chemical could be released into the atmosphere. To minimize the risk of fire Valzano recommends that compost windrows are built shorter and further apart than what is typically recommended. Valzano also recommends that when composite wood products are processed and stored in an enclosed facility, sufficient ventilation systems should be in place to dissipate formaldehyde fumes.

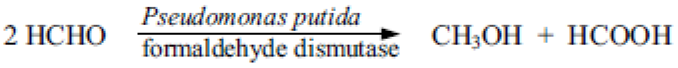
2.3.9 Other Research

A trials research report, conducted by Davies et al. (2006) involved both a literature review as well as an experiment on the composting of certain types of wood. It took place over 15 months commencing in July of 2005. It is a very thorough paper that covers many aspects of composting certain types of manufactured woods and also covers the composting of cardboard and market waste. The paper covers composting trials on both MDF and chipboard and includes a dedicated section to formaldehyde, and how it degrades in both trials. It should be noted that the paper recommends that the wood should be cut up into small pieces and wetted to increase formaldehyde decay.

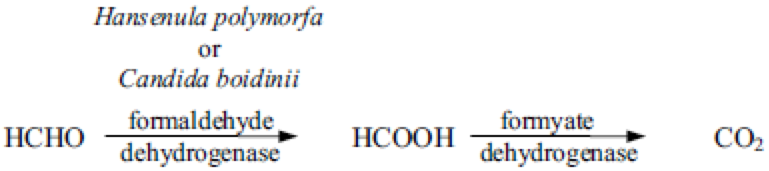
For the chipboard trials the formaldehyde did not decrease as much as previously thought, only between 39 and 68 %. To get the formaldehyde to acceptable levels, the chipboard should be diluted to approximately 5 % inclusion. It also makes the point that urea-formaldehyde is used as a fertilizer, so its addition to the soil in low concentrations is not inappropriate. However, the trial did not test phenol and melamine formaldehyde, but it suggests that they would also easily be composted.

For the MDF trials, there was some error in their data collection, as the formaldehyde levels actually increased. Several reasons are given as to why this error was made, such as insufficient mixing of the compost causing a sampling error, longer than expected polymer chains slowing the breakdown rate and using a screen that was to large. It also stated that despite the high formaldehyde levels, that plant growth and appearance seemed to be unaffected. The paper concludes by saying that most of the chipboard and the MDF compost was at an acceptable level and also briefly discussed the economic viability of the project.

While it is known that formaldehyde will decompose over the composting process, the steps it takes to get there are not well known; Glancer-Soljan et al. (2002) provides an answer. Although the focus of the article is on wastewater, the decomposition of formaldehyde using certain types of microorganisms (*Pseudomonas*, *Hansenula* and *Candida*) are given as:



$$2\,HCHO \xrightarrow[\text{formaldehyde dismutase}]{\textit{Pseudomonas putida}} CH_3OH + HCOOH \qquad (1)$$



$$HCHO \xrightarrow[\text{dehydrogenase}]{\substack{\textit{Hansenula polymorfa} \\ \text{or} \\ \textit{Candida boidinii} \\ \text{formaldehyde}}} HCOOH \xrightarrow[\text{dehydrogenase}]{\text{formyate}} CO_2 \qquad (2)$$

Therefore formaldehyde usually degrades into formic acid, which can then be broken down again into carbon dioxide. As for the rest of the article, it was found that *Pseudomonas putida, Pseudomonas cepacia* and *Trichosporon peicillatum* were the best organisms for degrading the formaldehyde and formic acid.

McKeever (1998) published an article on waste wood in the United States including C&D waste. While the article mostly focuses on the recovery of wood products, it contains useful statistics including the fact that 33.2 million tons of C&D waste were generated in the United States in 1996. Much of the wood waste goes into the landfill, indicating a need to find an alternative disposal solution. One problem that the article brings up, however, is the contamination of C&D woods, especially with demolition. The wood and other waste in older buildings that are being demolished typically contain toxic materials that would be unhealthy to compost, such as asbestos, lead, mercury and PCBs.

In a paper presented at the International Symposium on Microbial Ecology in 1999, Reddy and Michel investigate the fate of xenobiotics during composting. Xenobiotics are defined here in the context of an artificial human synthesized substance, non-existent in nature before humans introduced it. The laboratory scale study investigated the extent of mineralization, incorporation into humic matter, and volatilization during the composting of yard trimmings amended with ^{14}C labelled xenobiotics such as TNT, PCBs, chlorophenols and PAHs. The study found that the fate of xenobiotics varied considerably in compost. A full list of the xenobiotics tested can be found in the Appendix C along with the degradation results.

An article by McMahon et al. (2008) follows work on composting C&D waste in three different mixtures. Wood products including OSB, MDF, hardboard, and melamine are composted. Full-scale tests were done in Eco Pods. Focus is put on creating a situation where on-site C&D composting can be done economically, thereby eliminating the transportation inherent with centralized systems. The research indicated that biodegradation occurred, toxicity levels decreased over time, and the composting of manufactured and treated woods was possible.

Peltola et al. (2000) tested the biodegradability of various wood products, such as chipboard and plywood. They used various tests, such as bio-mineralization, size reduction, and bacterial analysis using an electron microscope. They concluded that the chipboard and the plywood were at least partially biodegradable in aerobic conditions and plywood was biodegradable in anaerobic conditions. It also concluded that the toxicities from the biodegradation were low. The heavy metal levels were all under 10 ppm. All the manufactured woods were aerobically biodegradable, with plywood also being anaerobically biodegradable.

The growth of plant life was observed from composts consisting in part of post-use wood waste by Wroblewska (2008). Willow (*Salix purpurea*) was used to evaluate the compost samples. Wood with more urea-formaldehyde contained higher nitrogen levels which easily met the suggested C:N ratio between 25:1 and 30:1. Samples of compost that had been sitting for two years provided greater plant growth than that of the one-year sample. The post-use wood was said to contain worn out furniture, doors, windows, building structures, and other goods made of composite wood products (raw and finished particleboards – laminated, veneered, lacquered; painted flax boards, hardboards and soft boards – lacquered and raw; MDFs finished with artificial veneers and laminates, furniture panels, plywood, and boards on frame), and also worn out products made of solid wood, raw and preserved with painted coatings and containing wood preservatives (fungicides and pesticides).

A study by Atagana et al. (2003) focused on composting soil with high levels of creosote. This would be similar to creosote treated wood being composted. It was found that the levels of creosote did decrease over the course of the experiment. For the control (no added products to the composting soil) the creosote levels decreased by 17% and when vegetable waste or cattle manure was added, the creosote levels decreased by over 99%. However, this study took place over the course of 19 months, as opposed to 14 weeks seen in trials above. It should be noted however, that this study did not test the compost to see if it was acceptable to use on plants, only if composting was an effective way to break down creosote.

Beebe and England (1998) considered the lead concentrations in C&D wood waste. Lead and many other heavy metals are commonly found in C&D wood waste. This is due to the coatings of the wood. However the article does make a point of stating that the amount of heavy metals in the C&D wood waste is generally low, due to the fact that heavy metals make up a low part of the coating, which in itself is a very small part by mass of the entire piece of wood.

Cao and Ma (2004) considered plants that grow near CCA treated wood and testing to see if compost will lower the amount of arsenic absorbed by the plant. The test was done in soil that was highly contaminated by arsenic (as if the soil was beside CCA treated wood). It was found that the arsenic levels were drastically reduced when compost was added to the soil. This is because the organic matter in the compost absorbed the arsenic so that the plants could not absorb it. This is interesting because if the CCA does not break down over the composting process the compost itself could possibly be used because the plants will not absorb the arsenic.

Ghaly et al. (2012) completed a study to determine if the fungus *Thermoascus aurantiacus* could be added to the composting process of creosote treated wood and have a positive effect on degrading the phenolic compounds found in creosote. It was found that the addition of Thermoascus did not cause the phenolic compounds to break down faster, and perhaps even retarded their degradation, as the control had a higher degradation rate (73%) than the trial (68%). The explanation given is that Thermoascus must have inhibited the metabolic activity of the organisms that normally process the compost.

The purpose of the work by Groot and Woodward (1999) was to find a fungus that would help with the degradation and reuse of copper treated woods (such as CCA). The fungus Wolfiporia cocos was chosen. However it is found that different isolates of W. cocos have wildly varying efficiencies when it comes to decomposing copper treated wood, meaning that the fungi should be tested on a case by case basis before being used on a commercial scale. The paper does state though, that bioprocessing could be a viable option for copper treated woods. However besides copper citrate, all other copper-based preservatives must have some preliminary leaching and extraction in order to be successful. The W. cocos proved to be successful, the more that was added, the higher the weight loss.

Lane et al. (1997) determined what would happen to chlorophenol compounds during the composting process. PCP, a common wood preservative, is a chlorophenol compound that was tested. The experiment involved composting wood chips from a sawmill contaminated with chlorophenols over 25 weeks. It was found that the chlorophenols completely biodegraded over the test. Also there was a large decrease in the toxicity of the compost pile. The high concentration of chlorophenol compounds at the beginning of the trial yielded high toxicity. At the end of the composting process, the toxicity was greatly reduced. This also means that the biodegradation of the chlorophenol compounds did not create toxic or harmful by products, with a large portion of the carbon within the compound ending up increasing bacteria biomass.

The fate of microbial populations in composting wood treated with CCA and creosote was assessed by McMahon et al. (2009). It was found that the levels of both CCA and creosote did not decrease over 18 and 14 weeks respectively. The filters showed no signs of CCA or creosote, and the difference in samplings could be attributed to error in sampling. However, despite this the microbial counts in both the CCA and creosote piles were not significantly different than the control. While the preservatives did slow the growth somewhat, composting could still be done. In conclusion the authors stated that because of the high microbial count, the composting of both creosote and CCA might be possible but it would have to be over a longer time scale.

Mollah and Allen (2009) completed a study to determine if biodegradation could be used to treat areas affected with PCP leachate. Since this is the same PCP that is used for preserving wood, it is relevant to know if it is biodegradable. Over the 5-month period, the PCP was completely degraded, however, the test was done within a special reactor using a special type of bacteria (Arthrobacter sp.).

The biodegradability of varnished wood was assessed by Souza and Gaylarde (2002) who performed a 30-day experiment on how varnished wood biodegrades. The varnished wood was placed in a series of test panels, each subjected to various amounts of fungal spores, bacteria and yeast. A preservative (2,3,5,6-tetrachloro-4 (methylsulfonyl) pyridine) was also applied to a number of panels to test its effectiveness. It was found that the microorganisms did break down the varnish, however depending on what type of microorganism it was, the results differed. For yeast and fungi, the best results came from them being under the varnish (being on the wood before it was applied), which is not useful in a composting process. The bacteria *Corynebacterium* sp. and *Bacillus* sp., did better being on top of the varnish, which could be added to the composting process to get rid of varnished wood.

A final article by Moussavi and Heidarizad (2010) assessed how phenol formaldehyde (PF) breaks down over time. While this article is about PF in wastewater, it can easily be applied to compost as well. The PF-rich substance was composted for 50 days. At the end of this time, it was found that 97% of it had biodegraded into non-harmful substances. Therefore phenol formaldehyde should biodegrade over the composting process.

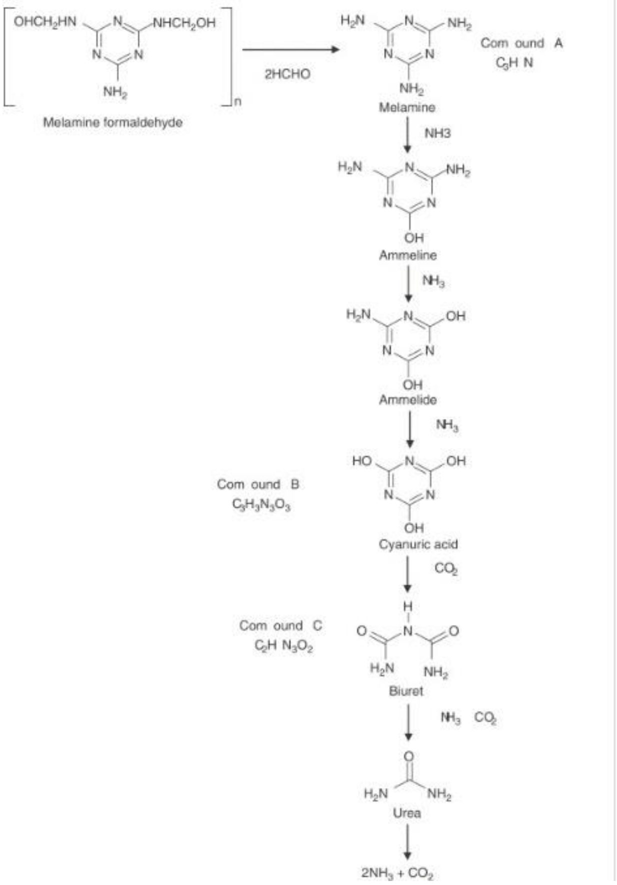
2.3.10 Testing Protocols

As formaldehyde is a common constituent in manufactured woods, developing tests to measure its presence is very important. A British standard for testing the amount of formaldehyde in textiles is presented (BS EN ISO14184-1:1999). The authors first run water through the material at 40^{o}C, which then is tested for formaldehyde using two main methods:

- Method A: Using a colorimeter, the amount is found after standard curves. An acetyl acetone reagent and an ethanolic solution of dimedone are used to prepare the formaldehyde solution.
- Method B: Sodium sulfite, thymolphthalein, and sulfuric acid are used in a titration to find the amount of formaldehyde in the solution.

Various test kits for formaldehyde in air can be purchased for approximately $100. These kits could be placed into the headspace of the composting units periodically. Accurate test kits are sent back to labs, while there are kits that work with color and give you a reading on the spot (similar to pool test kits).

Leungprasert and Otten’s paper (2000) used EPA Method 8315A HPLC (HPLC = High Performance Liquid Chromatography) to detect the presence of formaldehyde. Other research on the bio-decomposition of formaldehyde and its varieties includes the biodegradation of melamine formaldehyde by *Microoccus* sp. in wastewater effluent (El-Sayed et al., 2006). This article focuses on how melamine formaldehyde decomposes using a certain type of bacteria. While this article looks at melamine formaldehyde from wastewater, this would easily also apply to composting manufactured woods that use melamine formaldehyde as the resin (such as melamine board). The article makes a point of noting that both melamine and formaldehyde are hazardous chemical compounds, so their degradation is of particular interest. The method used to test melamine formaldehyde levels was interesting. The bacteria was grown using melamine formaldehyde as its main carbon and nitrogen source. The more bacteria that was grown, the higher the levels were. This method would not be suitable for testing levels of melamine formaldehyde in compost because it would be impossible to isolate. However, the pathway of biodegradation for melamine formaldehyde is mapped out, as seen below:



It may be possible to test for one of these compounds to see the rate at which the melamine formaldehyde is decomposing during testing if no way can be found to test for melamine formaldehyde directly.

A method to measure the formaldehyde concentration in the biodegradation of formaldehyde and its derivatives in industrial wastewater was also employed by Kaszycki and Koloczek (2002). The method to measure formaldehyde levels in this study was through the use of colorimeters. Two techniques were used: one to measure the concentration of “free” formaldehyde, and the other to find the total formaldehyde load. The free formaldehyde is measured using the Nash reagent. In summary, it relies on the synthesis of diacetyldihydrolutidine from acetylacetone and formaldehyde in the presence of excess ammonium salt. The total amount of formaldehyde was determined with a simplified chromotropic method, based on chromotropic acid reagent in strong acid.

3. Experimental Design

The experimental process took place in three distinct periods over six years. In all experimental trials, manufactured and coated wood waste was chipped and composted with municipal source-separated organic (SSO) waste in aerated, insulated 55 gallon drums with removable lids (Figure 3.1). Air was supplied by a compressor, flowing through a header system of ½" hoses and fittings which was subsequently split between the drums and controlled with dedicated flow meters (Figure 3.2). The air continued through a fitting at the bottom of each drum, passing through a supported horizontal pipe, then up through a vertical riser in the center of each drum that was perforated to allow distribution of air throughout the composting mass (Figure 3.3); exhaust gas was passed through a flask sitting on the top of the barrel to collect any condensate and then released. Periodically, the lids were removed to agitate the composting mass with a manual compost agitation device (Figure 3.4).

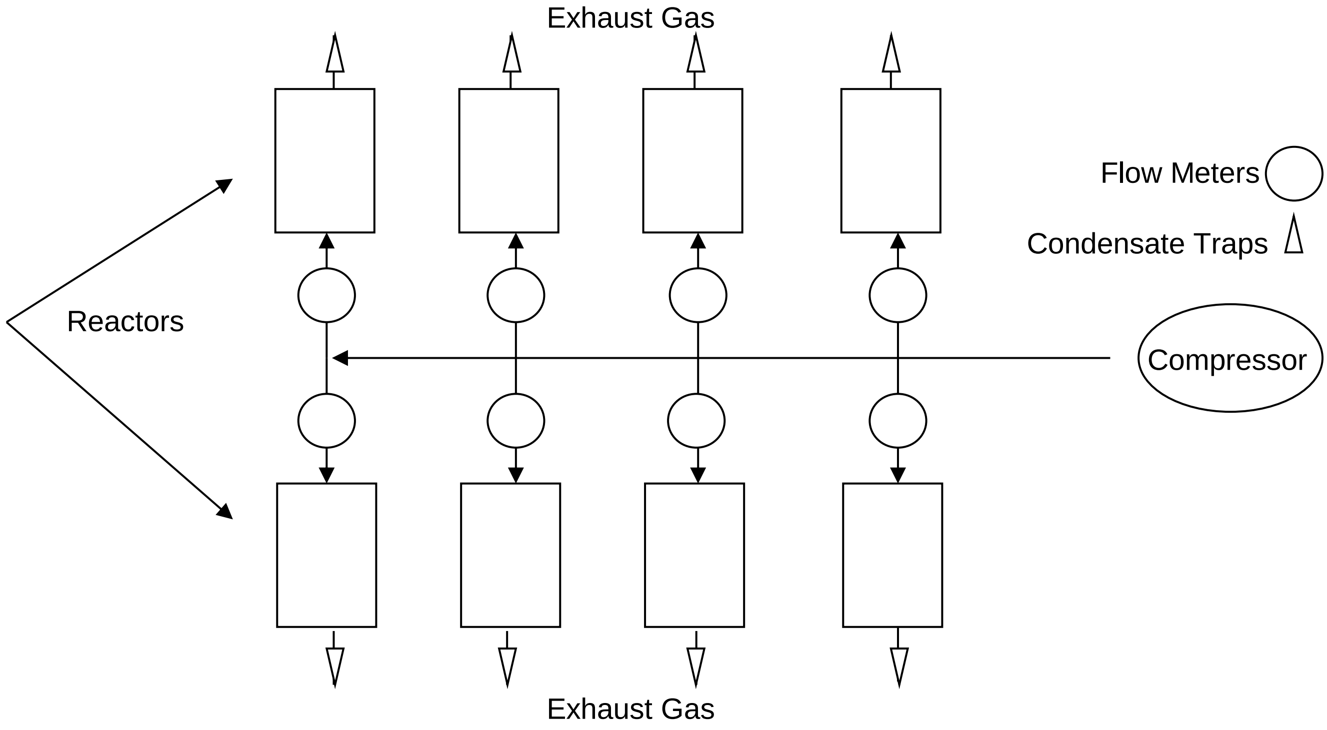


Figure 3.1 General Equipment Layout

Figure 3.2 Air Supply and Header System

Figure 3.3 Actual Equipment Layout with Internal Riser Superimposed

Over the three years of experimental work, the experimental system was utilized six times in terms of six sets of eight batches each—the first set of eight drums were used at the Edmonton Waste Management Centre of Excellence (EWMCE) in Edmonton, Alberta in 2009, the second and third sets were run in 2013 at the KCIC Environmental Science Centre at Acadia University in Wolfville, NS and the final three sets were also processed at the KCIC Environmental Science Centre in 2014.

Figure 3.4 Compost Agitation Device

4. Experimental Procedure

The same experimental procedure was followed for all six batches using different types of feedstock and consisted of a mix of nitrogen-rich SSO and wood waste from various sources (Figure 4.1).

Grass Clippings Food Waste Wood Waste

Figure 4.1 Natural Feedstocks

In batches using pure wood waste of a known constitution, the wood product was purchased, then chipped before being mixed with the nitrogen-rich constituents; batches using a wood mix of unknown origin consisting of coated and uncoated wood products were obtained from construction and demolition (C&D) sites.

All batches were prepared and run in a similar manner:

1. Wood products were either purchased from a commercial retail store or obtained from a regional C&D site (such as Halifax C&D Recycling Ltd.). Wood products purchased included:

    - spruce strapping, which served as the control
    - oriented strand board (OSB)
    - melamine
    - spruce plywood
    - hardboard
    - medium density fiberboard (MDF)
    - corkboard
    - particle board, and
    - pressure treated spruce.

2. The purchased wood was chipped (typicaly in a 4” Vermeer wood chipper (Figure 4.2).
3. A nitrogen-based feedstock (food waste, grass) was obtained from the Edmonton Waste Management Center (batch 1), New Era Technologies of Halifax (batches 2 & 3), and Northridge Farms NS Ltd. of Alyesford (batches 4-6), Figure 4.3).

4. The food and wood chips were mixed on a 40:60 basis (by volume) and placed in reactors (Figure 4.4).
5. The lids were put in place and the air lines were hooked to the air supply (Figure 4.5).
6. The temperature data loggers were activated to record reactor temperatures on an hourly basis.
7. The contents were sampled and agitated periodically.
8. Over time, the contents were agitated and sampled less as the material matured.
9. The product was tested periodically for pH, electrical conductivity, microbial population, maturity (dissolved oxygen and Solvita) tests and in particular, chemicals of interest unique to manufactured wood products.

Figure 4.2 Wood Chipper

Figure 4.3 SSO Supply

Figure 4.4 Preparing Barrels

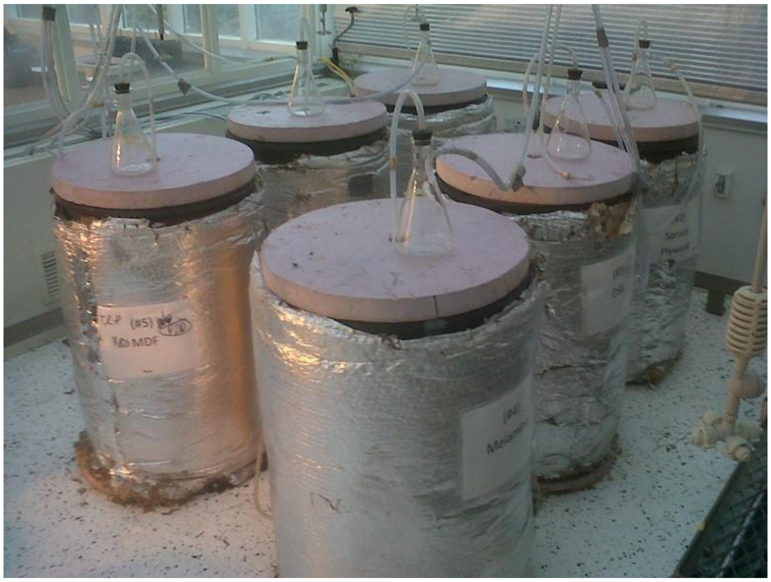


Figure 4.5 Sealed and Charged Reactors

5. Test Methods

The following sections outline the methods followed to gather data related to the report.

5.1 Particle Size Distribution

Particle size distribution data examined the statistical distribution of the wood particles for the various mixtures. The distribution can be found for any sample that is dry enough to pass through the filter screens readily without undue adhesion.

To conduct this test procedure, the following screens (Table 5.1) were utilized in addition to large pails, a 10-kg digital scale (with 10 gram/0.01 kg resolution):

Table 5.1 Screen Sizes

Screen №	Opening (mm) / Opening (inches)
1	25.4 / 1”
2	19 / ¾”
3	16 / ⅝”
4	10 / ⅜”
5	8 / $^{5}/_{16}$”

Thus, any particles larger than 25.4 mm in diameter are considered “over-sized” and any material passing through the final screen (diameter < 8 mm) was considered “product” by size. Material of intermediate size may be useful for addition to a subsequent batch of compost dependent on specific process-dependent requirements. Note that 8 mm corresponds to 5/16”, the standard screen utilized for compost samples.

A large sample was taken (~2 kg) and weighed. It was then sifted through the first screen and the screened-out portion was weighed and removed. This process was repeated for each screen size. Thus, there was one “total weight” processed and six composite masses (“over-sized” down to “product”). To check the relative validity of the results, the 6 composite masses were summed and this was compared to the original mass. If the two masses differed by < 2 %, it was considered an acceptable trial. It was assumed this error was introduced due to ultra-fine particulate matter escaping during the screening process and thus the lost mass could be assigned to the “product” mass; the finer materials (such as MDF-product and hardboard-product) had higher error initially and the test procedure had to be repeated with increased caution to reduce the error.

Performing a particle size distribution with a sufficiently large initial sample size (>2 kg by experience with this material) provided two full zip-lock bags of product material that were able to be stored. A zip-lock bag of the remaining material (non-product) was also taken and stored.

5.2 pH Sampling

While pH is not formally defined for solid material, it is common industry practice to verify the pH of compost at various stages; Test Method for the Examination of Composting and Compost (TMECC) defines that compost maturity is insufficient as a sole basis of a report on compost quality and must also include other information such as nutrient content, pH, and electrical conductivity (TMECC, 2008).

The test method used mixed deionized water (DI) to a 5/16” screened sample at a mass ratio of 1:5 in a tap-water rinsed beaker with a magnetic stirrer on a stir plate. For example, for a 10 g sample of compost, 50 g of DI was added, yielding a total mass of 60 g. The DI was kept at room temperature, approximately 25 ºC for the summer session, and the samples were typically cooled to approximately 4 ºC in a refrigerator, thus the resultant temperature was sub-ambient. The stir plate was operated at a moderate temperature and was allowed to run for several minutes until the sample appeared to be mostly homogeneous. If a pH reading was taken and was unstable, the reading was recorded and the sample was stirred for several additional minutes and this process was repeated as needed.

5.3 Compost Maturity

Fundamentally, the study of compost maturity has assumed, by way of empirical and anecdotal evidence, that the rate of microbial activity is inversely related to maturity, and therefore, low microbial activity implies mature compost. There are two fundamental means of observing maturity that stem from the belief that microbial life will remain aerobic in the presence of adequate oxygen: one is to measure the rate of oxygen consumption in a test container (SOUR or BOD_5, for example) and the other is to measure the carbon dioxide generated by respiration (Arthur Respirometry, for example). The latter operates under the assumption that carbon is the only substance being oxidized within the sample, or at least, that all non-carbon oxidation can be assumed insignificant. In terms of establishing a maturity threshold, composted product must possess a respiration rate below 400 mg oxygen per kg of organic matter per hour in order to be considered mature (CCME, 2005).

5.3.1 Standard Methods of Measurement

Existing test methods, as defined in Standard Methods for the Testing of Water and Wastewater (the BOD_5 test, typically) or the TMECC (SOUR, Solvita, CO_2 Evolution Test methods) or by third-party manufacturers (such as the Arthur respirometer, utilized by the Bureau de Normalization du Quebec) utilize inherently mechanical and readily available equipment beyond the test kit. Thus earlier test methods are designed to offset the burden placed on the laboratory/operator. For example, the BOD_5 test requires specialized laboratory equipment and bacterial inoculant, but remains unobserved for five days and analysis is a simple five-day drop in dissolved oxygen content.

Similarly, other test methods favour either minimal operator intervention (as in the BOD_5 test) or intense operator intervention over a short duration (such as SOUR with a 1-minute sampling frequency or Arthur respirometry, which necessitates operator intervention to reset the manometer/system pressure to prevent overflow of the measurement fluid). Thus, most existing systems performing these tests acquire a complexity to observe what is fundamentally a simple principal.

5.3.2 Modified BOD Test

Developed over the past number of years, the modified BOD test aims to modernize the test procedures without introducing undue operator complexity while providing more meaningful data. The test repeats a cycle of aerated and unaerated periods to a compost-water mix. During periods of non-aeration, the decline in oxygen content is measured and the rate of decline is calculated on the basis of mg of oxygen consumed per mg of organic matter per hour. Over time, the rate of consumption will decline as the available organic matter is consumed.

The test procedure is as follows: a carboy is filled with approximately 20 L of tap water. A 10–15 g sample of compost is added as is typical for compost maturity tests; a duplicate sample is also analysed for moisture and organic matter content. A YSI ProODO meter is installed and mounted to sit at a midpoint in the bottle and an air hose is installed with a diffusing (bubbling) stone. The air pump, an aquarium grade pump, is connected to a timer that controls the duration of the air supply. Nominally, for normal samples, an aeration period of 30 minutes and a test period of 5.5 h is used. That is, data is collected for 5.5 h by the meter, then the tank is re-aerated for 30 minutes to reset, and another test follows. Thus, using standard timings, four tests can be done per day. The meter is configured to collect data every 15 minutes, aligned to the timer to allow for ease of data analysis as fewer assumptions need to be made from the dataset. A shorter 3-hour cycle (2.5 h test, 0.5 h aeration) is used for active samples. In any case, the tests are typically allowed to run for 5 days, to become aligned with the BOD_5 test timeframe. It is given that a longer duration allows for more sample maturation, thus yielding steadily declining rates of oxygen uptake, thus producing a reduced reported average rate of oxygen consumption.

5.4 Moisture Content and Organic Matter

The moisture content was measured in a traditional fashion. After the masses of the empty aluminum pan and the pan and the fresh sample were recorded, the sample was dried at 104 ^{o}C for 24 hours and re-weighed. The difference in mass represented the moisture loss with the percent moisture calculated as moisture loss divided by the mass of the fresh sample and pan less the pan mass.

The organic matter was calculated as the difference between the mass of the dry sample less the pan mass and the ashed sample (at 550 ^{o}C for 30 minutes) less the pan mass, divided by the dry sample less the pan mass.

5.5 Metals Analysis

The content of available metals in composted products were tested by AGAT Laboratories in Dartmouth, NS using inductively coupled plasma mass spectrometry (ICP-MS) and following the EPA protocol SW 846 6020A/3050B & SM 3125 according to AGAT's standard operating procedure MET-121-6105 & MET-121-6103.

5.6 Contaminant Chemical Analysis

The contaminant chemical analysis was completed in the Chemical Engineering Department at the University of Alberta. The analysis consisted of two components: a gas chromatograph (GC) analysis and a gas chromatograph-mass spectrometry analysis (GC-MS). Typically, peaks indicating the presence of chemicals of interest that are produced from the GC test are investigated further with the more precise GC-MS. As the tests analyse chemicals in an aqueous environment and compost is essentially a solid matrix, chemicals within the compost matrix need to be extracted, or washed out of the compost matrix. Therefore, a number of preliminary extraction tests were undertaken to determine the most effective means of capturing the chemicals of interest.

5.6.1 Soxhlet Solvent Extraction

Because of the extensive mixture of compounds present in samples from complex organic matter such as compost, it is desirable to perform a solvent extraction before analysis. This procedure enables the recovery of organic compounds based on their affinity to a solvent. Soxhlet extraction (Figure 5.1) is an efficient method used for the extraction of compounds from a solid sample. In a nutshell, a sample of compost is placed in a thimble and the solvent of interest (methanol) is boiled on a hot plate underneath the sample. The solvent evaporates and its vapour reaches a condenser, where it cools, condenses and drips back on the solid sample. When enough solvent has accumulated in the Soxhlet chamber, the flows back down to the boiling vessel along with organic components that have been extracted from the sample.

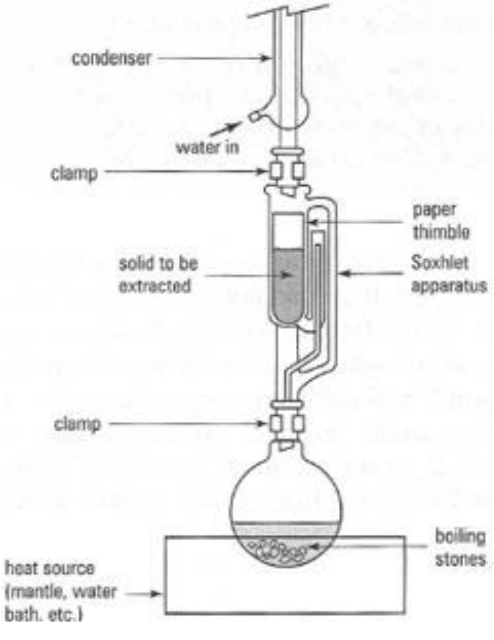


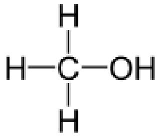
Figure 5.1 Schematic of Soxhlet Extraction Set-up (taken from www.eplantscience.com/index/dean/solidliquid_extraction.php)

Development of Soxhlet extraction procedure

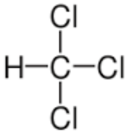
Initial efforts focused on the development of a reproducible and reliable extraction procedure. Fractions of samples 1, 2 and 3 were to test the Soxhlet extraction performed under variable conditions. Chloroform was used as a model solvent for this work. Sample size, ratio of sample to solvent and duration of extraction were evaluated. Solvent losses, sample recovery, sample mass loss were measured as crude assessments of the extraction efficacy. From the results obtained, the Soxhlet extraction protocol was developed.

Solvents used in Soxhlet extraction

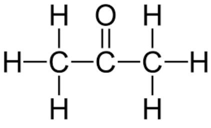
Since the extraction of organic compounds from solid matter is highly dependent on the solvent used, three different organic solvents were selected (methanol, chloroform and acetone) for further experiments. These were selected because, for a wide variety of organic compounds, they have very different solvent-water partition coefficients from one another. This should enable each solvent to extract different compounds and should provide a broader array of extracted molecules for analysis.



a) methanol



b) chloroform



c) acetone

Duration of Soxhlet extraction procedure

Longer extraction procedures are generally preferred to ensure the recovery of most compounds of interest. However, since different molecules display different affinities with the solvent used, they are extracted at different rates. Moreover, the signal obtained by Gas Chromatography (GC) analysis for a compound present at low concentration can sometimes be overshadowed by the signal of another compound present at high concentration and having a similar residence time. This is especially of importance for analysis of complex mixtures such as compost.

For this reason, 3 different durations are to be performed for each sample and solvent combination: 4h, 6h and 24h. This will enable a differentiation between easily extracted compounds and compounds that are extracted slower. It will also allow the generation of time trends of extracted compounds.

The urea-formaldehyde, phenol-formaldehyde, melamine-formaldehyde Soxhlet Extraction (based on EPA method 3540C) procedure is as follows:

1. Superclean glassware (based on EPA SW846 Chapter 4 Section 4.1.4)
    a. Immediately after use flush with isopropanol
    b. Soak in hot water (>50 °C) with Sparkleen 30 min or overnight
    c. Rinse in hot water
    d. Soak in 5% Contrad 70 solution 2-12 hours (5% in deionized water)
    e. Rinse in hot water
    f. Rinse in distilled water

   g. Rinse with isopropanol
   h. Dry glassware in 100 °C oven, cover with tin foil to keep dust free in storage
   i. Immediately before use, flush with the solvent used for the extraction
2. Sample preparation
   a. Weigh 5 g wood compost sample (compost should be broken up into small pieces)
   b. Weigh 5 g anhydrous sodium sulphate, mix with compost
   c. Pack (not too tightly) into cellulose thimble
3. Using glass pipet and a Pasteur pipet, use volumetric flasks (25 mL and 50 mL flasks) to measure 75 mL of extraction solvent. Add to 125 mL round bottom flask.
4. Assemble Soxhlet, heat to 75 °C, remember to turn on water for condensers (water in at bottom, out at top)
5. Extract for desired time (4, 6, 20 hours)
6. Remove from hot plate and allow apparatus to cool.
7. Sampling for GC/MS
   a. Rinse glass syringe 5-10 times with extraction solvent
   b. Use syringe to remove 1ml of extracted sample, put into GC vial (in triplicate). Store at 4 °C.
   c. Rinse syringe 5-10 times with extraction solvent
8. Cleaning and waste disposal
   a. Extracted wood compost and paper thimble into organic solid waste
   b. Solvent into organic liquid waste
      acetone is incompatable with chloroform
   c. Superclean the glassware for next extraction (step 1)

Solvents to Test: acetone (boiling temp=56 °C), chloroform (boiling temp=61 °C),
methanol (boiling temp 65 °C), hexane (boiling temp=68 °C)

Extraction Times: 4 hours, 6 hours, 20 hours

Extraction Thimbles: Whatman High Performance Cellulose Extraction Thimbles
25x80mm single thickness
cat: WHT2800258 Fisher

Although all extractions were carried out over different lengths of time (4 h, 6 h, 20 h) and with different solvents (methanol, chloroform, acetone), all results presented in the report were obtained from samples extracted in methanol for 6 h. These samples were found to provide the most information at this point.

GC-FID analysis

Once the chemicals have been successfully extracted, the solutions are tested in a gas chromatograph. In gas chromatography, compounds present in a sample (analytes) move through a column in which they are separated based on characteristics such as their volatility and their affinity for the column contents (liner film or packing). This separation determines the number and relative quantity of analytes present in a sample. A schematic of the apparatus is presented in Figure 5.2.

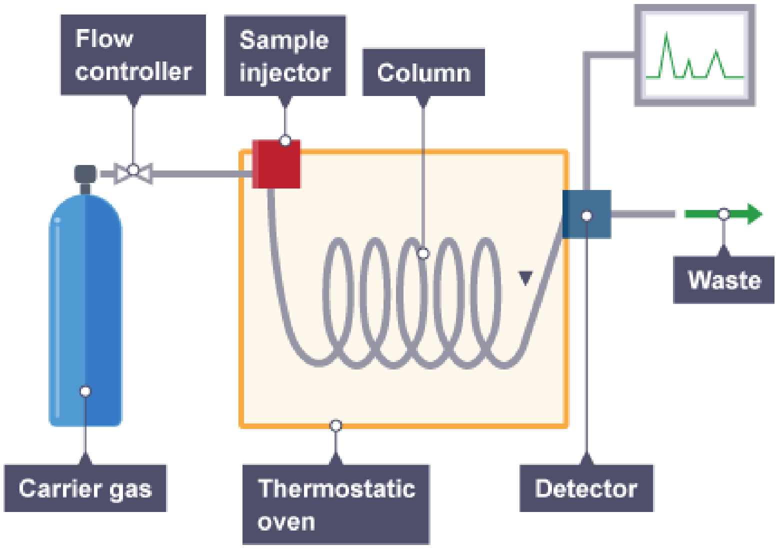


Figure 5.2 Schematic of Gas Chromatography Set-up (www.bbc.co.uk/schools/gcsebitesize/science/triple_ocr_21c/further_chemistry/chromatography/revision/5/)

For this analysis, a sample is injected at a high temperature to volatilize the solvent and analytes present in the sample. A carrier gas carries the analytes through a heated column contained in an oven. The analytes move along the column at different rates based on their volatility and affinity towards the column material. As they exit the column at different times, the analytes enter a detector and lead to a measurable signal, which results in a chromatogram (Figure 5.3) where each peak represents an analyte.

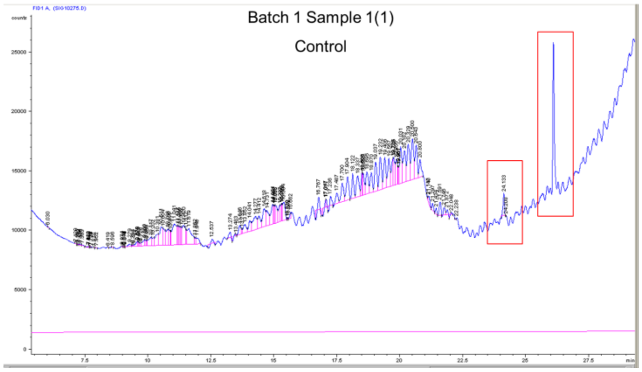


Figure 5.3 Example of Chromatogram from Sample Set 1, Batch 1- Control

In the study at hand, an HP 5890 Series II chromatograph equipped with a flame ionization detector (FID) was used in conjunction with a DB-5 chromatography column (Agilent Technologies, 30 m length, 0.25 mm ID, 0.25 μm film thickness). The column was selected for its versatility and robustness. A method with a slow temperature ramp and low carrier gas flow rate was developed to maintain a good separation of the analytes. This method takes longer than other methods but provided a good definition of the components present. Adjustments to the temperature ramp, gas split and flow rate were made as more samples were tested and the profiles of the chromatograms were better known. The carrier gas was helium and the eventual method was based on the conditions found in Table 5.2.

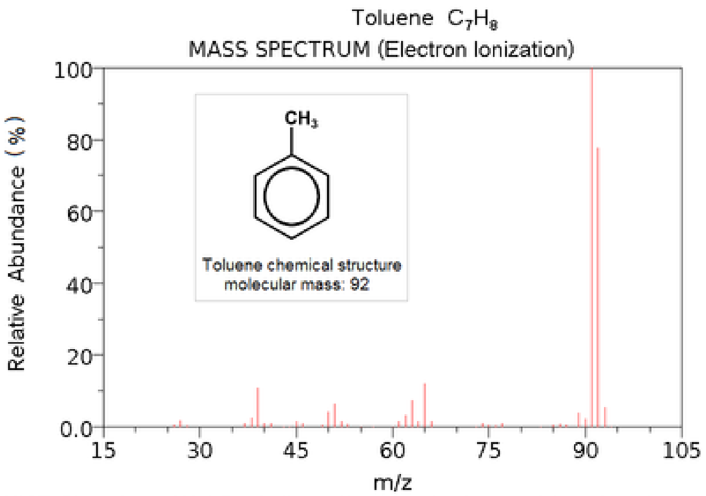
Table 5.2 Conditions for GC Analysis.

Parameter	Condition
Injector temperature	200 °C
Split ratio	1:1
Initial oven temperature	60 °C
Initial hold time	2 min
Oven temperature ramp	10 °/min
Final oven temperature	300 °C
Final hold time	15 min
Detector temperature	350 °C

Gas-Chromatography/Mass Spectrometry Analysis

The combination of Gas Chromatography followed by Mass Spectrometry allows the identification of the analytes present in a sample. Essentially, the analytes present in a sample are separated through a gas chromatograph before entering an ionization step, where they are broken down into smaller ions. These ions travel through a mass analyzer, in which the ions are characterized based in their molecular mass. The resulting spectrum of ions of different masses (Figure 5.4) can be used to reconstitute a probable original analyte. When this spectrum is compared to a library of spectra from different molecules, it is possible to assess the probability of a given molecule being the original analyte. Hence a list of potential corresponding analytes is provided along with their respective probability.

For this analysis, a 7820 A GC-MS (Agilent Technology) was used with a FID detector and a HP5-MS UI column (30 m length, 0.25 mm ID, 0.25 μm film thickness). The method was tailored to the method described in the above Table 5.2.



NIST Chemistry WebBook (http://webbook.nist.gov/chemistry)

Figure 5.4 Example of Mass Spectrum for Toluene (en.wikipedia.org/wiki/Mass_spectrum)

A summary of the various chemicals of potential interest based upon product information disclosed from MSDS sheets and other sources is presented in Table 5.3.

Table 5.3 Constituents of Potential Interest in Manufactured Wood

Product	Constituents	% by weight
	MDF	
Product 1	formaldehyde	<0.1
Product 2	urea-formaldehyde normally and phenol-formaldehyde for moisture resistance	
	Melamine	
Product 1	urea formaldehyde resin	<13
	melamine urea formaldehyde resin	<13
	paraffin wax	<2
Product 2	melamine-formaldehyde	
	OSB	
Product 1	polymeric phenol-formaldehyde resin	0-14
	polymeric diphenylmethane diisocyanate	0-14
	paraffin wax	0-2
	polyethylene coated and/or laminated paper/aluminum foil	1-2
	titanium dioxide	
Product 2	similar resins as plywood, formaldehyde	
Product 3	polymeric diphenylmethane diisocyanate	0-10
	wax emulsion	0-5
	phenol-formaldehyde	0-10
	free formaldehyde	<1
	zinc borate	0-3
	Hardboard	
Product 1	formaldehyde, urea and phenol (assumed urea formaldehyde and phenol formaldehyde)	
	Particleboard	
Product 1	polymerized urea formaldehyde, phenol-formaldehyde	
	melamine-urea-formaldehyde	
	isocyanates	
Product 2	polymeric diphenylmethane diisocyanate	
	urethane	
	polyurate	
	Corkboard	
Product 1	ethylene vinyl acetate polymer	15-40

Table 5.3 Constituents of Potential Interest in Manufactured Wood (continued)

Fiberboard		
Product 1	tannin F	
Product 2 (Glacier Green HDF)	urea formaldehyde	10-14
	formaldehyde content	<0.1
	wax (paraffin)	<1
	melamine	>1
Product 3 (Glacier Green HDF, MDF & LDF)	urea formaldehyde	7-10
	ammonia	1
	wax (paraffin)	<1
	formaldehyde content	<1
Product 4 (Glacier Green NAF, NAUF fibreboard)	methylene-diphenyl-diisocyanate	5-10
	phenol-formaldehyde	7-10
	wax (paraffin)	1
Product 5 (Glacier Green HDF/MDF)	urea formaldehyde	7-10
	wax (paraffin)	<1
	melamine	>1
	ammonia	1
	free formaldehyde	<0.1
Product 6 (Ultra Core HDF)	phenol-formaldehyde	
	methylene-diphenyl-diisocyanate	5-10
	wax (paraffin)	1
Plywood		
Product 1 (Softwood Plywood)	phenol-formaldehyde resin	<1
Product 2 (Sheathing Plywood)	hydrotreated petroleum distillate	
	phenol-formaldehyde resin	1.5-3.5
	free formaldehyde	<0.1
Product 3 (Softwood Plywood)	phenol-formaldehyde	
Product 4 (Overlay Plywood)	free formaldehyde	<0.4
	phenol-formaldehyde	<0.7
	methanol	<0.04
Product 5	urea-formaldehyde and phenol-formaldehyde	

Table 5.3 Constituents of Potential Interest in Manufactured Wood (continued)

Pressure Treated Spruce		
Product 1	ethanolamine	3-7
	copper complex expressed as copper oxides	1-5
	benzyl-C12-18-alkyldimethyl, chlorides	0.1-1
	ammonium, didecyldimethyl-, chloride	0.1-1
	didecyldimethylammonium carbonate/bicarbonate	0.1-1
Product 2	monoethanolamine	1-5
	copper complex expressed as copper oxides	0.3-2.1
	brown azo dye	0.1-1
	alkyl dimethyl benzyl ammonium chloride*	0-1
	dialkyl dimethyl ammonium carbonate/bicarbonate*	0-1
	didecyl dimethyl ammonium chloride*	0-1
	boric acid (H3BO3)	0-0.1
	*(contains one of the given quaternary ammonium compounds depending on the type of ACQ Wood Preservative used)	
Product 3	chromic acid	0.1-1; 1-4
	arsenic acid	0.1-1; 1-4
	copper oxide (CuO)	0.1-1; 1-2

MDF	medium density fiberboard	MDF	medium density fiberboard
OSB	oriented strand board	LDF	low density fiberboard
HDF	high density fiberboard	NAF	no added formaldehyde
NAUF	no added urea formaldehyde		

6. Composting Experiments

Six sets of compost trials were completed over three years—the first set of eight batches were completed in 2009 at the Edmonton Waste Management Center of Excellence, the second and third sets of eight batches each were completed in 2013 at Acadia University, and the fourth, fifth and sixth sets of eight batches each were completed in 2014, also at Acadia University.

6.1 Edmonton Waste Management Center of Excellence (Set 1)

In 2009, eight feedstocks were prepared at the EWMCE in order to determine the impact of various manufactured woods on compost quality. Table 6.1 lists the wood products purchased; each sheet was sliced into strips using a skill saw, then chipped and stored in tubs before mixing (Figure 6.1).

Table 6.1 Manufactured Wood Constituents

Batch Number	**Wood Constituent**
1	Natural Mixed Wood Waste (control)
2	Oriented Strand Board (OSB)
3	Spruce Plywood (SP)
4	Medium Density Fiberboard (MDF)
5	Particleboard (PB)
6	Melamine (ML)
7	Hardboard (HB)
8-1	Fir Plywood (FP) (tongue & groove)

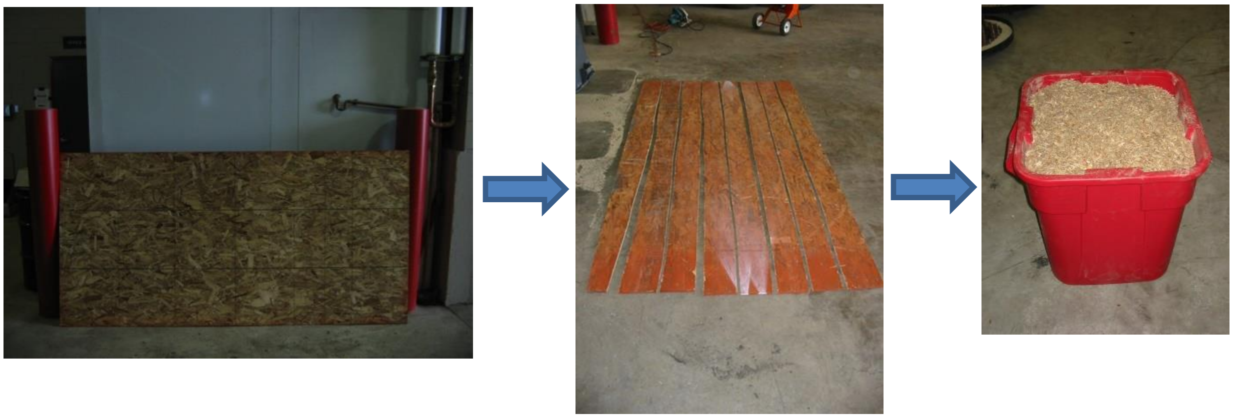


Figure 6.1 Preparation of OSB

Images of the remaining wood products incorporated into the compost mix are found in Figure 6.2.

Spruce Plywood MDF

Particleboard Melamine

Hardboard Fir Plywood (tongue & groove)

Figure 6.2 Remaining Wood Products Utilized in Set 1

The seven manufactured wood products were compared against a control, consisting of natural wood chips of a mixed origin obtained from a local arborist (Figure 6.3). The various wood constituents were then mixed with grass (Figure 6.4) and food waste (Figure 6.5) and composted over 74 days (August 26-November 7, 2009) in eight aerated barrels (Figure 6.6).

Figure 6.3 Natural Wood Waste

Figure 6.4 Grass Clippings

Figure 6.5 Food Waste

Figure 6.6 Barrels Loaded with Eight Mixtures

6.1.1 Process Results

Product from the eight samples were analysed in terms of temperature profile (Figures 6.7–6.14). The results are typical of a static aerated pile with a number of peaks associated with intermittent mixing. All batches achieved a temperature of over 55 ^{o}C which is typically associated with pathogen destruction and all batches produced high temperatures over the first two weeks, followed by a general decline with occasional temperature increases as the material was thoroughly re-mixed and re-aerated with the compost agitation device.

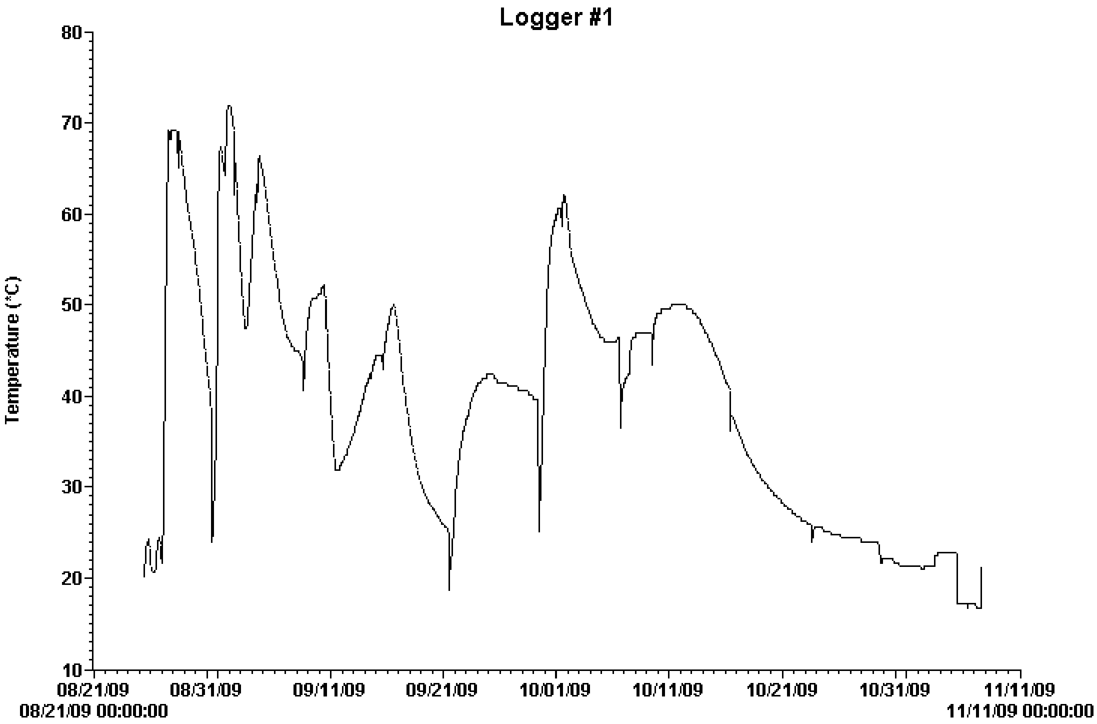


Figure 6.7 Natural Wood Waste (control) Temperature Profile

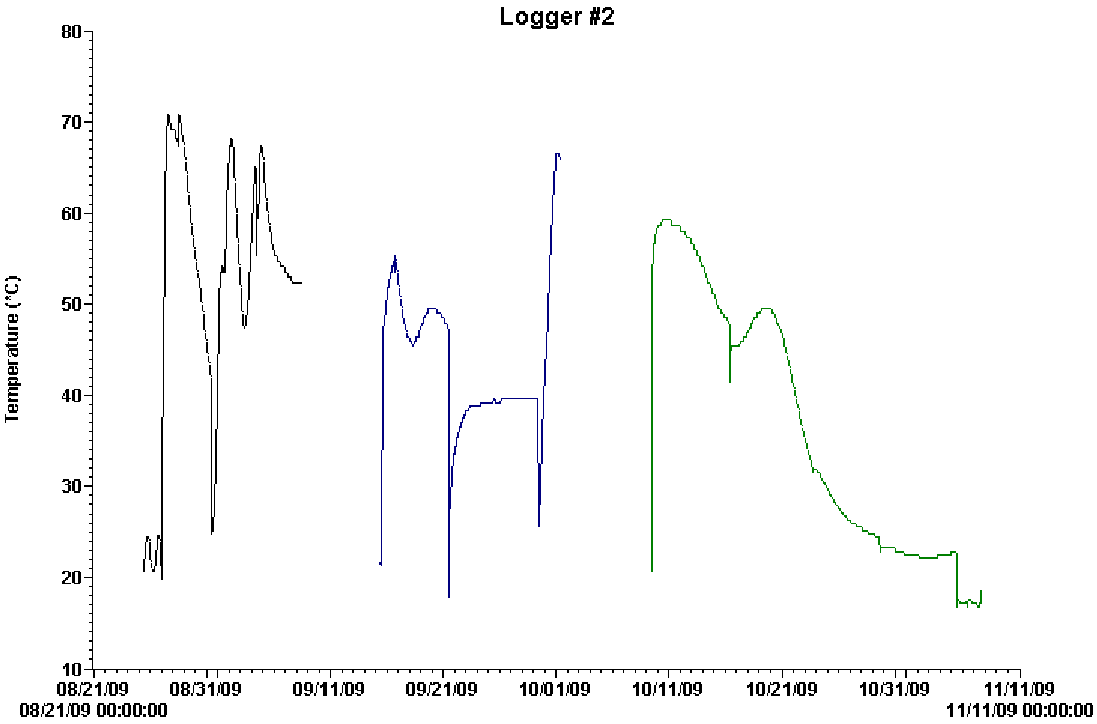


Figure 6.8 OSB Temperature Profile

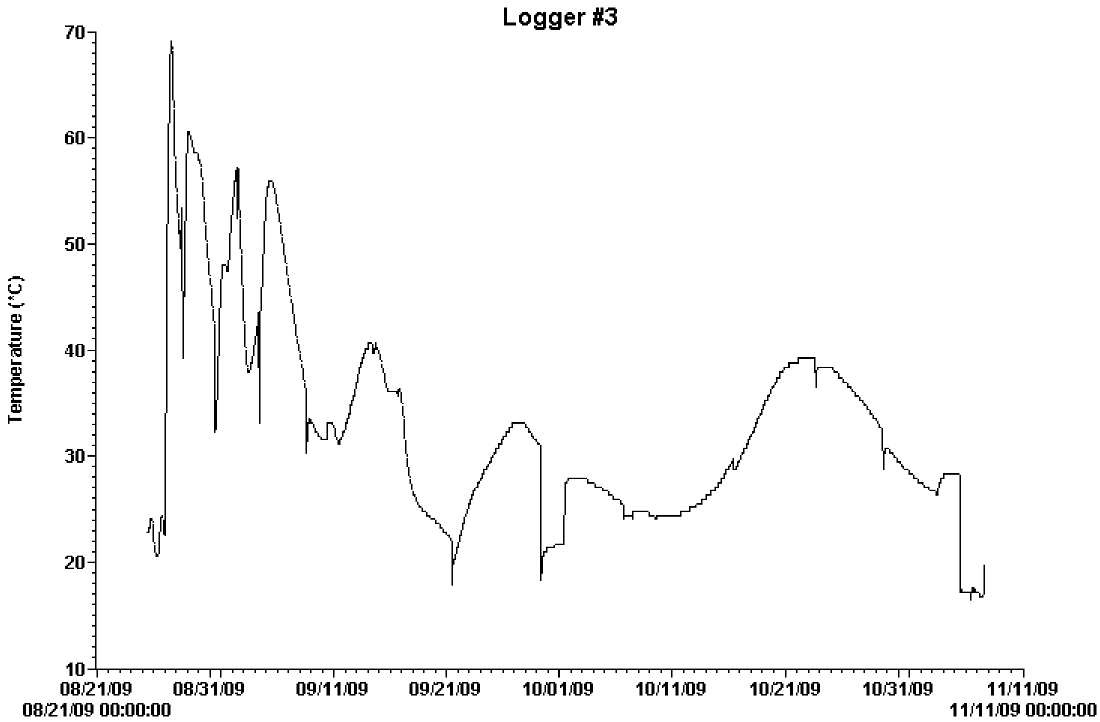


Figure 6.9 Spruce Plywood Temperature Profile

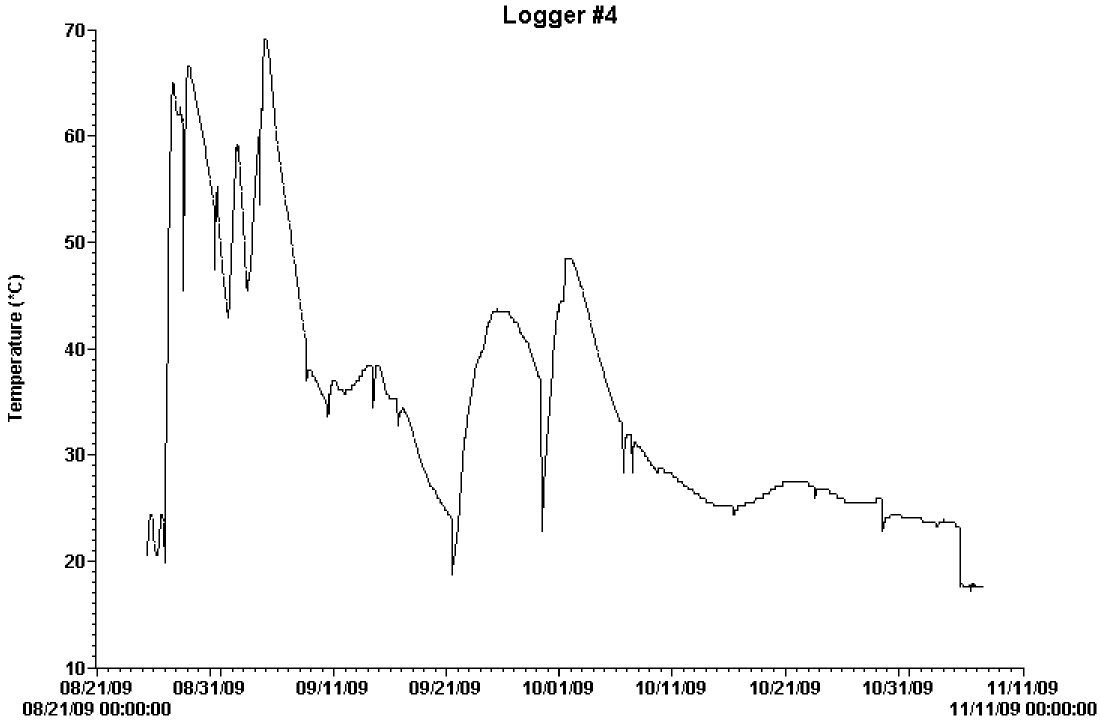


Figure 6.10 MDF Temperature Profile

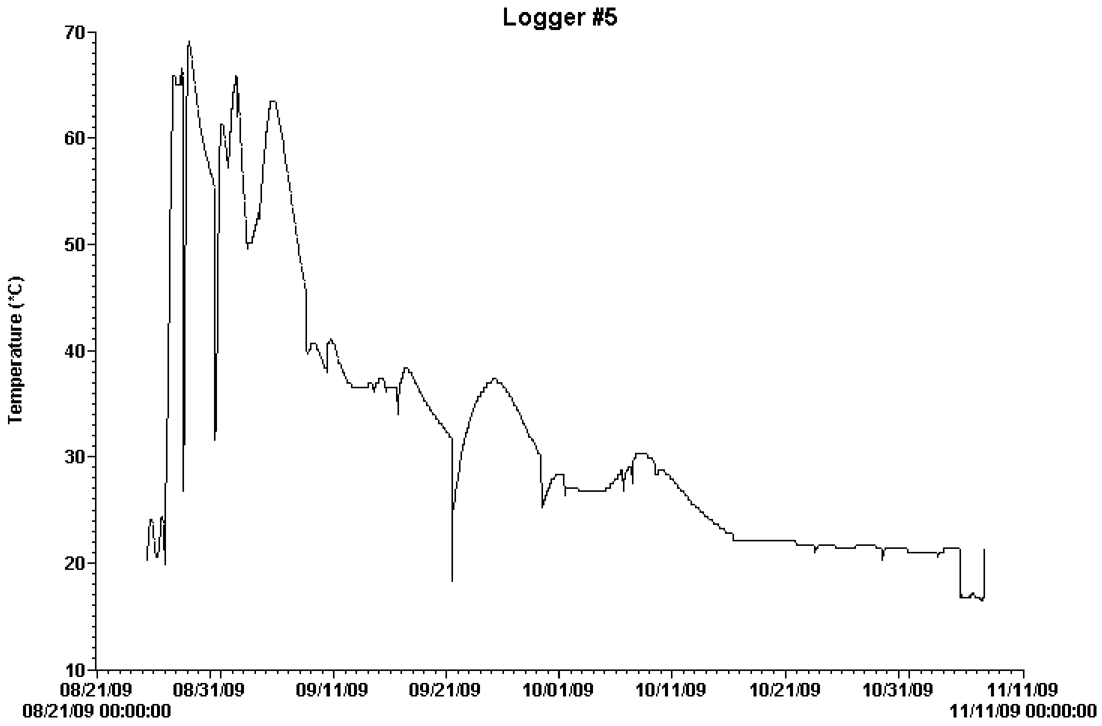


Figure 6.11 Particleboard Temperature Profile

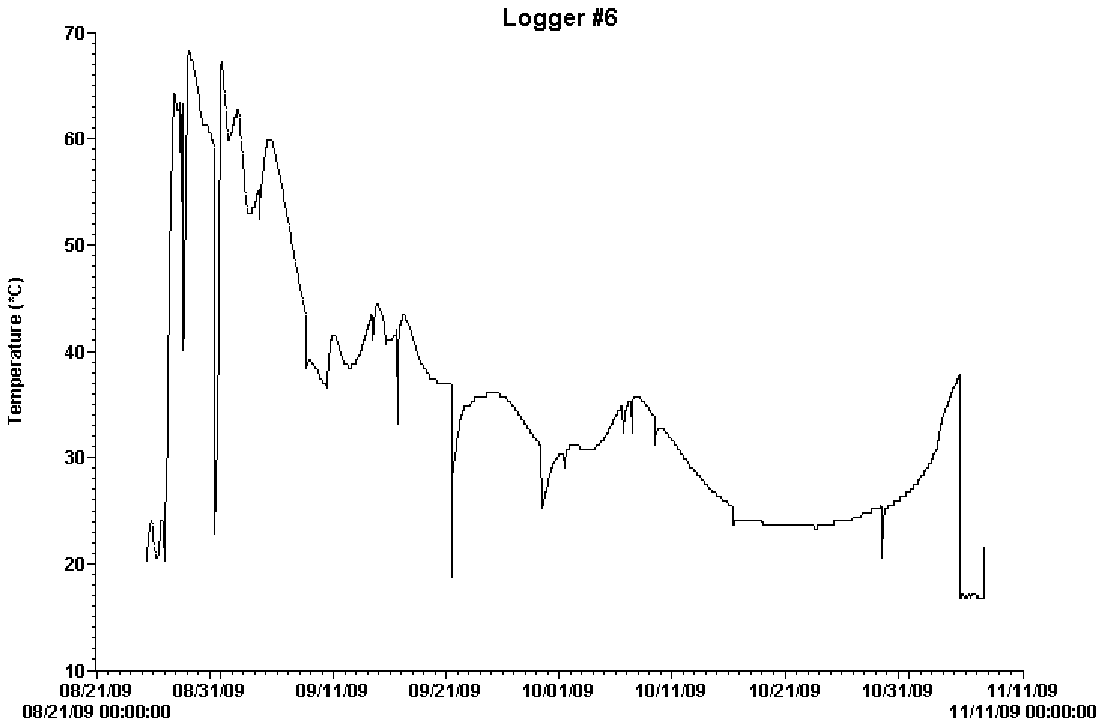


Figure 6.12 Melamine Temperature Profile

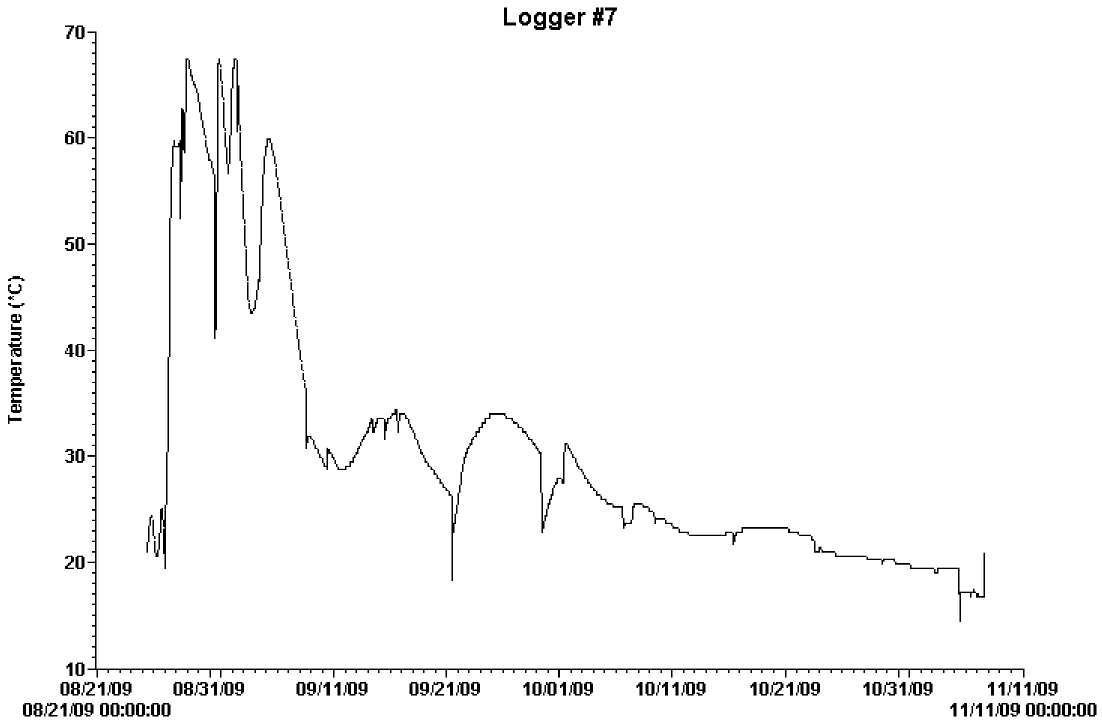


Figure 6.13 Hardboard Temperature Profile

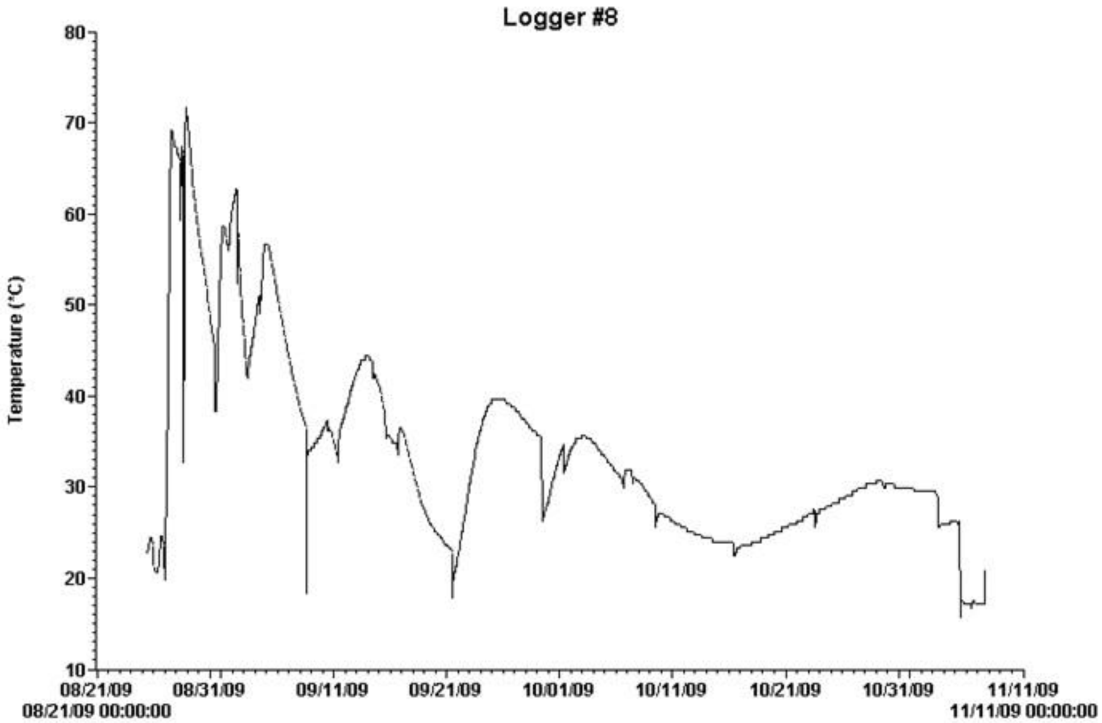


Figure 6.14 Fir Plywood (tongue & groove) Temperature Profile

To keep the samples at an appropriate moisture level, approximately 15 L of water was added on August 28 (day 3) and 7–15 L was added on August 31 (day 6); the corresponding moisture contents of the batches was reported between August 28–November 5 and remained above 50% (Figure 6.15).

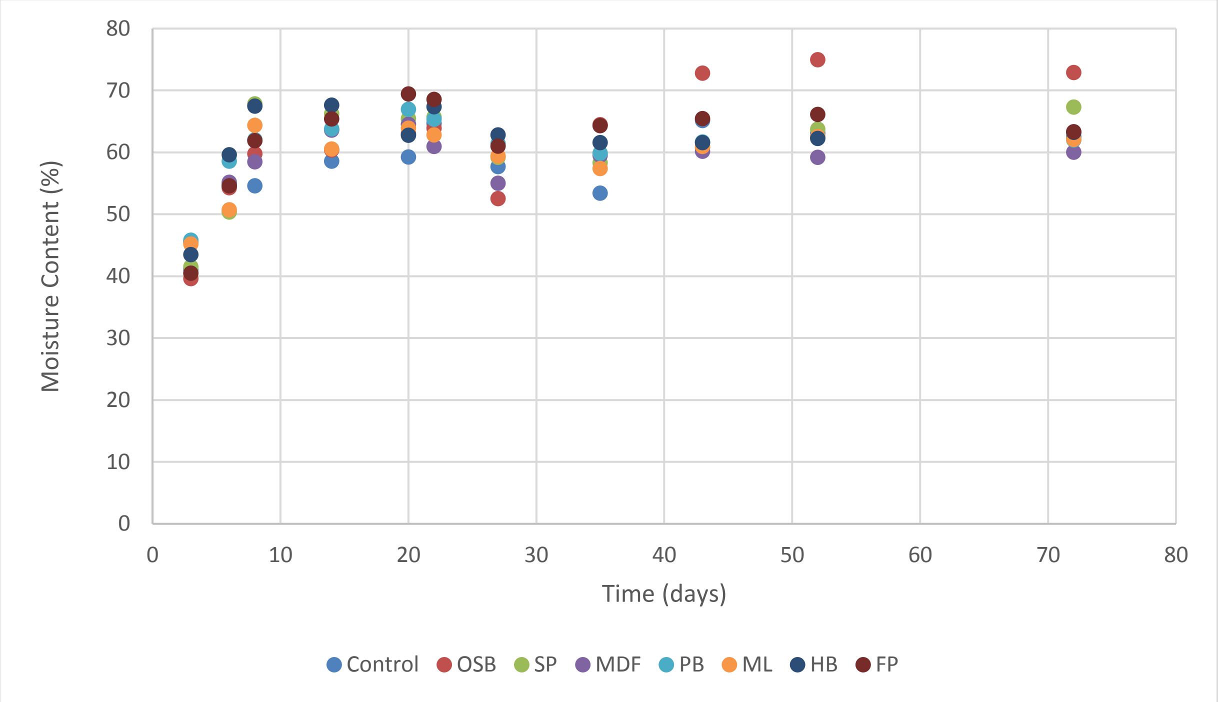


Figure 6.15. Moisture Content over Process Period

Table 6.2 Product Conductivities

	Conductivity (dS/m)
Control	2.39
OSB	2.42
Spruce Plywood	1.99
MDF	3.23
Particleboard	2.33
Melamine	1.96
Hardboard	3.61
Fir Plywood (T&G)	2.43

The electrical conductivity of the final product was measured; all products possessed conductivities between 2–3.6 dS/m which, according to the U.S. Composting Council, is within the typical range of 1–10 dS/m (http://compostingcouncil.org/test-methods-parameters/). Over the course of the composting period, samples were extracted from the composting batches for pH. The pH averaged 7.6 on August 31, rising to 8.9 by September 15 before falling back to 8.1 by October 7 which is indicative of a typical pH profile for compost systems in which the pH rises as the organic acids are consumed, leaving nitrogen-based (basic) compounds that are eventually consumed to lower the pH to a slightly basic state (Figure 6.16).

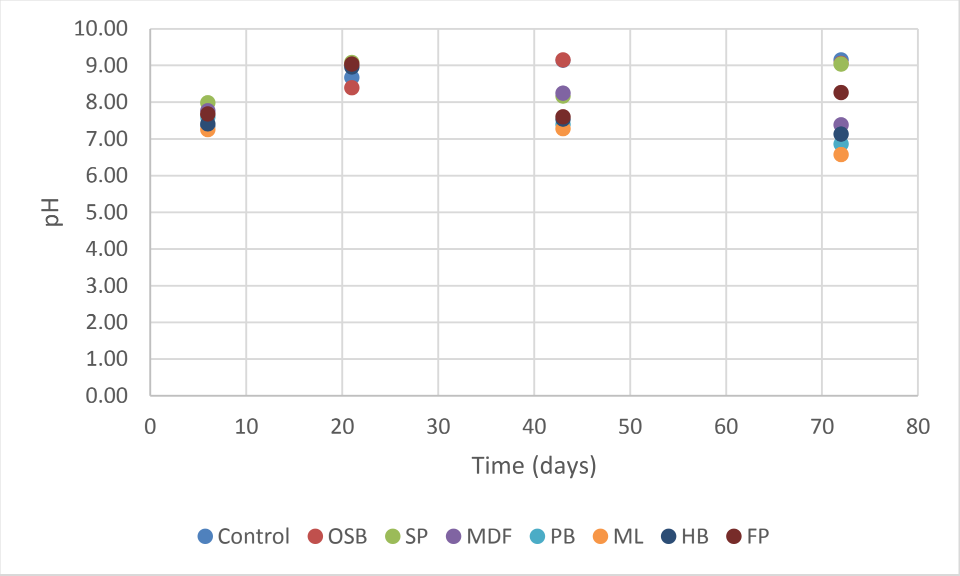


Figure 6.16 pH Readings over Compost Process

To provide some indication on the health of the microbial community, samples were extracted 14 and 21 days after the experiment began and plate counts were completed to estimate the total microbial population. As shown in Table 6.3 the number of colony-forming units (CFU) per gram of sample is extremely high, indicating a healthy microbial community.

Table 6.3 Estimate of the Microbial Population After 14 and 21 Days of Processing (CFU/g)

	Day 14	Day 21
Control	2.05×10^{11}	3.40×10^{10}
OSB	1.01×10^{11}	6.70×10^{10}
Spruce Plywood	1.57×10^{11}	7.70×10^{10}
MDF	3.11×10^{11}	1.71×10^{11}
Particle Board	4.90×10^{10}	6.50×10^{10}
Melamine	4.30×10^{11}	1.11×10^{9}
Hardboard	9.90×10^{10}	1.60×10^{10}
Fir Plywood (T&G)	5.80×10^{10}	1.50×10^{11}

6.2 Acadia University (Sets 2 & 3)

In the summer of 2013, two sets of eight batches each were completed at the KC Irving Center at Acadia University. The experimental design followed a similar path as the earlier trial in Edmonton, but also included a moisture trap to capture the liquid in the exhaust vapour before it was discharged to the room’s air handling system (Figure 6.17).

Figure 6.17 Experimental Apparatus for 2013 Trials

Wood products were purchased locally, cut into strips and chipped. As with the previous trial, batches contained natural wood waste that served as a control. The wood constituents used in the first of two trials are listed in Tables 6.4 and 6.5. The wood waste was mixed with source-separated organic waste from New Era Technologies (Figure 6.18), a regional composting facility, in proportions that produced an initial moisture content of 55%. The reactors were numbered in a manner continuing from the batch of 2009 based on their sample order.

Table 6.4 Manufactured Wood Constituents (Set 2)

Batch Number	Wood Constituent
10	Spruce Strapping I (control, SS I)
11	Hardboard (HB)
12	Spruce Plywood I (SP I)
14	Oriented Strand Board I (OSB I)
16	Corkboard (CB)
17	Melamine I (ML I)
19	Pressure Treated Spruce I (PT I)
20	Medium Density Fiberboard I (MDF I)

Table 6.5 Manufactured Wood Constituents (Set 3)

Batch Number	Wood Constituent
8-2	Spruce Plywood II (SP II)
13	Spruce Strapping II (control, SS II)
15	Spruce Strapping III (control, SS III)
21	Oriented Strand Board II (OSB II)
9	Spruce Strapping IV (control, SS IV)
32	Melamine II (ML II)
18	Medium Density Fiberboard II (MDF II)
33	Pressure Treated Spruce II (PT II)

Figure 6.18 SSO Waste from New Era Technologies Mixed with Wood Waste (insert)

6.2.1 Process Results

Temperature profiles typically provide the most immediate indication of composting process performance, for it is the release of heat through the exothermic process of composting that indicates the microbial community is consuming the organic waste. Figures 6.19-6.25 compare the temperature profiles of the various manufactured woods against the control for Set 2. In all cases, the manufactured wood samples experienced a delay in the temperature rise, quite possibly due to the initial inhibitory effect of the formaldehyde-bearing constituents. All samples, including the pressure treated spruce, did however eventually produce a temperature increase indicating that although activity was suppressed by approximately 5 days of composting, the microbial community had recovered and the decomposition had begun in earnest.

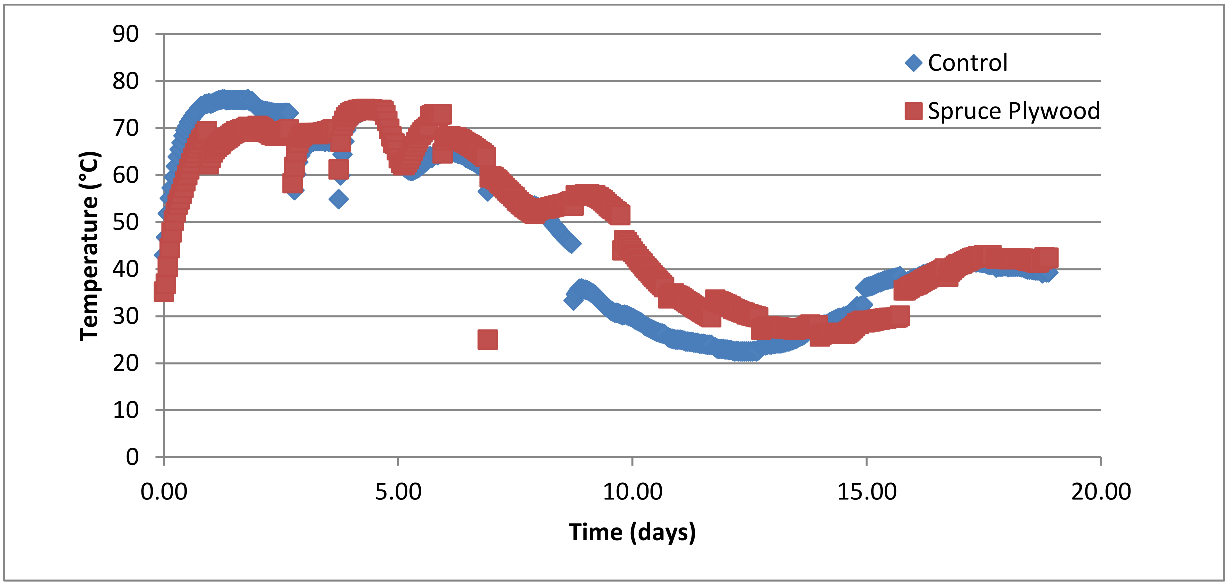


Figure 6.19 Temperature Profiles, Control vs. Spruce Plywood

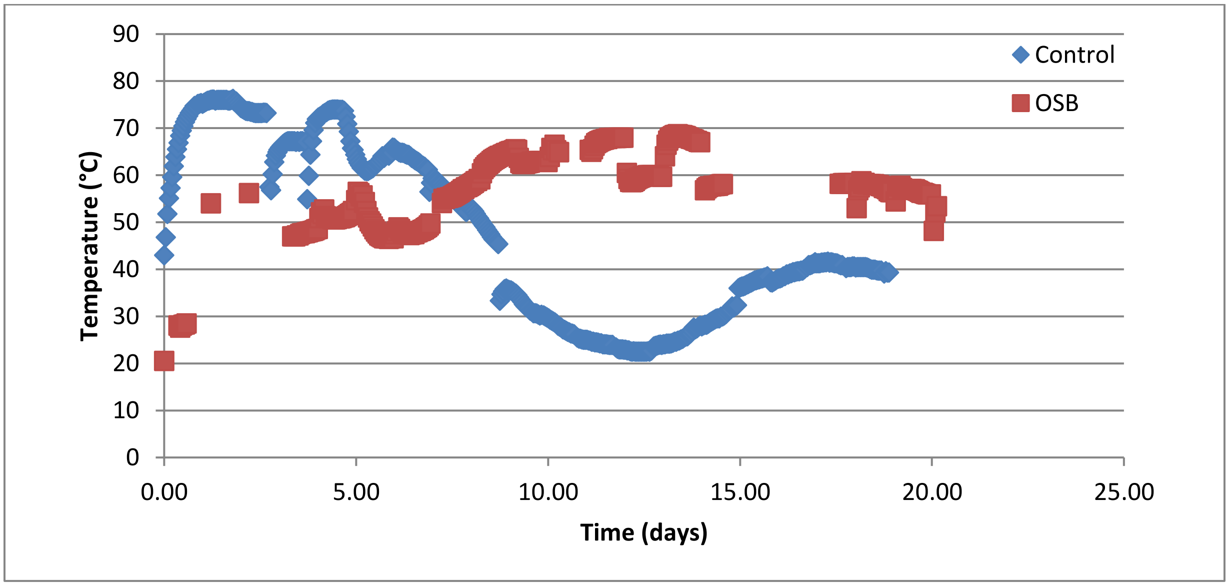


Figure 6.20 Temperature Profiles, Control vs. OSB

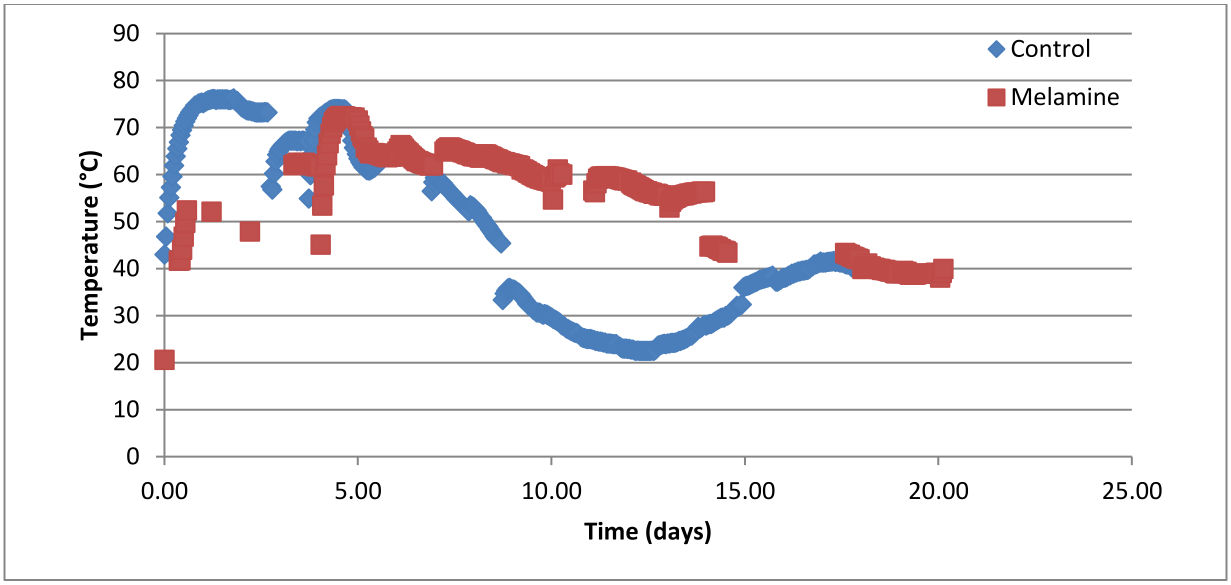


Figure 6.21 Temperature Profiles, Control vs. Melamine

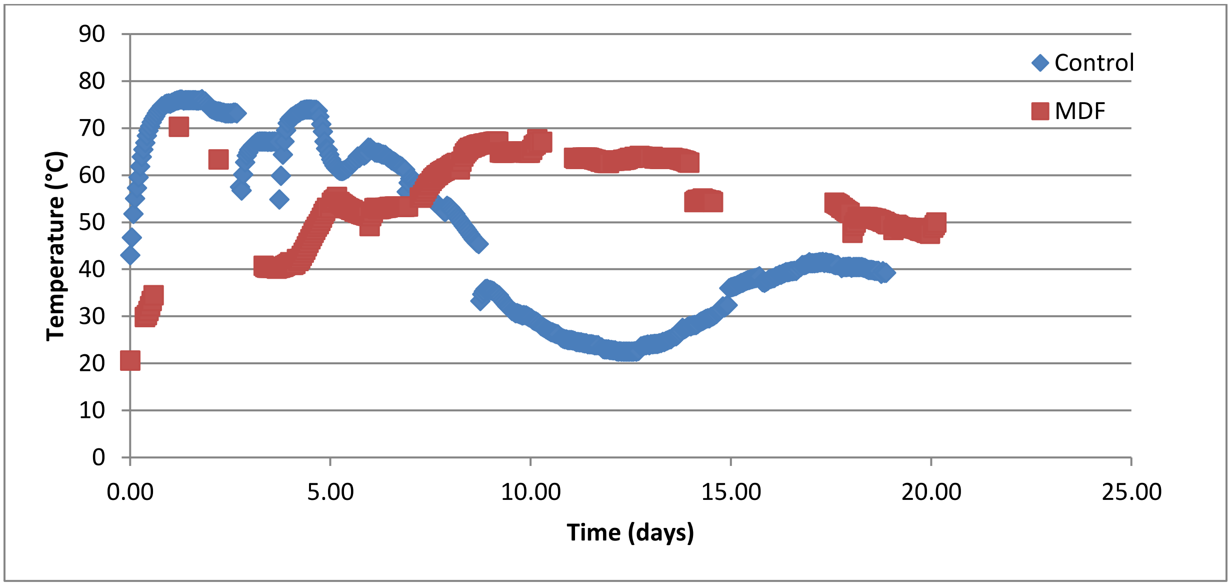


Figure 6.22 Temperature Profiles, Control vs. MDF

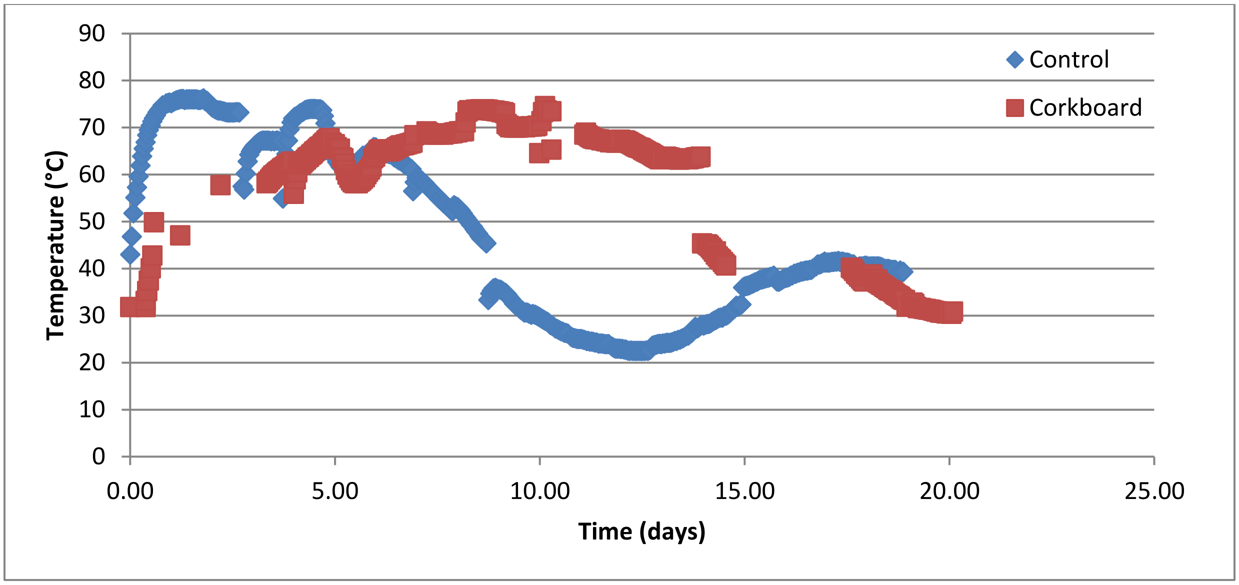


Figure 6.23 Temperature Profiles, Control vs. Corkboard

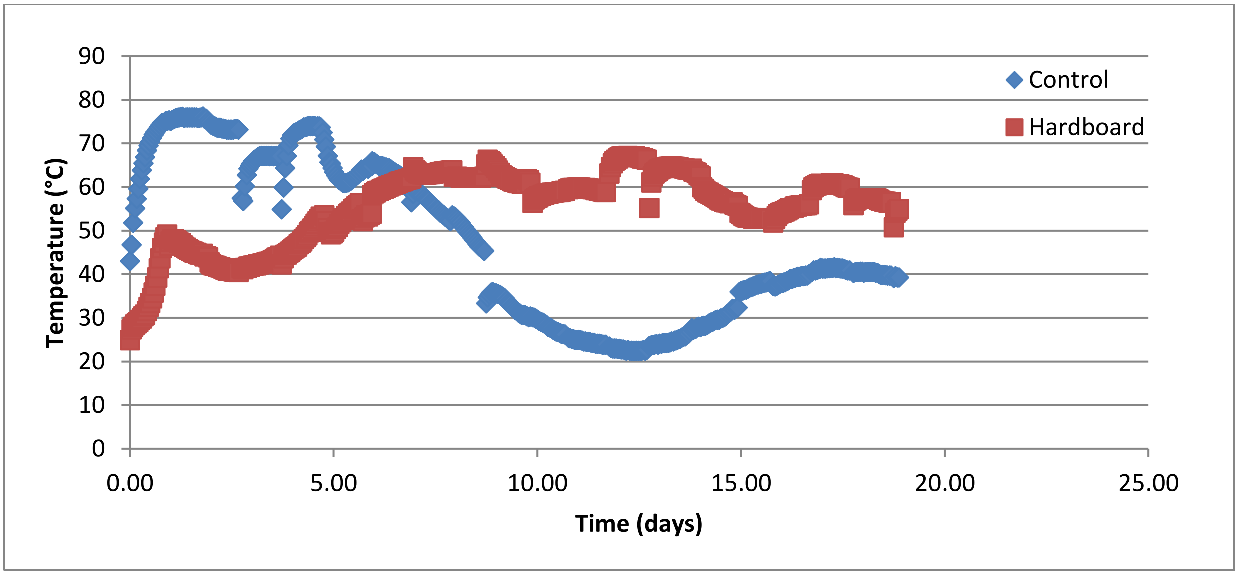


Figure 6.24 Temperature Profiles, Control vs. Hardboard

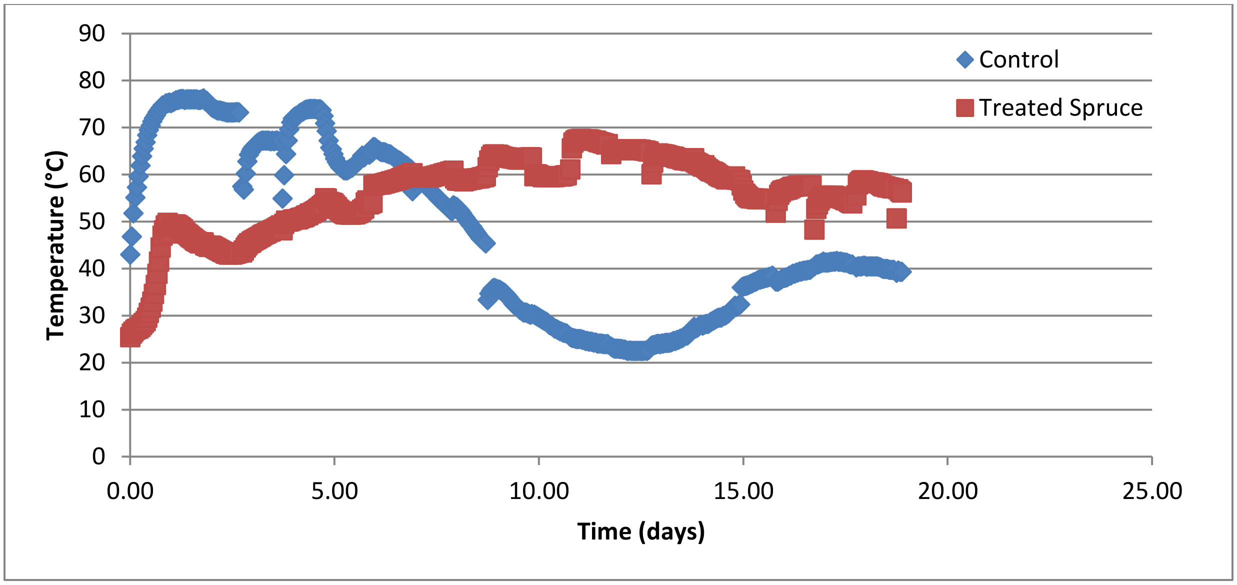


Figure 6.25 Temperature Profiles, Control vs. Treated Spruce

Unlike the initial trial in Edmonton, process gas from each batch was directed through a hose located on the top of the reactor which led to a condensate trap to collect any condensate before it was discharged through an additional hose directed to the room's exhaust system. Table 6.6 presents the amount of condensate produced over the initial stage of decomposition for Set 2. Although the rate varied over the 409 h of processing due to the temperature of the batch at any time, the total amount of leachate produced from each batch was reasonably consistent, ranging from 2.9 kg for pressure treated wood to 4.4 kg for spruce plywood.

Table 6.6 Mass of Condensate Collected Over Preliminary Stage of Decomposition, Set II (g)

Time (h)	Spruce Strapping I	Spruce Plywood I	OSB I	Melamine I	MDF I	Cork Board	Hard-board	Pressure Treated I
0	758	710	18	110	360	102	70	84
23.7	646	812	98	100	418	122	92	102
47.2	500	786	102	194	502	146	126	112
70.9	288	500	196	232	432	120	66	124
95.5	496	834	536	366	594	194	378	182
168.5	90	192	472	516	230	364	424	286
192.3	66	276	572	608	238	502	530	416
215.6	26	128	402	212	196	388	432	338
239.7	10	58	366	438	170	422	468	334
263.8	4	26	252	486	134	330	380	256
336.4	38	22	68	224	14	118	90	156
359.8	34	28	50	208	12	180	128	198
384.8	28	20	32	152	10	154	136	184
408.9	30	40	12	126	12	134	68	162
Total	3014	4432	3176	3972	3322	3276	3388	2934

The pH of the condensate from each batch was also measured 14 times during the primary stage of composting for Set 2; the results are found in Table 6.7.

Table 6.7 Condensate pH

Time (h)	Spruce Strapping I	Spruce Plywood I	OSB I	Melamine I	MDF I	Cork Board	Hard-board	Pressure Treated I
0	8.60	8.05	3.11	2.86	7.64	2.88	2.96	2.97
23.7	8.54	8.43	2.88	2.89	8.03	2.86	2.98	2.94
47.2	8.55	8.52	2.73	2.67	8.18	2.64	2.88	2.75
70.9	8.49	8.57	2.88	2.86	8.46	2.83	3.02	2.95
95.5	8.66	8.75	7.15	4.29	8.55	2.85	5.79	2.86
168.5	8.14	8.00	8.59	8.23	8.77	8.36	8.38	8.28
192.3	8.10	7.89	8.75	8.60	8.82	8.50	8.62	8.35
215.6	8.08	8.00	8.62	8.70	8.82	8.44	8.60	8.26
239.7	8.17	8.13	8.56	8.67	8.84	8.50	8.67	8.18
263.8	8.10	8.16	8.18	8.68	8.86	8.40	8.68	8.13
336.4	7.18	7.71	8.22	8.60	8.70	8.10	8.51	8.04
359.8	7.63	7.55	8.22	8.60	8.73	8.14	8.52	8.25
384.8	7.88	7.57	8.24	8.59	8.69	8.17	8.63	8.26
408.9	8.02	7.73	8.06	8.56	8.61	8.02	8.61	8.28

Clearly, the condensate from the OSB, melamine, corkboard, hardboard and pressure treated samples were very acidic initially, probably due to the constituents within those wood products and a lack of readily available nitrogen, however, all recovered to slightly basic conditions by 168.5 h as the readily available acids were neutralized.

The purpose of the composting process is, through the process of microbial activity, to stabilize organic waste such that, over time, the composting mass contains less readily compostable material and thus possesses a lower demand for the oxygen used by the microbes to digest the waste which implies a more mature compost. Table 6.8 provides the respiration rate of the three fresh SSO samples before being mixed with the wood wastes and compares the demand for oxygen (in terms of respiration rate) between the fresh samples and the product after 14 days of composting in the barrels for Set 2. Clearly, there is a significant decline in the respiration rates, which implies the decomposition process is effectual and the experimental design is supportive of a high rate of microbial activity and the product is well on its way to reaching the maximum threshold for a mature product of 400 mg oxygen per kg of organic matter per hour.

Table 6.8 Reduction in Respiration Rate (two-day average) over Two Weeks of Composting

	Respiration Rates (mg Oxygen/kg Organic Matter/h)		
	Day 0	Day 14	% Decline
Spruce Strapping I	5404	1331	75.4
Spruce Plywood I	8355	1328	84.1
OSB I	8197	1371	83.3
Melamine I	7062	1149	83.7
MDF I	4751	1213	74.5
Cork Board	9193	2217	75.9
Hard Board	14406	2417	83.2
Pressure Treated I	13860	3214	76.8
Fresh Feedstock Prior to Mixing With Wood	8193		
	10481		
	7763		

6.2.2 Particle Size Distribution

In 2014, one year after the various feedstocks were composted, the products were screened to determine the particle size distribution (Table 6.9). Note also that the table is sorted with descending values of “product” material such that the majority of most products can pass through a 5/16” screen. While many samples contained a significant quantity of product capable of passing through the 8 mm (5/16”) screen, the quality of the product was debatable for some materials such as MDF. As MDF in particular did not appear to decompose dramatically over the year of decomposition, the final product was predominantly light-coloured sawdust, which by its nature is more recalcitrant to decay.

Table 6.9 Particle Size Distribution of 2014 Products

Sample	S1 >25.4 mm	S2 19-25.4 mm	S3 16-19 mm	S4 10-16 mm	S5 8-10 mm	Product <8 mm
MDF I	8.2%	5.1%	2.8%	7.0%	5.5%	71.4%
Spruce Plywood II	6.9%	4.6%	5.6%	8.2%	6.5%	68.2%
Corkboard	7.2%	4.6%	3.7%	9.0%	7.5%	68.1%
Melamine I	8.2%	6.3%	4.7%	9.0%	7.2%	64.7%
Hardboard	9.3%	5.2%	5.7%	10.8%	6.0%	63.1%
OSB I	8.8%	4.7%	4.3%	11.6%	8.9%	61.7%
OSB II	17.9%	5.4%	4.5%	9.5%	6.2%	56.6%
Melamine II	7.0%	4.2%	4.0%	12.1%	18.5%	54.3%
Spruce Plywood I	9.6%	7.6%	4.7%	13.1%	11.3%	53.7%
Spruce Strapping I	4.6%	5.5%	6.4%	18.4%	12.4%	52.6%
Pressure Treated Spruce I	11.8%	7.3%	4.3%	14.4%	9.8%	52.3%
Pressure Treated Spruce II	6.8%	8.4%	8.3%	18.5%	9.2%	48.7%
Spruce Strapping IV	6.3%	5.0%	8.1%	21.1%	15.6%	44.1%
Spruce Strapping III	4.3%	5.3%	6.7%	23.4%	17.5%	42.8%
Spruce Strapping II	8.4%	5.4%	5.2%	21.0%	17.3%	42.7%
MDF II	12.3%	5.8%	12.7%	17.5%	13.4%	38.3%

6.3 Acadia University (Sets 4, 5 & 6)

In the summer of 2014, an additional three sets of eight batches each were completed on both manufactured wood and coated and treated woods. Set 4 composted SSO with manufactured woods similar to those of Sets 1-3 while Sets 5 and 6 composted SSO with typical mixed wood waste from C&D facilities that includes manufactured woods as well as coated and painted woods. The experimental design was identical to that of a year earlier. Each barrel reactor was set up with an air source installed in the bottom and sealable lid installed on top with all exhaust air being ventilated properly to control odours and condensate emanating from the compost collected from the exhaust air using an Erlenmeyer flask. The barrels were filled close to the brim to maximize the use of the barrel. The headspace was recorded periodically during the trial to track compaction as a means of indicating progress.

Air flow was regulated to the barrels using the Argon flow regulators for arc welding machinery; temperatures were logged continuously by Extec thermocouple loggers and K-type thermocouples.

6.3.1 Process Results: Set 4 (Manufactured Woods)

Prior to investigating streams of wood waste, it is important to understand, as a baseline, the impact of new manufactured wood products independently. This provided some understanding of the composition of the wood prior to introducing the addition of wood with uncontrollable amounts of coatings and paints. Further, by isolating the wood types, it is possible to identify wood types that may be necessary to eliminate or reduce.

As a starting point for this research, the first phase focused on comparing the effect of decomposing unused (new) isolated samples of each wood product type. The goal was to determine how each manufactured wood type behaves during decomposition. Note that while material isolation was considered important the same agitation tool was used for all samples and was cleaned but not washed between samples.

A 1:1 volume ratio of bulking agent to organic waste was assumed to emphasize the mediating effect of bulking agents as well as increase the concentration of any residual from the wood product. Note this 1:1 volume ratio corresponds to a mass ratio of approximately two parts of SSO to one part wood waste (Table 6.10).

Table 6.10 Manufactured Wood Constituents (Set 4)

Batch Number	Wood Constituent	Ratio of Wood to SSO by Volume	Initial Mass Contents (kg)
34	Spruce Strapping I (control, SS I)	1.13	46.3
35	Spruce Plywood (SP)	1.10	57.9
36	Oriented Strand Board (OSB)	1.10	59.2
37	Melamine	1.14	50.6
38	Medium Density Fiberboard (MDF)	1.10	62.4
39	Corkboard	1.12	19.0
40	Spruce Strapping (control, SS II)	1.11	61.0
41	Pressure Treated Spruce (PT)	1.16	59.0

6.3.2 Process Results: Set 5 (Manufactured & Coated Woods I)

While the first phase of this paper studied the isolated effect of each manufactured wood product independently, the second phase takes a practical approach by utilizing currently available processed construction waste. The wood waste was sourced from Halifax C&D in Goodwood, NS on July 4, 2014 and terminated on August 6, 2014 for a total run of 33 days.

Currently in NS, construction waste is diverted from traditional waste streams and landfills and is instead processed by private third-parties that are paid tip fees to process and dispose (resell, reuse, otherwise) of the waste. Halifax C&D processes the waste with the intent to resell the separated or processed waste as a product. Currently LaFarge (in Halifax, NS) purchases the bulk of the non-wood waste and Brooklyn Pulp and Power is the largest purchaser of wood waste which is used for biomass-sourced thermoelectric power generation.

Halifax C&D was also a participant in a 2010 Divert NS-funded program to encourage the use of recycled wood waste as a cattle bedding following the closure of lumber yards/mills in NS (from which the sawdust was previously used as cattle bedding). Through the program, Halifax C&D was able to tailor their finest-grade product to the needs of farmers and cattle by varying the composition (portion wood fibres and a portion of wallboard) as well as the specific process to manufacture the product. Ultimately the program was a success and Halifax C&D services more than 25 farms in NS with cattle bedding. The associated Divert NS report indicates a 20% savings in using the recycled product instead of fresh sawdust, in addition to other benefits of increased antibacterial properties of manufactured cattle bedding over raw sawdust.

Halifax C&D produces three wood product mixes: single grind (utilized predominantly by Brooklyn Pulp and Power), double grind, and triple grind (cattle bedding). The first two products are relatively inexpensive compared to the cattle bedding. Thus it would seem most interesting to investigate the use of single or double grind as a bulking agent given the economics. While it can be presumed that neither single or double-grind provide the same particle size distribution, these products would provide the most cost-effective means for compost facilities to enjoy the benefits of wood as a bulking agent, especially as not all facilities use bulking agents, at a more affordable price.

Seven barrel reactors were prepared for this trial using the three types of ground wood waste (Table 6.11) and SSO from Northridge Farms. The initial volumetric and mass ratios are reported in addition to the initial mass of the organic waste that was processed. A volumetric ratio of 1:1 was attempted for the barrel reactors 1-6 and a more economical 3:1 (SSO:wood) ratio was selected for the final barrel to determine if reducing the wood constituent would negatively impact the decomposition process. The material was provided by Halifax Construction and Demolition in Halifax, NS. All product was intended to be free of any metallics or nails.

Table 6.11 Constituent Mix for Set 5

Batch Number	Wood Constituent Halifax C&D	Volumetric Wood/SSO Ratio	Mass Wood/SSO Ratio	Initial Mass Contents (kg)
42	Single-grind A	1.10	0.369	73.0
43	Single-grind B	1.20	0.403	37.4
44	Double-grind A	1.10	0.381	73.6
45	Double-grind B	1.10	0.381	73.6
46	Triple-grind A	1.14	0.386	51.7
47	Triple-grind B	1.02	0.345	64.5
48	3:1 single-grind	0.33	0.115	107.0

The single grind is a product that Halifax C&D retails predominantly to Brooklyn Power Co. for the production of biomass energy (~27 MW as of 2014). Particles sizes are large and irregular. Machine costs are insignificant as material is only shredded and run past a magnet to remove metals (nails) but may contain aluminum.

Double grind offers the benefits of single-grind but decreased particle size (and thus density).; there is no substantial cost increase from single-grind product.

Triple-grind is processed to a much smaller particle size, kiln dried, and is amended with gypsum. The primary market for triple-grind product is for use as cattle bedding for farmers. Since the closure of the wood mills in Nova Scotia, the farmers needed a replacement for sawdust as bedding for animals. The triple-grind was trialed in 2010 with select farms in NS. In 2014, Halifax C&D serviced 25 farms in NS with the product. The product is refined and heavily processed and thus is prohibitively expensive (Table 6.12). It was noted that the triple grind product had gypsum added for increased calcium content (gypsum contains 21% calcium).

Table 6.12 Cost of Various Feedstocks

Material	Cost per tonne
Sawdust	$1,650
Wood-wallboard	$1,155
Kiln-dried	$1,425

(RRFB / Halifax C&D joint research project on alternative cattle-bedding material)

It was noted that the price of sawdust and kiln-dried shavings will increase with increased demand for biomass energy, however, an increase in the cost of wood-wallboard was not expected unless a demand for wood-wallboard as a soil amendment develops.

A particle size distribution was performed on the three wood types, producing the results in Figure 6.26; the cumulative particle size distribution is shown in Figure 6.27.

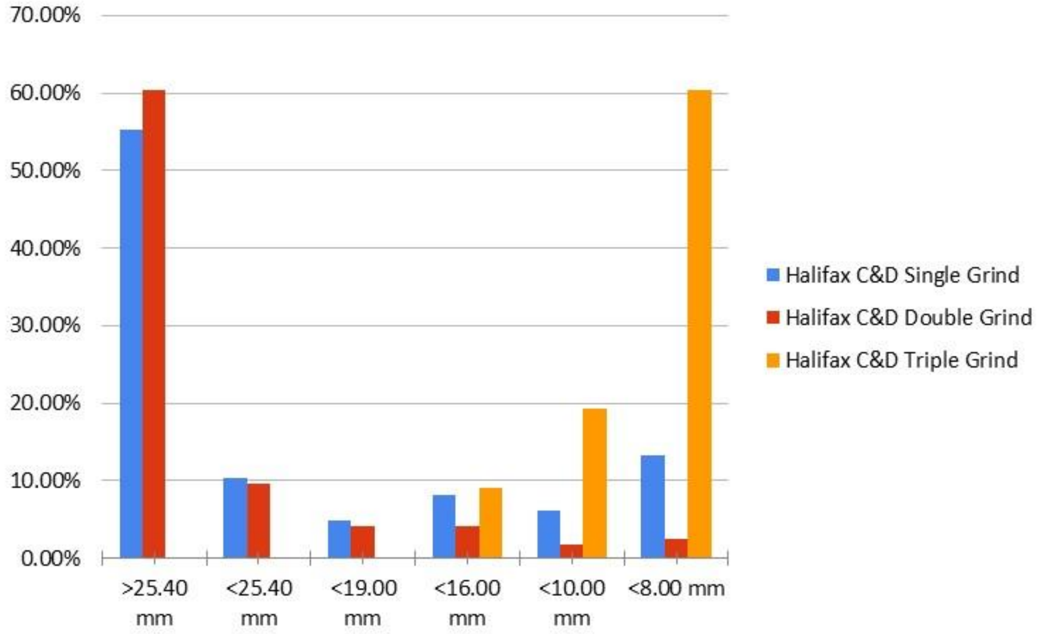


Figure 6.26 Particle Distribution of Three Halifax C&D Products

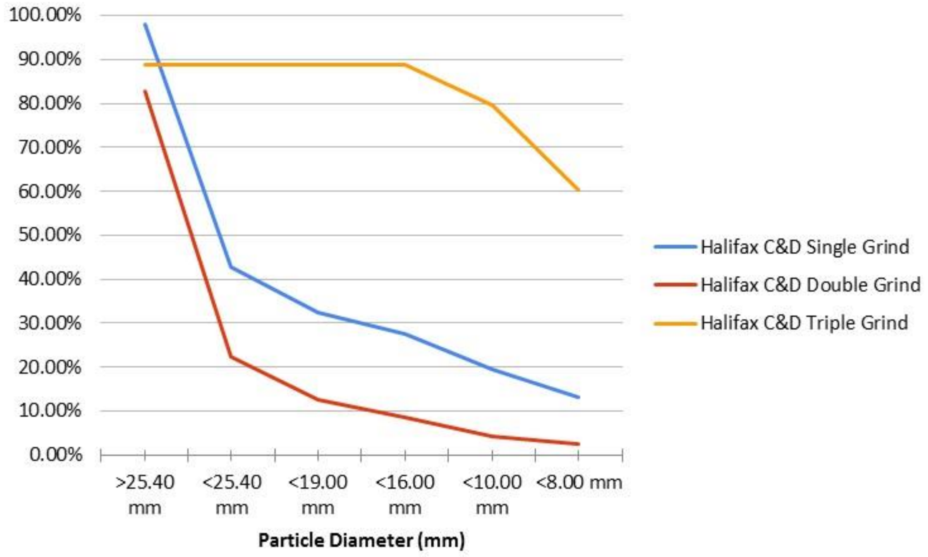


Figure 6.27 Cumulative Particle Size Distribution of Three Halifax C&D Products

6.3.2.1 Single-grind Products

Because of the very coarse nature of the single-grind product, it was very difficult to agitate the barrel's contents thoroughly (especially the bottom portion of each reactor below the aeration feed tube) during the composting process. This, in addition to the fact that the coarse wood had little moisture absorption capacity led to the formation of very odorous, opaque, free-standing leachate in the bottom of the barrels. In other barrel reactors this was also found, though not to the extent of the three single-grind barrel reactors.

It was noted that the product from the 3:1 mixture (v/v) of single grind wood visually resembled commercially produced compost in that it attained a darker hue during the trial period and developed a familiar white mold throughout (the mold, unlike in the others, was pure white and doesn't create fibrous filaments across the surface).

Given the procedures used, it was determined that the use of single-grind may be useful with larger-scale reactors that could accommodate the substantially larger particles, specifically with a more powerful mechanism for agitation (such as windrow turners and loaders utilized in various facilities in Nova Scotia). On this basis, the single-grind wood amendment was eliminated from use in Set 6.

6.3.2.2 Double-grind Products

Given that the double-grind contains less metallics (due to another pass by a magnet) and is further ground (thus increasing absorption capacity), the rate of breakdown was expected to be the higher. From a cost perspective, double-grind is perhaps the most promising, given that the particle size has already been reduced (thus increasing available surface area for microbial decomposition) and should, in theory, offer the greatest benefit to compost mixing.

It is worth noting that the double-grind material sourced from Halifax C&D for Set 6 was processed differently than the double-grind material in Set 5 in that it was processed using two different machines, whereas the Set 5 samples were doubly-processed by the same machine yielding a smaller average particle size and less metallic content.

6.3.2.3 Triple-grind Products

Triple-grind material experienced substantial compaction on the transport from Halifax C&D (in Goodwood, NS) back to Acadia (Wolfville, NS) shrinking by approximately 6" in the 100 USG barrel. In the barrel reactors, which were originally filled to just short of the brim, the level quickly fell low enough that the thermocouples had to be extended to reach the pile of compost for an accurate temperature reading.

During agitation, it was noted that the pile quickly became dense and agitation with the hand-powered rotating auger was arduous given the apparent composition (mostly fine sawdust particulate and sparse food waste that quickly broke down).

The triple grind was noted to contain gypsum and this was expected to produce an elevated presence of elemental calcium in the finished product; the gypsum is deliberately amended to the product as it improves the moisture retention ability beyond the wood product alone and was found to reduce microbial population counts in its application as a bedding material.

Ultimately the final composted product predominantly resembled the triple-grind wood waste and was not a visually appealing product for use as a compost, but may achieve reasonable results with the addition of sand or other soil/compost(s).

There was a clear reduction in the mass of the organic matrix over the compost process, in part due to the loss of moisture as the process proceeded, and also due to the conversion of organic matter to carbon dioxide as the microbial respiration process proceeded (Table 6.13).

Table 6.13 Mass Reduction in Composted Batches

Batch Number	Wood Constituent	Initial Mass Contents (kg)	Final Mass Contents (kg)	% Mass Reduction
42	Single-grind A	73.0	47.5	34.9
43	Single-grind B	37.4	21.1	43.6
44	Double-grind A	73.6	48.3	34.4
45	Double-grind B	73.6	53.3	27.6
46	Triple-grind A	51.7	38.3	25.9
47	Triple-grind B	64.5	28.9	55.2
48	3:1 single-grind	107.0	62.6	41.5

6.3.3 Process Results: Set 6 (Manufactured & Coated Woods II)

The final round of trials (Set 6) consisted of four batches and was operated from August 8, 2014 through until August 24, 2014, for a total run of two weeks. The schedule was established to agitate Monday, Wednesday and Friday with small screened samples collected for ashing each Monday and Friday (for a total of 5 samples collected). In addition to utilizing the double- and triple-grind from Halifax C&D, a single-grind wood product from the Eastern Management Centre of Valley Waste Resource Management (VWRM) was incorporated to provide an alternative wood amendment to the single-grind product from Haifax C&D used in Set 5.

6.3.3.1 VWRM Single-grind

The material is sold as hog fuel exclusively to Brooklyn Power for electricity generation, but VWRM offers composted brush to the public as mulch and soil for free. Unlike Halifax C&D, the pile had a much longer turnover period and appeared to be reasonably weathered and on track to decompose (the product had a dark brown colour indicative of partial decomposition), as compared to the almost-new quality at Halifax C&D. This could be attributed to the relative handling capacities and inflow volumes likely being substantially different between the two facilities.

The particle size distribution analysis was performed on the single-grind material from VWRM and is found in Table 6.14.

Table 6.14 Particle Distribution of Single-grind Wood from VWRM

>25.40 mm	<25.40 mm	<19.00 mm	<16.00 mm	<10.00 mm	<8.00 mm	<4.00 mm
11.2%	11.8%	7.11%	14.3%	8.41%	17.8%	29.4%

By standard convention, material screened to 8 mm is considered "product" and thus, from this data it can be concluded that, from the start, 47.2% of the single grind material was already reduced to product size. Further, it is the small particles with greater surface area per unit mass that are responsible for facilitating microbial activity. Thus single-grind material appears innately useful as a carbon source amendment, but the relative proportion of oversized particles is small and thus the utility as a bulking agent may be reduced (due to less airspace created in the pile via amendment).

6.3.3.2 Double-grind Halifax C&D

The double-grind material for Set 6 was noted as being different than the material that was procured for the previous Set 5. Instead of being double-processed with the same machine as last time, the wood was instead first processed through the AK-430, then through an additional shredder. From a practical standpoint, this means the wood waste should be of smaller particle size on average and contain less metallics due to a stronger magnet.

From a material properties perspective, the double-grind would seem to provide a reasonable blend of bulking properties due to larger airspace created by larger particle sizes (58.3% > 25.4 mm in diameter by mass) and biologically active fine particles (7.11% < 8 mm in diameter by mass). It is expected that the normal decomposition process combined with frequent agitation of the barrel reactors will result in a shift in particulate distribution as larger wood particles are broken down (Table 6.15).

Table 6.15 Particle Distribution of Double-grind Wood from Halifax C&D

>25.40 mm	<25.40 mm	<19.00 mm	<16.00 mm	<10.00 mm	<8.00 mm	<4.00 mm
58.3%	12.5%	7.59%	8.83%	4.92%	5.22%	1.90%

6.3.3.3 Triple-grind Halifax C&D

The triple-grind wood for Set 6 was produced in the same manner as in Set 5 and was thus expected to have a nearly identical particle size distribution (Table 6.16).

Table 6.16 Particle Distribution of Triple-grind Wood from Halifax C&D

>25.40 mm	<25.40 mm	<19.00 mm	<16.00 mm	<10.00 mm	<8.00 mm	<4.00 mm
0.00%	0.00%	0.00%	7.53%	15.8%	40.4%	34.2%

As with Set 5, it was expected that the triple-grind material will fail to provide the physical bulking properties that aid in aeration and effective decomposition of the compost in the barrel reactor. Furthermore, if the wood:SSO ratio is too high, the final product would be expected, as was found in Set 5, to yield a fibrous product that is visually unappealing and dusty. Conversely, given the high fine particulate portion (74.6% by mass), which provides a significant total available surface area, rapid decomposition would be expected.

It is also worth repeating that the product is deliberately mixed with gypsum (due to benefits for use in cattle bedding as it is intended to retard microbial activity, perhaps through moisture absorption) and thus elevated calcium levels would be expected in the resultant product. A comparison of particle distribution between the three wood sources on an individual and size distribution basis is provided in Figures 6.28 and 6.29, while the cumulative distributions are shown in Figure 6.30. Note that the triple grind material had an error of approximately 2.1% that was attributed to losses of ultra-fine particulates; thus this error was added to the smallest particle size bin (<4.00 mm) to normalize the results.

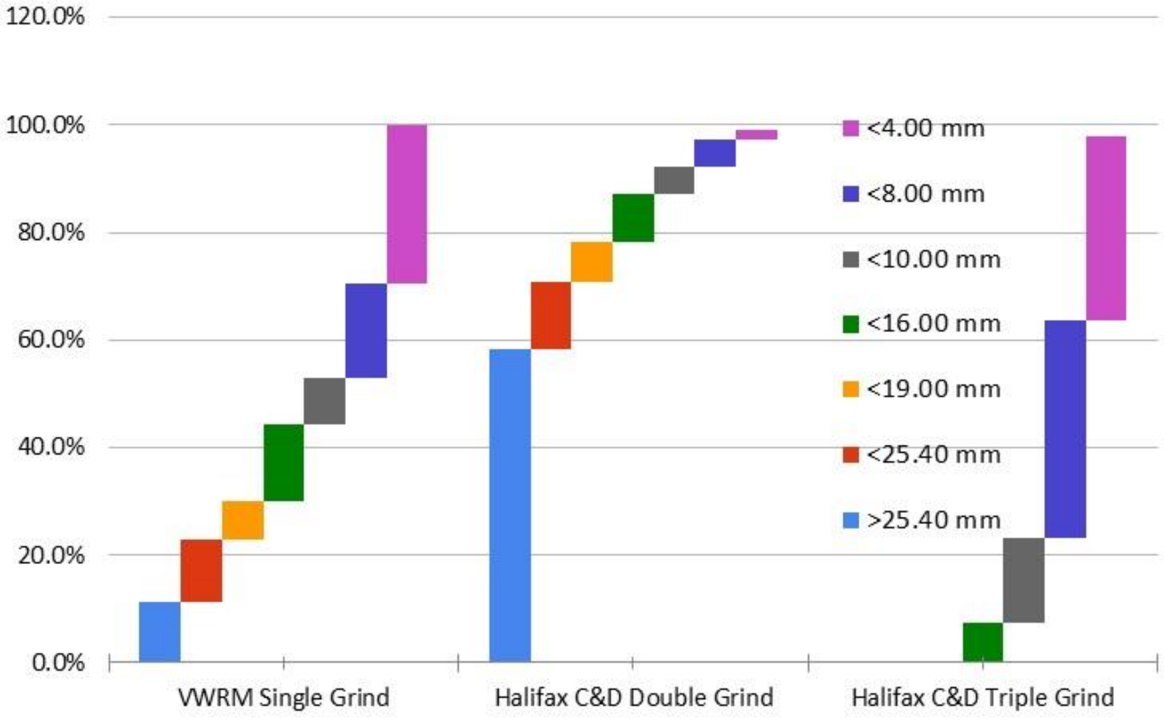


Figure 6.28 Particle Distribution of Individual Wood Products

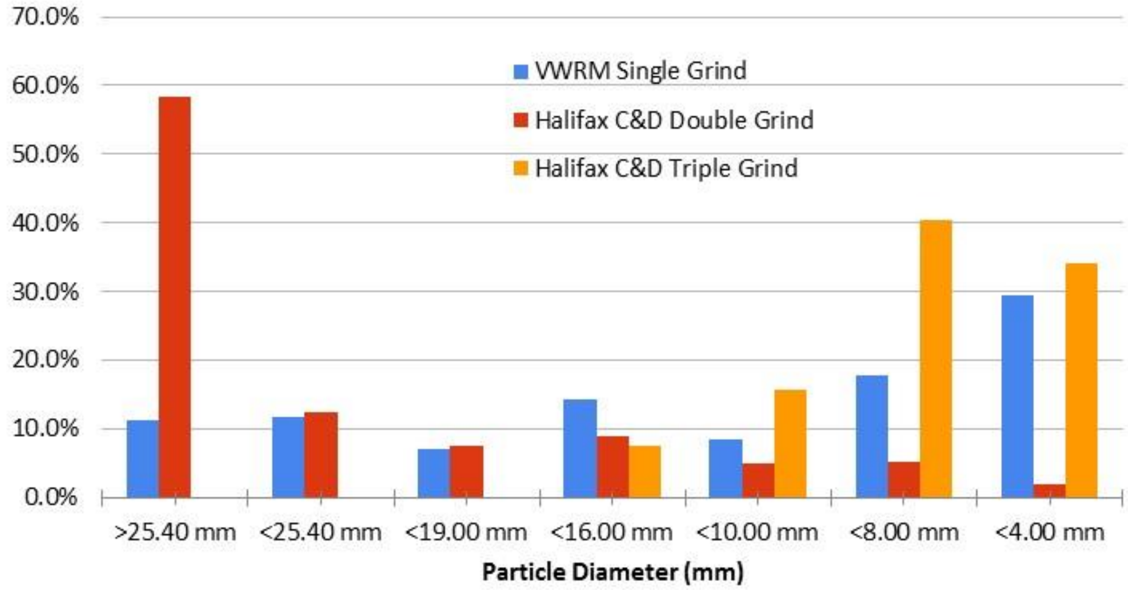


Figure 6.29 Comparison of Particle Distributions Between Wood Products

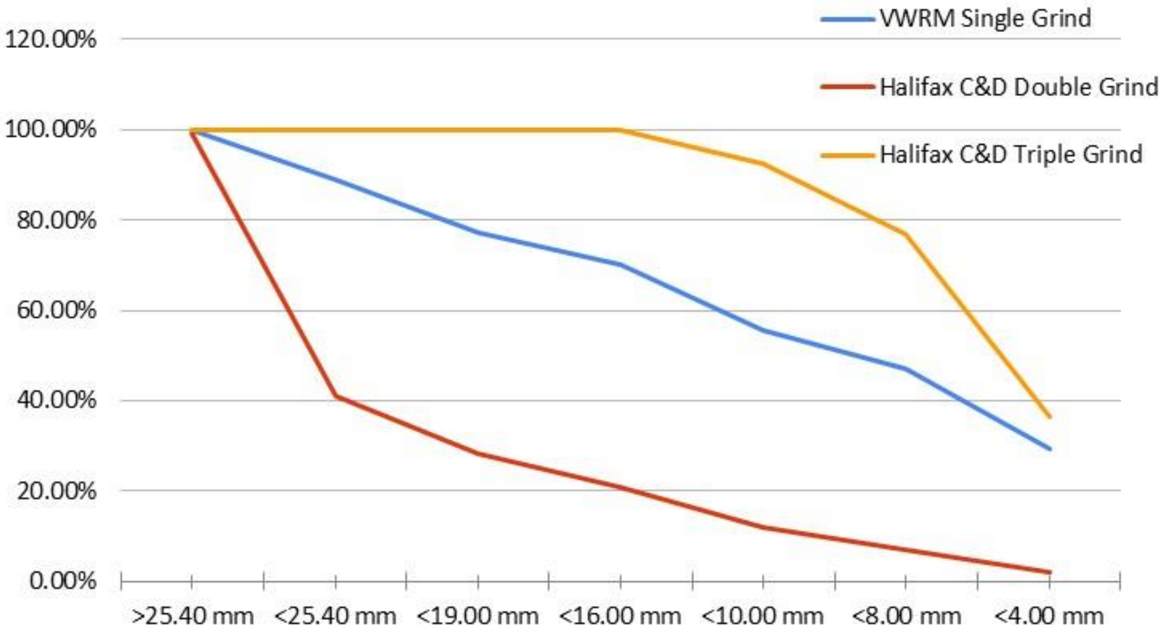


Figure 6.30 Cumulative Particle Distribution of Wood Products

6.3.3.4 Other Feedstock Properties & Product Analyses

Samples were initially analyzed to determine physical properties that may be useful in determining external reproducibility of the tests and to contextualize the findings. Further, it characterized the wood waste provided by Halifax C&D and VWRM. These tests included a determination of the unpacked density of the material by filling and weighing a container of known volume of 11.32 L (Table 6.17).

Table 6.17 Density of Experimental Feedstocks

	VWRM Single-grind	Halifax C&D Double-grind	Halifax C&D Triple-grind	SSO
Mean density (kg/m^3)	252.9	145.3	127.6	450.1

Further, a screened sample of each was taken for determination of volatile solids, and in the process, moisture content. These results are presented below (Table 6.18).

Table 6.18 Volatile Solids & Moisture Content of Feedstocks

	Average Pan wt (g)	Average Wet wt (g)	Average Dry wt (g)	Average Ash wt (g)	Average Moisture Content (%)	Average Volatile Solids Content (%)
VWRM Single-grind	2.885	7.545	5.585	3.700	41.11%	69.34%
Halifax C&D Double-grind	1.883	4.890	4.413	1.921	15.87%	98.60%
Halifax C&D Triple-grind	1.941	3.878	3.639	1.978	12.29%	97.85%
SSO	2.346	12.284	6.033	3.566	63.14%	67.47%

Note that VS contents near to 98/99/100% were considered erroneous and were re-samples; as the two wood samples are relatively stable, it would not be expected for these to change dramatically over weeks or even months in laboratory conditions. It was, however, found that these follow-up samples also yielded unexpectedly high results. It was noted that for both the original and follow-up samples, that the muffle furnace did not exceed normal operating conditions (with the temperature stable approximately between 530ºC and 570ºC; that is, the recommended 550ºC ± 3.6%, within standard temperature accuracy expected by standard convention (note that the TMECC defines that an immersion heater must maintain temperature at 25.0 ± 1.0 ºC, which represents a 4% allowable variance).

Set 6 consisted of four batches involving double- and triple-grind wood waste from Halifax C&D and single-grind wood waste from VWRM (Table 6.19).

Table 6.19 Constituent Mix for Set 6

Batch Number	Wood Constituent	Volumetric Wood/SSO Ratio	Mass Wood/SSO Ratio	Initial Mass Contents (kg)
42	Double-grind A	1.0	0.32	73.0
43	Double-grind B	0.5	0.16	37.4
44	Triple-grind	0.5	0.14	73.6
45	Single-grind	1.25	0.70	73.6

The temperature profiles of two of the four samples are provided in Figure 6.31 (the temperature profile of the single-grind sample was unavailable due to a faulty thermocouple). The temperature of both batches easily exceeded the required threshold for pathogen disinfection and remained high as the monitoring stage came to a close.

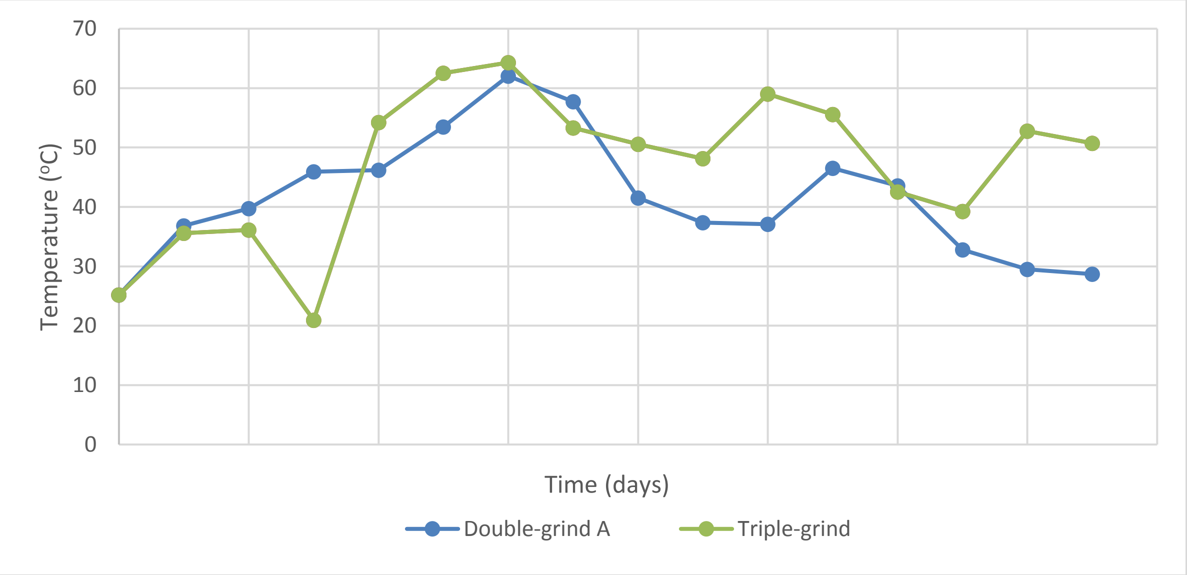


Figure 6.31 Temperature Profiles of Double-grind and Triple-grind Batches

Overall, in under two weeks the organic content was reduced by over 10% (on average), which is perhaps a limited means of tracking maturity or progression of the compost process. As the particles were initially large and exceedingly heterogeneous, the agitation and decomposition progressively degraded the material to smaller particle sizes (Table 6.20).

Table 6.20 Constituent Mix for Set 6

Wood Constituent	Organic Matter Day 0 %	Organic Matter Day 11 %	Organic Matter Decrease %
Double-grind A	87.0	74.4	14.5
Double-grind B	81.5	75.8	7.0
Triple-grind	75.0	59.5	20.7
Single-grind	86.8	79.0	9.0

7. Metals Analysis

Metals analyses constitute a major part of assessing compost quality. Compost samples are typically tested for 11 metals to determine if they exceed the threshold established in the CCME Guidelines (2005). Based on test results, compost is either declared as Category A (unrestricted use) or Category B (restricted to non-agricultural applications). Metals thresholds for the two categories are found in Table 7.1

Table 7.1 Metals Thresholds as Established by the CCME

Trace Metals	Category A Maximum Concentration (mg/kg DS)	Category B Maximum Concentration (mg/kg DS)
Arsenic	13	75
Cadmium	3	20
Chromium	210	
Cobalt	34	150
Copper	400	
Lead	150	500
Mercury	0.8	5
Molybdenum	5	20
Nickel	62	180
Selenium	2	14
Zinc	700	1850

Thirty-one samples were tested for their metal content to determine their acceptability. The samples were grouped as composted wood-SSO products, pure C&D wood samples, and pure manufactured wood samples.

The metals content of the composted wood-SSO products from 2009 and 2013 are presented in Tables 7.2 and 7.3. In comparing the natural wood with the manufactured woods of 2009, there was very little difference in the metals concentrations, as the natural wood metals concentrations fell between those of the manufactured woods with the exception of zinc. A similar comparison of composted wood-SSO products from 2013 indicated an unacceptably high concentration of copper in the pressure treated spruce sample which was expected, as copper is a major constituent in the preservative. The metals content of the remaining samples differed in terms of copper and zinc content, however, all were within acceptable standards for Category A compost and, with the exception of copper and zinc, the highest metals content was found in one of the four natural spruce samples.

Table 7.2 Metals Concentrations in Composted SSO-Wood Products from 2009 (Set 1)

	Maximum Concentration (mg/kg DS) Category		Control (natural wood)	OSB	Spruce Plywood	Particle Board	Melamine	Hardboard	Tongue & Groove Plywood
	A	B							
Arsenic	13	75	3	3	2	2	2	7	3
Cadmium	3	20	1.3	1.9	<0.3	0.3	0.4	0.4	<0.3
Chromium	210		6	5	4	4	4	10	6
Cobalt	34	150	2	2	1	1	<1	2	2
Copper	400		42	29	26	15	16	58	23
Lead	150	500	8.6	5.9	3.9	6.4	9.6	28.5	7.9
Mercury	0.8	5	0.13	0.12	0.14	0.07	0.08	0.07	0.16
Molybdenum	5	20	3	3	2	<2	<2	<2	2
Nickel	62	180	13	9	6	6	6	13	7
Selenium	2	14	<1	<1	<1	<1	<1	<1	<1
Zinc	700	1850	205	182	83	76	66	83	135

Table 7.3 Metals Concentrations in Composted SSO-Wood Products from 2013 (Sets 2&3)

	Maximum Concentration (mg/kg DS) Category		Spruce Strapping (natural) Control				Spruce Plywood I	Spruce Plywood II	Hardboard
	A	B	I	II	III	IV			
Arsenic	13	75	9	8	7	7	7	7	5
Cadmium	3	20	0.4	0.6	1.2	0.4	0.4	0.4	0.4
Chromium	210		15	15	17	15	14	14	11
Cobalt	34	150	3	4	3	4	3	3	3
Copper	400		53	55	52	55	75	44	35
Lead	150	500	52.9	40.6	58	37.7	51.3	47.5	26.8
Mercury	0.8	5	0.06	<0.05	<0.05	0.06	<0.05	<0.05	<0.05
Molybdenum	5	20	<2	<2	<2	<2	<2	<2	<2
Nickel	62	180	11	11	11	12	11	10	8
Selenium	2	14	<1	<1	<1	<1	<1	<1	<1
Zinc	700	1850	209	201	175	201	334	214	136

Table 7.3 (con't) Metals Concentrations in Composted SSO-Wood Products from 2013 (Sets 2&3)

	Maximum Concentration (mg/kg DS) Category A	B	Corkboard	Melamine	MDF I	MDF II	OSB I	OSB II	Pressure Treated Spruce
Arsenic	13	75	7	6	4	5	6	7	8
Cadmium	3	20	0.4	0.4	<0.3	<0.3	0.6	0.5	0.4
Chromium	210		13	13	8	10	12	14	21
Cobalt	34	150	3	3	2	2	3	3	3
Copper	400		43	50	30	27	47	44	1220
Lead	150	500	38.2	41.4	17.2	33.8	29.3	47.4	52.9
Mercury	0.8	5	0.05	0.05	<0.05	0.05	<0.05	<0.05	0.06
Molybdenum	5	20	<2	<2	<2	<2	<2	<2	2
Nickel	62	180	9	10	6	7	9	10	12
Selenium	2	14	<1	<1	<1	<1	<1	<1	<1
Zinc	700	1850	188	198	95	133	205	224	184

In assessing the pure, uncomposted manufactured wood sources (Table 7.4), it quickly becomes clear that manufactured woods contribute little to the metals content of a composted product. Manufactured woods had available metals well below the CCME thresholds and the highest metals contents were often in the natural wood. This could be due in part to the fact that manufactured woods go through a process of high temperature and pressure in which some of the more mobile constituents within the wood may leach from the product, thus lowering the content of the remaining metals.

In all cases, the products were below the maximum allowable concentration of Category A compost and therefore would enjoy unrestricted use regardless of the type of wood used as an amendment; the full metals analyses are found in Appendix D.

Table 7.4 Metals Concentrations in Pure Wood Sources

	Maximum Concentration (mg/kg DS) Category		Pure OSB	Pure Particle-board	Pure Fir Plywood	Pure Hard-board	Pure MDF	Pure Spruce Plywood	Pure Melamine	Pure Control (natural wood)
	A	B								
Arsenic	13	75	2	2	2	3	2	1	2	5
Cadmium	3	20	1	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	1.5
Chromium	210		3	3	4	3	<2	2	6	6
Cobalt	34	150	<1	<1	<1	<1	<1	<1	<1	1
Copper	400		4	<2	3	20	2	<2	<2	13
Lead	150	500	6.8	7.7	8	8	1.2	1.8	18.2	5.9
Mercury	0.8	5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.13
Molybdenum	5	20	<2	<2	<2	<2	<2	<2	<2	<2
Nickel	62	180	<2	<2	<2	<2	<2	<2	<2	9
Selenium	2	14	<1	<1	<1	<1	<1	<1	<1	<1
Zinc	700	1850	81	15	23	19	19	15	23	195

Uncomposted C&D wood waste from two provincial sites, however, did have metal concentrations in exceedance of provincial thresholds (Table 7.5). Single grind wood waste from Valley Waste Resource Management had arsenic and zinc concentrations above Category A thresholds, while the lead content even exceeded the allowable concentration for Category B compost. Triple ground wood waste from Halifax C&D also had higher lead levels, although it was acceptable for Category B standards, however, the arsenic level exceeded the Category B threshold

Table 7.5 Metals Concentrations in Mixed C&D Wood Waste

	Maximum Concentration (mg/kg DS) Category		Mixed Wood Waste I*	Mixed Wood Waste II**
	A	B		
Arsenic	13	75	28	103
Cadmium	3	20	0.9	0.5
Chromium	210		40	148
Cobalt	34	150	9	3
Copper	400		109	314
Lead	150	500	1860	232
Mercury	0.8	5	0.55	0.33
Molybdenum	5	20	<2	<2
Nickel	62	180	17	4
Selenium	2	14	<1	<1
Zinc	700	1850	1640	426

*single grind from Valley Waste Resource Management

**triple grind from Halifax C&D

8. Chemical Analyses

Sample extractions to date

Each extraction condition (sample, solvent, duration) is performed in triplicate to account for variability of the samples. All samples are treated in a blind fashion and the extraction and GC analyses are randomized for each sample to avoid biases.

The table below indicates the preliminary extractions performed for each sample and condition to be tested. Triplicates are shown as columns 1, 2, and 3. Note that the quantities of samples initially provided for testing were not sufficient to treat all conditions. For example, samples 1, 3 and 5 were not extracted with acetone. One extraction with acetone was performed on sample 2.

	Methanol									Chloroform									Acetone								
	4h			6h			20h			4h			6h			20h			4h			6h			20h		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Sample 1 (1)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨									
Sample 2 (2)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨							▨		
Sample 3 (1)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨	▨	▨	▨											
Sample 4																											
Sample 5 (2)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			▨											
Sample 6 (1)																											
Sample 7 (2)																											
Sample 8 (1)																											

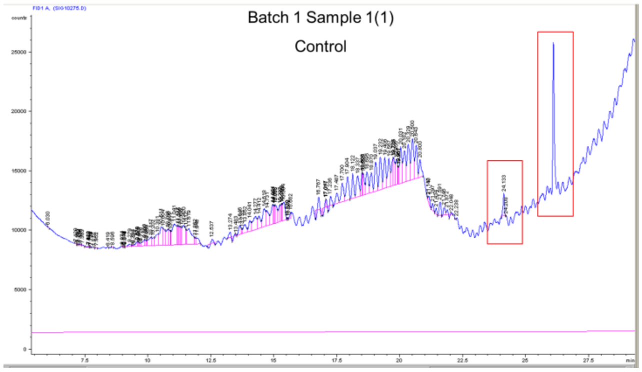
▨ completed samples

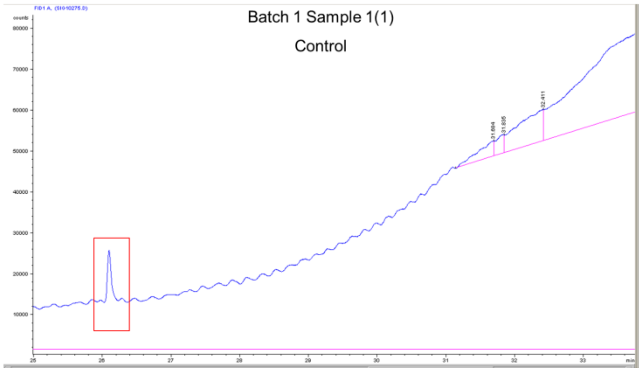
Preliminary experiments showed that the samples extracted in methanol for 6 h lead to the best compromise between a high number of compounds extracted and significant definition between these samples when performing GC analysis.

The following chromatograms were obtained from samples processed by Soxhlet extraction with methanol for 6 h. The comparisons are performed according to each samples' source. Results from GC and GC-MS analyses are presented.
It is important to note that all three batches of samples were under active compost conditions for 3 months but that their dried, matured periods varied (6.5 years for Set 1, 3 years for Sets 2 and 3).

A brief overview of the GC results is shown, followed by a discussion which incorporates the GC-MS analyses.

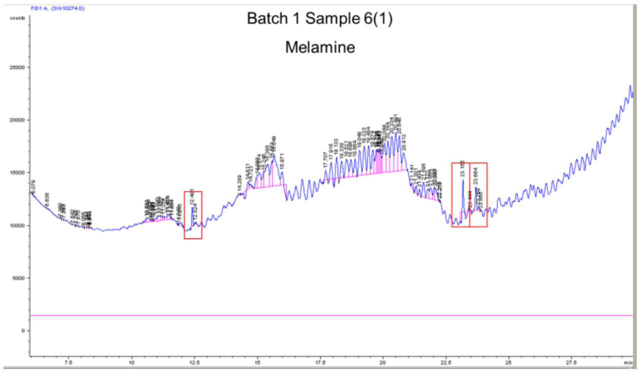
<u>Control</u>
The Set 1, Batch 1 sample (control), shows two significant peaks, one at 24 min and a larger peak at 26 min. It should be noted that these peaks are seen in many of the other samples but with varying magnitudes. This suggests that the peaks at 24 and 26 min are not characteristic of the wood samples that undergo composting but rather are characteristic of compost in general.

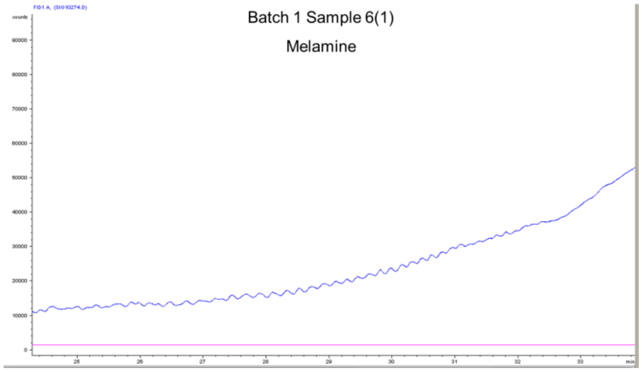


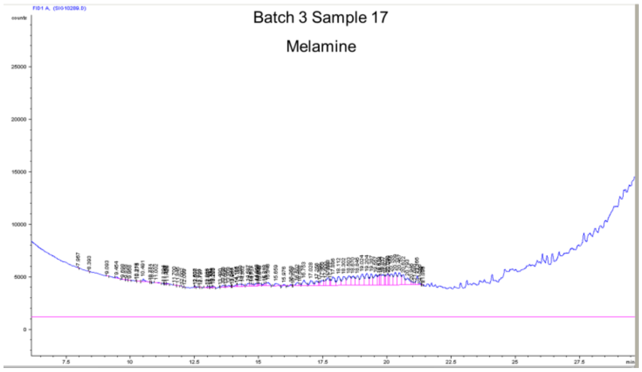


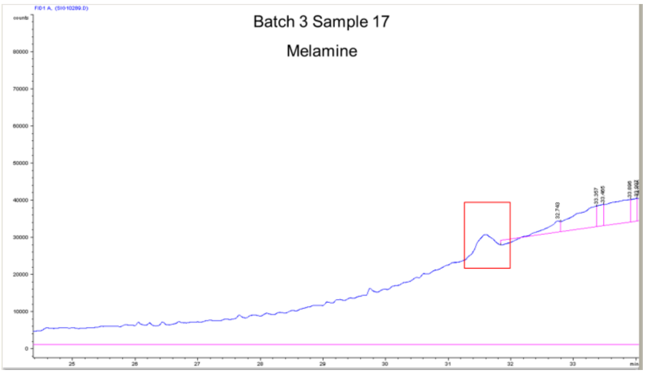
Melamine Samples

Set 1, Batch 6 and Set 2, Batch 17 have very different peak patterns. Set 1, Batch 6 has a peak at 12.5 min and a double peak at 23 min; while batch 3 sample 17 has a single broad peak at 31.5 min.



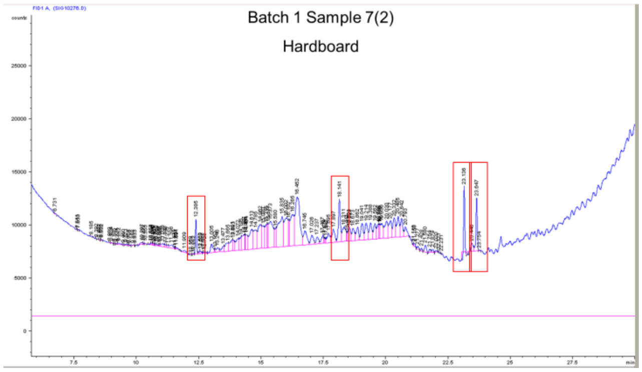


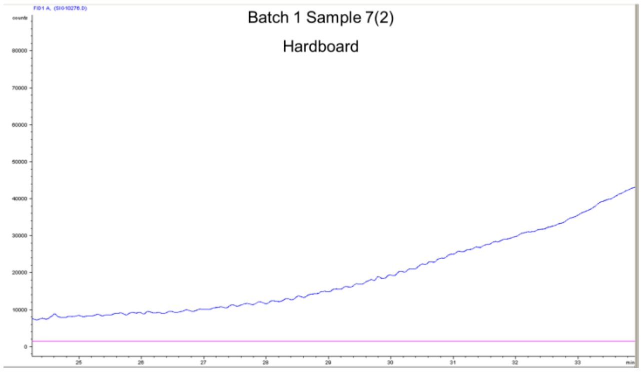


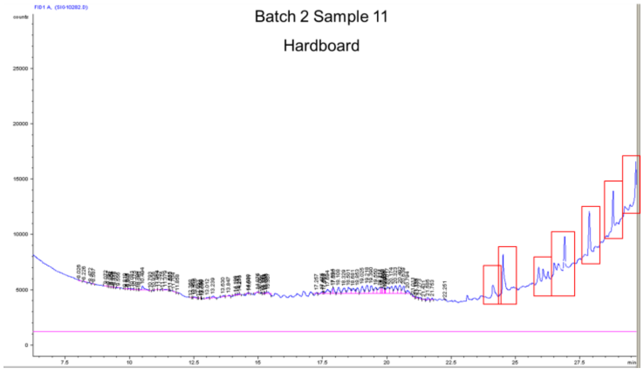


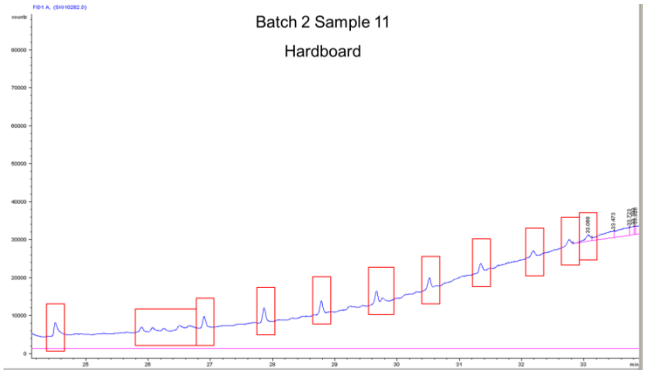
Hardboard Samples

The hardboard samples did not display the same peak pattern. Set 1, Batch 7 has a peak at 12 min, a peak at 18 min and a double peak at 23 min. Set 2, Batch 11 has a series of small peaks approximately every minute from 24.5 min to 33 min.


Batch 1 Sample 7(2)
Hardboard

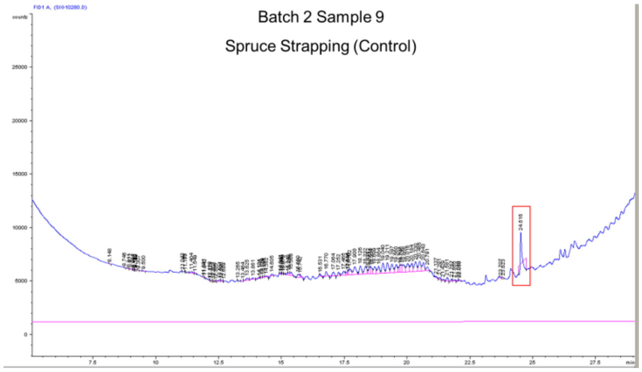

Batch 1 Sample 7(2)
Hardboard


Batch 2 Sample 11
Hardboard

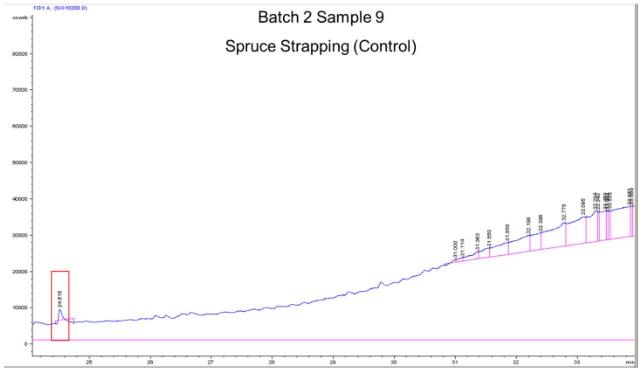

Batch 2 Sample 11
Hardboard

Spruce Strapping (Control) Samples

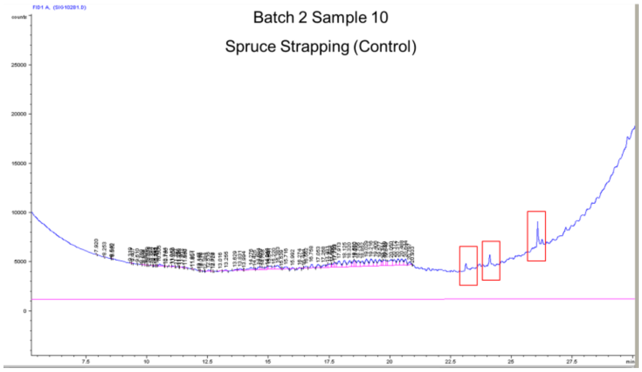
These 3 samples did not have the same peak patterns. Set 2, Batch 9 shows a single peak at 24.5 min. Set 2, Batch 10 has a small peak at 23 min, a peak at 24.5 min and a peak at 26.5 min. Set 2, Batch 13 has 2 peaks, the first at 24 min and the second at 26 min. This is similar to Set 2, Batch 10, but Set 2, Batch 13 is missing the peak at 23 min.


Batch 2 Sample 9

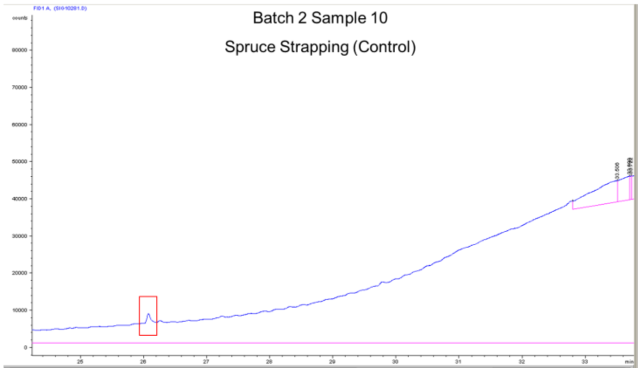
Spruce Strapping (Control)


Batch 2 Sample 9

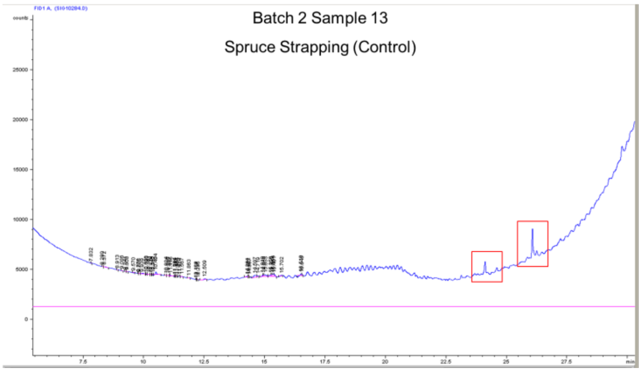
Spruce Strapping (Control)


Batch 2 Sample 10

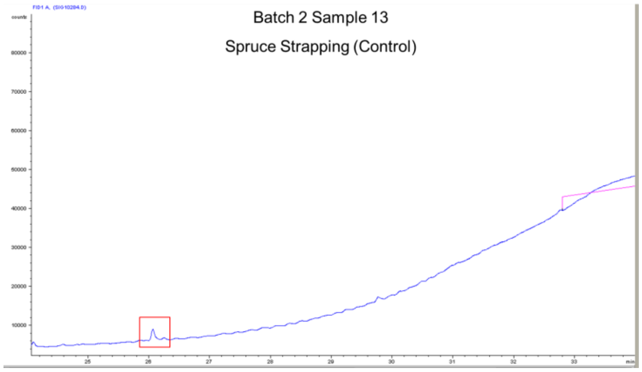
Spruce Strapping (Control)


Batch 2 Sample 10

Spruce Strapping (Control)


Batch 2 Sample 13

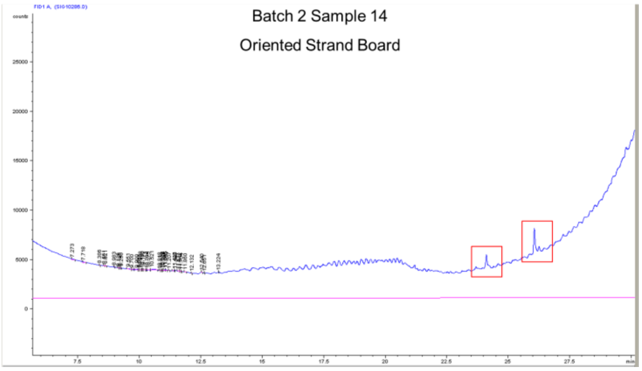
Spruce Strapping (Control)

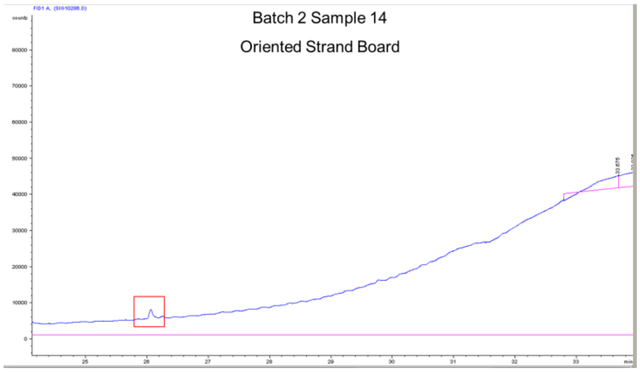

Batch 2 Sample 13

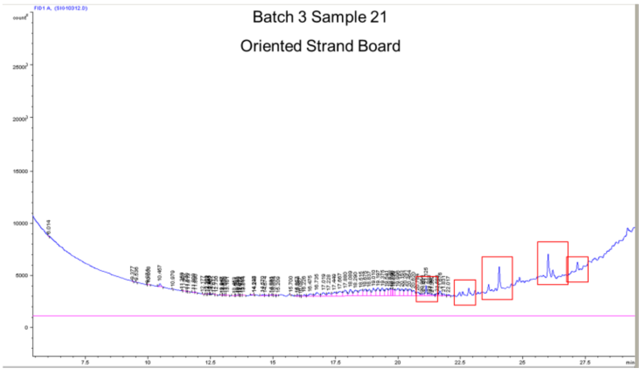
Spruce Strapping (Control)

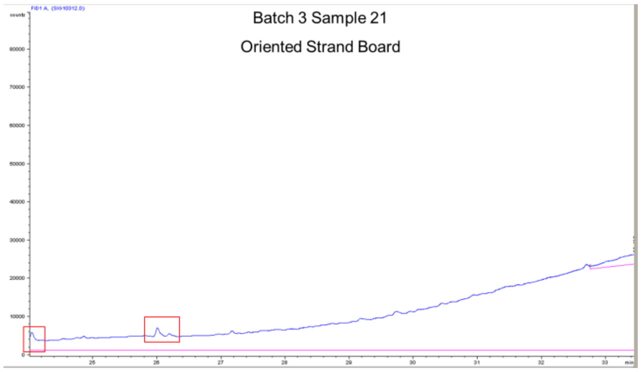
Oriented Strand Board Samples

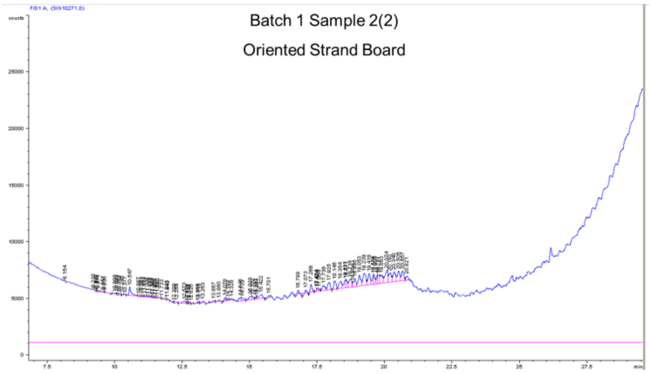
All three samples have different peak patterns from each other. Set 2, Batch 14 has a small peak at 24 min and a second peak at 26 min. Set 3, Batch 21 has a small peak at 21 min, a cluster of small peaks at 22.5 min, a couple small peaks at 24 min, a double peak at 26 min and a small peak at 27.5 min. The reproducibility of the peaks at 24 and 26 min between these two conditions suggests that these analytes are likely to be the same components. Set 1, Batch 2 did not show any significant peaks, although small peaks can again be observed at 24 and 26 min.

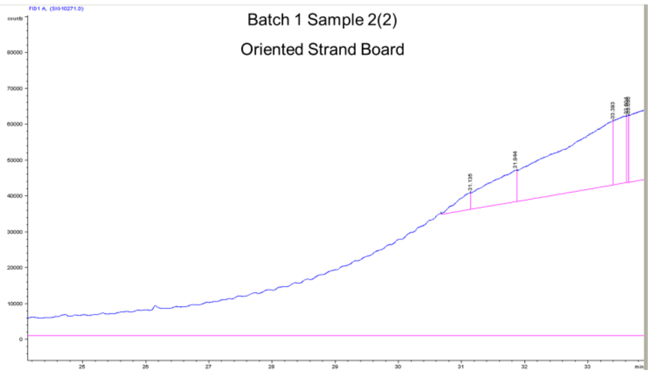

Batch 2 Sample 14
Oriented Strand Board


Batch 2 Sample 14
Oriented Strand Board


Batch 3 Sample 21
Oriented Strand Board

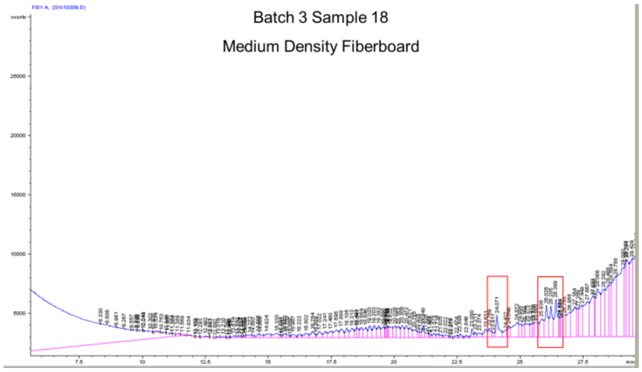

Batch 3 Sample 21
Oriented Strand Board

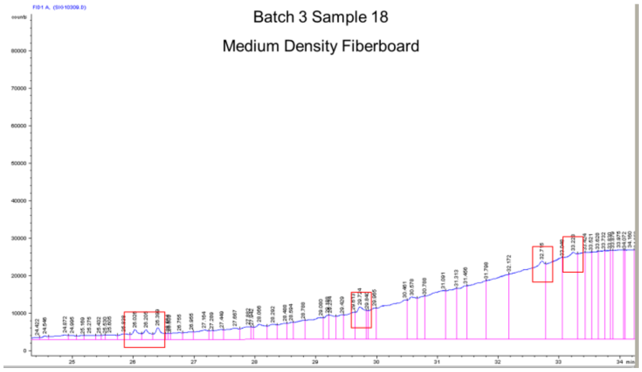

Batch 1 Sample 2(2)
Oriented Strand Board

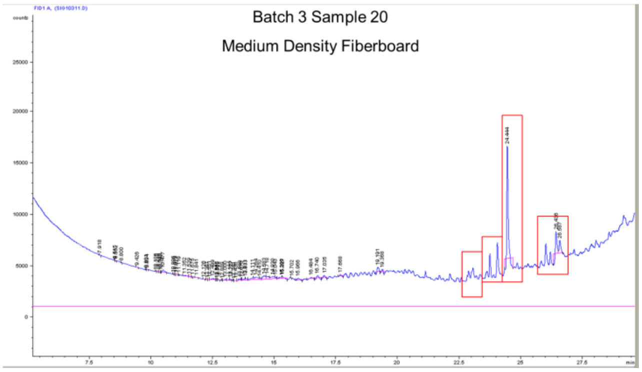

Batch 1 Sample 2(2)
Oriented Strand Board

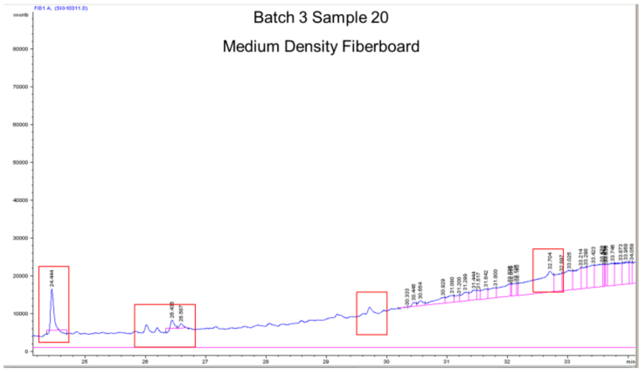
Medium Density Fiberboard Samples

These samples had fairly similar peak patterns but of different peak intensities, suggesting different concentrations of analytes present. Set 3, Batch 18 has a small peak at 24 min, a cluster of 3 small peaks at 26 min, a small peak at 29 min, a peak at 32 min, and a peak at 33 min. Set 3, Batch 20 has a cluster of small peaks at 22.5 min, a double peak at 23.5 min, a large peak at 24 min, a cluster of peaks at 26 min, a small peak at 29.5 min and a peak at 32.5 min.



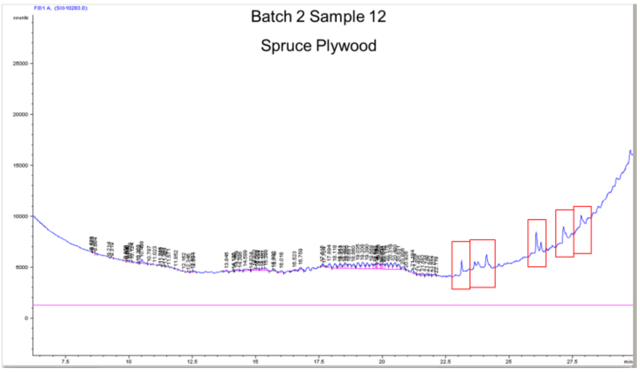




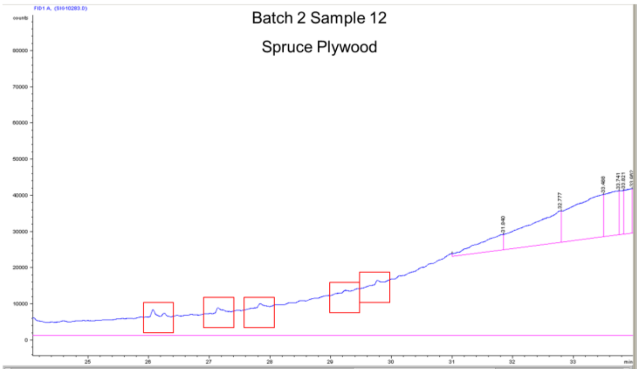


Spruce Plywood Samples

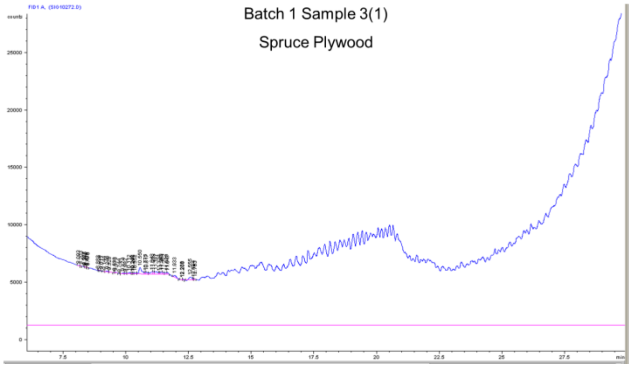
Set 2, Batch 12 has a small peak at 23 min, a peak at 24 min, a peak at 24.5 min, a peak at 26.5 min, a peak at 27.5 min, a peak at 28.5 min and a double peak at 29.5 min. Set 1, Batch 3 did not have any significant peaks.


Batch 2 Sample 12

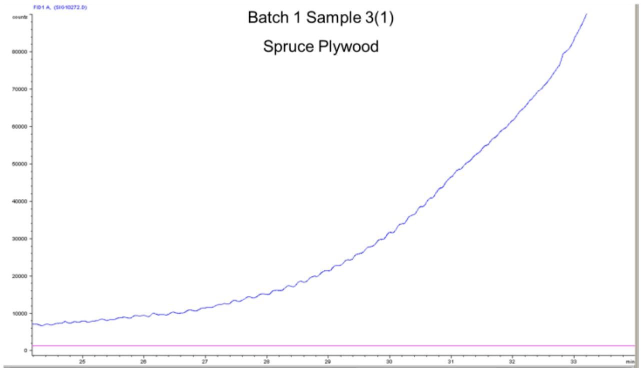
Spruce Plywood


Batch 2 Sample 12

Spruce Plywood


Batch 1 Sample 3(1)

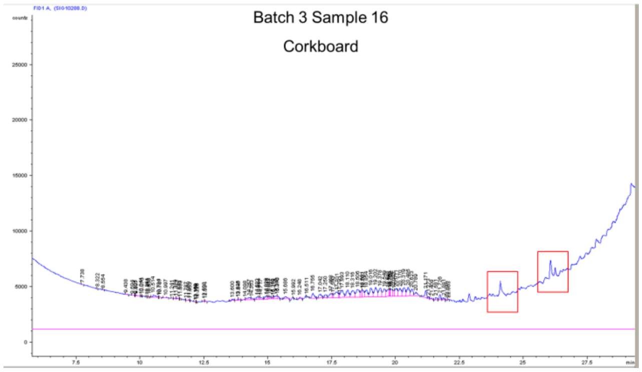
Spruce Plywood

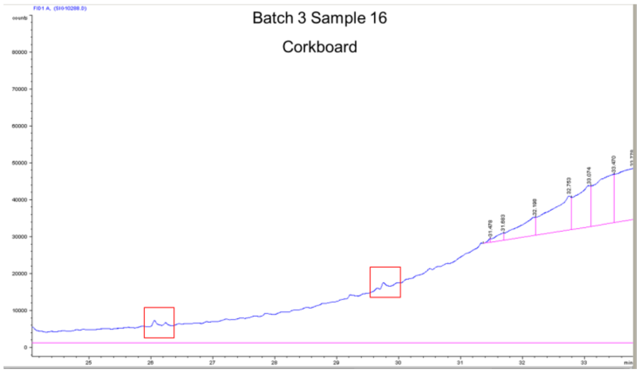

Batch 1 Sample 3(1)

Spruce Plywood

Corkboard Sample

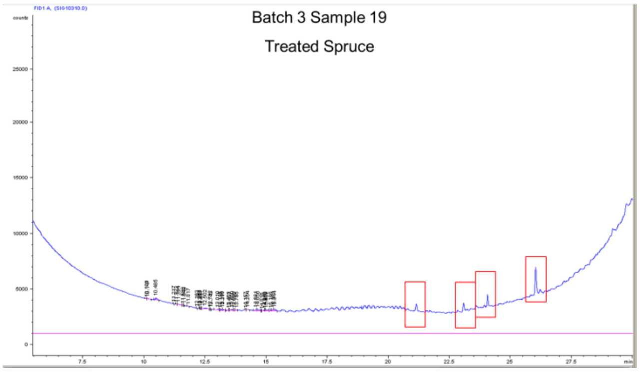
Set 3, Batch 16 has a small peak at 24 min, a peak at 26 min and a peak at 30 min.

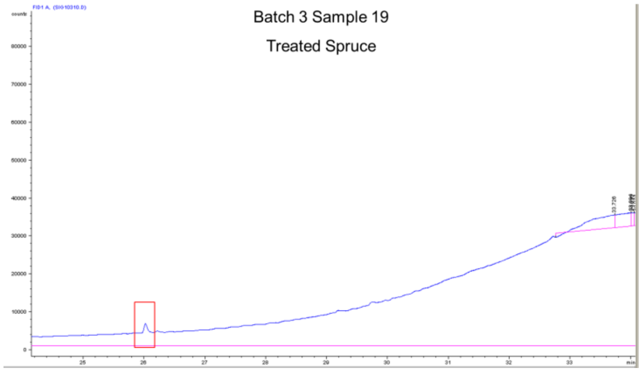




Treated Spruce Sample

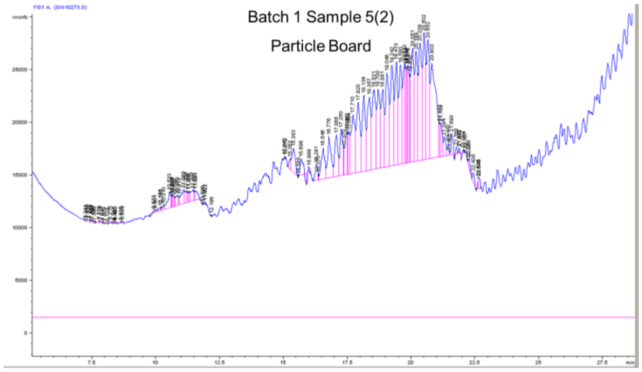
Set 3, Batch 19 has a small peak at 21 min, a peak at 23 min, a peak at 24 min and a peak at 26 min.

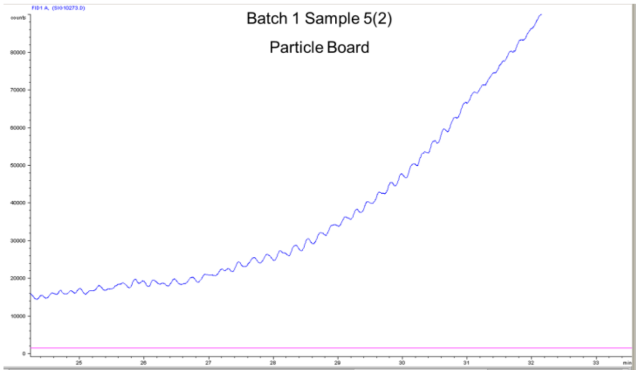


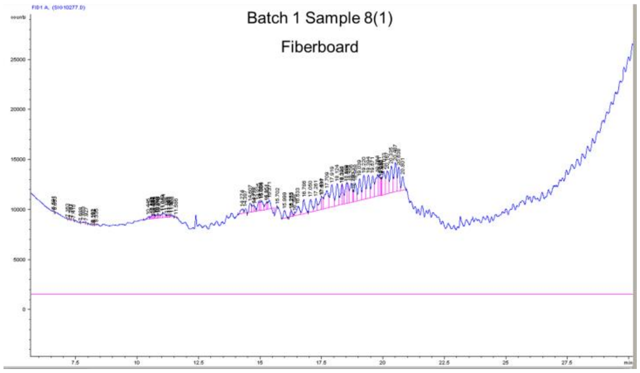


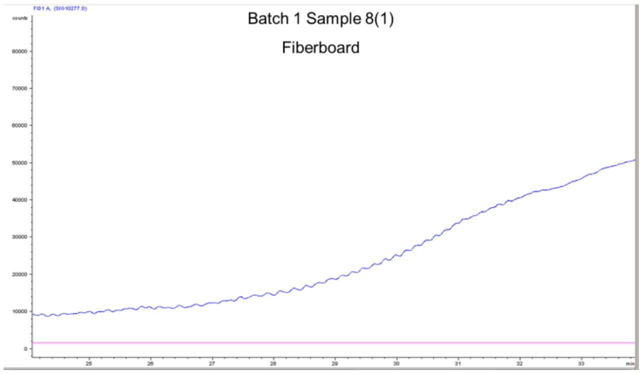
Samples without Peaks

Set 1 sample 5 (particle board) and Set 1, Batch 8 (fiberboard) did not show any significant characteristic peaks.



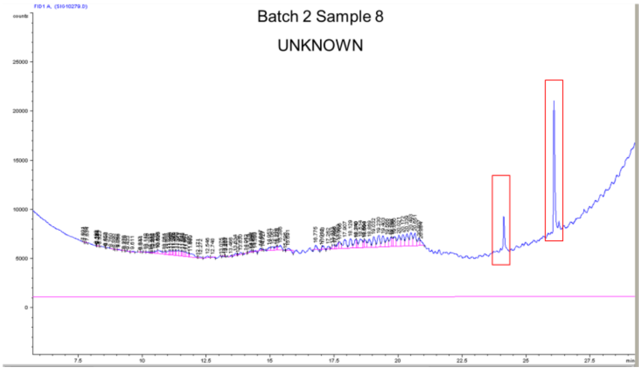


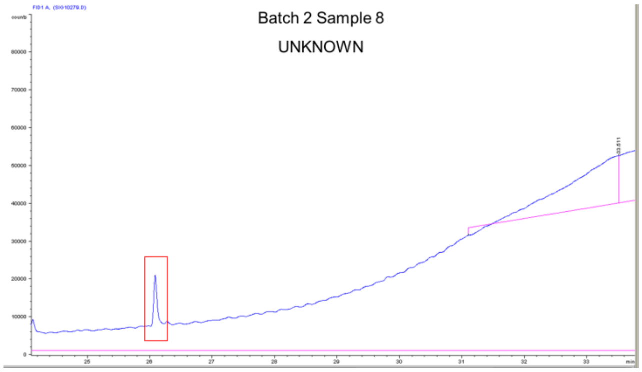


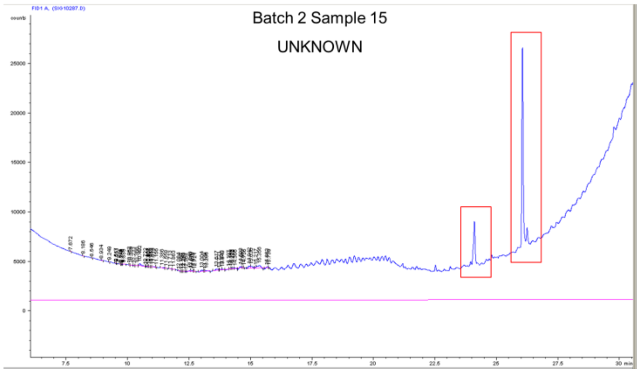


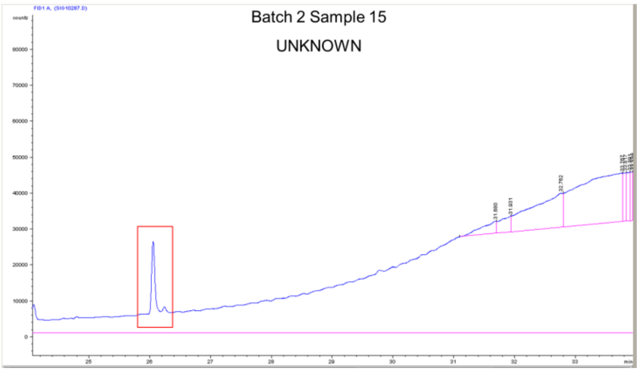
Other Samples

Set 2, Batch 8-2 and Set 2 sample 15 all have very similar chromatograms with peaks present at 24 min and a larger peak at 26 min. This pattern aligns exactly with the chromatogram of the initial control, Set 1, Batch 1 (control), suggesting no significant difference in the components extracted.









IDENTIFICATION OF PEAKS OF INTEREST

GC-MS analysis suggests that these peaks correspond to hexadecanoic acid methyl ester (at 24 min) and 13-octadecenoic acid methyl ester (at 26 min). It is likely that the compost samples actually contain hexadecanoic acid and 13-octadecenoic acid; the methyl ester is most probably the result of an esterification reaction occuring with methanol during the extraction process.

It should also be noted that these two peaks are present in most samples tested (see Table below). Interestingly, the presence or absence of these two compounds seems linked. In fact, none of the samples from batch 1 (melamine, oriented strand board, spruce plywood, particulate board, fiberboard), show the presence of these compounds except for the control (Sample 1(1)). Since samples from Batch 1 had longer matured periods, it is possible that these compounds were degraded over the length of time during which the compost was stored, indicating a potentially significative biological activity beyiond the initial active period.

In all samples tested by GC analysis, clusters of peaks were observed between approximately 10 and 22 min. These are typical of extractions of complex organic matter composed of a plurality of components. In the GC analyses, the clusters were not directly analyzed but peaks that were significantly distinguishable from the clusters were highlighted as characteristic. Moreover, small modifications to the GC method and detector conditions for the GC-MS analysis allowed us to have a better definition/separation of these peaks. The analysis was also more sensitive and many more characteritic peaks could be observed for all samples tested – see last column in Table 8.1 and Appendix E in Excel file format. The Excel file compiles the data from all the GC-MS analyses performed. Each sample is listed and the peaks reported for this sample are identified as a coloured cell according to their retention time in the GC. Green cells denote peaks of interest. Blue cells indicate the presence of 2 peaks of interest with a short period of time (0.1 min). For each peak of interest, a comment which lists the 6 most probable corresponding compounds with their respective probability is included - these comments can be seen by bringing the cursor over the cells of interest. Yellow, orange and red cells correspond to peaks resulting from compounds originating from the GC column (not from the samples of interest) - these usually include silicon, nickel or molybdenum.

Other methyl esters of carboxylic acids were found in some samples:

- pentanedoic acid dimethyl ester (dimethyl ester of glutaric acid) and hexanedioic acid ethyl methyl ester (a diester of adipic acid) were found in the control, one hardboard and two spruce strapping samples.

- 12-methyl methyl tetradecanoate and other methylated esters of tetradecanoic acid were found in the control and one spruce strapping sample.

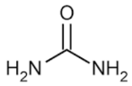
- methyl hexadecanoate and methyl acetoxyhexadecanoate were found in the control.

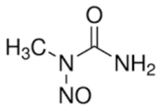
- octadecanoic acid was found in one hardboard and one MDF sample.

- cyclopropanetetradecanoic acid methyl ester and other cyclopropane-carbolxylic acid methyl esters were found in MDF. Methyl stearidonate was also found in one MDF sample.

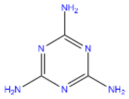
It is important to consider that, at this point, all analyte identification is made from a probability stand-point. That being said some potentially relevant compounds were found in the various samples. The following should be noted:

- Both medium density fiberboard samples showed a probability for the presence of n-nitroso-n-methylurea, a potent carcinogen and mutagen. This compound is of relevance as it could result from the transformation of urea-formaldehyde, a component of MDF. In at least one instance, urea was also present in the sample.





- In the melamine samples some melamine and melamine-derived compounds such as 2,4-diamino-6-guanidino-1,3,5-triazine were found, suggesting that even after the active composting period, significant melamine and derivatives could still remain in the compost. Spectra similar to that of melamine were found in OSB and MDF samples (although the identification also suggest acorenol, a floral compound).



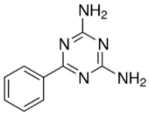
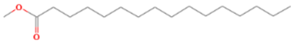
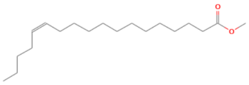
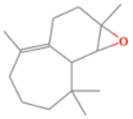


Table 8.1 Presence (+) or absence (-) or methyl esters of hexadecanoic acid and 13-octadeceneoic acid in compost samples

Sample	Hexadecanoic acid methyl ester	13-octadecenoic acid methyl ester	Total # of Relevant Peaks Detected by GC-MS
			
Control Set 1, Batch 1	+	+	18
Melamine Set 1, Batch 6	-	-	10
Melamine Set 3, Batch 17	+	+	9
Hardboard Set 1, Batch 7	+	+	17
Hardboard Set 2, Batch 11	+	+	14
Spruce Strapping Set 2, Batch 9	+	+	8
Spruce Strapping Set 2, Batch 10	+	+	7
Spruce Strapping Set 2, Batch 13	+	+	27
Oriented Strand Board Set 2, Batch 14	+	+	0
Oriented Strand Board Set 3, Batch 21	+	+	1
Oriented Strand Board Set 1, Batch 2	-	-	43
Spruce Plywood Set 2, Batch 12	+	+	8
Spruce Plywood Set 1, Batch 3	-	-	0
Corkboard Set 3, Batch 16	+	+	7
Particle Board Set 1, Batch 5	-	-	0
Fiberboard Set 1, Batch 8	-	-	0

- Another compound of interest, β-himachalenoxide, is found in multiple samples (melamine, 2 OSB samples, both MDF samples, one spruce plywood and corkboard). This component is one of the main compounds of some essential oils. The fact it resists biodegradation is of relevance.



- Some fluor-containing compounds such as 2-trifluoroacetoxydodecane (control), 3-trifluoroacetoxydodecane (control), 9-octadecenoic acid, 2,2,2-trifluoroethyl ester (spruce plywood), 1-Amino-2-acetamino-3-fluorobenzene (MDF) and 2,2-Difluoroheptacosanoic acid (MDF) can pose some health risks.

Other compounds that are of relevance for human exposure but that may not result from the wood resiude include:

- Benzoic acid, 4-ethoxy-, ethyl ester (a human metabolite) in one melamine, one hardboard and one spruce plywood sample.

- Caffeine was found in multiple compost samples.

- Many different versions of the non-steroidal anabolic agent spirostan-diol-one-one were likely present in melamine, OSB and MDF samples.

- Vitamin D (Secocholestatrienol) and derivatives were found in many samples.

- Brassicasterol acetate, a sterol produced by certain algal growth, was found in a melamine sample. Other sterols, such as estratrienol were also found.

- Pharmaco-active compounds, such as 8-azidoasedosine were also identified.

- The degradation product of plasticizers phthalic acid monoehtyl ester was found in a hardboard sample. This compound has a relatively high toxicity and is a potential carcinogen.

- Purines were also found in many samples. These compounds are typically found in meat products.

- Pterins and imidazole-based components were also found in many samples. These include some flavors and colorants. Other flavors and colorants encountered include curcurbitacin derivatives and sesquisabinene hydrate.

- Fluorene and fluoranthene were found in a spruce plywood sample, suggesting the presence of tar coal in the compost.

9. Economic Viability

Effective compost operations require woody waste as an amendment to absorb moisture and provide adequate air space to allow aerobic organisms to consume the readily available organic waste. Notwithstanding capacity issues, in many cases, compost operations are in short supply of woody waste as the clean wood supply is limited and expensive (approximately equal to the value of good quality product at $30/tonne), and the over-sized material from product screenings is often contaminated with plastic film. Thus, there is a need for an additional, inexpensive supply of wood waste for most compost facilities—one of those sources is from manufactured wood waste.

The practice of diverting manufactured wood waste not only provides compost operators with a cheap source of carbon, but also, in the cases where C&D wood waste is buried, avoids the unnecessary consumption of valuable space in the landfill. Avoiding the burial of wood waste will prolong the life of the landfill and delay the costs of locating future disposal sites.

Operating a C&D disposal site obviously costs money—typically the more contaminated the delivered waste, the higher the disposal cost. The notion of avoiding unnecessary wood disposal costs, coupled with reducing the fee for needed wood at compost facilities is an initiative worth pursuing.

Notwithstanding the presence of potential contaminants in some manufactured woods, the most economical means of minimizing costs would be operating a compost facility and a C&D site in close proximity to each other. Although there would be costs associated with separating the desired woods from the undesired wood (such as treated lumber), these costs could be minimized if the wood was delivered free of other building contaminants, much like the way the province now expects source-separated organics to be delivered. To provide extra incentive to the waste producers, C&D sites could consider accepting clean manufactured wood at a lower tip fee, or even free if there is sufficient demand for the collected wood waste. Extending this thought further, compost facilities themselves could consider direct delivery of desired manufactured woods to avoid the unnecessary transportation and management costs if the wood was delivered to a C&D site. Obviously, policies and operating permits would need adjustment, and some care would be required to ensure clean wood is in fact delivered, however, the value and need of acceptable wood in the compost process is unquestioned; options on economically acquiring the wood are worth pursuing.

10. Conclusions

Typically, compost facilities throughout the province lack a reliable supply of dry, contaminant-free woody waste to balance the wet, nitrogen-rich food waste collected in SSO systems; manufactured woods (which are currently disposed of in C&D facilities) provide a potential source of this much-needed woody amendment.

The diversion of manufactured wood waste provides a significant potential source of bulking material for composting processes. Fortunately, the artificial constituents in many manufactured woods are relatively common from product-to-product so the constituents sought in the product analyses is relatively consistent regardless of the feedstock.

The decomposition and heat of the compost process will encourage the release of any volatile organic compounds still remaining within the wood products which could negatively impact air quality. This concern is typically minimized through the use of normal forced aeration systems, the relatively low concentrations of the chemical of concern, and common use of N-95 respirators by employees working within the active compost area. Minimizing the residual presence of foreign compounds is realized through the active management of the decomposition process; poorly operated facilities using traditional feedstocks could experience additional issues of worsening air quality and an even poorer quality product if manufactured woods are incorporated into the feedstock mix.

From a composting perspective, the presence of unnatural substances in manufactured woods does not appreciably inhibit the response of microbial activity; every batch tested successfully produced temperatures above the required threshold of 55 ^{o}C for pathogen disinfection. Although in some cases, there was a slight delay in a temperature rise, it was only temporary as the compost process recovered quickly; the presence of formaldehyde-related compounds did little to suppress microbial activity. Batches with pressure treated wood even produced impressive temperature profiles, as the readily available organic waste was consumed despite the presence of anti-microbial agents within the wood (which was less prone to decomposition as one would expect).

In terms of metals, the clean manufactured woods did not elevate the content of the 11 metals of typical concern with the exception of the pressure treated samples which had unacceptably high copper concentrations. In fact, the metals content in the pure wood waste was in many cases below that of the SSO-wood mix.

The type of chemicals produced as by-products of the decomposition process varies continuously. Associating chemicals of interest with particular manufactured wood products and not the incorporated SSO can only occur with repeated testing. A detailed chemical analysis detected the presence of a number of complex chemicals, however, many of them are the result of circumstantial conditions which includes the nature of the SSO, temperature and oxygen content of the batch and the microbial agents present at the time. In comparing changes in the chemical composition of the compost product over time, there is a distinct lessening of chemical peaks, implying that even the most resilient of compounds will degrade with time. Of the manufactured woods tested, melamine derivatives remained identifiable and persisted throughout the decomposition process. From a cosmetic perspective the presence of melamine is also problematic as it produces white resin flecks that continue to persist after the composted product is mature which, in some cases, would preclude it from being universally accepted as a wood-based amendment.

In light of these results, it seems that, if indeed n-nitroso-n-methylurea is the proper compound identified in compost samples containing MDF, and if indeed this compound originates from this wood product, composts containing MDF may not be fit for applications leading to comestible products. This compound shows high toxicity and is considered highly carcinogenic.
Similarly, the presence of melamine and its derivatives in composts containing melamine, OSB or MDF makes the resulting compost products likely unsuitable for applications leading to human consumption.

The presence of fluorinated compounds, pharmaco-active and toxic metabolites (for example from phthalate plasticizers), while likely not originating from the wood products themselves, highlight the potential concerns that may arise in composts in general.

It should be noted that, beside the composts containing MDF, melamine or OSB, most samples tested showed no or few compounds leading to major concerns. Some care should be taken since, at this point, the analyses performed rely on the probability of molecular identification. In addition, the analyses do not provide a full survey of the molecules present in the samples (due to the extraction process) but do provide a good sampling of the organic components that should be of interest. It is also interesting to note that composts with longer maturation times had noticeably lower numbers of peaks and/or of toxic components present. This bodes well for the potential use of composts containing some wood products.

In general, the simpler the manufactured wood product is, the less concern is posed in terms of potential contaminants. Plywoods and OSB, because of their larger particle size (and hence their lower need for excessive glue and adhesives) pose the least amount of concern. In addition, as most manufactured wood suppliers continue to produce more products with less potentially harmful constituents, and work towards eco-acceptability, the options for composting manufactured wood will rise. Operational conditions also have a part to play in minimizing the presence of chemicals of concern—the more the composting mix is maintained in an aerobic, unsaturated state, the lower the risk of offensive or problematic chemicals of concern.

Currently, thousands of tonnes of manufactured wood waste are disposed of in C&D facilities across the province; this material can provide significant bulking capacity to compost facilities, particularly those located in regions where wood waste is scarce. The preceding results have established a body of knowledge that can now be built upon and indicate that most manufactured wood (in particular plywood and OSB) does not appear to negatively impact the quality of compost and therefore should be considered as an alternative and inexpensive option as a bulking agent for the compost process.

11. Recommendations

A definitive decision on the appropriateness of manufactured woods can only occur as the body of evidence on the subject grows. Based on the foregoing study, it is recommended that if Category A compost to be produced, pressure treated wood and mixed wood waste continue to remain in the C&D waste stream. It is recommended that some manufactured woods (plywood and OSB) be incorporated into the compost process as a less expensive alternative to virgin wood waste on a pilot-scale basis. Ideally, the site should be adjacent to, or at, an operating C&D or landfill site for easy and inexpensive collection and isolation of this waste stream. The process should run in parallel with the existing process and compared at equivalent stages to determine if the product quality is compromised in any way due to the presence of manufactured wood.

As the decomposition process is very complex and produces a myriad of chemical compounds that are impossible to duplicate from one composting batch to another, it is advised any future compost products utilizing manufactured woods be required to include additional tests for particular chemicals of concern (to be determined through further discussion based on the fore-going study) and that a data bank of test results be established and reviewed periodically.

Many issues associated with the normal composting process, such as leachate production and the release of offensive odours can also control the composting of manufactured woods. If the unnatural constituents in manufactured woods are to be minimized through oxidation to simpler and safer by-products, it is necessary to maintain the composting matrix in an unsaturated (no free-standing water) and oxygenated state of greater than five per cent.

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APPENDIX C

The Action Plan developed by Bonigut and Kearley for composting panelboard waste

What are the issues with this process / technology?

Technical	Triesse Ltd reported that it takes them about 5 years to produce compost from panelboard waste (Triesse, 2004). It is believed however that the composting process can be speeded up significantly. The process of composting wood-based panel waste by itself needs to be refined, as well as the process of co-composting panel waste with e.g. green waste. A process time of weeks rather than months or even years is envisaged If panel material is collected from CA sites it is likely to be from furniture and thus coated in one way or another. Thus screening possibilities need to be explored and developed. If coated material is chipped prior to composting it may be possible to separate the coatings after composting. Alternatively the presence of coatings may be acceptable to low-grade compost markets as long as they are melamine coatings However composted wood-based panel waste may not meet the quality specification PAS 100
Political (regulatory)	There may be planning issues requiring control of dust from a composting operation, but apart from that there should be no regulatory issues
Financial	Composting of wood-based panel waste can be regarded as either a commercial activity or a waste-disposal opportunity. If it is commercial, processors may be given the waste material free of charge and be able to make a profit from selling the compost. If it is regarded as an option of waste disposal then processors (e.g. farmers) may be paid for taking material on (less than landfill cost, of course) and spreading it on their fields
Capacity	The capacity for composting wood-based panel waste is rather very large. The issue is whether the compost can be sold or whether it would still need to be disposed of, in which case it could be spread on farm or forestry land
Market	A market needs to exist that can accommodate large volumes of composted panel waste. This can be in various forms, e.g. large growers, municipal horticultural activities, gardening products retailers, land remediation

How can these issues be resolved?

Sorting	Sorting facilities need to be in place where the wood-based panel waste destined for composting is delivered. This could be to be CA sites, since most panel waste is delivered there. Of course this could be wood recyclers or compost operators, as well
Co-composting	Once the proportions of green waste to panelboard waste are determined one possible solution could be to mix them at CA sites already. This requires however that the wood-based panel waste is screened and separated already
Screening	Materials that need to be screened out are mostly coatings, edgebandings and metals. Thus screening possibilities of the compost need to be explored and developed

Which of these issues are the most important, i.e. are key to holding back?

	Separating / screening usable material from contaminants is the biggest issue. If this could be resolved, i.e. if mechanisms / technologies would be in place to separate the wanted material from the unwanted, the wanted material could all go to be composted

Who is responsible for resolving and / or overcoming barriers?	
WRAP / DEFRA	Technology for separating metals is readily available. What is required are trials to optimise the composting or co-composting possibilities of wood-based panel waste and to demonstrate the quality of compost that can be produced. These trials could be supported by WRAP or DEFRA

What resources are needed? / What is the timeframe?	
What will be the expected role of the technologies?	If screening and co-composting issues could be resolved composting of panel waste will play an important role in diverting panel waste from landfill
When could they come on stream?	Trials could start very quickly and if successful panel waste could be incorporated into existing composting operations
What are the tonnes that could be handled?	The only volume limitation this process has is the limitation of how much compost could be accommodated by the market. If it cannot all be sold then it could be given away for disposal by spreading on farm or forestry land
What no. of facilities would be needed?	In order to process large amounts of panel waste into compost plants / facilities would have to be spread out all over the UK in order to minimise transport cost and pollution. Some small to medium scale plants do exist (predominantly in England's north) thus reducing the number of new plants to be set up

APPENDIX A

Full list of the xenobiotics tested by Reddy and Michel with degradation results

Table 1. Fate of xenobiotics during composting.

		Concentration (ppm)		Fate of Xenobiotic (% conversion)			
Xenobiotic/ Pollutant[a]	Feed stock[b]	Initial	Final	CO_2	Humics[c]	Volatiles	*Ref.*
PESTICIDES							
2,4-D	YT	11	<0.1	48	49	<1	*7*
Atrazine	NP	500	<10	7	52	-[d]	*12*
Carbaryl	B, WC	2	< 0.1	4	95	-	*11*
Chlordane	M, SD	100	-	04	5	50	*13*
Diazinon	M, SD	100	-	02	39	22	*13*
Diazinon	YT	10	<0.3	11	52	<0.5	*8*
Diazinon	GC	9	<0.1	-	-	-	*5*
Pendimethalin	YT	10	<0.1	13	72	25	*9*
Pendimethalin	GC	7-40	<0.1	-	-	-	*5*
CHLORPHENOLS							
Chlorophenols	BK, S	210	15	-	-	-	*15*
Chlorophenols	BK, S	850	40	-	-	-	*4*
PCP	BK, S	-	-	63	-	-	*4*
PCP	BK, S	210	-	30-40		1-3	*15*
EXPLOSIVES							
TNT	M,SD,A, S	3135	<300	02	48	-	*10*
TNT	M,SD,A, S	11,700	3	-	-	-	*16*
POLYCHLORINATED BIPHENYLS (PCBs)							
Aroclor 1248	YT, S	12	9	-	-	-	[e]
Aroclor 1232	B	11	2	-	-	16	*2*
Aroclor 1221	NP,M,B,SD,S	500	175	-	-	-	*14*
POLYAROMATIC HYDROCARBONS							
Pyrene	B,WC, S	15	35	17-20	-	-	*3*
Phenanthrene	B,WC	15	13	1	16	-	*11*
Phenanthrene	B	1000	96	-	-	05	*2*

[a] TNT-trinitrotoluene, PCP-pentachlorophenol

[b] A-alfalfa, B- biosolids, BK-Bark, GC-grass clippings, M-manure, NP-newspaper, S-soil, SD-sawdust, WC- wood chips, YT- yard trimmings (leaves, grass and brush)

[c] Conversion to humic acids, fulvic acids and humin.

[d] - not determined

[e] Michel, FC, unpublished results

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CLIENT NAME: **MISC AGAT CLIENT NS, NS**
(902)

ATTENTION TO: **Paul Arnold**

PROJECT:

AGAT WORK ORDER: **17X180829**

SOIL ANALYSIS REVIEWED BY: **Laura Baker, Inorganics Data Reporter**

DATE REPORTED: **Jan 30, 2017**

PAGES (INCLUDING COVER): **11**

VERSION*: **1**

Should you require any information regarding this analysis please contact your client services representative at (902) 468-8718

NOTES

All samples will be disposed of within 30 days following analysis. Please contact the lab if you require additional sample storage time.

Member of: Association of Professional Engineers and Geoscientists of Alberta (APEGA)
Western Enviro-Agricultural Laboratory Association (WEALA)
Environmental Services Association of Alberta (ESAA)

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Results relate only to the items tested and to all the items tested
All reportable information as specified by ISO 17025:2005 is available from AGAT Laboratories upon request

Certificate of Analysis

AGAT WORK ORDER: 17X180829

PROJECT:

CLIENT NAME: MISC AGAT CLIENT NS

SAMPLING SITE:

ATTENTION TO: Paul Arnold

SAMPLED BY:

Available Metals in Soil

DATE RECEIVED: 2017-01-24

DATE REPORTED: 2017-01-30

			SAMPLE DESCRIPTION:	HB-1	FP-1	PB-1	5	6	7	8-1	8-2
			SAMPLE TYPE:	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
			DATE SAMPLED:	2017-01-24	2017-01-24	2017-01-24	2017-01-24	2017-01-24	2017-01-24	2017-01-24	2017-01-24
Parameter	**Unit**	**G / S**	**RDL**	**8145024**	**8145035**	**8145038**	**8145040**	**8145041**	**8145043**	**8145045**	**8145046**
Aluminum	mg/kg		10	129	177	66	1060	1120	1800	1630	5590
Antimony	mg/kg		1	<1	<1	<1	<1	<1	<1	<1	<1
Arsenic	mg/kg		1	3	2	2	2	2	7	3	7
Barium	mg/kg		5	15	14	11	51	50	75	78	112
Beryllium	mg/kg		2	<2	<2	<2	<2	<2	<2	<2	<2
Boron	mg/kg		2	6	40	<2	18	15	22	60	26
Cadmium	mg/kg		0.3	<0.3	<0.3	<0.3	0.3	0.4	0.4	<0.3	0.4
Chromium	mg/kg		2	3	4	3	4	4	10	6	15
Cobalt	mg/kg		1	<1	<1	<1	1	<1	2	2	4
Copper	mg/kg		2	20	3	<2	15	16	58	23	55
Iron	mg/kg		50	184	272	233	4310	2630	5410	4160	10200
Lead	mg/kg		0.5	8.0	8.0	7.7	6.4	9.6	28.5	7.9	37.7
Lithium	mg/kg		5	<5	<5	<5	<5	<5	<5	<5	12
Manganese	mg/kg		2	60	30	87	230	178	152	286	417
Molybdenum	mg/kg		2	<2	<2	<2	<2	<2	<2	2	<2
Nickel	mg/kg		2	<2	<2	<2	6	6	13	7	12
Selenium	mg/kg		1	<1	<1	<1	<1	<1	<1	<1	<1
Silver	mg/kg		0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Strontium	mg/kg		5	10	6	<5	53	44	56	77	76
Thallium	mg/kg		0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tin	mg/kg		2	3	3	3	4	4	13	4	6
Uranium	mg/kg		0.1	<0.1	<0.1	<0.1	0.1	0.1	0.2	0.2	0.6
Vanadium	mg/kg		2	4	4	3	6	5	17	9	13
Zinc	mg/kg		5	19	23	15	76	66	83	135	201

Certified By: Laura Baker

Certificate of Analysis

AGAT WORK ORDER: 17X180829

PROJECT:

CLIENT NAME: MISC AGAT CLIENT NS

ATTENTION TO: Paul Arnold

SAMPLING SITE:

SAMPLED BY:

Available Metals in Soil

DATE RECEIVED: 2017-01-24

DATE REPORTED: 2017-01-30

			SAMPLE DESCRIPTION:	9	10	11	12	13	14	15	16
			SAMPLE TYPE:	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
			DATE SAMPLED:	2017-01-24	2017-01-24	2017-01-24	2017-01-24	2017-01-24	2017-01-24	2017-01-24	2017-01-24
Parameter	**Unit**	**G / S**	**RDL**	**8145048**	**8145050**	**8145051**	**8145052**	**8145053**	**8145054**	**8145055**	**8145056**
Aluminum	mg/kg		10	4430	4500	4930	4590	5740	4110	4660	4410
Antimony	mg/kg		1	<1	<1	<1	<1	<1	<1	<1	<1
Arsenic	mg/kg		1	9	7	5	7	8	7	7	7
Barium	mg/kg		5	92	100	79	100	101	82	92	73
Beryllium	mg/kg		2	<2	<2	<2	<2	<2	<2	<2	<2
Boron	mg/kg		2	23	25	14	31	20	24	27	16
Cadmium	mg/kg		0.3	0.4	0.4	0.4	0.4	0.6	0.5	1.2	0.4
Chromium	mg/kg		2	15	14	11	14	15	14	17	13
Cobalt	mg/kg		1	3	3	3	3	4	3	3	3
Copper	mg/kg		2	53	75	35	44	55	44	52	43
Iron	mg/kg		50	11000	12100	8240	12100	10800	11700	9700	9150
Lead	mg/kg		0.5	52.9	51.3	26.8	47.5	40.6	47.4	58.0	38.2
Lithium	mg/kg		5	8	9	8	9	11	8	9	9
Manganese	mg/kg		2	444	361	369	345	440	316	513	342
Molybdenum	mg/kg		2	<2	<2	<2	<2	<2	<2	<2	<2
Nickel	mg/kg		2	11	11	8	10	11	10	11	9
Selenium	mg/kg		1	<1	<1	<1	<1	<1	<1	<1	<1
Silver	mg/kg		0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Strontium	mg/kg		5	67	68	54	68	78	65	67	62
Thallium	mg/kg		0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tin	mg/kg		2	4	4	4	4	4	4	4	4
Uranium	mg/kg		0.1	0.5	0.5	0.4	0.5	0.6	0.4	0.5	0.4
Vanadium	mg/kg		2	12	11	10	12	13	10	11	10
Zinc	mg/kg		5	209	334	136	214	201	224	175	188

Certified By: Laura Baker

Results relate only to the items tested and to all the items tested

Certificate of Analysis

AGAT WORK ORDER: 17X180829

PROJECT:

CLIENT NAME: MISC AGAT CLIENT NS

ATTENTION TO: Paul Arnold

SAMPLING SITE:

SAMPLED BY:

Available Metals in Soil

DATE RECEIVED: 2017-01-24

DATE REPORTED: 2017-01-30

			SAMPLE DESCRIPTION:	17	18	19	20	21	22	23	24
			SAMPLE TYPE:	Soil	Soil	Soil	Soil	Soil	Soil	Soil	Soil
			DATE SAMPLED:	2017-01-24	2017-01-24	2017-01-24	2017-01-24	2017-01-24	2017-01-24	2017-01-24	2017-01-24
Parameter	**Unit**	**G / S**	**RDL**	**8145057**	**8145058**	**8145059**	**8145063**	**8145064**	**8145065**	**8145066**	**8145067**
Aluminum	mg/kg		10	4360	2250	4260	3000	4650	6370	807	208
Antimony	mg/kg		1	<1	<1	<1	<1	<1	3	2	<1
Arsenic	mg/kg		1	6	5	8	4	6	28	103	2
Barium	mg/kg		5	81	49	84	47	77	661	114	93
Beryllium	mg/kg		2	<2	<2	<2	<2	<2	<2	<2	<2
Boron	mg/kg		2	20	16	141	14	18	18	18	8
Cadmium	mg/kg		0.3	0.4	<0.3	0.4	<0.3	0.6	0.9	0.5	1.0
Chromium	mg/kg		2	13	10	21	8	12	40	148	3
Cobalt	mg/kg		1	3	2	3	2	3	9	3	<1
Copper	mg/kg		2	50	27	1220	30	47	109	314	4
Iron	mg/kg		50	15200	15700	23800	6650	9750	12800	2590	692
Lead	mg/kg		0.5	41.4	33.8	52.9	17.2	29.3	1860	232	6.8
Lithium	mg/kg		5	7	<5	7	6	9	16	<5	<5
Manganese	mg/kg		2	413	250	373	247	374	619	154	35
Molybdenum	mg/kg		2	<2	<2	2	<2	<2	<2	<2	<2
Nickel	mg/kg		2	10	7	12	6	9	17	4	<2
Selenium	mg/kg		1	<1	<1	<1	<1	<1	<1	<1	<1
Silver	mg/kg		0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Strontium	mg/kg		5	54	35	60	38	73	72	21	20
Thallium	mg/kg		0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tin	mg/kg		2	5	5	4	5	4	5	6	3
Uranium	mg/kg		0.1	0.4	0.2	0.4	0.3	0.4	0.4	<0.1	<0.1
Vanadium	mg/kg		2	10	7	11	8	11	31	5	2
Zinc	mg/kg		5	198	133	184	95	205	1640	426	81

Certified By: Laura Baker

Certificate of Analysis

AGAT WORK ORDER: 17X180829

PROJECT:

CLIENT NAME: MISC AGAT CLIENT NS

ATTENTION TO: Paul Arnold

SAMPLING SITE:

SAMPLED BY:

Available Metals in Soil

DATE RECEIVED: 2017-01-24

DATE REPORTED: 2017-01-30

			SAMPLE DESCRIPTION:	**28**	**29**	**30**	**31**
			SAMPLE TYPE:	**Soil**	**Soil**	**Soil**	**Soil**
			DATE SAMPLED:	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**
Parameter	**Unit**	**G / S**	**RDL**	**8145068**	**8145069**	**8145070**	**8145071**
Aluminum	mg/kg		10	112	93	453	1870
Antimony	mg/kg		1	<1	<1	<1	<1
Arsenic	mg/kg		1	2	1	2	5
Barium	mg/kg		5	11	17	23	114
Beryllium	mg/kg		2	<2	<2	<2	<2
Boron	mg/kg		2	2	66	3	34
Cadmium	mg/kg		0.3	<0.3	<0.3	<0.3	1.5
Chromium	mg/kg		2	<2	2	6	6
Cobalt	mg/kg		1	<1	<1	<1	1
Copper	mg/kg		2	2	<2	<2	13
Iron	mg/kg		50	204	192	237	2960
Lead	mg/kg		0.5	1.2	1.8	18.2	5.9
Lithium	mg/kg		5	<5	<5	<5	<5
Manganese	mg/kg		2	85	47	95	118
Molybdenum	mg/kg		2	<2	<2	<2	<2
Nickel	mg/kg		2	<2	<2	<2	9
Selenium	mg/kg		1	<1	<1	<1	<1
Silver	mg/kg		0.5	<0.5	<0.5	<0.5	<0.5
Strontium	mg/kg		5	<5	10	10	89
Thallium	mg/kg		0.1	<0.1	<0.1	<0.1	<0.1
Tin	mg/kg		2	3	3	3	9
Uranium	mg/kg		0.1	<0.1	<0.1	<0.1	0.2
Vanadium	mg/kg		2	3	2	4	11
Zinc	mg/kg		5	19	15	23	195

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

8145024-8145071 Results are based on the dry weight of the sample.

Certified By: Laura Baker

Certificate of Analysis

AGAT WORK ORDER: 17X180829
PROJECT:

CLIENT NAME: MISC AGAT CLIENT NS
SAMPLING SITE:

ATTENTION TO: Paul Arnold
SAMPLED BY:

Mercury Analysis in Soil

DATE RECEIVED: 2017-01-24

DATE REPORTED: 2017-01-30

			SAMPLE DESCRIPTION:	**HB-1**	**FP-1**	**PB-1**	**5**	**6**	**7**	**8-1**	**8-2**
			SAMPLE TYPE:	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**
			DATE SAMPLED:	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**
Parameter	**Unit**	**G / S**	**RDL**	**8145024**	**8145035**	**8145038**	**8145040**	**8145041**	**8145043**	**8145045**	**8145046**
Mercury	mg/kg		0.05	<0.05	<0.05	<0.05	0.07	0.08	0.07	0.16	0.06

			SAMPLE DESCRIPTION:	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
			SAMPLE TYPE:	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**
			DATE SAMPLED:	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**
Parameter	**Unit**	**G / S**	**RDL**	**8145048**	**8145050**	**8145051**	**8145052**	**8145053**	**8145054**	**8145055**	**8145056**
Mercury	mg/kg		0.05	0.06	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05

			SAMPLE DESCRIPTION:	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
			SAMPLE TYPE:	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**	**Soil**
			DATE SAMPLED:	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**
Parameter	**Unit**	**G / S**	**RDL**	**8145057**	**8145058**	**8145059**	**8145063**	**8145064**	**8145065**	**8145066**	**8145067**
Mercury	mg/kg		0.05	0.05	0.05	0.06	<0.05	<0.05	0.55	0.33	<0.05

			SAMPLE DESCRIPTION:	**28**	**29**	**30**	**31**
			SAMPLE TYPE:	**Soil**	**Soil**	**Soil**	**Soil**
			DATE SAMPLED:	**2017-01-24**	**2017-01-24**	**2017-01-24**	**2017-01-24**
Parameter	**Unit**	**G / S**	**RDL**	**8145068**	**8145069**	**8145070**	**8145071**
Mercury	mg/kg		0.05	<0.05	<0.05	<0.05	0.13

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

8145024-8145071 Results are based on the dry weight of the soil.

Certified By: Laura Baker

Quality Assurance

CLIENT NAME: MISC AGAT CLIENT NS
PROJECT:
SAMPLING SITE:

AGAT WORK ORDER: 17X180829
ATTENTION TO: Paul Arnold
SAMPLED BY:

Soil Analysis

RPT Date: Jan 30, 2017			DUPLICATE			Method Blank	REFERENCE MATERIAL			METHOD BLANK SPIKE			MATRIX SPIKE		
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD		Measured Value	Acceptable Limits		Recovery	Acceptable Limits		Recovery	Acceptable Limits	
								Lower	Upper		Lower	Upper		Lower	Upper
Available Metals in Soil															
Aluminum	1252017	8145064	4650	4630	0.4%	< 10	111%	80%	120%	110%	80%	120%	NA	70%	130%
Antimony	1252017	8145064	< 1	< 1	0.0%	< 1	86%	80%	120%	111%	80%	120%	88%	70%	130%
Arsenic	1252017	8145064	6	6	0.0%	< 1	100%	80%	120%	97%	80%	120%	102%	70%	130%
Barium	1252017	8145064	77	78	1.3%	< 5	104%	80%	120%	106%	80%	120%	116%	70%	130%
Beryllium	1252017	8145064	< 2	< 2	0.0%	< 2	113%	80%	120%	111%	80%	120%	103%	70%	130%
Boron	1252017	8145064	18	17	5.7%	< 2	111%	80%	120%	115%	80%	120%	106%	70%	130%
Cadmium	1252017	8145064	0.6	0.6	0.0%	< 0.3	100%	80%	120%	104%	80%	120%	99%	70%	130%
Chromium	1252017	8145064	12	13	8.0%	< 2	100%	80%	120%	105%	80%	120%	121%	70%	130%
Cobalt	1252017	8145064	3	3	0.0%	< 1	100%	80%	120%	105%	80%	120%	108%	70%	130%
Copper	1252017	8145064	47	46	2.2%	< 2	104%	80%	120%	108%	80%	120%	109%	70%	130%
Iron	1252017	8145064	9750	9370	4.0%	< 50	96%	80%	120%	103%	80%	120%	114%	70%	130%
Lead	1252017	8145064	29.3	29.0	1.0%	< 0.5	109%	80%	120%	111%	80%	120%	109%	70%	130%
Lithium	1252017	8145064	9	9	0.0%	< 5	109%	70%	130%	111%	70%	130%	109%	70%	130%
Manganese	1252017	8145064	374	373	0.3%	< 2	96%	80%	120%	100%	80%	120%	113%	70%	130%
Molybdenum	1252017	8145064	< 2	< 2	0.0%	< 2	99%	80%	120%	97%	80%	120%	102%	70%	130%
Nickel	1252017	8145064	9	9	0.0%	< 2	104%	80%	120%	107%	80%	120%	115%	70%	130%
Selenium	1252017	8145064	< 1	< 1	0.0%	< 1	105%	80%	120%	86%	80%	120%	98%	70%	130%
Silver	1252017	8145064	< 0.5	< 0.5	0.0%	< 0.5	107%	80%	120%	110%	80%	120%	97%	70%	130%
Strontium	1252017	8145064	73	71	2.8%	< 5	98%	80%	120%	102%	80%	120%	115%	70%	130%
Thallium	1252017	8145064	< 0.1	< 0.1	0.0%	< 0.1	112%	80%	120%	108%	80%	120%	NA	70%	130%
Tin	1252017	8145064	4	4	0.0%	< 2	102%	80%	120%	100%	80%	120%	89%	70%	130%
Uranium	1252017	8145064	0.4	0.4	0.0%	< 0.1	107%	80%	120%	108%	80%	120%	98%	70%	130%
Vanadium	1252017	8145064	11	11	0.0%	< 2	98%	80%	120%	101%	80%	120%	125%	70%	130%
Zinc	1252017	8145064	205	213	3.8%	< 5	102%	80%	120%	105%	80%	120%	108%	70%	130%
Mercury Analysis in Soil															
Mercury	1		< 0.05	< 0.05	0.0%	< 0.05	91%	70%	130%		70%	130%	NA	70%	130%

Certified By:

AGAT Laboratories is accredited to ISO/IEC 17025 by the Canadian Association for Laboratory Accreditation Inc. (CALA) and/or Standards Council of Canada (SCC) for specific tests listed on the scope of accreditation. AGAT Laboratories (Mississauga) is also accredited by the Canadian Association for Laboratory Accreditation Inc. (CALA) for specific drinking water tests. Accreditations are location and parameter specific. A complete listing of parameters for each location is available from www.cala.ca and/or www.scc.ca. The tests in this report may not necessarily be included in the scope of accreditation.

Results relate only to the items tested and to all the items tested

Method Summary

CLIENT NAME: MISC AGAT CLIENT NS
PROJECT:
SAMPLING SITE:

AGAT WORK ORDER: 17X180829
ATTENTION TO: Paul Arnold
SAMPLED BY:

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Soil Analysis			
Aluminum	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Antimony	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Arsenic	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Barium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Beryllium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Boron	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Cadmium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Chromium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Cobalt	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Copper	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Iron	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Lead	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP-MS
Lithium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP-MS
Manganese	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Molybdenum	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Nickel	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Selenium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Silver	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Strontium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Thallium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Tin	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Uranium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Vanadium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Zinc	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Mercury	INOR-121-6101 & INOR-121-6107	Based on EPA 245.5 & SM 3112B	CV/AA

AGAT Laboratories

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Dartmouth, NS
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P: 902.468.8718 ▪ F: 902.468.8924

Chain of Custody Record

Laboratory Use Only

Arrival Condition: ☐ Good ☐ Poor (see notes)
Arrival Temperature:
Hold Time:
AGAT Job Number: 17X180829
Notes: Hold remaining samples for collection containers

Report Information

Company: Bio-Logic Environmental
Contact: PAUL ARNOLD
Address: 18 Erin Drive
Dartmouth NS
Phone: 902 449 6910 Fax:
Client Project #: #157485
AGAT Quotation: Emailed by Abbey
Please Note: If quotation number is not provided client will be billed full price for analysis.

Report Information (Please print):

1. Name: PAUL ARNOLD
Email: bio-logic@ns.sympatico.ca
2. Name:
Email:

Report Format

☐ Single Sample per page
☑ Multiple Samples per page
☑ Excel Format Included
☐ Export

Turnaround Time Required (TAT)

Regular TAT ☑ 5 to 7 working days
Rush TAT ☐ Same day ☐ 1 day ☐ 2 days ☐ 3 days
Date Required:

Regulatory Requirements (Check):

☐ List Guidelines on Report ☐ Do not list Guidelines on Report
☐ PIRI
☐ Tier 1 ☐ Res ☐ Pot ☐ Coarse
☐ Tier 2 ☐ Com ☐ N/Pot ☐ Fine
☐ Gas ☐ Fuel ☐ Lube
☐ CCME
☐ Industrial
☐ Commercial
☐ Res/Park
☐ Agricultural
☐ FWAL
☐ Sediment
☐ CDWQ
☐ NSEQS-Cont Sites
☐ HRM 101
☐ Storm Water
☐ Waste Water
☐ Other

Drinking Water Sample: ☐ Yes ☐ No **Salt Water Sample** ☐ Yes ☐ No
Reg. No.:

Invoice To Same Yes ☐ / No ☐

Company: As above
Contact:
Address:
Phone: Fax:
PO/Credit Card#:

Sample Identification	Date/Time Sampled	Sample Matrix	# Containers	Comments – Site/Sample Info. Sample Containment
HB-1		Compost		
FP-1		''		
PB-1		''		
5		''		
6		''		
7		''		
8-1		''		
8-2		''		
9		''		
10		''		
11		''		
12		''		

Sample Identification	Field Filtered/Preserved	Standard Water Analysis	Metals: ☐ Total ☐ Diss ☑ Available	Mercury	☐ BOD ☐ CBOD	pH	☐ TSS ☐ TDS ☐ VSS	TKN	Total Phosphorus	Phenols	Tier 1: TPH/BTEX (PIRI) ☐ low level	Tier 2: TPH/BTEX Fractionation	CCME-CWS TPH/BTEX	VOC	THM	HAA	PAH	PCB	TC + EC ☐ P/A ☐ MPN ☐ MF	☐ HPC ☐ Pseudomonas	Fecal Coliform ☐ MPN ☐ MF	Other:	Other:	Hazardous (Y/N)
HB-1			✓	✓																				
FP-1			✓	✓																				
PB-1			✓	✓																				
5			✓	✓																				
6			✓	✓																				
7			✓	✓																				
8-1			✓	✓																				
8-2			✓	✓																				
9			✓	✓																				
10			✓	✓																				
11			✓	✓																				
12			✓	✓																				

Samples Relinquished By (Print Name): PAUL ARNOLD	Date/Time: Jan 24/17	Samples Received By (Print Name): C. Deamel	Date/Time: Jan 24/17	Pink Copy - Client Yellow Copy - AGAT White Copy- AGAT
Samples Relinquished By (Sign): Paul Arnold	Date/Time:	Samples Received By (Sign):	Date/Time: 15:45	

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Nº: 58458

Document ID: DIV 133-1501.004
Date revised: May 19, 2016

AGAT Laboratories

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Chain of Custody Record

Laboratory Use Only

Arrival Condition: ☐ Good ☐ Poor (see notes)
Arrival Temperature:
Hold Time:
AGAT Job Number: 17X 180829
Notes: Hold remaining samples for collection + containers

Report Information

Company: Bio-Logic Environmental
Contact: Paul Arnold
Address: 18 Erin Drive
Dartmouth NS
Phone: 902 449 6910 Fax:
Client Project #:
AGAT Quotation: Emailed #157485
Please Note: If quotation number is not provided client will be billed full price for analysis.

Report Information (Please print):

1. Name: PAUL ARNOLD
   Email: bio-logic@ns.sympatico.ca
2. Name:
   Email:

Report Format

☐ Single Sample per page
☑ Multiple Samples per page
☑ Excel Format Included
☐ Export

Turnaround Time Required (TAT)

Regular TAT ☑ 5 to 7 working days
Rush TAT ☐ Same day ☐ 1 day ☐ 2 days ☐ 3 days
Date Required:

Regulatory Requirements (Check):

☐ List Guidelines on Report ☐ Do not list Guidelines on Report
☐ PIRI
- ☐ Tier 1 ☐ Res ☐ Pot ☐ Coarse
- ☐ Tier 2 ☐ Com ☐ N/Pot ☐ Fine
- ☐ Gas ☐ Fuel ☐ Lube

☐ CCME
- ☐ Industrial
- ☐ Commercial
- ☐ Res/Park
- ☐ Agricultural
- ☐ FWAL
- ☐ Sediment

☐ CDWQ
☐ NSEQS-Cont Sites
☐ HRM 101
- ☐ Storm Water
- ☐ Waste Water

☐ Other

Drinking Water Sample: ☐ Yes ☐ No **Salt Water Sample** ☐ Yes ☐ No
Reg. No.:

Invoice To Same Yes ☐ / No ☐

Company:
Contact:
Address:
Phone: Fax:
PO/Credit Card#:

Sample Identification	Date/Time Sampled	Sample Matrix	# Containers	Comments – Site/Sample Info. Sample Containment	Field Filtered/Preserved	Standard Water Analysis	Metals: ☐ Total ☐ Diss ☑ Available	Mercury	☐ BOD ☐ CBOD	pH	☐ TSS ☐ TDS ☐ VSS	TKN	Total Phosphorus	Phenols	Tier 1: TPH/BTEX (PIRI) ☐ low level	Tier 2: TPH/BTEX Fractionation	CCME-CWS TPH/BTEX	VOC	THM	HAA	PAH	PCB	TC + EC ☐ P/A ☐ MPN ☐ MF	☐ HPC ☐ Pseudomonas	Fecal Coliform ☐ MPN ☐ MF	Other:	Other:	Hazardous (Y/N)
13		Compost					✓	✓																				
14							✓	✓																				
15							✓	✓																				
16							✓	✓																				
17							✓	✓																				
18							✓	✓																				
19							✓	✓																				
20							✓	✓																				
21							✓	✓																				
22							✓	✓																				
23							✓	✓																				
24							✓	✓																				

Samples Relinquished By (Print Name): PAUL ARNOLD
Date/Time: Jan 24/17
Samples Received By (Print Name): C. Deamel
Date/Time: Jan 24/17
Samples Relinquished By (Sign): Paul Arnold
Date/Time:
Samples Received By (Sign):
Date/Time: 15:45

Pink Copy - Client
Yellow Copy - AGAT
White Copy- AGAT

Page 2 of 3

Nº: 58459

Document ID: DIV-133-1501.004

Date revised: May 19, 2016

AGAT Laboratories

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Dartmouth, NS
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Chain of Custody Record

P: 902.468.8718 ▪ F: 902.468.8924

Laboratory Use Only

Arrival Condition: ☐ Good ☐ Poor (see notes)
Arrival Temperature:
Hold Time:
AGAT Job Number: 17x180829
Notes: Hold remaining samples for collection + containers

Report Information

Company: Bio-Logic Environmental
Contact: Paul Arnold
Address: 18 Erin Drive
Dartmouth NS
Phone: 902 449 6910 Fax:
Client Project #:
AGAT Quotation: # 157485
Please Note: If quotation number is not provided client will be billed full price for analysis.

Report Information (Please print):

1. Name: Paul Arnold
Email: bio-logicens
2. Name: .sympatico.ca
Email:

Report Format

☐ Single Sample per page
☑ Multiple Samples per page
☑ Excel Format Included
☐ Export

Turnaround Time Required (TAT)

Regular TAT ☑ 5 to 7 working days
Rush TAT ☐ Same day ☐ 1 day
☐ 2 days ☐ 3 days
Date Required:

Invoice To Same Yes ☐ / No ☐

Company:
Contact:
Address:
Phone: Fax:
PO/Credit Card#:

Regulatory Requirements (Check):

☐ List Guidelines on Report ☐ Do not list Guidelines on Report
☐ PIRI
☐ Tier 1 ☐ Res ☐ Pot ☐ Coarse
☐ Tier 2 ☐ Com ☐ N/Pot ☐ Fine
☐ Gas ☐ Fuel ☐ Lube

☐ CCME
☐ Industrial
☐ Commercial
☐ Res/Park
☐ Agricultural
☐ FWAL
☐ Sediment

☐ CDWQ
☐ NSEQS-Cont Sites
☐ HRM 101
☐ Storm Water
☐ Waste Water
☐ Other

Drinking Water Sample: ☐ Yes ☐ No **Salt Water Sample** ☐ Yes ☐ No
Reg. No.:

Sample Identification	Date/Time Sampled	Sample Matrix	# Containers	Comments – Site/Sample Info. Sample Containment	Field Filtered/Preserved	Standard Water Analysis	**Metals:** ☐ Total ☐ Diss ☑ Available	Mercury	☐ BOD ☐ CBOD	pH	☐ TSS ☐ TDS ☐ VSS	TKN	Total Phosphorus	Phenols	**Tier 1:** TPH/BTEX (PIRI) ☐ low level	**Tier 2:** TPH/BTEX Fractionation	CCME-CWS TPH/BTEX	VOC	THM	HAA	PAH	PCB	TC + EC ☐ P/A ☐ MPN ☐ MF	☐ HPC ☐ Pseudomonas	Fecal Coliform ☐ MPN ☐ MF	**Other:**	**Other:**	Hazardous (Y/N)
28							✓	✓																				
29							✓	✓																				
30							✓	✓																				
31							✓	✓																				

Samples Relinquished By (Print Name): Paul Arnold
Date/Time: Jan 24/17
Samples Relinquished By (Sign): Paul Arnold
Date/Time:
Samples Received By (Print Name): C.Deamel
Date/Time: Jan 24/17
Samples Received By (Sign):
Date/Time: 15:45

Pink Copy - Client
Yellow Copy - AGAT
White Copy- AGAT

Page 3 of 3
Nº: 58460

AGAT Laboratories

11 Morris Drive, Unit 122
Dartmouth, Nova Scotia
CANADA B3B 1M2
TEL (902)468-8718
FAX (902)468-8924
http://www.agatlabs.com

CLIENT NAME: MISC AGAT CLIENT NS, NS
(902)

ATTENTION TO: Paul Arnold

PROJECT:

AGAT WORK ORDER: 17X181393

SOIL ANALYSIS REVIEWED BY: Laura Baker, Inorganics Data Reporter

DATE REPORTED: Jan 27, 2017

PAGES (INCLUDING COVER): 6

VERSION*: 1

Should you require any information regarding this analysis please contact your client services representative at (902) 468-8718

NOTES

All samples will be disposed of within 30 days following analysis. Please contact the lab if you require additional sample storage time.

Member of: Association of Professional Engineers and Geoscientists of Alberta (APEGA)
Western Enviro-Agricultural Laboratory Association (WEALA)
Environmental Services Association of Alberta (ESAA)

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Results relate only to the items tested and to all the items tested
All reportable information as specified by ISO 17025:2005 is available from AGAT Laboratories upon request

AGAT Laboratories

Certificate of Analysis

AGAT WORK ORDER: 17X181393

PROJECT:

11 Morris Drive, Unit 122
Dartmouth, Nova Scotia
CANADA B3B 1M2
TEL (902)468-8718
FAX (902)468-8924
http://www.agatlabs.com

CLIENT NAME: MISC AGAT CLIENT NS

ATTENTION TO: Paul Arnold

SAMPLING SITE:

SAMPLED BY:

Available Metals in Soil

DATE RECEIVED: 2017-01-26

DATE REPORTED: 2017-01-27

			SAMPLE DESCRIPTION:	#1	#2	#3
			SAMPLE TYPE:	Soil	Soil	Soil
			DATE SAMPLED:	2017-01-26	2017-01-26	2017-01-26
Parameter	**Unit**	**G / S**	**RDL**	**8149389**	**8149390**	**8149391**
Aluminum	mg/kg		10	1990	1350	973
Antimony	mg/kg		1	<1	<1	<1
Arsenic	mg/kg		1	3	3	2
Barium	mg/kg		5	140	203	67
Beryllium	mg/kg		2	<2	<2	<2
Boron	mg/kg		2	45	37	59
Cadmium	mg/kg		0.3	1.3	1.9	<0.3
Chromium	mg/kg		2	6	5	4
Cobalt	mg/kg		1	2	2	1
Copper	mg/kg		2	42	29	26
Iron	mg/kg		50	5960	3480	2300
Lead	mg/kg		0.5	8.6	5.9	3.9
Lithium	mg/kg		5	<5	<5	<5
Manganese	mg/kg		2	230	147	184
Molybdenum	mg/kg		2	3	3	2
Nickel	mg/kg		2	13	9	6
Selenium	mg/kg		1	<1	<1	<1
Silver	mg/kg		0.5	<0.5	<0.5	<0.5
Strontium	mg/kg		5	149	133	87
Thallium	mg/kg		0.1	<0.1	<0.1	<0.1
Tin	mg/kg		2	7	8	3
Uranium	mg/kg		0.1	0.4	0.2	0.2
Vanadium	mg/kg		2	9	7	6
Zinc	mg/kg		5	205	182	83

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

8149389-8149391 Results are based on the dry weight of the sample.

Certified By: Laura Baker

Results relate only to the items tested and to all the items tested

Certificate of Analysis

AGAT WORK ORDER: 17X181393

PROJECT:

11 Morris Drive, Unit 122
Dartmouth, Nova Scotia
CANADA B3B 1M2
TEL (902)468-8718
FAX (902)468-8924
http://www.agatlabs.com

CLIENT NAME: MISC AGAT CLIENT NS

ATTENTION TO: Paul Arnold

SAMPLING SITE:

SAMPLED BY:

Mercury Analysis in Soil

DATE RECEIVED: 2017-01-26

DATE REPORTED: 2017-01-27

			SAMPLE DESCRIPTION:	#1	#2	#3
			SAMPLE TYPE:	Soil	Soil	Soil
			DATE SAMPLED:	2017-01-26	2017-01-26	2017-01-26
Parameter	**Unit**	**G / S**	**RDL**	**8149389**	**8149390**	**8149391**
Mercury	mg/kg		0.05	0.13	0.12	0.14

Comments: RDL - Reported Detection Limit; G / S - Guideline / Standard

8149389-8149391 Results are based on the dry weight of the soil.

Certified By: Laura Baker

Quality Assurance

CLIENT NAME: MISC AGAT CLIENT NS **AGAT WORK ORDER: 17X181393**
PROJECT: **ATTENTION TO: Paul Arnold**
SAMPLING SITE: **SAMPLED BY:**

Soil Analysis

RPT Date:			DUPLICATE			Method Blank	REFERENCE MATERIAL			METHOD BLANK SPIKE			MATRIX SPIKE		
PARAMETER	Batch	Sample Id	Dup #1	Dup #2	RPD		Measured Value	Acceptable Limits		Recovery	Acceptable Limits		Recovery	Acceptable Limits	
								Lower	Upper		Lower	Upper		Lower	Upper
Available Metals in Soil															
Aluminum	1272017	8149391	973	1060	8.6%	< 10	113%	80%	120%	116%	80%	120%	NA	70%	130%
Antimony	1272017	8149391	< 1	< 1	0.0%	< 1	80%	80%	120%	108%	80%	120%	105%	70%	130%
Arsenic	1272017	8149391	2	2	0.0%	< 1	97%	80%	120%	100%	80%	120%	105%	70%	130%
Barium	1272017	8149391	67	72	7.2%	< 5	99%	80%	120%	104%	80%	120%	113%	70%	130%
Beryllium	1272017	8149391	< 2	< 2	0.0%	< 2	101%	80%	120%	101%	80%	120%	105%	70%	130%
Boron	1272017	8149391	59	61	3.3%	< 2	100%	80%	120%	105%	80%	120%	103%	70%	130%
Cadmium	1272017	8149391	< 0.3	< 0.3	0.0%	< 0.3	97%	80%	120%	101%	80%	120%	103%	70%	130%
Chromium	1272017	8149391	4	4	0.0%	< 2	92%	80%	120%	99%	80%	120%	127%	70%	130%
Cobalt	1272017	8149391	1	1	0.0%	< 1	94%	80%	120%	98%	80%	120%	102%	70%	130%
Copper	1272017	8149391	26	28	7.4%	< 2	92%	80%	120%	99%	80%	120%	102%	70%	130%
Iron	1272017	8149391	2300	2710	16.4%	< 50	89%	80%	120%	100%	80%	120%	126%	70%	130%
Lead	1272017	8149391	3.9	4.6	16.5%	< 0.5	107%	80%	120%	112%	80%	120%	105%	70%	130%
Lithium	1272017	8149391	< 5	< 5	0.0%	< 5	105%	70%	130%	109%	70%	130%	115%	70%	130%
Manganese	1272017	8149391	184	186	1.1%	< 2	93%	80%	120%	95%	80%	120%	108%	70%	130%
Molybdenum	1272017	8149391	2	2	0.0%	< 2	90%	80%	120%	95%	80%	120%	101%	70%	130%
Nickel	1272017	8149391	6	7	15.4%	< 2	95%	80%	120%	99%	80%	120%	103%	70%	130%
Selenium	1272017	8149391	< 1	< 1	0.0%	< 1	97%	80%	120%	103%	80%	120%	101%	70%	130%
Silver	1272017	8149391	< 0.5	< 0.5	0.0%	< 0.5	98%	80%	120%	101%	80%	120%	96%	70%	130%
Strontium	1272017	8149391	87	93	6.7%	< 5	91%	80%	120%	94%	80%	120%	105%	70%	130%
Thallium	1272017	8149391	< 0.1	< 0.1	0.0%	< 0.1	105%	80%	120%	111%	80%	120%	NA	70%	130%
Tin	1272017	8149391	3	3	0.0%	< 2	97%	80%	120%	102%	80%	120%	100%	70%	130%
Uranium	1272017	8149391	0.2	0.2	0.0%	< 0.1	102%	80%	120%	109%	80%	120%	102%	70%	130%
Vanadium	1272017	8149391	6	7	15.4%	< 2	92%	80%	120%	95%	80%	120%	126%	70%	130%
Zinc	1272017	8149391	83	86	3.6%	< 5	94%	80%	120%	95%	80%	120%	99%	70%	130%
Mercury Analysis in Soil															
Mercury	1		< 0.05	< 0.05	0.0%	< 0.05	91%	70%	130%		70%	130%	99%	70%	130%

Certified By:

AGAT Laboratories is accredited to ISO/IEC 17025 by the Canadian Association for Laboratory Accreditation Inc. (CALA) and/or Standards Council of Canada (SCC) for specific tests listed on the scope of accreditation. AGAT Laboratories (Mississauga) is also accredited by the Canadian Association for Laboratory Accreditation Inc. (CALA) for specific drinking water tests. Accreditations are location and parameter specific. A complete listing of parameters for each location is available from www.cala.ca and/or www.scc.ca. The tests in this report may not necessarily be included in the scope of accreditation.

Results relate only to the items tested and to all the items tested

11 Morris Drive, Unit 122
Dartmouth, Nova Scotia
CANADA B3B 1M2
TEL (902)468-8718
FAX (902)468-8924
http://www.agatlabs.com

Method Summary

CLIENT NAME: MISC AGAT CLIENT NS **AGAT WORK ORDER: 17X181393**

PROJECT: **ATTENTION TO: Paul Arnold**

SAMPLING SITE: **SAMPLED BY:**

PARAMETER	AGAT S.O.P	LITERATURE REFERENCE	ANALYTICAL TECHNIQUE
Soil Analysis			
Aluminum	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Antimony	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Arsenic	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Barium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Beryllium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Boron	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Cadmium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Chromium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Cobalt	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Copper	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Iron	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Lead	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP-MS
Lithium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP-MS
Manganese	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Molybdenum	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Nickel	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Selenium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Silver	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Strontium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Thallium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Tin	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Uranium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Vanadium	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Zinc	MET-121-6105 & MET-121-6103	EPA SW 846 6020A/3050B & SM 3125	ICP/MS
Mercury	INOR-121-6101 & INOR-121-6107	Based on EPA 245.5 & SM 3112B	CV/AA

Results relate only to the items tested and to all the items tested

AGAT Laboratories

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Chain of Custody Record

Laboratory Use Only

Arrival Condition: ☐ Good ☐ Poor (see notes)
Arrival Temperature: 16° just taken.
Hold Time:
AGAT Job Number: 17X181393
Notes: Hold remaining samples for collection

Report Information

Company: Bio-Logic Environmental
Contact: Paul Arnold
Address: 18 Elvin Drive
Dartmouth NS
Phone: 9024496910 Fax:
Client Project #:
AGAT Quotation:
Please Note: If quotation number is not provided client will be billed full price for analysis.

Report Information (Please print):

1. Name: Paul Arnold
   Email: bio-logicens.
2. Name: Sympatico.ca
   Email:

Report Format

☐ Single Sample per page
☐ Multiple Samples per page
☐ Excel Format Included
☐ Export

Turnaround Time Required (TAT)

RUSH!

Regular TAT ☐ 5 to 7 working days
Rush TAT ☐ Same day ☐ 1 day
☐ 2 days ☑ 3 days
Date Required:

Regulatory Requirements (Check):

☐ List Guidelines on Report ☐ Do not list Guidelines on Report

☐ PIRI
- ☐ Tier 1 ☐ Res ☐ Pot ☐ Coarse
- ☐ Tier 2 ☐ Com ☐ N/Pot ☐ Fine
- ☐ Gas ☐ Fuel ☐ Lube

☐ CCME
- ☐ Industrial
- ☐ Commercial
- ☐ Res/Park
- ☐ Agricultural
- ☐ FWAL
- ☐ Sediment

☐ CDWQ
☐ NSEQS-Cont Sites
☐ HRM 101
- ☐ Storm Water
- ☐ Waste Water

☐ Other

Drinking Water Sample: ☐ Yes ☐ No **Salt Water Sample** ☐ Yes ☐ No
Reg. No.:

Invoice To

Same Yes ☐ / No ☐
Company: As Above
Contact:
Address:
Phone: Fax:
PO/Credit Card#:

Sample Identification	Date/Time Sampled	Sample Matrix	# Containers	Comments – Site/Sample Info. Sample Containment	Field Filtered/Preserved	Standard Water Analysis	Metals: ☐ Total ☐ Diss ☑ Available	Mercury	☐ BOD ☐ CBOD	pH	☐ TSS ☐ TDS ☐ VSS	TKN	Total Phosphorus	Phenols	Tier 1: TPH/BTEX (PIRI) ☐ low level	Tier 2: TPH/BTEX Fractionation	CCME-CWS TPH/BTEX	VOC	THM	HAA	PAH	PCB	TC + EC ☐ P/A ☐ MPN ☐ MF	☐ HPC ☐ Pseudomonas	Fecal Coliform ☐ MPN ☐ MF	Other:	Other:	Hazardous (Y/N)
#1	26-Jan-17	Compost					✓	✓																				
#2	|	"					✓	✓																				
#3		"					✓	✓																				

Samples Relinquished By (Print Name): Paul Arnold	Date/Time Jan 26/17	Samples Received By (Print Name): T MacDonald	Date/Time 26-JAN-17	Pink Copy - Client Yellow Copy - AGAT White Copy- AGAT	Page 1 of 1
Samples Relinquished By (Sign):	Date/Time 10:00	Samples Received By (Sign): T MacDonald	Date/Time 09:50		Nº: 58466