ASH MANAGEMENT AT CANFOR PULP – TURNING A WASTE PRODUCT INTO A PROFIT STREAM

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Table of Contents

List of Tables

List of Figures

Abstract

Canfor Pulp Ltd. produces bleached and unbleached softwood Kraft Pulp and Paper products at mills located in Prince George British Columbia. They burn biomass to generate energy, and they produce ash as a by-product. Due to the changing nature of the business, the amount of waste ash produced by Canfor Pulp has increased significantly over the last 10 years - using conservative estimates, by at least 100%.

This project examined the options available for beneficial reuse of the ash, measured them against defined criteria in order to select preferred options and then and evaluated the viability of those options for the diversion and sale of this ash.

It was determined that use of the ash as an agricultural supplement presents a viable market for the ash. Market size and price are not barriers to enter into this market. Other markets, such as mine reclamation, and petroleum site reclamation may also be viable outlets for the ash, pending the outcome of further financial analysis.

Introduction

Canfor Pulp Ltd. is a publicly traded Canadian company that produces bleached and unbleached softwood Kraft Pulp and Paper products at 3 mills located in Prince George British Columbia. With the three facilities combined, Canfor Pulp is the largest industrial producer of "green electricity" and energy in North America. It is generated using biomass feedstock and supplemented with natural gas.

Canfor Pulp purchases wood residue in the form of wood chips, sawdust, shavings and bark. The wood chips are used as a raw material for the pulping process and converted to pulp and paper, which is then sold. The bark, sawdust and shavings are used to produce energy by incinerating them in power boilers to produce steam. The bark, sawdust and shavings are more commonly referred to as "hog fuel." The steam is used in the process to produce pulp, but is also used at each mill to generate electricity.

The two by-products of the power boilers are bottom ash and fly ash. Bottom ash is the heavier material that accumulates on the boilers grates (bottom of the firing chamber) as the wood is burned – consisting mainly of heavy unburned material, rocks and other inert matter or impurities that are in the hog fuel and combusted material that is too heavy to be carried up the flu with hot combustion gasses. Fly ash is the material that travels up and through the boiler with the combustion gasses and is removed from the gas stream before the waste gas is discharged to the environment (Figures 6 through 9).

The current practice at all three of Canfor Pulp Mills is to landfill both streams of this ash. Waste sites are developed by excavating a hole, depositing ash and then covering it. At some point, new locations need to be developed to landfill more ash. The capital cost for developing landfill sites is prohibitive and usually is in the magnitude of tens of millions of dollars. New landfill codes of practice in the Province of British Columbia restrict the location of new landfill sites and contain stringent site preparation requirements. There is also a significant potential for future environmental liability regarding large landfilled stockpiles of waste material on the mill sites.

With this in mind, and considering objectives related to operating costs and profit, Canfor Pulp has determined that it is desirable to minimize costs related to ash disposal and if possible should turn this waste material into a revenue stream.

The purpose of this project is to research whether there are technically feasible options available for re-use or sale of the power boiler ash, evaluate the options for "fit" with Canfor

Pulp's strategic objectives, evaluate the market for the ash and then conduct financial analysis to determine which (or if any) of the options should be pursued.

The Current Situation

The waste wood market is complex. Wood chip availability and price is dependent on sawmill production volumes, distance between sawmills and pulp mills, and the market price for pulp. The cost of transportation is a major factor in determining if a source is viable and creates complicated trading agreements – even between direct competitors- in order to minimize haul costs. Chip purchase agreements are usually accompanied by agreements to purchase the other residuals, in particular bark. Bark is the lowest valued material of the types of wood residuals and available supply can swing significantly depending on the lumber market. Canfor Pulp depends on the use of hog fuel to generate a significant portion of the energy required by the mills. The total thermal energy requirements for the mills are seasonal. More steam is required by the mills in the winter and less steam is required in the summer. This translates to seasonal swings in hog fuel demand. The net result is that Canfor Pulp will typically purchase more fuel than required to ensure that the fuel supply does not run out.

There are four power boilers across the three Canfor Pulp mill sites that continuously operate. A fifth power boiler, #2 power boiler at the Northwood mill does not usually operate, but it can be started if energy requirements demand it. All of the power boilers produce significant quantities of ash. All of this ash is currently disposed in on-site landfills at the facilities.

Pulp mill production rates have been incrementally increasing over the years. The net effect has been an increase in the requirement for steam production, an overall increase in consumption of hog fuel, and an increase in the production of ash. There have been upgrades at all three mills over the last fifteen years that have increased the production of electricity at the mills. All three mills have also upgraded the pollution control equipment for their respective power boilers. This means that there has been a reduction of the discharge of particulate to air, and that captured particulate is now collected as ash. The net result has been a gradually increasing rate of ash discharge over the years, a trend that is expected to continue.

The relevant changes (affecting the production of ash) that have been made at the pulp mills are as follows:

- Installation of an electrostatic precipitator on the outlet of the Intercontinental Pulp Mill (Intercon) power boiler, resulting in an increase in ash generation.
- Conversion of the #2 power boiler at Prince George Pulp from a recovery boiler to a power boiler, the installation of a condensing steam turbine, and a net increase in steam demand and ash generation.
- Installation of a side stream scrubber on the outlet of the #4 Power Boiler at the Northwood Pulp Mill, an increasing in bark firing rates and an accompanying increase in ash generation.
- Conversion of the #1 Recovery Boiler at the Northwood Pulp mill to a low odour system and a significant increase in steam production. The change has resulted in the ability to shut down the older #2 Power Boiler with the exception of two weeks per year. The rest of the year when the boiler is not running, it does not produce ash. Unfortunately this has been offset by the increased firing rates in the #4 Power Boiler.
- Installation of an electrostatic precipitator on the outlet of the #1 Power Boiler at the PG Pulp Mill in 2013 and an accompanying increase in ash generation.

One of the key questions to be considered is the consistency of the properties and characteristics of the ash. Because there are five power boilers with different operating conditions and potentially differing feedstock, it is important to understand the differences and similarities so that the strategy that emerges will properly consider them. It should also be noted that there may be opportunities to undertake different solutions for one, some, or all of the three mills based on these differences and similarities. The following three sections will describe the systems at each of the three mills:

Northwood Pulp

The Northwood Pulp Mill is a dual production line pulp mill with a total target production rate of 1680 air-dry tonnes (adt) of pulp per day. The mill has two power boilers, #2 and #4. #2 Power Boiler was built with the original mill in the 1960's and is only equipped with multiclones for particulate removal from its gas discharge. #2 Power Boiler is not currently operated for more than two weeks per year and is only used as a backup boiler for periods where #4 Power Boiler or one of the recovery boilers may not be available, or undergoing maintenance. It has an antiquated manual grate system for removing bottom ash.

#4 Power Boiler was built in the mid 1980's and is equipped with considerably newer technology. It is equipped with automated moving grates for bottom ash removal, multiclone banks, plus a side-stream scrubber for particulate removal from stack gas.

Ash collected by the multiclones and the side-stream scrubber is conveyed via a wet ash sluicing system to an ash lagoon where the ash settles out of the stream and clean supernatant continues on into the mill's effluent treatment system. The ash lagoon is usually drained once per year and the dewatered ash is trucked to landfill. The quantity of ash removed to the landfill depends on the annual budget for cleaning the pond and the annual landfill permit limit. The bottom ash from both of the boilers goes into an ash bunker from which material is trucked directly to the landfill. The boilers burn hog fuel which is comprised mostly of bark, and a small quantity of primary clarifier sludge from the effluent treatment plant. The primary clarifier sludge consists of dewatered reject pulp and small quantities of lime mud ($CaCO_3$).

Intercon Pulp

Intercon Pulp is a single line pulp mill with a target production rate of 925 adt of pulp per day. It operates one Power Boiler. Bottom and combustion ash is conveyed via a wet sluicing system to an ash lagoon which like the Northwood lagoon system, allows the ash to settle and then the clean supernatant carries on to the effluent treatment system. The ash lagoon is drained periodically and then the remaining ash is trucked to landfill. Precipitator ash is collected and trucked to the landfill dry and in bulk quantities.

PG Pulp

PG pulp is an integrated pulp and paper mill with one production line specific to a pulp machine and one for a paper machine. The combined pulp (440 adt) and paper (389 adt) production target is 829 adt/d. The mill operates two power boilers: #1 Power Boiler and #2 Power Boiler. #2 Power Boiler is a recovery boiler that was converted into a power boiler in 2005. #2 Power Boiler is capable of burning about 225,000 Oven Dried Tonnes (ODT) of hog fuel per year. The boiler conversion project also changed the existing wet bottom recovery boiler electrostatic precipitator into a dry bottom system suitable for capturing ash from a power boiler discharge. An electrostatic precipitator was also added to #1 Power Boiler in 2013.

Bottom ash from #2 Power Boiler is conveyed via a wet ash sluicing system to an ash bunker from which the ash is trucked to landfill. Ash from the precipitator is collected in bins which are used to convey the ash directly to the mill landfill site. Ash from the #1 Power Boiler is now handled the same way as #2 Power Boiler, with a wet conveying system taking bottom ash to a bunker and dry precipitator ash is conveyed into a bin which is then used to take that ash to the landfill.

The annual estimated quantity of ash generated by all of the Canfor Pulp power boilers is provided in Table 1. The Northwood Pulp Mill power boiler ash systems are combined and counted as one source.

Table 1 2012 Ash Generation at Canfor Pulp

MILL	Bunker Bottom Ash (Tonnes)	Ash to Lagoons or removed from lagoons (Tonnes)	Ash to landfill in Bins (Tonnes)	**TOTAL (Tonnes)**
Northwood	1,050	3,830	N/A	4,880
PG #1 Power Boiler	Not counted	5,730	4,600	10,330
PG #2 Power Boiler	Not counted	N/A	30,600	30,600
Intercon Power Boiler	N/A	5900	3,000	8,900
TOTAL	**1,050**	**15,460**	**38,200**	**54,710**

Chemical analysis and the physical properties of the ash streams are included in Appendix 1.

Literature Review

Existing literature was searched for two facets that are key to this project. First, what is the technical feasibility of the potential options for ash re-use? Second, what are the relevant aspects of pricing and market opportunities for the sale of ash in business journals? Due to the substantial history of the use of wood to heat homes and provide energy for industrial purposes, there is a significant amount of general information available regarding physical properties and uses for wood ash. There is a large amount of technical information available regarding the use of wood ash as a raw material for secondary industrial processes.

Some literature reviewed was specific to coal or municipal solid waste (MSW) incinerator flyash (e.g., Yeboah et al. (2013), Ferreira et al. (2012), Pacelli (2006) and Siddique (2010)), but those articles provided insight that was also relevant to wood ash. Comprehensive characterization has been conducted which provides good differentiation between biomass ash and coal ash (Yeboah et al., 2014). Yeboah et al. (2014) determined that pure biomass ash had significantly lower specific gravity, primary oxide content, coarser particle size distribution, higher residual carbon, higher heating value and higher specific surface area, than pure coal fly ash or fly ash from coal co-fired with biomass. Consideration of these differences when evaluating secondary uses may identify characteristics of the ash that are distinct from coal ash and may actually provide a market alternative.

Despite the large quantity of information available regarding the technical feasibility of wood ash uses, there is currently not as much information in literature regarding successful implementation of wood ash marketing programs. My impression after researching the wood ash market is that the most similar product that is marketed on a large scale in North America is coal fly-ash. This is not necessarily negative since it can be interpreted to suggest that if there is good technical support for beneficial reuse options then the marketplace may be underserved. There are likely good opportunities that exist for marketing wood ash that can be exploited by being a first mover in the region.

Technical Feasibility

There is an abundance of literature regarding proven science that justifies the use of wood ash for a variety of purposes. In order for those potential uses to even be considered for this project, the literature reviewed was evaluated in order to determine if there was potential to engage in the activity on an industrial scale, and if the "product" had the potential for ongoing sale. The options for use will be discussed and their relative benefits and disadvantages identified.

One of the oldest and well known uses of ash is the process of dissolving wood ash in water in order to produce "lye" or potassium carbonate which in turn can be further processed using glycerine products into soap or detergent (Matteoni, 1972). Production of soap will require secondary processing and in turn, once the ash has been processed, produce further secondary solid waste for disposal. Although wood ash has been used in the past for this purpose, does this mean that the ash from the wood boilers at Canfor Pulp is suitable for this purpose?

Review of current literature turned up research which provided general characterization of wood ash and potential uses based on the chemical and physical properties of the ash. For example, Vassilev et al. (2010 and 2013) have documented an extensive characterization of both biomass and biomass ash. Vallsiev et al. (2010 and 2013) also evaluated possible ash products based on those characterizations.

In their most recent research, Vassilev et al. (2013) conducted a two-part study that characterized Biomass ash based on its material of origin and subsequent physical properties. Waste wood biomass ash evaluation and analysis was organized and grouped by wood components – i.e. stems, barks, stumps, leaves, twigs, roots, and others, with each category consisting of a number of different species available. In all 50 wood ash samples were evaluated.

Other types of biomass ash were also evaluated in addition to wood waste ash (Vassilev et al., 2013). The study included ash from the following biomass sources: wood and woody biomass, herbaceous and agricultural biomass, herbaceous and agricultural grass, herbaceous and agricultural straw, herbaceous and agricultural residue, animal biomass, mixture of biomass, contaminated biomass, peat, lignite, sub-bituminous coal, bituminous coal, and algae.

Vassilev et al. (2013) characterized these biomass ashes according to the Type and Sub-type matrix that was used in their papers in 2010 and 2013 (Type based on chemical composition and Subtypes based on acidity), and then evaluated each type and subtype of ash against a list of proposed uses.

Wood ash was classified as "C Type" ash in the "Low Acid" range (C-LA) which was characterized by higher concentrations (45% by weight) of CaO + MgO +MnO (carbonates, oxyhydroxides, glass silicates, and some phosphates and sulphates) , lower concentrations (35% by weight) of SiO_2+Al_2O_3+FeO_3+Na_2O+Ti (mostly glass, silicates and oxyhydroxides) and even lower concentrations (20% by weight) of K_2O+P_2O_3+SO_3+Cl_2O (normally phosphates, sulphates, chlorides, glass and some silicates and carbonates) (Vassilev et al., 2013).

The following Tables 2 through 4 have been revised from a table presented by Vassilev et al. (2013). Potential applications have been ordered by suitability (alphabetically in each category) for the use of waste wood biomass ash. Each product evaluation is categorised first by the Type and then by Sub Type (high, medium and low acid - HA, MA, LA). The four chemical biomass ash types identified in Tables 2 through 4 (S, C, K and CK types) are defined by their proportional chemical composition as shown in Figure 12 (developed and presented by Vassilev et al. (2010)).

Table 2 Applications of use where Type C, subtype C-LA is the most suitable type of biomass feedstock (Source: Vassilev et al., 2013)

	Type of Ash	Sub-type of Ash
Biochar production	C, CK, K, S	C-LA, C-MA, K-LA, K-MA, S-MA, S-HA
Binders for low strength materials (mortars, masonry, cementing materials, embedding pipes)	C, S, CK	C-LA, C-MA, S-HA, S-MA
Bricks	C, S, CK	C-LA, S-HA, C-MA, S-MA
Cellular concrete	C, S	C-LA, S-HA, C-MA, H-MA
Cement (Portland) as pozzolanic mineral admixture and chemical activator	C, S, CK, K	C-LA, C-MA, S-MA, S-HA, K-MA
Compost (colour and odour control agent)	C	C-LA
Construction blocks	C, S, CK, K	C-LA, S-HA, C-MA, S-MA, K-MA
Glaze (glazing base for ceramics)	C, K	C-LA, K-LA
Gypsum wallboards	C, K, CK	C-LA, K-LA
Mine backfilling and excavation work	C, S, CK	C-LA, S-HA, C-MA, S-MA
Neutralizing agent of tannin (in high-tannin sorghums)	C	C-LA
Neutralization of acid water and wastes (odour and pH control, acid mine reclamation)	C, CK, K, S	C-LA, K-LA, C-MA, K-MA, S-MA
Recovery of char	C, S, CK, K	C-LA, S-HA, C-MA, S-MA, K-MA, K-LA
Road sub-base construction	C, CK	C-LA, C-MA
Self-cementing mortars	C, CK, K	C-LA, C-MA, K-LA, S-MA
Self-cleaning fuel ash	C, K, CK	C-LA, K-LA, C-MA, K-MA
Soil amendment (liming, neutralization, stabilization) and fertilization	C, CK, K, S	C-LA, K-LA, C-MA, K-MA, S-MA, S-HA
Synthesis of wollastonite and other Ca and Ca–Mg silicates	C, S	C-LA, C-MA, S-HA, C-MA

Based on this research alone there are 18 potential products that have been identified where wood waste ash will be the primary type of biomass ash that provides the best characteristics for inclusion in or use as that product.

Table 3 Applications of use where Type C, subtype C-LA is the SECOND most suitable type of biomass feedstock (Source: Vassilev et al., 2013)

	Type of Ash	Sub-type of Ash
Acid resistant materials	S, C	S-HA, C-LA, S-MA, C-MA
Adsorbents (plus self-cleaning fuel and ash)	S, C, K, CK	S-HA, C-LA, K-LA
Catalysts	S, C, K, CK	S-HA, C-LA, K-LA
Concrete	S, C, CK, K	S-HA, C-LA, S-MA, C-MA, K-MA
Fire-resistant and fireproof materials (silica minerals, Ca silicates)	S, C	S-HA, C-LA, C-MA, S-MA
Immobilization and solidification of hazardous wastes	S, C	S-HA, C-LA
Pigments	S, C, K	S-HA, C-LA, K-LA
Recovery of water-soluble major, minor and many trace elements	K, CK, C, S	K-LA, C-LA, K-MA, C-MA, S-MA, S-HA
Refractory materials (silica minerals, Ca silicates, lime)	S, C	S-HA, C-LA

Table 4 Applications of use where Type C, subtype C-LA is the THIRD or lower most suitable type of biomass feedstock (Source: Vassilev et al., 2013)

	Type of Ash	Sub-type of Ash
Landscaping materials	S, C, CK, K	S-HA, S-MA, C-LA, C-HA, K-M, K-LA
Activated carbons	K, S, C, CK	K-LA, S-HA, S-MA, C-LA, K-MA
Recovery of Fe fraction enriched in some trace elements	S, C, K, CK	S-HA, S-MA, C-MA, K-MA, C-LA, K-LA
Recovery of heavy fractions enriched in trace elements	S, C, K, CK	S-HA, S-MA, C-MA, K-MA, C-LA, K-LA
Fuel	K, CK, S, C	K-LA, K-MA, S-MA, C-MA, S-HA, C-LA

In addition to the source of the biomass ash, the conditions under which the biomass is burned can affect ash characteristics (Vassilev et al., 2013). The way the fuel is prepared, the type of combustion technology, conditions in the combustion chamber and conditions in the collection and cleaning equipment will all impact the properties of the ash (Vassilev et al., 2013). The way that the ash is handled and stored will also impact characteristics (Vassilev et al., 2013).

The work done by Vassilev et al. (2013) can therefore be used to identify products with the highest potential for successful use of C-LA ash as feedstock, but all of the Canfor Pulp Ltd. ash must be analysed and tested against this criteria.

There are a number of additional studies related to a general overview or reuse options for biomass ash. Ahmaruzzaman (2010) for example has conducted a very comprehensive review of the technical factors relating to the use of coal fly ash and biomass fly ash for utilization in construction, adsorbent for the removal of contaminants in wastewater and flue gas, light weight aggregate, mine back fill, road sub base, and zeolite synthesis (Ahmaruzzaman, 2010).

The following sections will look at literature that was found which is relevant to specific products identified in Table 2.

Fly Ash Use In Brick

Fly ash is a viable lightweight aggregate. Brick manufactured using fly-ash has been shown by several studies to be a superior building material than burnt clay brick (Ahmaruzzaman, 2010). Fly ash brick is more durable, provides better protection from salinity, requires less mortar during installation and the dimensions of the brick itself can be controlled better during the manufacturing process. Fernandez-Pereira et al. (2011) had similar findings in their study of bricks manufactured using biomass gasification fly-ash.

The brick manufacturing process requires mixing, extrusion and curing (Clay Brick Association of Canada, 2014) which represents additional costs for capital, energy and manpower. Ash could be transported for secondary manufacturing in an existing brick manufacturing facility, but there are only three facilities in BC and Alberta – two in Abbotsford BC and one in Medicine Hat Alberta (Dumont, 2008). While not directly comparable, biomass transportation costs can provide some perspective. In the Williams Lake BC area the cost to transport biomass up to 88km has been estimated to be as high as $33/ODT (Akhtari, 2012). It is not unreasonable to project that hauling to Abbotsford or Medicine Hat could entail significant transportation costs - but the economics are worth investigating.

Larger building blocks manufactured using similar principles as brick is also possible. Building blocks made with biomass bottom ash exhibited an increase in porosity and decrease in compressive strength but as long as the biomass bottom ash has a better than 1:1 Si/Ca ratio it is usable for this purpose (Carrasco et al., 2013).

Use as Adsorbents

The use of fly ash as an adsorbent is a very promising technology, but the issues raised are twofold. Adsorption relies on the large surface area presented by the high carbon ash particulate. The first issue is that the material will accumulate contaminants on its surface and once the available surface is exhausted, the material will either need to be treated, or disposed of in a substantially more contaminated state than when it started. The second issue is that the ash has the potential to leach substances such as potassium into the water it is intended to treat (Ahmaruzzaman, 2010) as the water runs through the ash. The technology is feasible, but if the waste is only diverted from ultimate disposal and becomes an environmental concern, this option may not be a good fit.

Fly Ash Use in Construction

Fly ash has been used extensively in the construction of roads and embankments and typically has shear strength equal to or better than soils – primarily because of its self-hardening or pozzolonic action (Ahmaruzzaman, 2010). The properties of fly ash are well suited for use in construction projects when borrow materials (soil for fill) are not readily available and when there is an ample supply of ash within 100Km of the project (Ahmaruzzaman, 2010). Research by Bajaj et al. (2011) has documented the pozzolonic effects of the ash (i.e. which allows stabilization of soil in construction embankments) and included brief economic analysis showing that at a cost of $8.88 CDN the fly ash can reduce the direct cost of soil for geotechnical construction projects by 50% .

Fly Ash use in Mine Reclamation

The use of coal fly ash to control and treat acid mine drainage has been investigated by Penney (2009) and separately by Wang (2009). They concluded that applying coal fly ash to acidic tailings was an effective treatment process as long as it was combined with clay in order to reduce the hydraulic conductivity of the applied material. Ahmaruzzaman (2010) examined the ability to use ash to stabilize decommissioned mine sites and found that ash could be injected dry or as a slurry into underground chambers and be used successfully to prevent site degradation and structural instability. Because conditions will vary from site to site, each mine site must be looked at independently in order to ensure that fly ash is appropriate for the geotechnical conditions. The decision to use fly ash for mine site reclamation will be purely economic (Ahmaruzzaman, 2010) unless it can be proven to have other advantages, such as the neutralization of acid mine drainage due the high pH exhibited by biomass ash.

Soil Remediation Using Ash

In line with the work of Penney (2009) and the work of Wang (2009), Demirkan (2008) examined the use of high carbon content fly ash for the remediation of petroleum contaminated soils. High carbon content fly ash (HCCFA) was compared to the performance of powder activated carbon (PAC) to determine if the HCCFA could be used to stabilize hydrocarbon contaminated soils, or if it could be used as a reactive medium in permeable sorptive Barriers for remediation of hydrocarbon contaminated groundwater (Demirkan, 2008). The study showed that when HCCFA was used as a reactive medium to stabilize soils, high levels of hydrocarbon degradation occurred (Demirkan, 2008). The study also found that when used in a permeable sorption barrier the sorption was strongly correlated with the carbon content of the ash. The higher the carbon content, the better the sorption. The ash also had physical properties that satisfied limits set for highway bank construction (Demirkan, 2008).

Zeolite Manufacture

Zeolites are naturally occurring crystalline aluminum-silicates that are used for Ion exchange, gas adsorption and water adsorption, with the unique property that they can remove contaminants using anion exchange and then be recharged and reused (Rhodes, 2010). Fly ash can be converted into low grade zeolites, which are particularly well suited for the removal of phosphates and heavy metals from wastewater. Low grade zeolites cannot be used for selective ion exchange and this significantly limits their usefulness and makes them an inappropriate choice for high value applications (Ahmaruzzaman, 2010).

Nurmesniemi et al. (2007), published a review of waste reuse options for a Finnish pulp and paper mill complex and found that the mill was able to go from 42,990 tonnes of process waste landfilled in 1994 to 6083 tonnes landfilled in 2005, an 86% reduction. The mill was able to do this by incinerating organic waste more efficiently, utilization of dregs as a neutralizing agent for acidic wastewater, using ash as a hardener in filling mine cavities, as a landscaping material, as a hydraulic barrier material for landfill management , and using $CaCo_3$ waste as a soil ameliorating agent (Nurmesniemi et al., 2007).

Use in Landfill Cover

Pacelli (2006) evaluated the use of municipal solid waste (MSW) Incinerator ash and compost for cover material and found that metals were a concern when using that type of ash. The municipal ash could not be used in areas without leachate collection, and Pacelli (2006) recommended that it should be used in conjunction with cover crops that have a tolerance for metals in soil. It can be expected that pulp mill biomass ash will have a significantly different metal profile than MSW incinerator ash which will have a higher likelihood of metal contamination in its feedstock than pulp mill biomass (which is typically free of feedstock metal contamination).

Manufacture of Glass

Two studies specific to the production of glass from fly ash had positive conclusions. According to Hnat and Bartone (1996) there are at least five distinct product markets for glass aggregates, and at least eight product applications for use of the glass as filler or substrate. They also identified prices (in 1996 dollars) for all of the possible products ranging from \$4 to \$1000 USD per imperial ton (Hnat and Bartone, 1996). Hnat and Bartone (1996) used a cyclone melting system to vitrify ashes into a glass product and used coal fired boiler ashes, MSW incinerator ashes, and a sewage sludge incinerator ash as feedstock. The benefit of this type of process is that it will stabilize the metals into a form which binds the metals and reduces the amount of leachable waste going to landfill. The process is limited by the fact that it cannot work with high concentrations of metals in the feedstock (Hnat and Bartone, 1996). The economics of the process as it applies to a current day facility could not be properly evaluated based on the work presented by Hnat and Bartone (1996) because the pricing and capital cost information is two decades old and was based on a 20 year life cycle for payback. What can be gleaned is that the capital costs in 1985 were quoted between \$6 and \$8 million USD, with annual operating cost between \$49 USD/tonne and \$58 USD/tonne (Hnat and Bartone, 1996). Given the change in energy prices, material costs and inflation, a current capital cost estimate would be required and it is safe to assume that the cost will be higher in today's dollars. The major drawback to vitrification is that there will be some air and solid waste emissions from the process and the quality and quantity of those emissions are not stated. In addition, a letter to the editor in the June 18, 2000 edition of the Paducah Sun expresses displeasure with the proposal to build a plant based on Hnats process, and specifically identifying dioxins as a potential pollutant of concern. There is a history of controversy regarding emissions of dioxins from pulp and paper mills. The requirement to add lead to this manufacturing process (Hnat and Bartone, 1996) would make this a project with a significant public relations and environmental risk.

A second and more thorough study specific to the production of glass from pulp and paper mill biomass ash showed more promising results without the need to add metals. The only additive required was sodium carbonate – a material readily available at a Kraft Pulp Mill (Ribeiro et al., 2010). It was determined that with an initial calcination process prior to the melting process, ash was very suitable for the production of glass. Analytical results for leachability metals from the glass product showed that the leachability of chromium and copper was reduced to well below the US Environmental Protection Agency (USEPA) standards, and while there was an increase in the leachability of nickel, lead and zinc, all leachates tested were significantly below USEPA standards (Ribeiro et al., 2010).

Manufacture of Glass Ceramics

Monteiro et al. (2004) and Sivasundaram (2000) looked at producing glass ceramics from coal fly ash and pulp and paper waste ash respectively. The study of coal ash found that the unburnt carbon present in the ash inhibited densification during firing and increased the porosity of the product (Monteiro et al., 2004). This is a negative aspect as the required physical properties of the finished product increase with density. To counteract this effect the fly ash had to be calcined prior to preparation by adding dolomite (as a source of CaO and MgO) at a 10% ratio to the ash (Monteiro et al., 2004). This led to a product with the properties required by buyers of ceramic products.

In the study specific to pulp and paper ash Sivasundaram (2000) pre-burned the ash at 1000°C to remove moisture and residual unburnt material, and was successful in producing both glass and ceramics that had commercially acceptable physical characteristics.

Burning the carbon off prior to ceramic manufacturing may help avoid the final product brightness issues found in ceramics manufactured with fly ash that have been identified by the Pulp and Paper Research Institute of Canada (PAPRICAN) (Elliot and Mahmood, 2005). Whether or not this additional processing step will make ceramic manufacturing uneconomical is unknown, but it will help identify sources of ash at the Canfor Pulp mills that are best suited for this process.

Use in Asphalt Cement Manufacture

According to the US Federal Highway administration, fly ash can be used as a cost effective mineral filler in hot mix asphalt as long as its organic impurity (i.e. unburned carbon) content is less than 10% (United States Department of Transportation - Federal Highway Administration. 2011). The ash from the Intercon power boiler can meet this standard. The ash would be incorporated as a light-weight mineral filler so the ash must conform to the standard as defined by the American Association of State Highway and Transportation Officials (AASHTO) M 17 as shown in Table 5 (United States Department of Transportation - Federal Highway Administration, 2011). There is a significant amount of paving activity that is undertaken every year, for example, the 2013 City of Prince George paving budget was almost $5 million CAD (Prince George Citizen, 2013). Asphalt manufacturing is a potential long term outlet for secondary manufacturing using pulp mill biomass ash.

Table 5 AASHTO M 17 Requirements for mineral filler use in asphalt paving mixtures. (United States Department of Transportation - Federal Highway Administration. 2011)

Particle Sizing		Organic Impurities	Plasticity Index
Sieve Size	**Percent Passing**		
600mm (No. 30)	100	Mineral filler must be free from any organic impurities	Mineral filler must have plasticity index not greater than 4
300mm (No. 50)	95 - 100		
75mm (No. 200)	70 - 100		

Most fly ashes typically fall within a size range of 60 to 90 percent passing the 75 μm (No. 200 sieve).

Use in Portland Cement Manufacture

There is abundant literature available regarding the use of fly ash in cement. Ash has been used in cementous building material for at least 2000 years (Fly Ash Information Center, 2013; ACI, 2003) so the progression to the use of waste fly ash from industrial sources is consistent with long established human building practices.

Unfortunately the standards for use of fly ash in concrete are specific to coal fly ash (ACI, 2003). While biomass ash does exhibit many similar characteristics as coal fly ash, the existing standards may act as a barrier to the cement production as a target market for the use of pulp and paper mill biomass ash (Wang, 2008).

Abundant literature is available regarding the use of MSW incinerator ash in concrete, the use of coal fly ash and the use of biomass fly ash. Because specific standards have been well established and accepted regarding the use of coal ash, literature regarding its use has been intentionally left out of this project (ACI, 2003; ASTM, 2012).

In a review of the literature related to MSW incinerator ash in concrete, there was a comprehensive evaluation of the general physical properties of the ash, including chemical composition and elemental analysis (Siddique, 2010). There was also an evaluation of the properties of the concrete containing the ash which included compressive strength, chloride resistance and shrinkage (Siddique, 2010). While there were concerns regarding the high sulfate and chloride concentrations in the MSW incinerator bottom ash, which could create potential sulphide attack on reinforcing steel, it was found that MSW incinerator fly ash had good chemical and physical properties for the production of concrete mixtures, and that MSW incinerator bottom ash could be a suitable aggregate capable of producing a 25 megapascal (MPa) concrete with 50% substitution for aggregate in the concrete mixture (Siddique, 2010).

An evaluation of two biomass fly ashes from power plants in Portugal found that the ashes contained levels of SiO_2, Al_2O_3, and FeO_3 – which indicated that the ash could exhibit pozzolanic properties and that the ashes were chemically similar to Class C coal fly ashes (Rajamma et al., 2009). This finding is corroborated by the work of Vassilev et al. (2013). Compressive strength was maintained with 10% substitution of the ash in the cement, but at a 20% substitution rate the compressive strength dropped to 75% (Rajamma et al., 2009). The authors proposed that significant levels of chloride and sulphate affected the compressive strength (Rajamma et al., 2009). Compressive strength is an important physical characteristic for concrete as concrete is used to bear compressive loads in structures and its specified strength is a design parameter used when specifying the inclusion of Portland Cement Concrete in structural design (Kosmatka and Panarese, 1991). Also worth noting is that the high level of chlorides in the biomass ash may be a sign that the wood has been exposed to saltwater at some point in its lifecycle (it is common to transport logs via large floating bundles through water – in freshwater lakes and in slat laden seawater along coastlines) and this may not be a concern for interior biomass that has not been transported in saltwater.

A 2012 study into the pozzolonic properties of wood biomass ash from a wood energy plant in North Carolina, found that while the chemical and mineralogical composition of the biomass fly ash was similar to coal fly ashes, the biomass fly ash had a high carbon content (Lowe, 2012). In order to be used in cement, an additional step was necessary to remove the excess carbon by pre-burning it at a temperature of 950°C (although the author suggested that this step may not be necessary for all biomass ashes) (Lowe, 2012). The research also found that even after processing the compressive strength of the concrete sample containing 20% of the wood biomass fly ash was less than the control but did not significantly affect the porosity of the finished product (Lowe, 2012). Carbon content was the primary issue limiting the ability to use the ash in cement manufacturing.

Fly ash that had been obtained from the co-firing of lignite and wood pellets had a loss on ignition of less than 1% by weight (and thus avoiding the carbon content issues described above) (Johnson et al., 2010)., With a substitution rate of 20%, the concrete met 75% of the compressive strength requirements for ash-free mortar after 28 days of curing and met 100% of the compressive strength requirements after 90 days (Johnson et al., 2010). There were some issues identified with the entrained air content of the cement when using the co-fired fly ash, but those effects vanished with the addition of an air entraining agent (Johnson et al., 2010). These issues were also identified by Wang et al. (2008) who compared cement made with pure coal fly ash, co-fired coal and biomass (at 10% biomass), wood biomass fly ash and regular cement. They noted a significant increase in the requirement for air entraining agents and with substantial decreased compressive strength in the wood biomass fly ash samples (Wang et al., 2008).

An older study specific to wood ashes determined that while most wood ashes did not conform to the American Society for Testing and Materials (ASTM) standard C618 requirement for coal fly ash, the source of the wood ash had a significant impact on their properties and must be properly tested on a source by source basis in order to determine their suitability for use as construction materials (Naik et al., 2001). The study identified several potential applications for wood ash in cement based construction materials including controlled low strength material, low and medium strength concrete, cast concrete products, roller compacted cement concrete, road base materials, and blended cements (Naik et al., 2001).

Follow up study by Naik et al. (2002) concluded that Pozzolanic contributions of wood ash were significant. Naik et al. (2002) blended wood ash with Class C fly ash and found that this significantly improved the performance of the concrete - structural concrete made using wood ash and/or its blends achieved compressive strengths up to 50MPa at 28 days. This is an acceptable strength for most normal applications of Portland Cement Concrete (Kosmatka & Panarese, 1991).

There has been significant work done and there are standards in place against which ash can be tested and then classified for uses in specific types of cement manufacture. The use of fly ash in cement manufacturing is well researched and proven, and is clearly a viable market for fly ash as long as it meets the required technical specifications (Bouzoubaa and Fournier, 2005). The primary quality concern Ahmaruzzaman (2010) identified regarding fly ash for use in cement manufacturing was that the presence of carbon is not desirable.

There are clearly issues related to strength, porosity and air entrainment that must be considered when using wood biomass fly ash as pozzolanic material in Portland Cement. In order to properly assess the ability of the fly ash from Canfor Pulp's facilities, ash streams from each of the Canfor Pulp mills will need to be assessed against the ASTM 618-12a specification for use of coal fly ash in cement. In addition, a strength testing trial for cement and concrete mixes based on each of the four pulp mill ash streams should be conducted in order to determine if the ashes are consistent and if not, which ones are usable for this purpose.

Use as an Agricultural Amendment

The last option covered by this literature review is land application of biomass wood ash as a fertilizer or liming agent (Sharafi et al., 2013). Wood ash has many properties that make it potentially viable as an agricultural product. Qiu (2005) examined the potential to utilize the ash as a delivery matrix in a secondary fertilizer manufacturing process. By putting ash into a carbonitridation process in a reducing atmosphere in a vessel such as a kiln and adding nitrogen to the mix via nitridation, a slow release fertilizer matrix is created (Qiu, 2005). Unfortunately, the addition of an extra process reaction with the additional associated capital, operating and energy costs is likely not desirable. Ash is typically low in nitrogen so its fertilizing effects will not be fully realized unless there is some element of existing nitrogen in the soil, pre-existing nitrogen concentrations in the ash, and/or additional nitrogen based fertilizer is co-mixed or applied in addition to the ash (Sharafi et al., 2013).

One option for agricultural use is an additive for liming or pH adjustment. Cabral et al. (2008) conducted an 18 week controlled study to determine the impacts of pulp mill wood ash, dregs and grits on an acidic soil with low organic content, low extractable phosphorous and low extractable potassium (Cabral et al., 2008). Cabral et al. (2008) found no evidence of excessive heavy metal mobility into the soil from the ash, and no concerns with sodium accumulation. The experiment showed pH adjustment due to the ash was similar to commercially available limestone (Cabral et al., 2008). There was also evidence that the wood ash increased the soil available potassium and phosphorous indicating that the ashes contribute to soil fertility in addition to the liming characteristics (Cabral et al., 2008). Sharifi et al. (2013) conducted two bench studies: one specific to the acid neutralizing capacity of the biomass wood ashes, and another specific to the potassium nutrient enrichment capacity of the ashes. Self-hardening of the ashes is an important characteristic for liming as it extends the liming effects and avoids shocking effects of sudden high pH and decreases the leaching of calcium and sulphur from the ash (Sharifi et al.,2013). Acid neutralizing value of the ash was good and it was shown to be a good alternative liming agent (under greenhouse conditions) – increasing soil pH within the first 50 days after application and stabilizing soil pH for at least 8 months, but the properties varied noticeably between the ashes from the two pulp mills and the wood power plant (Sharifi et al., 2013). While analysis of the feedstock for each of the processes was not examined, it is likely that the Brooklyn Power plant had a higher white wood component in its feedstock as power plants usually have better ability to manage white wood into their fuel mix because they do not have to work in restrictive chip agreements that require the constant purchase of bark.

The nutrient bench tests showed that the all of the biomass wood ashes displayed a high amount of potassium availability but nitrogen content was not consistent (Sharifi et al., 2013) which again suggests that the type of feedstock, the type of incineration process, and the subsequent ash handling methods may have an impact. It was noted that the specific ash characteristics and the requirements of the soil are therefore the key variables to consider before initiating an ash fertilization program (Sharifi et al., 2013). At the Canfor Pulp PGI complex there are two different methods of ash handling from similar boilers and similar feedstock characteristics. This presents an opportunity to assess how post production ash handling affects nutrient concentrations and availability to determine if that is the reason for the variability observed in the Sharifi et al. (2013) study. Regardless of the reason for variability, all of the ash samples showed good potassium availability and high rates of application did not have a negative impact on crop yield.

Further establishing the need for source specific evaluation before engaging in land application of biomass ash is the Poykio et al. (2005) study on Finnish pulp and paper mill fly ash leachability. The initial total metal quantities in the fly ash gave no indication of the quantities of those metals that were in fact mobile – with cadmium found to be the most mobile and the primary element of concern (Poykio et al., 2005). Potassium was also found to be highly soluble (Poykio et al., 2005) but the point of fertilization is making the nutrient in question available to the crops. Campbell (1990) found a similar outcome with heavy metal concentrations typically below the state standards in Maine and New Hampshire, but with periodic exceedances due to cadmium exceeding the 10 parts per million (ppm) limit.

All Canfor Pulp ash samples (with the exception of PG Pulp #2 Power Boiler) contained levels of cadmium below 10ppm (Exhibit 3). PG pulp #2 Power Boiler was 20ppm.

A study specific to the impacts of hardening treatments of pelletized biomass fly ash in order to reduce the rate of rapid pH increase in the upper soil horizon and the surfaces of existing vegetation and reduce metal leaching rates was undertaken in Sweden (Mahmoudkhani et al., 2007). The study showed benefits resulted from hardening of the ash, but results varied greatly between samples from a grate fired boiler versus a fluidized bed boiler. All of Canfor Pulps Power boilers are grate fired so only the results from the grate fired samples are relevant. Thermal treatments increased the strength and reduced the specific surface area of the pellets, while natural hardening reduced the strength and had no apparent impact on specific surface area (Mahmoudkhani et al., 2007). However, the fact that high doses of ash application produce inconclusive results and are ash specific, may mean further hardening may not be necessary for Canfor Pulp ash.

Hardening is a specific solution primarily used to minimize impacts on existing vegetation. As such, two studies related specifically to forest application of waste wood biomass ash to forested lands were examined. The first study found that heavy metal leaching into surface and ground waters have been insignificant and that fertilization effects were optimum in nitrogen rich soils with ash application rates greater than 2 t/ha – and more than 5 t/ha appropriate if it is a onetime only application (Vesterinen, 2003). It was also noted that in mineral rich soils with low nitrogen availability or no nitrogen present there is a risk of inhibited plant growth because of the liming effects and lack of nitrogen (Vesterinen, 2003). Site specific evaluation is therefore important if forest application is to be considered. Hardening may also need to be considered with respect to the types of equipment selected for spreading the ash as material characteristics may determine the type of equipment that can be used (Wilhoit and Aygarn, 1994).

The second forest application study reviewed was conducted in England. Pitman (2006) determined that ash granulation contributed to slow delivery of elements and that wood ash is an effective NPK fertilizer in organic forest soils. Ash did not increase heavy metal loadings in soils, and at application rates of 10 t/ha replaces nutrient losses due to forest harvesting (Pitman 2006). Conversely, application rates > 5 t/ha had deleterious effects on ground flora in upland areas – particularly those with bryophytes and lichens that thrive in more acidic conditions (Pitman, 2006). Pitman's (2006) research complements Vesterinen's (2003) research in that the ash in Pitman's (2006) study was a "complete" fertilizer with a measureable available nitrogen component. It is worth noting that of the three ash streams at Canfor Pulp, only the Northwood Mill produces ash with measureable Nitrogen. This could presumably be due to the relatively (when compared to Prince George Pulp and Intercon Pulp) high unburnt content in the Northwood Pulp Mill ash.

In a 2012 study examining fertilizer potential for bubbling fluid bed boiler ash from two separate pulp mills in Finland, it was determined that the nutrient (potassium + phosphorous) did not meet the requirements for application of ash (2.0% by weight) in Finland, but was usable as a liming agent (Nurmesniemi et al., 2012). Again the feedstock or type of boiler operation producing the ash appears to have an impact on the nutrient content and characteristics of the ash produced.

Goldemund (2000) used Pulp Mill Boiler Ash from the Georgia Pacific Mill at Brunswick Georgia that used tires co-fired with wood derived fuel to study trace element mobility in soil after application. The study found increased calcium and potassium in soil solutions and higher soil zinc and nickel concentrations, and that ash application had no significant effect on trace element mobility in soil columns (Goldemund, 2000).

Etiegni (1990) evaluated the growth of winter wheat and poplar using Idaho soils and six different ash application rates using fly ash and bottom ash produced in the University of Idaho wood-fired combustion system that burned wood chips, wood residue and bark on an inclined, sliding pinhole grate. In addition to the wheat and poplar, Etiegni (1990) utilized bush beans and increasing ash application rates in order to determine phytotoxicity of the ash. The study found detrimental effects at application rates exceeding 460 kg/ha (Etiegni, 1990). It was also noted that wood ash leachate inhibited the retention of metals by the soils (Etiegni, 1990).

Geographically, the study that had done field trials of pulp mill biomass ash in closest proximity to the Canfor Pulp operations was undertaken in Alberta by Patterson (2001). The field study used ash from the Alberta Pacific Mill near Boyle, Alberta at rates from zero (control) to 25 t/ha on soil with a pH range from 5 to 6 and used crops that included barley and canola. The study found that there were no environmental or agronomic concerns resulting from the application of biomass wood ash at rates less than 25 t/ha and the ash provided supplemental nutrients in the form of boron, iron potassium, sulpher and zinc with additional benefits of increasing soil pH without exceeding a pH of 7.7 over the two year study period (Patterson, 2001).

A greenhouse study of alfalfa undertaken at UNBC in 2004 used local soils and samples of power boiler ash from the Northwood Pulp Mill at application rates between zero and 80 t/ha and showed minimal uptake of cadmium and increased plant growth with ash addition (Rutherford, 2004). This however, was a very short term study and further research has been undertaken to develop more in-depth analysis.

Review of Literature and Industry Practices Related To Ash Marketing and Sales

Wood ash has a long history as a feedstock for other industrial processes, going back as far as the 1700's where wood was burned for the sole purpose of producing ash for chemical extraction (Campbell, 1990). By the early 1800's, in the north-eastern United States, ash was used on a commercial scale to produce potash for fertilizer in addition to manufacturing of soap, glass, and potassium cyanide which was used for the extraction of gold from tailings and ores (Campbell, 1990).

Research regarding the price structure and market for ash is not as abundant in the literature as technical evaluations. This is perhaps due to antitrust legislation in the United States which can interfere in the disclosure of pricing and supply strategy. There can also be a tendency in situations where diversion of waste is desired that the potential value of the material itself is not recognised (Etsy and Porter, 1998). The majority of literature reviewed looked purely at the altruistic vision of diverting a waste and solving an environmental problem but did not delve into the economics. While this project is not focused on general environmental economics, they do play some part in the decision making matrix that will ultimately decide which solution(s) for the problem at hand will be selected.

A paper that is specific to Pulp and Paper mill biomass ash is a PAPRICAN special report (Elliot and Mahmood, 2005) which provided analysis of the use of wood waste biomass ash in building products, construction material, land application, wastewater treatment filtration, and glass and ceramic manufacturing. The building products that were discussed consisted of cement and cement based construction products. A potential limitation for the use of the ash, assuming the ash meets the raw material specifications, is the presence of carbon, which interferes with the pozzolanic properties of cement (pozzolan in the presence of water chemically reacts with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (ASTM, 2013). This could be an issue for the reuse of high carbon ashes such as those originating from the Northwood mill. Construction material was identified as a very viable option if the ash can meet specific hurdles related to moisture content, dry density, degree of contamination and leachability of contaminants (Elliot and Mahmood, 2005). Elliot and Mahmood (2005) referred to a mill in Georgia which sells its ash as aggregate to the local county as an example of how ash can be viewed as a valuable raw material.

The land application option has been well researched elsewhere, but was discussed by Elliot and Mahmood (2005) in both the context of sole land application as well as the use of ash in admixture of waste water treatment plant sludge's in a compost that would meet all regulatory requirements for land application. Again economics were not discussed. High carbon ashes were stated to be very effective at removing colour and chemical oxygen demand from pulp mill effluents but the ultimate fate and disposal of the contaminated ashes was not discussed.

Because sustainability and elimination of a waste is an important aspect of the desired outcome of this project, this option is not consistent with the project objectives. Ceramic and glass manufacturing was identified as a viable option for ash as a raw material but there were reported issues with ash potentially lowering the brightness of the finished product (Elliot and Mahmood, 2005).

Two PAPRICAN surveys referenced by Elliot and Mahmood (2005) indicated that in 1995 3% of biomass ash produced by pulp and paper mills in Canada was beneficially used with the rest going to landfill. By 2002, 9% of the ash produced by Canadian pulp and paper mills was being land-spread, 1% was being composted and 12 % was being used for other beneficial purposes including landfill capping, road construction, construction filling and soil conditioning with the remaining 78% going to landfill (Elliot and Mahmood, 2005).

In 2002, it was estimated that pulp and paper mills in Canada generated 775,000 tonnes of wood ash (Elliot and Mahmood, 2005). As of 2001, approximately 100,000 tonnes of wood ash was produced by wood fired cogeneration facilities in Alberta (Patterson, 2001). Canfor Pulps ash output in 2012 was just under 50,000 tonnes/year. Recent estimates of the total ash generation from pulp and paper mills in New Brunswick and Nova Scotia are 40,000 tonnes/year (Sharifi, 2013) and are generated by New Page, Brooklyn Paper and JD Irving.

JD Irving has been steadily getting into the business of distribution of ash for agricultural purposes. Based on media reports (Dwyer, 2006) the Irving mill in Saint John New Brunswick produces approximately 16,000 tonnes of ash per year. According to the JD Irving website, they divert 7000 tonnes/year as fertilizer. The application rates indicated in the same article stated that over a two year period at least one 400 acre farm had 100 tonnes delivered (Dwyer, 2006), or 0.6 tonnes/ha and at costs of five to 10 percent of commercial fertilizers. In addition, Irving Pulp has delivered at least 25,000 tonnes of ash to Canadian Forces Base - Gagetown where it is being used to "rejuvenate" training areas (Dwyer, 2006).

Personal communication with the owner of B&B Environmental – the company that handled the initial logistics related to distribution of the Irving Pulp ash (Crowe, 2014), provided some insight into how the Irving Pulp ash was distributed. The ash has been registered under the Canada Food and Inspection Agency (CFIA) as a Farm Fertilizer and testing of the ash is conducted once a month in order to maintain that registration. The ash was distributed for no charge for the first two years and then the onus was placed on the agricultural customers to pay for the delivery ($12 per tonne delivered), and transport/delivery is to be arranged through a pre-approved company. An agrologist has been hired in order to handle the logistics of delivery. Ash is stockpiled through the winter and delivered in the spring and fall – the benefit of stockpiling is that the ash needs some moisture content in order to spread properly (Crowe, 2014). B&B Environmental continues to rent spreaders out for customers to spread the ash in the event they do not own the required equipment.

Correspondence with Dave Muir (2012) at JD Irving also indicated that the program has been so successful that lime producers began campaigning against the Irving product in local grocery chains, but was counteracted with a well thought out public relations program (Muir, 2012).

Based on a search of the CFIA website JD Irving is the only Pulp and Paper Company in Canada that has registered their ash as a fertilizer.

Soils in the central and north eastern area of BC are generally acidic (Arocena and Sanborn, 1999), and lend themselves to the application of higher pH materials such as wood biomass ash.

Data and Methodology

Pricing

Does the Irving model with initial free samples send the right signal to consumers regarding value? In a word, no. Samples and demonstration might be necessary, but the research clearly establishes that there is a value to the ash and Canfor would be making a mistake by not optimizing the indirect opportunities of value as proposed by Etsy and Porter (1998):

Resource Productivity of Input (x) = f (value added by (x)
– direct costs of (x)
– indirect costs of (x)
+ indirect opportunities for value added from (x))

In this case, the direct cost is the price paid for buying, handling and storing the hog fuel, the indirect costs are the disposal costs and the indirect opportunities are whatever we can get an outside agency to pay for the material (including handling). The goal is to minimize the indirect costs while maximizing the indirect opportunities, and that means maximizing the value.

There are a number of examples available regarding price:

- Fly ash cost per meter converted from rupees at January 2014 exchange rate is $8.88 CAD in India (Bajaj et al., 2011).
- In Singapore Coal Fly ash is being offered at US $20 per ton (http://www.alibaba.com/product-detail/fly-ash_133360730.html) (or $22.05/tonne).
- 1985 Prices for fly ash in the United States ranged from $15 to $40 USD per ton (The Aberdeen Group, 1985).
- 2006 Reported international prices were $70 to $130 USD per ton (Economic Times, 2006)

There are examples of companies specializing in ash distribution management and sales. In India (Chara, http://charah.com/ccp-management-services/ccp-sales-marketing/) and in the United States - Flyash Direct (http://www.flyashdirect.com/services/asphalt.asp) and the SEFA group http://www.sefagroup.com.

There appears to be a profit that can be made and there are established markets for coal fly ash. The goal should now be to establish similar specialty markets for pulp mill biomass ash and get ahead of any other companies that are looking at similar business activities. In this case the first in a region to establish a market presence should also establish a significant advantage due to consumer recognition and brand familiarity and recognition.

Market Intelligence

Primary industry manufacturing data is presented in Appendices 3 & 4. The data unfortunately is not available by regional district, but it does show significant activity in the Province for the majority of industries that could potentially accept wood waste biomass ash as raw materials.

Opportunities for reclamation include the Giscome Quarry northeast of Prince George which has a 5 year expected life as well as a number of gravel mining operations throughout the Regional District of Fraser Fort George.

Acidic runoff from mine tailings is a significant environmental concern related to mineral mine decommissioning. As previously stated, wood ash is a potential fit for minimizing acid drainage and stabilizing mine sites. There are 5 active metal mines within a 500km radius of Prince George (Mining Association of BC, 2014) and they may provide a good fit for ash reuse.

Census data is available for the New Brunswick district of Saint John Saint Stephen (SJSS) where JD Irving Ltd distributes its ash as well as the Cariboo District which includes the Cariboo Regional District (CRD) and the Regional District of Fraser Fort George (RDFFG) where the Canfor pulp mills operate. There were 1781 active farms in the Cariboo District vs. 574 in SJSS and 196,287 Acres of land in Agriculture in the Cariboo district vs. 58,231 in the SJSS district (Community Information Database. 2014). In 2006, 250 farms in the Cariboo district reported organic products vs 42 in the SJSS district (Community Information Database, 2014).

Canfor Pulp produces three and a half times the mass of ash that Irving does and the available market (based on agricultural area) in the Cariboo District is four times that in the District of Saint John Saint Stephen. This indicates that the agricultural market in the Cariboo District could support the volume of ash generated by the Canfor pulp mills

Cement manufacturing statistics are not as robust at those for agriculture, but there is significant activity in the RDFFG and the ability to substitute for pozzolanic material should be investigated further.

Barriers to Utilization

Public perception can present barriers or encouragement. Recent land application trials with municipal sewage sludge on agricultural land raised significant media attention and localized protests (CBC News, 2012; Opinion 250, 2011). Management of public perception will be an important activity regardless of which options are selected for using the ash.

Presence of persistent organic pollutants (POP's) is a risk that pulp mills need to be aware of when planning reuse of waste. POP's at pulp mills have typically consisted of complex chlorinated organic chemicals such as 2,3,7,8 TCDD (dioxin) and hexachlorobenzene, primarily related to the use of chlorine as bleach and in the case of power boiler ash – the incineration of garbage or wood that has been transported by boom through salt water. Neither case applies to the Canfor pulp mills, but the ash should be tested to ensure that any potential concerns can be laid to rest.

Leaching of metals from the ash has been identified as a potential concern. Sylvis (2012) has completed brief land application trials with Canfor pulp ash and determined that while there was evidence of cadmium leaching, it was well below what the contaminated sites regulation would allow on agricultural land (Sylvis, 2012).

Transportation costs can be a significant barrier and increase the farther the material is transported. Also worth considering is the minimization of greenhouse gas emissions by utilizing the shortest haul distances possible.

Evaluation Criteria for Reuse Options

The question for Canfor Pulp regarding its ash, is "what is the fit?" The literature is conclusive that wood waste biomass ash can be used as a feedstock for a significant number of products, but the option that provides the best value to Canfor Pulp must be determined. There are a number of specific value driven items that need to be considered including: the price to be obtained for the ash, the cost of transportation, handling costs, costs of additional infrastructure and labour costs for managing whatever arrangement evolves.

There are also a number of not so cost specific items that must be considered in addition to the factors mentioned above. These considerations include:

- Can the customer(s) handle a substantial proportion of, or all of the ash stream?
- Will there be liability issues related to product use and handling?
- Are there public relations issues that could develop around the transportation, storage and/or use of the ash?

- Will there be requirements for consultant / 3rd party involvement / costs?
- How does the product option fit with the company's corporate sustainability strategy?
- Is the product option a potentially viable long term continuous solution (i.e. greater than 10 years?) or will it be intermittent?
- Can existing infrastructure at the mills accommodate the customers' requirements regarding condition and volume of the product?
- Are there potential social responsibility driven partnerships with other entities (such as the University of Northern British Columbia's Energy Plant) that may affect the choice of the product option?
- How does the strategy correspond with the fibre supply dynamics and existing fibre supply agreements.

Canfor Pulp's first priority and objective is to eliminate the requirement for landfill development. Strategically this means that the wood waste biomass ash at the Prince George Pulp / Intercon Pulp (PGI) complex is the priority. The Northwood Pulp mill Landfill site has an estimated lifespan of 50 years at the current deposit rates and will have minimal development costs. The landfill lifespan at PGI is much shorter and there is a cost curve associated with developing new landfill sites for PGI that is estimated at $1 million CDN per year. In addition, there is a very limited amount of space on the mill site and this will ultimately lead to development off site at what is expected to be significant cost. An off-site landfill will require the direct purchase of real estate, or indirectly through operating costs paid to a third party. This also assumes that an appropriate site would be available and that environmental permits could be obtained for such a site.

Can Canfor Pulp use one of these options for beneficial use of its ash to minimize costs, minimize potential long term environmental liability, and if possible generate a profit?

Results

An assessment of the most technically feasible options for sale or re-use of power boiler ash is presented in Table 6. I prepared the contents of Table 6 based on the technical options presented in the literature review, the evaluation of the potential markets near Prince George, BC, and whether the options represented a "strategic fit" with Canfor Pulps objectives.

The options for "Available Market" were (in increasing order of likelihood): "None", Not likely", "Possible" or Good Potential". When a market was "Possible" and there is existing secondary processing in the same geographic region of the pulp mills, the "Additional Process" option was assumed to be "no".

VRINE analysis (Figures 1, 3 and 4) were conducted on the agricultural, mine reclamation and petroleum site reclamation options and used as a basis for the decision making process for evaluating "Strategic Fit"

Table 6 Matrix of Options vs. Objective Criteria

Option	Technically feasible	Proven technology	Available Market	Additional Process Required	Additional Handling Required	Strategic Fit?	Score
Re-inject Ash to Minimize volumes	Yes	Yes	N/A	Yes	Yes	No - Hog deliveries are expected to increase & less hog burned is not desirable	2/5
Glass	Yes	Yes	Not Likely	Yes	Yes	Yes	2/6
Composting	Yes	Yes	Possible	Yes	Yes	Yes	3.5/6
Cement	Yes	Yes	Possible	No	No	Yes	5.5/6
Mine Reclamation	Yes	Yes	Good potential	No	No	Yes	6/6
Petroleum site remediation	Yes	Yes	Good Potential	No	No	Yes	6/6
Road Construction	Yes	Yes	Possible	No	No	Yes	5.5/6
Brick	Yes	Not Yet	Not Likely / Possible	Yes / No	Yes/ No	Yes	3/6
Fertilizer	Yes	Yes	Good Potential	No	No	Yes	6/6

The above options were evaluated using objective criteria. The options for "Available Market" were (in increasing order of likelihood): "None", Not likely", "Possible" or Good Potential". When a market was "Possible" and there is existing secondary processing in the same geographic region of the pulp mills, the "Additional Process" option was assumed to be "no".

While there are a number of equally attractive options based purely on technical feasibility, there are three options that stand out based on fit with Canfor Pulp's objectives: metal mine site reclamation, petroleum site remediation and agricultural application.

Agricultural Use

Agricultural application of the ash is a good choice for a first pick because there is ample information available regarding the potential market, and there is a process that has been established in New Brunswick that should be easy to replicate.

Sylvis Environmental has been hired to coordinate the sampling and application process for CFIA registration of the Canfor Pulp ash streams. The four ash streams will be sampled, characterized according to the CFIA application process and if they meet the requirements each ash stream will be registered separately (assuming the parameters are not consistent between the mills).

Registering the ash with CFIA will provide third party legitimacy to the product and enable Canfor Pulp to approach any issues that arise regarding product safety from a very defensible position. Registration will also provide an opportunity to present the product to the community from the standpoint of an announcement that the product exists, is safe, available and introduce the brand associated with the product. Post announcement, Canfor Pulp will need to proactively advertise the product in order to gain interest from potential consumers and also to establish brand identity as a familiar local product.

Differentiation should be established in the form of ecologically sound practices, use of fertilizer which originates from the forest, and the use of a local product that supports the local economic cycle.

Price should be established at a point where the ash will cost less to apply than regular chemical fertilizers, but must reflect that fact that there is value to the product, and attract farmers who wish to reduce their operating costs.

The goal of the marketing effort will revolve around the creation of a good perceived value for and ecologically sound product, and to develop a preference for the product with local consumers. It may make sense to partner with UNBC to associate with the marketing effort in return for attaching "Canada's Green University" tagline to the campaign.

Branding is an important aspect of the CFIA registration process – the brand is identified directly in the product registration. Suggested bands include "Green Power Grow", "Green Power Growth", "Green Energy Boost" or "Green Energy Charge". The intent will be to identify the product with the green renewable energy produced at the Canfor pulp mills and the carbon neutrality of the ash product (because it originates from biomass).

Mine Reclamation

The second most viable option is the use of ash for metal mine reclamation, or underground reclamation of coal and mineral mine sites for structural rehabilitation. The use of ash for this purpose is technically viable but market, quantity and price are uncertain. While it is likely that mining companies would be interested in this activity, and quantities that would be used are potentially very large, the price is uncertain.

This option should be pursued as the ability to avoid capital investment for landfill development in the immediate future may offset the transportation costs to move the ash to mines. Transportation may be more attractive with this option if rail transport is available at prospective mine sites. All three pulp mills have access to rail infrastructure. Further economic and market research is required.

Petroleum Site Reclamation

As with the use of ash for mine reclamation, the market, quantity and price associated with this option is uncertain. The main factor that makes this option less desirable than mine reclamation is the longer haul distances from Prince George to the northeast of BC and into Alberta.

While this option appears to have potential, there needs to be full market analysis of quantity, price and cost of transportation in order to determine if it is viable.

Conclusion

There is evidence that pulp mill biomass ash can be marketed and sold. Agricultural use is the best market option to start with for the sale of ash but it should not be the only option investigated. Research clearly shows that biomass ash can be safely applied to agricultural land and that it can be provided in a safe manner to agricultural customers. It was also determined that a well thought out public relations program can overcome barriers to implementing this type of an effort.

The potential market size per unit of ash is similar to that of a successfully implemented program in New Brunswick. Ash can be safely applied to agricultural land at rates of 0.5 to 25 tonnes per hectare and specific application rates can be determined based on the specific chemical characteristics of the ash. Chemical analysis should also be conducted to verify that the Canfor pulp biomass ash product is safe for its intended purpose.

The registration of ash as a fertilizer product with the CFIA will help offset the potential for negative public reaction. A careful and well thought out public relations effort is recommended prior to initiating any fertilizer sales.

Mine and petroleum site remediation should also be pursued as potential viable options for ash sales. Further consideration should be given to the next most favorable options – road construction and cement manufacture. Canfor Pulp should also pay close attention to major civil projects such as dams or new roads and highways as ash is a desirable martial for slope stabilization and fill for dams, highways and other civil works that may utilize embankments.

Prior to establishing the venture, the pro forma costs can be estimated and used to establish a minimum pricing level for the ash in order to ensure profitability of the ash venture. Costs should include handling costs, management costs and costs for any anticipated marketing and public relations campaigns. Because it can be anticipated that the full volume of sales will potentially not be reached in the first (and possibly second) years of the venture, profitability should be planned for years two or three when the sales volumes might be expected to support the ash enterprise.

Recommended activities:

1. Develop a specific mission statement that will guide the effort to market the ash,
2. Pursue registration of the ash as an agricultural supplement with the CFIA,
3. Evaluate the operational requirements for handling, testing, sales and delivery of the ash and allocate appropriate resources,
4. Develop an identifiable brand for the product,

5. Develop a public relations effort specific to the beneficial reuse of the ash,
6. Develop relationships with, and complete market analysis of, the three targeted sectors:
   - Agriculture
   - Mining
   - Oil and gas extraction/site clean up
7. Establish a market presence (where viable) in the three target sectors.
8. Evaluate the predicted costs of operating the venture and establish a minimum price per tonne of ash based on a reasonable projection for sales in order to plan for profitability.

This study is limited by the lack of information that is specific to the price of materials that ash could be displacing in; mine site reclamation, petroleum site reclamation, cement manufacturing and road construction. There is a lack of market specific data related to price and transportation, and further work is required to prepare proper economic analysis for the remaining options mentioned. Economic analysis of the market demand, price and transportation costs to each of the potential markets should be evaluated in order to prioritize which market(s) to put effort in developing. Basic pro forma analysis should be conducted in order to model pricing, project sales and plan for profitability.

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http://flyashbricksinfo.com/success-formula-flyash-bricks.html.

http://charah.com/ccp-management-services/ccp-sales-marketing/.

Figure 1 Canfor Pulp Ash Generation Statistics

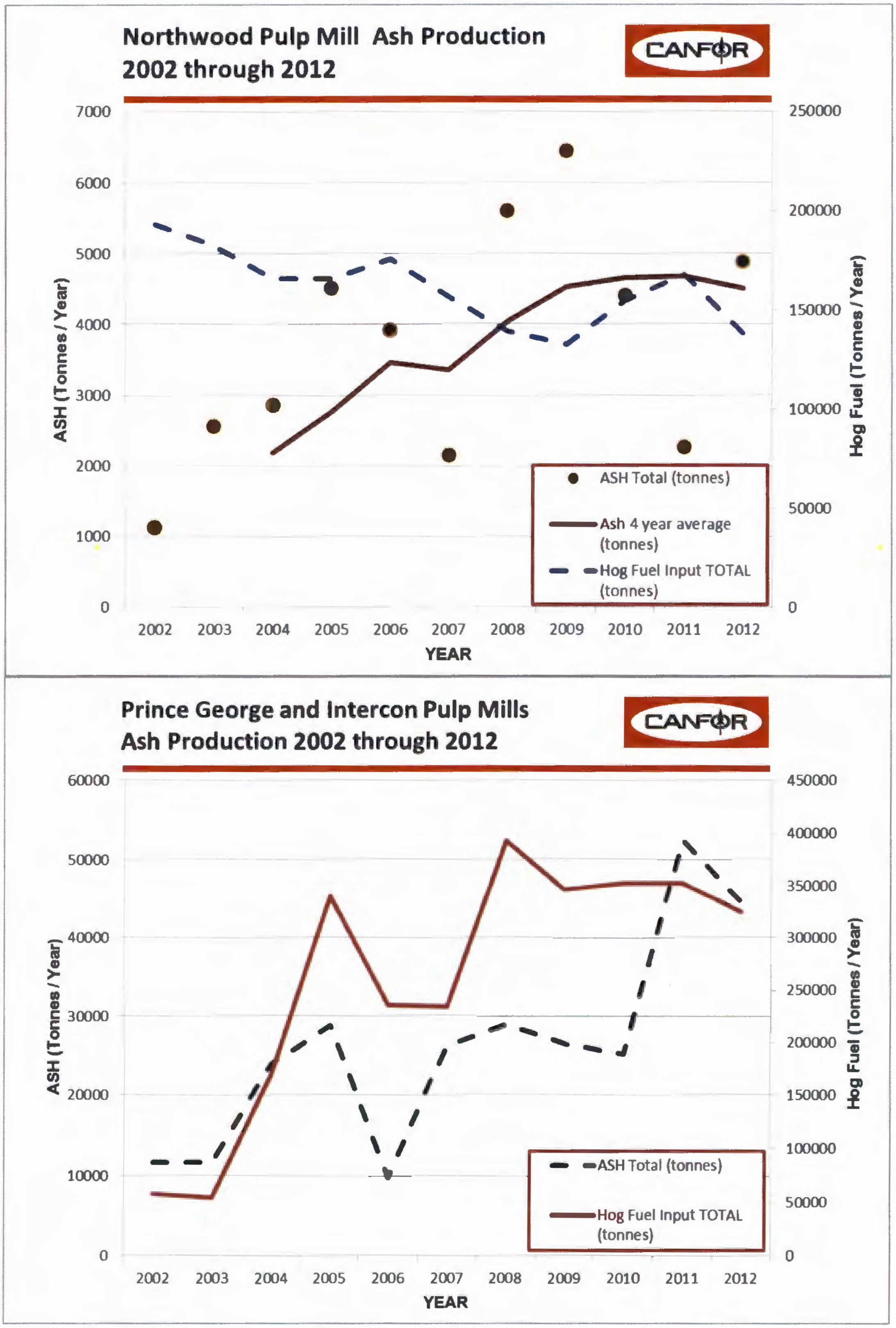


Figure 2 VRINE Analysis – Agricultural Use Of Ash

Value

Potential linkage to organic farming

reasonable price for an effective fertilizer product

Rarity

Duplication possible, but there is geographical advantage because pulp mills are spread somewhat evenly around the province. Less duplication likely to the North

Inimitable

Branding may be an important way to differentiate

Non-substitutable

substitutable, but very flexible on where price settles

brand loyalty for premium products

Exploitable

Can be a large volume supplier. Able to stockpile product if necessary. No similar products in local market. Potential to duplicate success experienced in New Brunswick

Figure 3 SWOT Analysis – Agricultural Use Of Ash

Internal / External	Strengths	Weaknesses
Internal **External**	Multiple sources available Possible Internal logistics support from transportation group Potential Technical support from Irving Proven application elsewhere	Limitations on quality control - boiler operation will define quality Ash handling system reliability can affect ash handling (dry or wet) Logistics and delivery may become complicated Demand may not keep up with supply
Opportunities Low cost Flexible "Green Product" Low entry costs fits with corporate sustainability initiative	Possible Strategies Leverage strengths and develop a market entry plan based on a sustainable and low cost fertilizer replacement	Possible Strategies sell into more than one market to avoid dependance incorporate potential variability into sales agreements
Threats Low switching costs Substitution - other pulp mills in region may be followers Protests (public perception) Slow or low uptake by market Transportation costs	Possible Strategies focus on convenience devlop a recognizable brand CFIA registartion Leverage sustainability and green product image	Possible Strategies focus on analyzing the behaviors and needs of the target market and look for opportunities for differentiation Develop a well thought out Public relations program Be a "first mover" and lock in relationships with desirable customers

Figure 4 VRINE Analysis – Mine Reclamation

Value

Potential to link sustainable business practices at Pulp Mills to mine reclamation

Will allow Mining companies to reduce overall environmental impacts

May reduce borrow requirements for mine reclamation

Rarity

Duplication possible

Inimitable

Branding and CFIA registration may be an important way to differentiate

Non-substitutable

Risk of competition from mills in the Quesnel and Mackenzie area

Need to be a first mover and potentially enter into long term agreements

Exploitable

Can be a large volume supplier

Able to stockpile product if necessary

Ample experience with supply relationships with other industrial companies

Figure 5 VRINE Analysis – Petroleum Site Reclamation

Value

Potential to link sustainable business practices at Pulp Mills to Petroleum Site reclamation

Will allow Petroleum extracting companies to reduce overall environmental impacts

Rarity

Duplication possible

Inimitable

Branding and CFIA registration may be an important way to differentiate

Non-substitutable

Risk of competition from mills in Mackenzie and Northern Alberta

Need to be a first mover and potentially enter into long term agreements

Exploitable

Can be a large volume supplier
Able to stockpile product if necessary
Ample experience with supply relationships with other industrial companies

Figure 6 Northwood Pulp Mill #4 Power Boiler Ash Collection System Layout

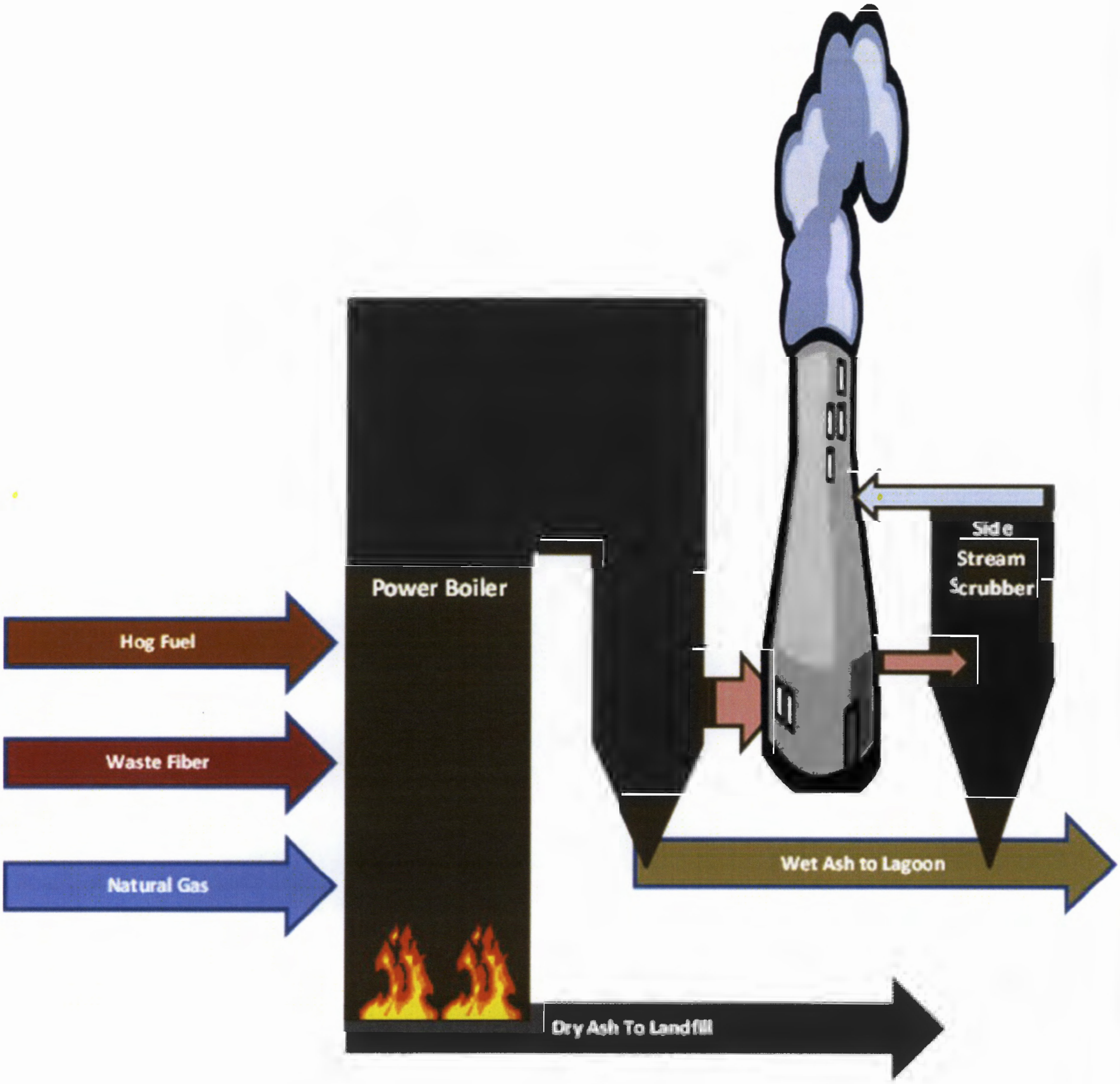


Figure 7 Intercon Pulp Mill Power Boiler Ash Collection System Layout

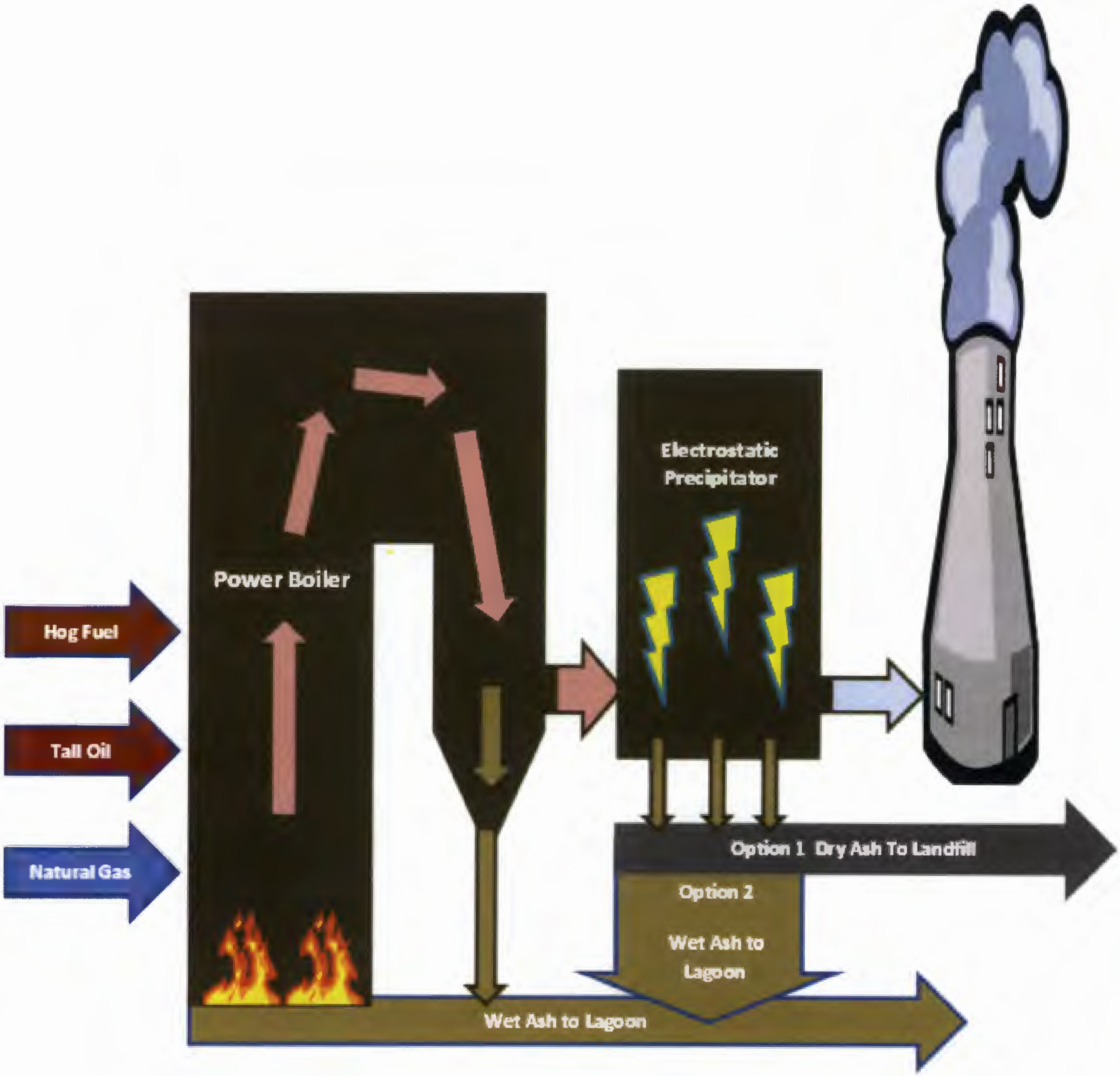


Figure 8 Prince George Pulp Mill #1 Power Boiler Ash Collection System Layout

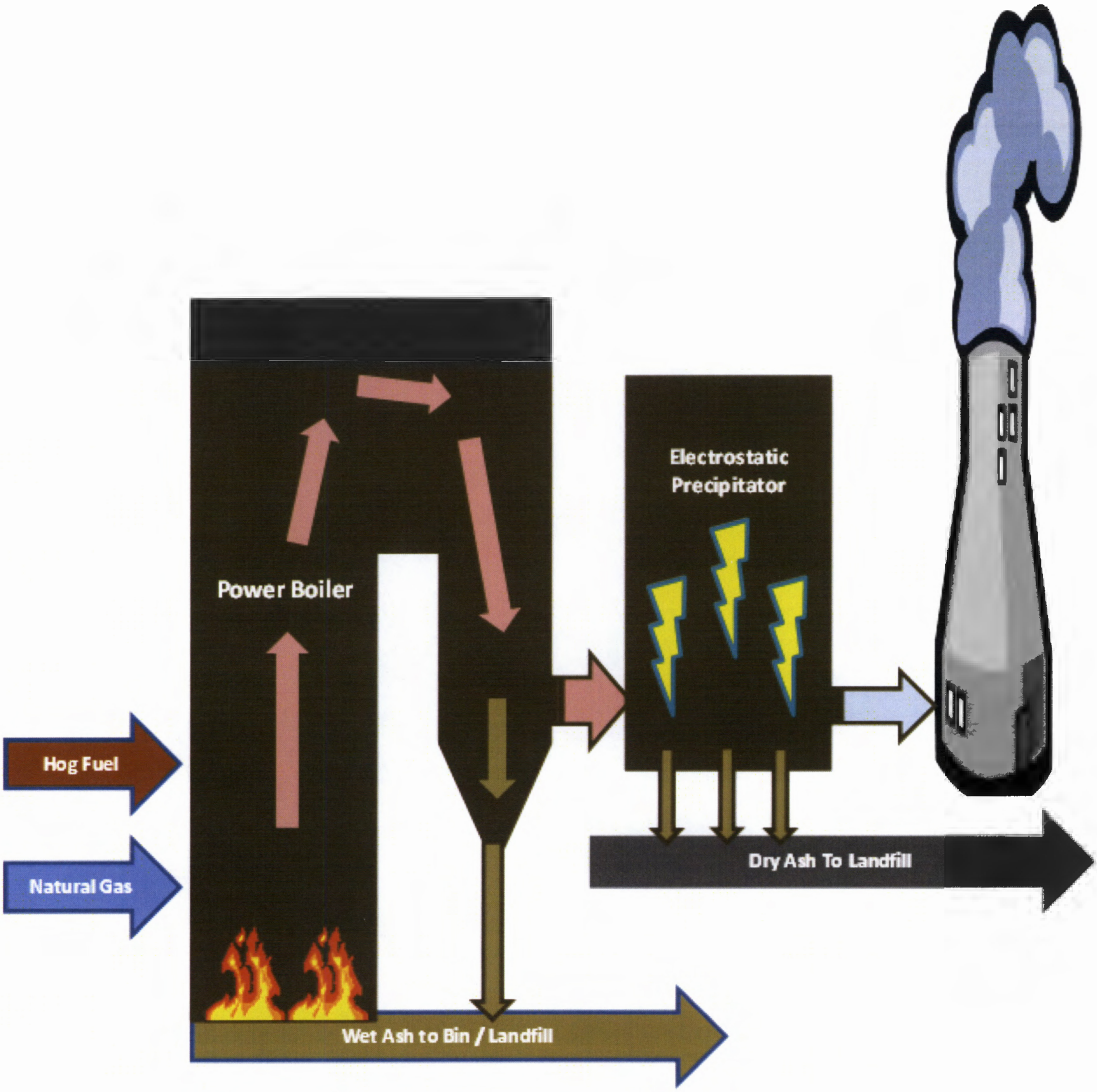


Figure 9 Prince George Pulp Mill #2 Power Boiler Ash Collection System Layout

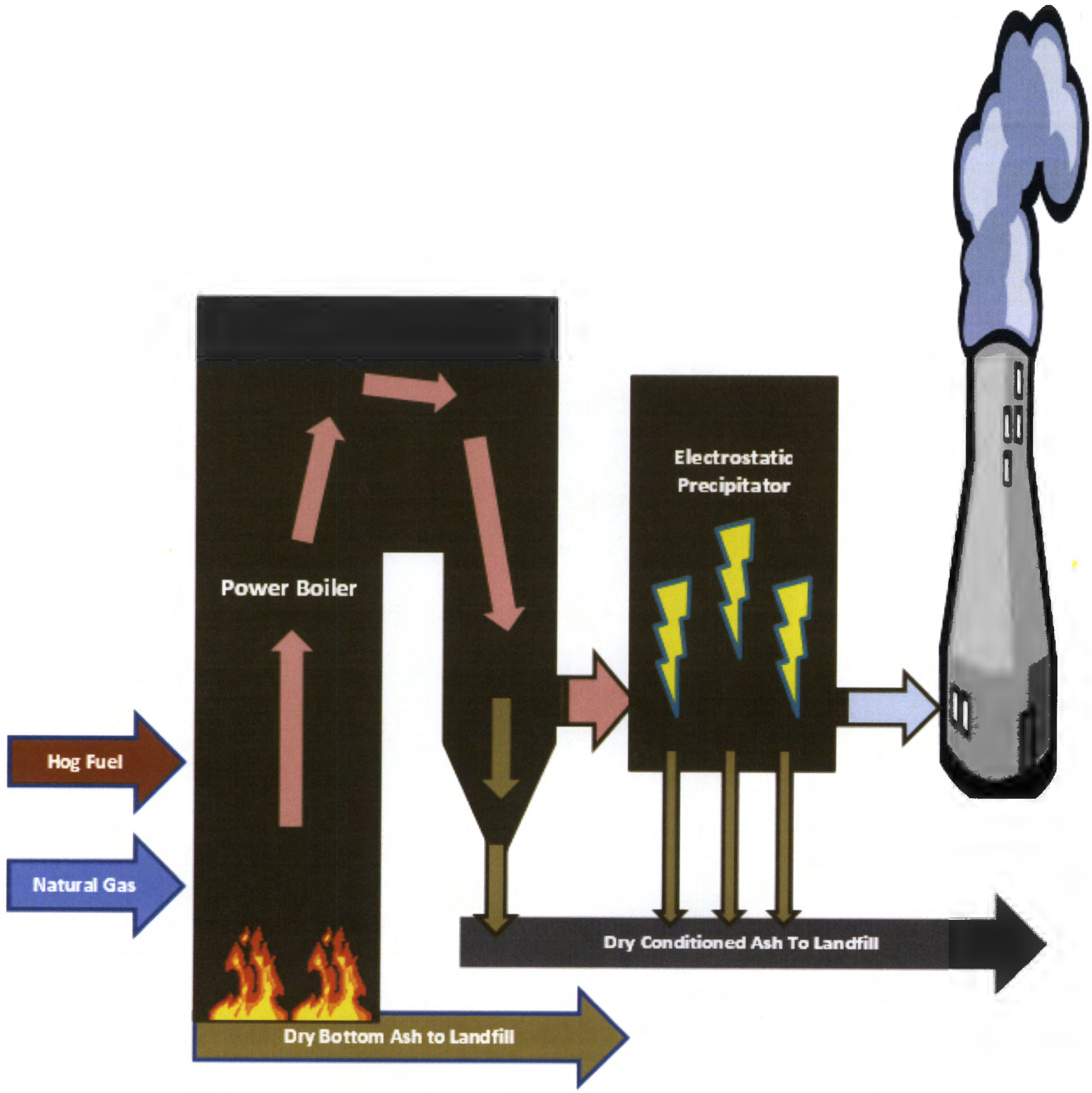


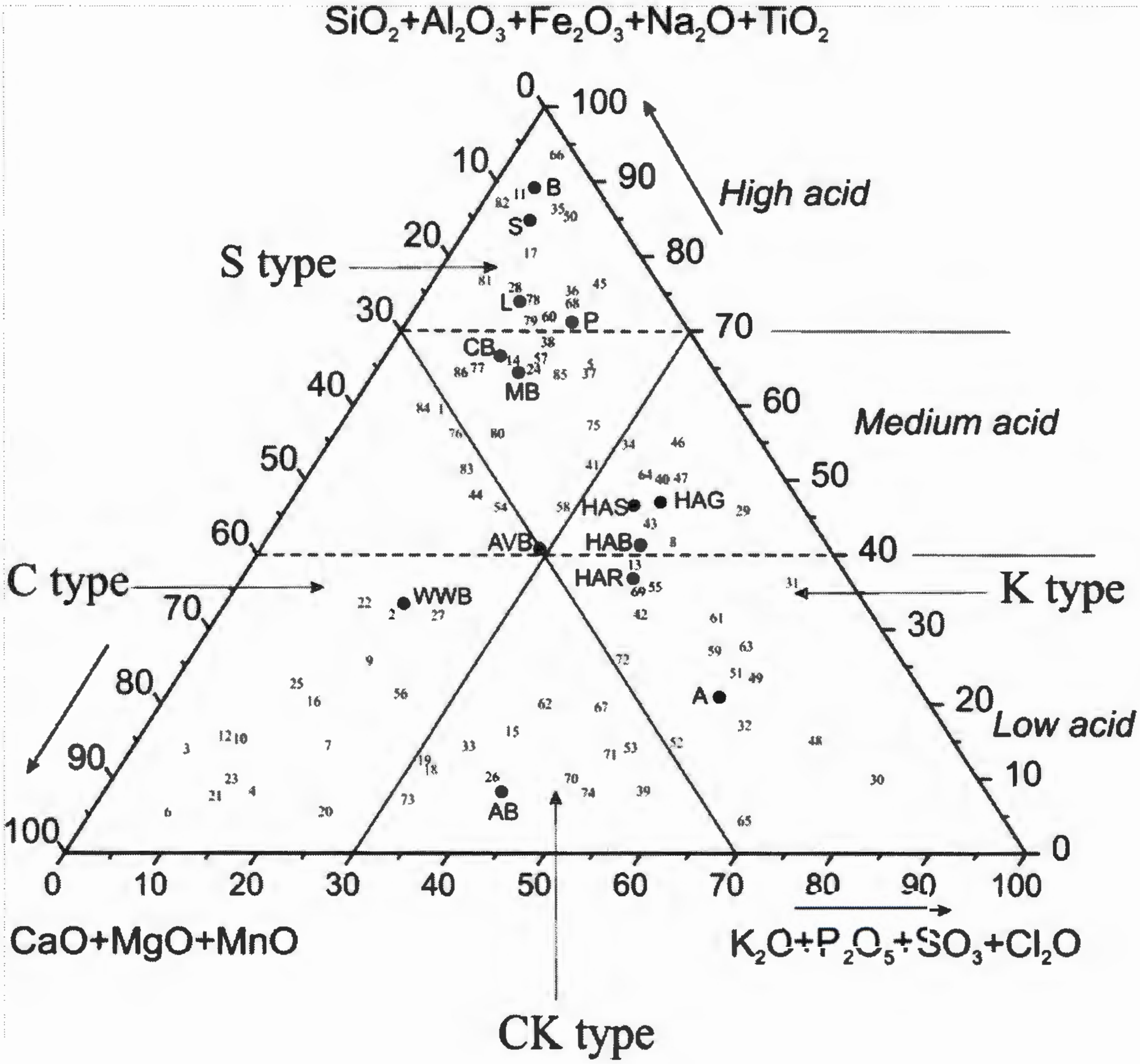
Figure 10 CANSIM Stats Can selected manufacturing statistics for BC

Table 301-0006 Principal statistics for manufacturing industries, by North American Industry Classification System (NAICS), annual (dollars unless otherwise noted)(1,2,3,9,10)					
Survey or program details:					
Annual Survey of Manufactures and Logging - 2103		Number of establishments (8,11)			
Geography	North American Industry Classification System (NAICS)	2007	2008	2009	2010
British Columbia	Asphalt paving, roofing and saturated materials manufacturing [32412]	11	12	12	12
British Columbia	Asphalt paving mixture and block manufacturing [324121]	6	8	8	10
British Columbia	Synthetic dye and pigment manufacturing [32513]	3	3	2	2
British Columbia	Chemical fertilizer (except potash) manufacturing [325313]	11	9	8	8
British Columbia	Mixed fertilizer manufacturing [325314]	17	18	16	18
British Columbia	Soap and cleaning compound manufacturing [32561]	53	48	43	40
British Columbia	Pottery, ceramics and plumbing fixture manufacturing [327110]	62	63	59	63
British Columbia	Clay building material and refractory manufacturing [327120]	11	13	14	12
British Columbia	Glass manufacturing [327214]	45	42	41	40
British Columbia	Glass product manufacturing from purchased glass [327215]	89	87	82	79
British Columbia	Cement manufacturing [32731]	9	9	9	8
British Columbia	Cement manufacturing [327310]	9	9	9	8
British Columbia	Ready-mix concrete manufacturing [32732]	116	119	113	119
British Columbia	Ready-mix concrete manufacturing [327320]	116	119	113	119
British Columbia	Concrete pipe, brick and block manufacturing [32733]	25	28	32	33
British Columbia	Concrete pipe, brick and block manufacturing [327330]	25	28	32	33
British Columbia	Other concrete product manufacturing [32739]	69	70	65	62
British Columbia	Other concrete product manufacturing [327390]	69	70	65	62
Source:					
Statistics Canada. Table 301-0006 - Principal statistics for manufacturing industries, by North American Industry Classification System (NAICS), annual (dollars unless otherwise noted)					

Figure 11 Statistics Canada, selected manufacturing activity statistics for BC

BRITISH COLUMBIA MANUFACTURING SHIPMENTS - MANUFACTURING ACTIVITY ($MILLIONS)						
NAICS CODE	INDUSTRY	2007	2008	2009	2010	2011
32412	Asphalt paving, roofing and saturated materials manufacturing	x	x	x	x	x
32513	Synthetic dye and pigment manufacturing	x	x	x	x	x
3253	Pesticide, fertilizer and other agricultural chemical manufacturir	x	x	x	x	x
32531	Fertilizer manufacturing	80.77	x	x	x	x
3256	Soap, cleaning compound and toilet preparation manufacturing	105.44	x	x	x	x
32561	Soap and cleaning compound manufacturing	44.69	43.69	42.20	44.92	48.86
3271	Clay product and refractory manufacturing	35.28	x	x	x	x
3272	Glass and glass product manufacturing	295.10	269.09	164.27	122.34	117.24
32721	Glass and glass product manufacturing	295.10	269.09	164.27	122.34	117.24
327214	Glass manufacturing	128.31	x	x	x	x
327215	Glass product manufacturing from purchased glass	166.79	x	x	x	x
3273	Cement and concrete product manufacturing	1,326.03	1,211.49	859.05	913.74	903.49
32731	Cement manufacturing	x	x	x	x	x
32732	Ready-mix concrete manufacturing	738.36	634.69	409.96	449.81	433.57
32733	Concrete pipe, brick and block manufacturing	x	x	x	x	x
x	Suppressed to meet the confidentiality requirements of the Statistics Act					
Footnotes						
1	Data for the three months prior to the last month of reference have been revised.					
2	Starting in January 2004, the data are reconciled with the ASML, but the aggregate industry estimates may be different					
3	Beginning with reference year 2007, the data are classified by industry based on the North American Industry Classification System (NAICS) 2007.					
Source:						
Statistics Canada. Table 304-0015 - Manufacturing sales, by North American Industry Classification System (NAICS) and province, annual (dollars)						
(accessed: August 15, 2012)						
http://www5.statcan.gc.ca/cansim/home-accueil?lang=eng&p2=50						

Figure 12 Chemical classification system of the inorganic matter in high-temperature biomass ashes based on 78 varieties of biomass, wt.% (source: Vassilev et al., 2010)



Appendix 1 Canfor Pulp Ash Analysis

Samples of Intercon Pulp Mill Ash

Intercon PB Ash, 6/15-9/12						
Sample Location		Int Ash (= "PB Ash")				
		Intercon	Intercon	Intercon	Intercon	UNBC analysis
Date		6/15/2011	6/29/2011	9/12/2011	8/9/2011	Nov. 2008
Solids	%	6.1	3.21	6.23	0.2	
Moisture	%	93.9	96.79	93.77	99.8	
HHV	BTU/lb, dry basis	340	625	<1	1,960	
Ash @ 400 °C	%, dry basis	90.8	83.7	91.6	88	
LOI @ 400 °C	%, dry basis	9.2	16.3	8.4	12	
Density	kg/m3	1,055	1,010	1,050	1,002	
Density (Ash)	kg/m3	300	269	425 (423/427)		
Carbon, C	%, dry basis	9.02	8.84	4.16	10.1	82.40
Nitrogen, N	%, dry basis		<0.1	<0.1		<0.1
Oxygen, O	%, dry basis					17.27
pH	--		12.3	12.4		
Conductivity	μS/cm		11,430	9,150		
Aluminum, Al	mg/kg OD	47,400	48,300	54,700	134	2340*
Arsenic, As	mg/kg OD	< 20	<10	< 20	< 20	<20
Barium, Ba	mg/kg OD	2,630	2,850	2,320	76.3	337*
Boron, B	mg/kg OD	135	127	121	38	23
Cadmium, Cd	mg/kg OD	6	11.6	6.1	< 1	3.1
Calcium, Ca	mg/kg OD	220,000	201,000	168,000	20,500	36400*
Chromium, Cr	mg/kg OD	44	39	52	15.6	6
Cobalt, Co	mg/kg OD	10	8	11	< 2	<2
Copper, Cu	mg/kg OD	64	67	64	11	<5
Iron, Fe	mg/kg OD	14,800	15,300	19,900	146	1550*
Lead, Pb	mg/kg OD	< 10	<10	< 10	< 10	<10
Lithium, Li	mg/kg OD	7	5	9	6	<2
Magnesium, Mg	mg/kg OD	22,000	21,500	21,200	4,520	3090*
Manganese, Mn	mg/kg OD	10,200	9,880	8,230	497	1620*
Mercury, Mg	mg/kg OD		0.026	0.020		
Molybdenum, Mo	mg/kg OD	< 10	<10	< 10	2	<10
Nickel, Ni	mg/kg OD	35	34	44	< 5	<50
Phosphorus, P	mg/kg OD	9,000	8,270	7,120	1,070	630*
Potassium, K	mg/kg OD	19,300	15,600	21,200	8,310	776
Selenium, Se	mg/kg OD		<0.6	< 0.6		
Silicon, Si	mg/kg OD	69,400	84,300	129,000	3,910	5910*
Sodium, Na	mg/kg OD	8,800	7,950	17,600	246,000	600
Strontium, Sr	mg/kg OD	695	627	594	92	70
Sulfur, S	mg/kg OD		5,330	9,910	1.7	
Titanium, Ti	mg/kg OD	1,090	1,180	1,880	< 2	133*
Vanadium, V	mg/kg OD	23	27.4	43.1	20.7	2.6
Zinc, Zn	mg/kg OD	398	582	415		133*

Samples of PG Pulp Mill Ash

PG Mill PB #1 Ash bucket -- all results 6/15-10/31								
			6/13/2011	7/28/2011	9/20/2011	10/31/2011	November 2008	November 2010
			PB Ash #1	PB Ash #1	PB Ash #1	PB Ash #1	PB #1	PB #1
Parameter	Units	Method	Ash Bucket	Ash Bucket	Ash Bucket	Ash Bucket	UNBC Analysis	UNBC Analysis
Total Solids As-received	%		19.3	33.0	14.5	12.5	27.2	
Moisture As-received	%	ASTM E871	80.7	67.0	85.5 (85.2,85.80)	87.5	72.8	40.0
pH (5% solution)	--							
Conductivity	µS/cm							
Higher Heating Value	BTU/lb, dry basis	ASTM - D5865/E711	9,880	4,510	11,880 (11900;11820)	12,210 (12160;12270)		
Ash @ 400 °C	%, dry basis	ASTM - D3174	32.17	64.10	16.40	11.50	33.7	39.9%
Loss On Ignition @ 400 °C	%, dry basis	ASTM - D3174	67.83	35.90	83.60	88.50		
Fixed carbon	%, dry basis						61.5	52.5%
% Volatiles	%, dry basis						4.8	7.7%
Density as-received	kg/m3		444	480(488/473)	416	413(403;423)		
Density (Ash)	kg/m3		257	860(845/884)	69.4	81.6(79.4;83.8)		
Carbon, C	%, dry basis	ASTM - D5373	84.2	71.1	84.1	87.4	77.1	38.2
Nitrogen, N	%, dry basis						<0.1	<0.1
Oxygen, O	%, dry basis						61.49	61.5
Aluminum, Al	mg/kg	ESM-266B	6,200	18,300	920		21,200*	
Arsenic, As	mg/kg	ESM-266B	< 20	< 10	< 10		<20	
Barium, Ba	mg/kg	ESM-266B	226	247	164		486	
Boron, B	mg/kg	ESM-266B	18	26	21		20	
Cadmium, Cd	mg/kg	ESM-266B	< 1	<1	< 1		<1	
Calcium, Ca	mg/kg	ESM-266B	20,800	22,800	13,100		27,200*	
Chromium, Cr	mg/kg	ESM-266B	25	9	3		31	
Cobalt, Co	mg/kg	ESM-266B	3	<2	< 2		4	
Copper, Cu	mg/kg	ESM-266B	21	15	5		12	
Iron, Fe	mg/kg	ESM-266B	13,000	8,180	1,050		11,400*	
Lead, Pb	mg/kg	ESM-266B	< 10	<10	< 10		<10	
Lithium, Li	mg/kg	ESM-266B	4	< 2	< 2		4	
Magnesium, Mg	mg/kg	ESM-266B	4,310	5,110	2,540		7,500*	
Manganese, Mn	mg/kg	ESM-266B	1,420	1,800	1,220		2,600*	
Mercury, Hg	mg/kg	ESM-266B						
Molybdenum, Mo	mg/kg	ESM-266B	< 10	<10	< 10		<10	
Nickel, Ni	mg/kg	ESM-266B	17	19	< 5		<50	
Phosphorus, P	mg/kg	ESM-266B	830	896	480		881*	
Potassium, K	mg/kg	ESM-266B	3,200	13,500	1,130		3,760	
Selenium, Se	mg/kg	ESM-266B						
Silicon, Si	mg/kg	ESM-266B	40,100	115,000	4,850		173,000*	
Sodium, Na	mg/kg	ESM-266B	1,600	1,300	300		1,800	
Strontium, Sr	mg/kg	ESM-266B	84	91	43		104	
Sulfur, S	mg/kg	ESM-266B			150			
Titanium, Ti	mg/kg	ESM-266B	481	694	52		1,910*	
Vanadium, V	mg/kg	ESM-266B	21.1	7.4	1		20.2	
Zinc, Zn	mg/kg	ESM-266B	45	49	28		558*	

Samples of PG [illegible] Mill Ash   #2 Power Boiler

Parameter	Units	Method	[illegible] PB Ash #2 Combined [illegible]	[illegible] [illegible] Combined	[illegible] [illegible] Combined	[illegible] PB Ash #2 Combined	[illegible] [illegible] (combined) UNBC analysis	[illegible] [illegible] UNBC analysis	[illegible] [illegible] UNBC analysis	4/27/2012 [illegible] UNBC analysis
Total Solids As-received	%		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		
Moisture As-received	%	ASTM [illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		
pH (5% solution)	--						[illegible]			
Conductivity	[illegible]						[illegible]			
CaCO3 equivalence	%						[illegible]			
Higher Heating Value	[illegible]	ASTM - [illegible]	6,170	[illegible]	[illegible]	[illegible]				
Ash @ [illegible] °C	% dry basis	ASTM - [illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		
Loss On Ignition @ [illegible] °C	% dry basis	ASTM - [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
Fixed C	% dry basis							[illegible]		
% Volatiles	% dry basis							[illegible]		
Density as-received	kg/m3		[illegible]	[illegible]	[illegible]	[illegible]				
Density (bin)	kg/m3		[illegible]		[illegible]	[illegible]				
Carbon, C	% dry basis	ASTM - [illegible]	[illegible]	[illegible]	15.8	[illegible]	[illegible]	30.2	[illegible]	[illegible]
Nitrogen, N	%, dry basis						[illegible]	[illegible]	[illegible]	[illegible]
Oxygen, O	% dry basis							[illegible]		
Sulfur S	% dry basis						[illegible]		[illegible]	[illegible]
C inorg	% dry basis						[illegible]			
Aluminum, Al	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Antimony, Sb	mg/kg						[illegible]		[illegible]	[illegible]
Arsenic, As	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Barium, Ba	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Beryllium, Be	mg/kg						[illegible]		[illegible]	[illegible]
Bismuth, Bi	mg/kg						[illegible]		[illegible]	[illegible]
Boron, B	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Cadmium, Cd	mg/kg	ESM-266B	5	<1	[illegible]		5.1	6.9	4.02	4.8
Calcium, Ca	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Chromium, Cr	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Cobalt, Co	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Copper, Cu	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Gold, Ag	mg/kg						<0.1		0.71	[illegible]
Iron, Fe	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Lead, Pb	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Lithium, Li	mg/kg	ESM-[illegible]	6	[illegible]	5		[illegible]	8	[illegible]	[illegible]
Magnesium, Mg	mg/kg	ESM-266B	[illegible]	[illegible]	[illegible]		10798.20	13200*	9060	8974.4
Manganese, Mn	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Mercury, Hg	mg/kg	ESM-[illegible]					[illegible]		[illegible]	[illegible]
Molybdenum, Mo	mg/kg	ESM-[illegible]	[illegible]	[illegible]	<10		[illegible]	[illegible]	[illegible]	[illegible]
Nickel, Ni	mg/kg	ESM-266B	28	18	32		[illegible]	<50	[illegible]	13.4
Phosphorus, P	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Potassium, K	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Selenium, Se	mg/kg	ESM-[illegible]							[illegible]	[illegible]
Silicon, Si	mg/kg	ESM-266B	75,000	[illegible]	[illegible]			146000*	285.19	276.4
Sodium, Na	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Strontium, Sr	mg/kg	ESM-266B	328	328	613		[illegible]	[illegible]	403	377.5
Sulfur, S	mg/kg	ESM-[illegible]			[illegible]		[illegible]			
Tin, Sn	mg/kg						[illegible]		[illegible]	[illegible]
Titanium, Ti	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Tungsten, W	mg/kg						[illegible]		[illegible]	[illegible]
Vanadium, V	mg/kg	ESM-[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Yttrium, Y							[illegible]		[illegible]	[illegible]
Zinc, Zn	mg/kg	ESM-[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Zirconium, Zr	mg/kg						[illegible]		[illegible]	[illegible]

Samples of PG Pulp Mill Ash

Exotic ash streams

			6/13/2011	6/13/2011	6/13/2013
Analysis	**Unit**	**Analytical Methods**	**PG PB Ash #1 - Overflow**	**PB Ash #2 -- Hopper (conveyor 365)**	**PB Ash #2 -- Precipitator (conveyor 364)**
Total solids	%, as-rec'd	ASTM E871	0.15	59.00	99.56
Moisture content	%, as-rec'd	ASTM E871	99.85	41.0	0.44
pH (5% solution)	--	ESM 090B			
Conductivity	μS/cm	APHA			
Density (as-rec'd)	kg/m^3			330	242
Density ash	kg/m^3			262	250
Nitrogen, N	%, dry basis	ASTM D5373			
Higher Heating Value	BTU/lb, dry basis			3610	750
Ash @ 400°C	%, dry basis			66.80	93.77
Loss On Ignition @ 400°C	%, dry basis			32.20	6.23
Carbon, C	%, dry basis			31.9	9.75
Metals scan					
Aluminum, Al	mg/kg, dry basis	ESM 266B		16,100	24,100
Arsenic, As	mg/kg, dry basis	ESM 266B		< 20	< 20
Barium, Ba	mg/kg, dry basis	ESM 266B		2,060	2,680
Boron, B	mg/kg, dry basis	ESM 266B		145	261
Cadmium, Cd	mg/kg, dry basis	ESM 266B		19	20
Calcium, Ca	mg/kg, dry basis	ESM 266B		149,000	220,000
Chromium, Cr	mg/kg, dry basis	ESM 266B		24	34
Cobalt, Co	mg/kg, dry basis	ESM 266B		8	11
Copper, Cu	mg/kg, dry basis	ESM 266B		71	112
Iron, Fe	mg/kg, dry basis	ESM 266B		11,400	17,000
Lead, Pb	mg/kg, dry basis	ESM 266B		13	20
Lithium, Li	mg/kg, dry basis	ESM 266B		9	11
Magnesium, Mg	mg/kg, dry basis	ESM 266B		16,500	25,800
Manganese, Mn	mg/kg, dry basis	ESM 266B		7,660	12,200
Mercury, Hg *	mg/kg, dry basis	ESM 266B			
Molybdenum, Mo	mg/kg, dry basis	ESM 266B		< 10	< 10
Nickel, Ni	mg/kg, dry basis	ESM 266B		29	43
Phosphorus, P	mg/kg, dry basis	ESM 266B		6,670	10,900
Potassium, K	mg/kg, dry basis	ESM 266B		20,300	57,600
Selenium, Se	mg/kg, dry basis	ESM 266B			
Silicon, Si	mg/kg, dry basis	ESM 266B		69,200	90,500
Sodium, Na	mg/kg, dry basis	ESM 266B		2,700	6,600
Strontium, Sr	mg/kg, dry basis	ESM 266B		599	798
Sulfur, S	mg/kg, dry basis	ESM 266B			
Titanium, Ti	mg/kg, dry basis	ESM 266B		1,040	1,440
Vanadium, V	mg/kg, dry basis	ESM 266B		20.5	29.3
Zinc, Zn	mg/kg, dry basis	ESM 266B		1,950	2,490

Samples of Northwood Pulp Mill Ash

September 13 2011 sampling

Analysis	Unit	Analytical Methods	Dregs Sept 13 NWP	Lime Sept 13 NWP	Ash fr. Lagoon NWP	UNBC analysis Nov. 2008
Total solids	%, as-rec'd	ASTM E871	51.3	100	44.2	
Moisture content	%, as-rec'd	ASTM E871	48.7	<0.1	55.8	
pH (5% solution)	--	ESM 090B	11.3	12.3	9.21	
Conductivity	µS/cm	APHA	714	8760	72.9	
Density (as-rec'd)	kg/m^3		773/821	1019	827	
Density ash	kg/m^3					
Carbon, C	%, dry basis					48.50
Nitrogen, N	%, dry basis	ASTM D5373	0.303	0.233	2.54	<0.1
Oxygen, O	%, dry basis					51.16
Higher Heating Value	BTU/lb, dry basis					
Ash @ 400°C	%, dry basis					
Loss On Ignition @ 400°C	%, dry basis					
Metals scan						
Aluminum, Al	mg/kg, dry basis	ESM 266B	3,330	2,390	2,550	13800
Arsenic, As	mg/kg, dry basis	ESM 266B	<10	<20	<10	<20
Barium, Ba	mg/kg, dry basis	ESM 266B	357	569	481	861
Boron, B	mg/kg, dry basis	ESM 266B	10	<10	40	59
Cadmium, Cd	mg/kg, dry basis	ESM 266B	6.4	1	1.9	4.1
Calcium, Ca	mg/kg, dry basis	ESM 266B	320,000	612,000	116,000	88400
Chromium, Cr	mg/kg, dry basis	ESM 266B	774	48	6	30
Cobalt, Co	mg/kg, dry basis	ESM 266B	4	<2	<2	5
Copper, Cu	mg/kg, dry basis	ESM 266B	139	<5	17	30
Iron, Fe	mg/kg, dry basis	ESM 266B	4,440	279	1,600	9320
Lead, Pb	mg/kg, dry basis	ESM 266B	<10	<10	<10	<10
Lithium, Li	mg/kg, dry basis	ESM 266B	<2	2	3	7
Magnesium, Mg	mg/kg, dry basis	ESM 266B	22,000	4,590	5,210	14500
Manganese, Mn	mg/kg, dry basis	ESM 266B	12,800	334	2,070	5360
Mercury, Hg *	mg/kg, dry basis	ESM 266B	0.067	0.024	0.052	
Molybdenum, Mo	mg/kg, dry basis	ESM 266B	<10	<10	<10	<10
Nickel, Ni	mg/kg, dry basis	ESM 266B	60	7	6	<50
Phosphorus, P	mg/kg, dry basis	ESM 266B	830	2,710	1,250	3740
Potassium, K	mg/kg, dry basis	ESM 266B	950	2,530	1,370	7970
Selenium, Se	mg/kg, dry basis	ESM 266B	<0.6	<0.6	<0.6	
Silicon, Si	mg/kg, dry basis	ESM 266B	1,350	1,240	8,140	73300
Sodium, Na	mg/kg, dry basis	ESM 266B	21,200	9,640	350	3000
Strontium, Sr	mg/kg, dry basis	ESM 266B	249	290	186	258
Sulfur, S	mg/kg, dry basis	ESM 266B	14,000	1,500	330	
Titanium, Ti	mg/kg, dry basis	ESM 266B	74.8	128	95.9	829
Vanadium, V	mg/kg, dry basis	ESM 266B	<0.5	<0.5	2.2	21.1
Zinc, Zn	mg/kg, dry basis	ESM 266B	783	<5	142	1470