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# Washington State Department of Ecology Industrial Footprint Project

Waste Stream Reduction and Re-Use in the Pulp and Paper Sector

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## Waste Stream Reduction and Re-Use in the Pulp and Paper Sector

### 1.0 Background

Center for Sustainable Economy prepared this report for the Industrial Footprint Project (IFP), identifying major components of the pulp and paper waste stream and opportunities for recycling and re-use of that stream in beneficial uses. The purpose of the report is to provide Washington State's Department of Ecology (Ecology) with an overview of potential waste stream reduction initiatives applicable to the sector in general and for mills participating in the IFP.

The report is organized as such:

- Section 2 provides a description of the major components of the pulp and paper sector waste stream. We focus our attention on three: wastewater treatment plant residuals, boiler ash residues, and causticizing residuals.
- Section 3 provides a summary of state of the art waste reduction techniques employed in the sector worldwide, drawing from industry sustainability reports and other published literature.
- Section 4 provides a comprehensive overview of potential markets for all major types of waste.
- Section 5 reviews some key barriers and challenges for re-use, and reports the results of an internal survey of mills participating in the IFP.
- Section 6 contains a brief overview of both industry-led and public programs to increase the reuse of pulp and paper residuals.

### 2.0 Pulp and Paper Mill Waste Stream Description

Papermaking produces significant residual waste streams consisting of:

- Wastewater treatment plant (WWTP) residuals.
- Boiler and furnace ash.
- Causticizing residues which include lime mud, lime slaker grits and green liquor dregs.
- Wood yard debris.
- Pulp and paper mill rejects.

The United States pulp and paper mill industry sees an annual generation of solid wastes and byproduct solids of 15 million dry tons. Composition varies by mill, but can be as much as 50 percent solids to 50 percent water. Solids are generally 50 percent fiber and as much as 50 percent minerals. Pulp pH is typically around 12, but mills neutralize residue before disposal. Residue can also contain recoverable titanium oxide and calcium sulfate (Wisconsin Biorefining Development Initiative).

Mills generate three types of solid waste:

- Sludge from wastewater treatment plants
- Ash from boilers

- Miscellaneous solid waste, which includes wood waste, waste from the chemical recovery system, non-recyclable paper, rejects from recycling processes and general mill refuse.

Mechanical and chemical pulp mills generate the same amount of total solid waste. In some cases, recycling-based paper mills produce more solid waste than virgin fiber mills. This residue consists almost entirely of inorganic fillers, coatings and short paper fibers that are washed out of the recovered paper in the fiber-cleaning process. Printing and writing paper mills tend to generate the most sludge, while paperboard mills produce the least (Environmental Defense Fund).

### *2.1 Wastewater treatment plant (WWTP) residuals*

WWTP residuals are the largest volume residual waste stream generated by the pulp and paper industry, producing 5.5 million dry tons annually industry-wide in the U.S (Thacker 2007).

There are four types of WWTP residuals:

- Primary (including deinking residuals), representing 40% of WWTP residuals,
- Secondary (waste activated sludge), representing 1%,
- Combined primary and secondary, representing 54%. and
- Dredged, representing 5%.

Mills most commonly process WWTP residuals through mechanical dewatering, with a solids content in the 30-40% range on average. When processed in this manner, waste generated doesn't fall into the hazardous category defined by the Resource Conservation and Recovery Act (RCRA). This solid waste is low in metals, with low to medium nutrients and low in trace organics. A small number of mills dry their residuals, producing a 70-95% solid waste rate (Thacker 2007).

Water is recycled in pulp and paper mills to conserve energy and raw materials; however, some must be discarded to minimize problems such as corrosion or scaling. Excess process water is either treated on-site by the facility or by a municipal wastewater treatment plant. On-site treatment often consists of clarification (primary) and biological (secondary) treatment to remove suspended solids and soluble organic materials. The solid materials are separated from the treated water and typically dewatered to a cake-like consistency utilizing belt presses or screw presses (RMT, Inc. 2003).

Primary WWTP residuals mostly consist of processed wood fiber and inorganic or mineral matter (e.g. kaolin clay,  $\text{CaCO}_3$ ,  $\text{TiO}_2$ ). The ash (inorganic material) produced from this process ranges by dry weight from less than 10% up to 70%. Secondary WWTP residuals consist mostly of bacterial biomass (non-pathogenic).

Because of the tendency for chlorinated organic compounds to move from liquid into solids, wastewater treatment sludge is a significant environmental concern for the pulp and paper industry. Recent trends away from elemental chlorine bleaching have reduced these hazards. None of the pulp mills in the IFP use elemental chlorine for bleaching. A continuing concern is

the very high pH (>12.5) of most residual wastes. They may meet the RCRA's definition of a corrosive hazardous waste if disposed of in an aqueous form.

Sludge generation rates vary widely among mills. For example, bleached kraft mills surveyed as part of EPA's 104-Mill Study reported sludge generation that ranged from 14 – 140 kilograms (kg) of sludge per ton of pulp. Total sludge generation for these 104 mills was 2.5 million dry metric tons per year, or an average of approximately 26,000 dry metric tons per year per plant. Pulp making operations are responsible for the bulk of sludge wastes, although treatment of papermaking effluents also generates significant sludge volumes. For the majority of pulp and integrated mills that operate their own wastewater treatment systems, sludges are generated onsite. A small number of pulp mills, and a much larger proportion of papermaking establishments, discharge effluents to publicly-owned wastewater treatment works (POTWs).

Landfill and surface impoundment disposal are most often used for wastewater treatment sludge, but a significant number of mills dispose of sludge through land application. Ecology and EPA consider proper land application of sludge as a beneficial use. Paper mill sludges can consume large percentages of local landfill space each year. When disposed of by being spread on cropland, concerns are raised about trace contaminants building up in soil or running off into area lakes and streams. Some pulp and paper companies actually burn their sludge in incinerators for onsite energy generation, compounding what can become serious air pollution problems (CWAC).

According to a 2002 study by the American Forestry and Paper Association, WWTP residuals were managed nationally in the following manners:

- Landfill/lagoon: 51.8%
- Land application: 14.6%
- Incineration for energy production: 21.9%
- Other beneficial use: 11.7%

The Confederation of European Paper Industries (CEPI) reported in 2003 that wastewater treatment residuals in member countries on average were managed with 33% going into energy recovery, 37% land application, 19% used in other industries and 11% landfilled (Barjic).

## *2.2. Boiler ash residuals*

Boiler ash, another waste product from mills, represents 4 million dry tons annually in the U.S. A Canadian study of pulp and paper mills saw a marked increase in the volume of boiler ash residuals between 1995 and 2002 (Camberato et al. 1997). Boiler ash in mill settings is produced from wood, coal, wood and coal combined, and a combination of wood, coal and other solid fuels. 99% of boiler ash comes from power boilers and 1% of ash waste comes from recovery boilers. Coal ash makes up about 15% of ash produced by the pulp and paper industry each year, however, in Washington State, this percentage is much less because coal is an insignificant source of energy. Wood-fired boiler ash (wood ash) makes up about 22% of the ash. Of the total wood ash generated, 28% (0.8 million tons) is used in a beneficial use application, leaving approximately 2.0 million tons of ash to be disposed in a landfill or lagoon (RMT, Inc. 2003).

Wood ash can be described as being high in unburned carbon, high in Mg and Ca (a source of K and P), alkaline (high pH), relatively little or no heavy metal content and cementitious. Unburned carbon can range from 10-50% of residuals in wood fly ash (Camberato et al. 1997). Compared to coal ash, wood ash is typically higher in calcium and potassium and lower in aluminum and iron. Wood ash is generally low in environmental contaminants. Potentially hazardous constituents include trace metals such as arsenic, cadmium, and selenium; however, wood ash generally has more consistent and lower metals concentrations compared to coal ash (RMT, Inc. 2003).

Mixed fuel source ash is the most common ash produced by the pulp and paper industry. It accounts for 63% of the 2.8 million tons of ash produced each year. Mixed fuel ash is managed similarly to wood ash and coal ash. As a whole, 72% of boiler ash produced by the pulp and paper industry is disposed in a landfill or lagoon, and 28% (or 2 million tons) is employed in beneficial use applications. Mixed fuel source ash includes noncombustible materials from the incineration of mixtures in varying proportions of wood, coal, WWTP residuals, and/or other materials during energy generation activities. The composition of mixed-fuel ash may be more variable from facility to facility, since the relative proportion of the different fuels is variable (RMT, Inc. 2003).

Energy for the manufacturing process can be provided by public utilities or generated on-site by the use of recovery boilers, power boilers, and turbines. Recovery boilers burn liquid called spent liquor, which is generated during the chemical pulping process. Power boilers typically burn coal, natural gas, wood, oil, and mixed solid fuels (*e.g.*, coal, wood residues, process residues, tires, etc.). Proportions of fuels used in this industry's power boilers have changed over the last few decades, with a decrease in the use of fossil fuels and an increase in the use of wood and process residues (RMT, Inc. 2003).

According to a 2002 study by the American Forestry and Paper Association, boiler ash was managed nationally in the following manners (NCASI 2007):

- Landfill/lagoon: 65.4%
- Land application: 9.3%
- Other beneficial use: 25.3%

### 2.3 Causticizing residuals

Causticizing residues such as slaker grits, green liquor dregs, and excess lime mud are among the significant by-product solids from kraft pulp mills. In 1995, about 1.7 million dry tons were produced annually, with excess lime mud representing 59% of the total, green liquor dregs 28% and slaker grit 14%. Overall, 81% of these materials were landfilled. These materials have chemical and physical properties that can make them suitable for a number of beneficial uses. They are alkaline, high in calcium, not-RCRA hazardous waste, and low in metals (NCASI 2001). As with other industrial by-products, the toxicity and leachability of trace constituents in the causticizing residuals should be assessed prior to any beneficial use application (RMT, Inc. 2003).

Green liquor dregs are composed of nonreactive and insoluble materials remaining after inorganic process chemicals (smelt) from the recovery furnace are mixed with water. The dregs are removed by gravity clarification. Green liquor dregs consist of carbonaceous material, along with compounds of calcium, sodium, magnesium, and sulfur. They typically contain 45 to 55 percent solids.

Lime mud (calcium carbonate and water) is burned in a lime kiln to regenerate the material to lime (calcium oxide). It normally is not a by-product; however, excess lime mud can be generated in those facilities with limited lime kiln capacity and during periods of kiln downtime. Lime mud is composed primarily of calcium carbonate, but may also contain unreacted calcium hydroxide, unslaked calcium oxide, magnesium, and sodium. The solids content of lime mud is generally between 70 and 80 percent.

Lime slaker grits are produced when lime is mixed with green liquor. They are composed of overburned and/or underburned lime that is produced in the lime kiln. The grits also contain sodium, magnesium, and aluminum salt, and the solids content ranges from to 70 to 80 percent.

Collectively, the causticizing materials can be characterized as having a pH above 11, and as containing varying proportions of calcium, aluminum, iron, sodium, potassium, sulfur, magnesium, and chlorine. Calcium is a predominant component.

According to 1995 figures, causticizing residuals were managed nationally in the following manner (NCASI 2001):

	<u>Lime Mud</u>	<u>Green Liquor Dregs</u>	<u>Slaker Grits</u>
Lagoon or landfill	70%	95%	91%
Land application	9%	3%	5.5%
Reuse in mill	1%	0%	3%
Other beneficial use	21%	2%	1%

### 3.0 State of the Art Waste Stream Reduction Techniques

Examination of pulp and paper mills around the world brings examples of where industry leaders are converting waste into a resource. Many companies are now able to label what formerly was designated as waste into a product category. In this section, we first identify numerous waste reduction and re-use initiatives published in industry sustainability plans and other industry reports. For the sake of brevity, this section contains bulleted lists with references to specific sustainability plans. We then identify some of the emerging waste reduction technologies that may play an important role in the near future.

#### 3.1 Industry leaders' waste reduction strategies

##### 3.1.1 Examples of wastewater treatment plant residual implementation:

- Sludge wastes burned in the power boiler at April, Inc. mills (April 2006).

- Byproducts used to make compost mixture, cement additives, potting soil, landscape bark, and roofing shingles at Boise mills (Boise 2006).
- Sludge that settles in the waste treatment process is dewatered and burned as an alternate renewable energy source to create steam at Boise mills (Boise 2006).
- The Catalyst Paper Recycling Division sent 31,000 tons of residuals (inert carbon ink and paper fiber) to customers instead of landfills in 2006. Customers use the residuals as a growing medium for turf (Catalyst 2006).
- Goal for bleached mills is to achieve a fiber loss rate of less than 1 percent and for unbleached mills to achieve a loss rate of less than 12 percent at International Paper (International Paper 2006).
- Fiber sludge from the paper and board mills and ashes left after energy production are used for soil improvement as such or composted at Metsäliitto Group mills (Metsäliitto 2006).
- Some 5,000 tons of sludge from all of Neenah's paper brands is converted to steam, electricity, and glass aggregate every year. The primary purpose of this recycling process is to reduce the load on landfills, which carries out a corporate environmental directive. Neenah then purchases the steam back to dry paper during manufacturing and also to heat its mill. The company projects that using this “green steam” will reduce its natural gas consumption by 80% annually (Neenah 2006).
- Paper sludge ash was used effectively in roadbed construction and soil improvement at Nippon Paper Group (2006).
- Nippon Paper Group has found that due to the trace amounts of heavy metals contained therein, untreated paper sludge ash cannot meet soil environmental standards. Nippon Paper Industries’ Kushiro mill has been developing hydrothermal solidification equipment that crystallizes and seals in heavy metals that are contained in paper sludge ash. Verification testing of the equipment began in fiscal 2006 to prepare for actual operation. Products that have gone through the granulation and hydrothermal reaction are lightweight, porous, and have good drainage properties. Taking advantage of these properties, such products are to be used as soil improvement agents (Nippon Paper Group 2006).
- Norske Skog’s modern mills utilize by-products, such as sludge from wastewater treatment and deinking plants, and other organic waste from the production process as biofuel for thermal energy production (Norske Skog 2006).
- Sludge and ash in Australia and Asia are sometimes used for soil improvement in agriculture at Norske Skog mills (2006).
- Stora Enso has worked on improvements in wastewater treatment plant nutrient control. Nitrogen and phosphorus are added as nutrient sources for the biological organisms in the wastewater treatment process (Stora Enso 2006).
- Stora Enso combusts wastewater treatment and de-inking sludge in Hylte Mill’s newly rebuilt biofuel boiler. The Duluth Mill has an increased use of de-inking sludge for daily cover at municipal landfills (Stora Enso 2006).

### 3.1.2 Examples of boiler ash residual implementation:

- Boiler ash has been applied in road construction and concrete brick manufacture from APRIL, Inc. mills (2006).



- Wood ash waste from the boilers at the Boise International Falls, Minnesota, paper mill is spread on local farmland to improve soil pH (Boise 2006).
- Wood ash is used as a fertilizer at Metsäliitto Group mills (2006).
- Nippon Paper Company continues to develop various technologies, including hydrothermal solidification technology, so as to find new uses for incinerated ash at each mill (Nippon Paper Company 2006).
- Stora Enso uses all boiler ash from Anjalankoski Mill in road construction projects. (Stora Enso 2006).

### 3.1.3 Examples of caustizing residual implementation:

- The boiler uses black liquor recovered from the manufacturing process, bark and reject chips at APRIL, Inc. mills (2006).
- Sources of self-generated energy, such as wood wastes, pulping liquors, and hydroelectric power, provided 63 percent of total energy requirements in 2005 at Boise mills (2006).
- In pulp production at the Metsäliitto Group mills, the chemicals in the cooking liquor are recovered for reuse, and the lignin dissolved in the cooking liquor is used for energy production (Metsäliitto Group 2006).

### 3.1.4 Examples of wood yard debris and mill reject implementation:

- The boiler uses black liquor recovered from the manufacturing process, bark and reject chips at APRIL, Inc. mills (2006).
- Use of screen rejects as material for second grade paper production at APRIL, Inc. mills (2006).
- Sources of self-generated energy, such as wood wastes, pulping liquors, and hydroelectric power, provided 63 percent of total energy requirements in 2005 at Boise mills (2006).
- Wood waste from wood products plants and paper mills is burned as fuel at Boise mills (2006).
- Most of the fiber Catalyst uses consists of residuals from British Columbia sawmills – chips, shavings and sawdust. The company also uses poor quality softwood logs that are defective or otherwise unsuitable for lumber manufacture, and deinked pulp recycled from old newspapers and magazines (Catalyst 2006).
- International Paper wood products mills frequently sell shavings and bark to companies that use these raw materials as a greenhouse gas neutral substitute for natural gas and coal (International Paper 2006).
- By-products, such as woodchips, sawdust and bark, are used as raw materials for chipboard and pulp production or in heat generation at Metsäliitto Group mills (2006).
- Most of the wood that is not converted into products is utilized either in energy production at Metsäliitto's own production units or as biofuel sold outside the Group (Metsäliitto Group 2006).

### 3.1.5 Examples of general waste reduction accomplishments:

- Aracruz treated solid waste with a high degree of recycling, reducing disposal to landfills by 85% (Aracruz 2006).
- Boise Paper landfilled 51% of residuals and Boise Wood Products landfilled 5% residuals (Boise 2006).
- Partial paper rolls on machines, a result of the changeover from making one grade of paper to another, is collected and repulped at Boise mills (2006).
- All Catalyst mills recycle solid waste, including wood, metal, paper, fluorescent light bulbs, and oil. 31,000 tons of residuals were diverted to customers in 2006 as a growing medium for turf. Catalyst Paper Recycling Division uses methane from a landfill for a portion of its energy needs (Catalyst 2006).
- Increasingly efficient utilization of wood is being developed by, for example, collecting and harvesting residues and stumps for fuel use at Metsäliitto Group mills (2006).
- Waste has been avoided at Mondi Paper Group through the introduction of reusable plastic cores in paper production at the sites in Austria, Israel, the Slovak Republic and Hungary (Mondi Paper Group 2006).
- Efforts at Nippon Paper Group are made to recover energy from combustibles and use waste acid to neutralize effluent (Nippon Paper Group 2006).
- Within the Oji Paper Group, 89% of waste discharge is recycled through recycling or effective utilization. Oji has a goal to reduce the volume of landfill disposal to zero through further efforts. They have set a goal to achieve a final disposal ratio of 0.5% by March 2011 (Oji Paper Group 2006).
- Stora Enso has a waste to landfill goal of 10% reduction by the end of 2009 from 2004. The most important biofuels for the Group are black liquor, bark, logging residues and internal residuals including de-inking sludge and biosludge (Stora Enso 2006).
- Votorantim disposes of manufacturing residues using the following methods: 47% co-processing, 29% composting, 4% reuse, 14% recycling, and 6% landfill. Composting is the use of residues for application in eucalyptus plantations. 100% of the industrial residues are treated through the 3R concept (reduce, reutilize, recycle). Composting is the destination of 95% of the solid wastes produced at the Luiz Antônio unit. Through this process, the residues are transformed into organic compost and used in the eucalyptus plantations. This initiative makes it possible to eliminate two residue streams (industrial and wood yard), as well as generating annual savings of \$170,107 for the substitution of chemical fertilizer used in the forests (Votorantim 2006).
- Metsäliitto Group reduced its total waste to landfill from 216,291 tons in 2005 to 176,416 tons in 2006 (Metsäliitto Group 2006).

### 3.2 *Emerging technologies in waste reduction*

The U.S. Department of Energy Office of Energy Efficiency and Renewable Energy (EERE) Industrial Technologies Program (ITP) specifically works with the pulp and paper mill industry to enhance their energy usage efficiencies and other industrial environmental improvements.

Examples of the EERE projects relevant to the reduction of waste in pulp and paper mills as outlined in the Forest Products FY 2004 Portfolio:

- Improved Recovery Boiler Performance Through Control of Combustion, Sulfur and Alkali Chemistry (*Brigham Young University*).
- Development of Methane de-NOX Reburning Process for Wastewood, Sludge and Biomass Fired Stoker Boiler (*Gas Technology Institute*).
- Particle Formation and Deposition in Recovery Boilers (*Sandia National Laboratory*).

*Agenda 2020* is an initiative supported by the American Forestry and Paper Association (AF&PA) that has formed alliances with federal agencies (including ITP) to fund cost-shared R&D projects aimed at improving U.S. forest products energy efficiency, industry competitiveness, and environmental performance. One example of waste reduction technology emerging from these alliances includes the Online Fluidics-Controlled Headbox. ITP and the Woodruff School of Mechanical Engineering at the Georgia Institute of Technology is investigating this new technology to modify fiber orientation in the forming of paper that can enhance paper and paperboard quality and lead to energy savings from reduced raw material (fiber) requirements. The static version of the technology (the Vortigen system) has been demonstrated in long-term commercial paper machine trials. The project is now focusing on devising a means for on-line control of the process.

A robust system – suitable for on-line pilot trials and final commercial implementation – using four turning vanes fabricated directly from shape memory alloy (SMA) was designed, built, and tested in laboratory experiments; it is now being adapted to two-way SMA actuation. The two-way SMA vanes were tested in pilot trials in 2005. This technology promises a better paper product, reduced rejects, increased productivity, and significantly reduced fiber costs and water and energy use.

Another example is the Lateral Corrugator: An Improved Method For Manufacturing Corrugated Boxes. ITP seeks to develop a commercially viable lateral corrugating process. This includes designing and building a pilot lateral corrugator, testing and evaluating the pilot machine, and developing a strategy for commercialization. The lateral corrugator will be designed and built as a retrofit to conventional pilot corrugating facilities at the ITP Industrial Engineering Center. If successful, the lateral corrugator could reduce fiber consumption and improve the compressive strength-to-weight ratio of corrugated shipping containers, thereby reducing energy usage in both manufacturing and transportation. An additional benefit of lateral corrugating is that with cut-to-width sheeting, paper roll management is simplified and corrugator trim waste is minimized, resulting in additional reductions in material consumption, waste generation and energy usage (U.S. Department of Energy 2005).

#### **4.0 Summary of Potential Markets for Waste Products**

One of the most promising ways to reduce pulp and paper waste streams is greater mill participation in emerging markets for use of residuals. In this section, we review potential markets for wastewater treatment plant (WWTP) residuals, boiler and furnace ash, caustizing residues, wood yard debris, and pulping and paper mill rejects.

#### 4.1 Potential markets or uses for WWTP residuals

WWTP residuals are the largest volume residual waste stream generated by the pulp and paper industry. When processed using mechanical dewatering, the waste does not fall into the hazardous category as defined by RCRA. The chemical composition of WWTP residuals makes them excellent candidates for land application to supply organic matter and nutrients in agricultural and forested soil. Primary WWTP residuals have the capacity to absorb large amounts of liquid, thus serving well for absorbent products.

*Table 1: WWTP Residual Markets and Beneficial Uses*

<b>Actual Markets or Beneficial Uses</b>	<b>Description</b>
Papermaking fiber and filler	In products such as fiberboard, residuals may be used as filler.
Industrial absorbent	Oil spill and general industrial absorbent product.
Animal bedding/cat litter	Bedding and litter available in major U.S. pet stores and department stores. Consumes small volume of material.
Manufactured soil component	Manufactured soils are created from a variety of sources to provide all necessary plant growth nutrients.
Landfill cover or barrier cap	Landfills must place a daily cover to prevent waste from blowing away. A landfill barrier cap or hydraulic barrier is used when closing a landfill.
Acid mine drainage (AMD) control cover	A manufactured soil using WWTP components can be used to prevent stormwater runoff on mine sites.
Building board/roof felt/tar paper	Structural and nonstructural solid panel and profile building products can be created by sludge pulp.
Brick or concrete additive	Deinking sludge provides certain chemical components (silicon dioxide and aluminum oxide) beneficial to cement kiln feedstocks.
Glass or lightweight aggregate	WWTP residuals are typically mixed with fly ash and pelletized. The pellets are placed in a rotary kiln and heated, creating a lightweight aggregate.
Fine mineral product	The mineral constituents of WWTP residuals, commonly referred to as the ash content, are valuable.
Cement kiln feedstock	WWTP residuals can be added as an admixture to concrete to serve as a source of wood fiber.
Fuel pellet additive	Use as an energy source.
Compost feedstock	When combined with other components, makes

an excellent composted product.
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The National Council for Air and Stream Improvement (NCASI, 2001) provides another classification, including: (a) plastics additives; (b) animal feed; (c) vermicomposting; (d) ethanol production; (f) levulinic acid production; (g) molded pulp products; (h) cellulose insulation; (i) minerals recovery, and (j) fuels from pyrolysis.

#### 4.1.1 Land application of WWTP residuals

WWTP residuals have been applied to land in the capacity of a soil conditioner, fertilizer, liming agent and as an erosion and weed control. Issues surrounding residual land application include the low nitrogen count of the product, especially with primary residuals. With a lack of nitrogen, vegetation may suffer. Management by composting the product with proper carbon and nitrogen mixes can improve the product (Thacker 2007b).

Composition of WWTP residuals from a variety of mill types was documented by a NCASI 54 mill study (Thacker and Vriesman 1984). Testing of nutrients is recommended per facility if land application for agriculture is planned. Mixing the sludge with lacking components ensures proper fertilizer formulas. The same study looked at heavy metals and toxic elements, finding that sludges didn't contain any elements in higher concentrations than allowed in the Federal Register regulations.

*Table 2: Macronutrients and Micronutrient Concentration in Pulp and Paper Mill WWTP Residues (Thacker and Vriesman 1984)*

<b>Nutrient</b>	<b>Range</b>	<b>Median</b>
<b>Macronutrients (g/kg):</b>		
N (all mill types)	0.51-87.5	8.98
N (combined mills)	1.1-59	8.5
N (primary mills)	0.5 1-9.0	2.7
N (secondary mills)	6.2-87.5	23.3
P (all mill types)	0.01-25.4	2.35
P (combined mills)	0.1-25.4	.67
P (primary mills)	0.01-4.0	1.6
P (secondary mills)	0.42-1 6.7	4.2
K	0.12-10	2.2
Ca	0.28-2 10	14.0
Mg	0.2- 19.0	1.55
S	0.2-20.0	4.68
<b>Micronutrients (mg/Kg)</b>		
B	<1-491	25.0
Cl	0.06-8,500	383
Cu	3.9-1,590	52.0
Fe	97.1 - 10,800	1540
Mn	13-2,200	155.0
Mo	2.5-14.0	-
Zn	13-3,780	188

Primary sludges are typically low in plant nutrients, especially N, and have high C:N ratios. Secondary sludges have higher concentrations of N and P and lower C:N ratios than primary sludges, because N and P are commonly added to the waste treatment system to enhance biological degradation. Mixtures of primary and secondary sludges are also generated, with properties dependent on the proportion of each sludge type in the mix.

Crop responses to land-applied paper manufacturing sludges have been variable, dependent on the sludge N concentration, C:N ratio, and amount applied. Increased crop yields resulting from application of low C:N ratio sludges have been obtained in some studies, whereas other studies have shown decreased crop productivity from high C:N ratio sludges. Plant N deficiencies in high C:N ratio sludges result from N immobilization, which occurs when the N concentration of the sludge is insufficient to meet the demands of the soil microbial community. Nitrogen from the sludge and soil is then immobilized into microbial tissues, rendering it unavailable for plant uptake.

As the sludge decomposes, C is evolved as CO<sub>2</sub>, resulting in a gradual decline in C:N ratio and an increase in N availability. Strategies to overcome this limitation include; (a) applying sludge well in advance of crop planting so that the C:N ratio of the sludge has been reduced to the point that immobilization no longer occurs, (b) adding additional N to satisfy microbial demand for N necessary to decompose the sludge, or (c) planting legumes so that soil N is not required by the crop (Camberato et al. 1997).

Adding fertilizer N to soil amended with high C:N ratio sludge is also an effective method of eliminating the effects of N immobilization on crop productivity. Composting residuals may be an alternative method of increasing N availability of high C:N ratio sludges. Studies show that composting reduced the C:N ratio of the sludge from 23:1 to 10:1. In another study, a primary sludge, tailings, ash, and N source mixture with an initial C:N ratio >270:1 was composted for 14 weeks and cured for 4 weeks, which, depending on the amount of the ash in the mixture, resulted in compost C:N ratios ranging from 14:1 to 67:1. Nitrogen immobilization would be considerably less with the composted mixture than with the initial sludge mixture.

Paper manufacturing sludges may also have positive effects on soil physical properties. High application rates (448 and 672 metric tons per hectare) of primary clarifier sludge to a sandy soil increased soil cation exchange capacity and available moisture content as much as two to five fold. In this case, both organic matter and kaolinite clay in the sludge were likely responsible for the increase in these parameters (Camberato et al. 1997).

#### 4.1.2 Composting waste stream solids

Creating compost, when managed by a pulp and paper mill facility that creates the residues, involves strong technical knowledge of the compost process.

Feedstocks that have been added to pulp and paper mill residues to create balanced composts include yard trimmings, municipal biosolids, food processing residues (dairy or paunch),

manures or animal bedding, pharmaceutical sludge, and textile residues. There are four methods of creating compost: windrows, static piles, aerated static piles and in-vessel systems.

Benefits of compost include increased cation exchange capacity and organic matter content of soil, addition of plant nutrients, suppression of plant pathogens, increased moisture retention and reduced weed growth when used as mulch and reduced water erosion of soil slopes. Quality measurements of compost include organic matter content, nutrient content (N-P-K), trace elements, pH value, moisture content, particle size/texture, water-holding capacity, stability and maturity. The most common problems are lack of stability and maturity (Thacker 2005).

Compost end-markets expand annually as the public and private sectors recognize the value of the product as a re-seeding agent, erosion control and soil stabilizer. A summary of end users include:

- Nurseries (field and container usage)
- Landscaping companies
- Retail/homeowners
- Topsoil blenders
- Landfill cover
- Agriculture
- Silviculture
- Roadside/Department of Transportation (DOT) development and reclamation (Thacker 2005)
- Mine reclamation

As of 2005, 25 mills had their by-products composted (not including wood residues). Most mills were smaller-scale, producing less than 10 dry tons per day (dtpd) of by-product, but the largest mill produced 100 dtpd. Primarily, the wastewater treatment and deinking residuals were composted, but some mills also supplied ash and grit residues for the mix. The median age of the compost programs were 7 years, with the longest running compost program coming in at 23 years. In most cases, the mill contracted with a municipal or private composter, paying for transportation as well as a tip fee. Most operations used the windrow method with periodic turning of the material (Thacker 2005).

Another potential end-market is providing mill residues for vermicomposting, where worms process the material and deliver a high-quality end product. One large-scale vermicomposting company used waste water treatment residuals as well as cardboard manufacture rejects as part of their feedstock.

For detailed instructions on composting residues from pulp and paper mills, the NCASI has developed Technical Bulletin No. 894, available to members. Another excellent resource is the On-Farm Composting Handbook created by the Natural Resource, Agriculture, and Engineering Science (NRAES) association.

#### 4.1.3 Erosion control applications

Several studies implementing mill WWTP residuals have shown that adding the byproduct to land applications for erosion control purposes, the soil was stabilized with aggregate formation and water infiltration rates increased. A 2003 study by Chow investigated the effects of residuals on gravelly loam soil for the purpose of erosion control. Chow found that after one year and a 4% organic-matter addition, that the study area saw a 23% reduction in runoff volume and a 70% reduction in soil loss. Residuals may also be applied to stabilize steep slopes as a means of erosion control (Thacker 2007b). Other relevant facts related to erosion control applications:

- State DOTs have increasingly employed compost for a variety of purposes.
- Erosion control has become an important market for compost.
- The American Association of State Highway and Transportation Officials (AASHTO) has published standard specifications for compost filter berms and for compost blankets.
- Studies in Iowa and Virginia demonstrated that composts made with mill WWTP residuals were effective in controlling erosion.
- Compost from a Michigan mill has received state DOT approval (Thacker 2005).

#### 4.1.4 Manufactured top soils using short paper fiber

Short Paper Fiber (SPF) has been identified as an organic component for manufactured top soils, using a mix of 1:1 with sand/silt by volume. SPF is used for increasing the soil organic matter. SPF is low in nutrients so that if applied to land without composting the material, SPF can be added in high volumes without risk of nutrient excess. SPF has a high C:N ratio and low concentrations of N,P and K and is sometimes a source of CaCO<sub>3</sub> (Carpenter 2005).

Topsoil utilizing SPF holds many times its weight in water, provides erosion resistance, withstands heavy rainstorms due to high water absorbency rates, can maintain 3:1 slope erosion before vegetation grows back, can reduce mulching requirements and increase length of uninterrupted slopes.

An important factor in creating topsoils using SPF is the C:N ratio in order to provide for maximum vegetation re-growth and avoid leaching. The optimal ratio is in the range of 25:1 to 35:1 C:N. When using wastewater treatment residuals from primary sources, high levels of N are required to achieve optimal balance. A reclamation project on 10 acres using this material required the purchase of \$13,000 of nitrogen.

Nutrient sources for manufactured topsoils can be biosolids and secondary waste water treatment residuals. These two products have a low C:N ratio, are high in plant available nitrogen, are rich in phosphorous, and provide such micro-nutrients as copper, zinc, iron, and molybdenum. Both products also help ignite soil microbial activity and help provide for a strong re-vegetation response.

Successful manufactured topsoil test plots have used 4.5 parts fiber clay, 4 parts sand and 1 part biomass ash. Re-vegetation using manufactured topsoil applications compared to natural topsoil seed denser vegetation re-growth. It is recommended that if product is created, to use



components such as biomass ash, wood yard wastes or wastewater treatment residuals to darken the soil to give a more earth-toned hue, as the initial product is gray.

#### 4.1.5 Soil amendment production

Optimizing soil chemistry is a critical process in sustaining agricultural and forested lands. The chemical composition of WWTP residuals makes them excellent candidates for land application to supply organic matter and nutrients in agricultural and forested soil. Secondary WWTP residuals generally have carbon to nitrogen ratios ranging from about 5:1 to 20:1, thus making the residuals a significant source of nitrogen. Secondary residuals also can be a good source of phosphorus. The organic matter in primary WWTP residuals can improve the water and nutrient-holding capacity of sandy soils, and the aeration and permeability of clay soils. Also, both primary and secondary WWTP treatment residuals can provide a significant source of other macro and micro-nutrients. In addition to providing nutrients and organic matter to soil, some WWTP residuals high in mineral content have been successfully applied as liming agents to raise the pH of acidic soil (RMT Inc. 2003).

Browning-Ferris Industries has created a patented formula utilizing WWTP residuals to create a product called BioMix soils. The soil mix has prohibited rain water contamination runoff from refuse piles and maintained water quality requirements. Waste sludge is combined with native soils, fertilizers and pH adjusting compounds to create the agronomic soil. The mix has been marketed to landfills for closures, daily cover, intermediate cover, grading material and base of service roads. It has been sold to coal, bauxite and phosphate mine reclamation sites. The product has also been used for golf courses and city parks (NCASI 2001).

In a particular acid mine drainage reclamation project, 700,000 tons of the Biomix product was used to regain positive water quality. BioMix soils have moisture-holding capacities exceeding 200% to 300% compared to native soils. The moisture holding capacity is due to the properties of the fiber. Once the rainwater comes into contact with the fiber it is immediately drawn into the fiber. As the water enters, the fiber swells giving it the ability to hold 10 to 20 times its weight in water. It has been shown that a 12-inch layer of a properly blended mix of BioMix soil can hold 16 inches of water before releasing water to the layer below.

#### 4.1.6 Alternative daily cover for landfills

WWTP residuals are successfully used as an alternative cover material to the traditional 6 inches of daily soil cover used for active faces of a landfill. An alternative daily cover can also help control blowing litter, animals, and insects at the landfill. Depending upon physical characteristics, some WWTP residuals may require modification for consistency and workability before use as daily cover material (RMT Inc. 2003).

#### 4.1.7 Hydraulic barrier layer for landfills and mine reclamation

Since 1990, more than 29 industrial and municipal landfills and 8 mine reclamation sites have been closed using residuals as the hydraulic barrier layer. Landfill size ranged from a 1.6-acre municipal landfill to a 30-acre industrial landfill. Combined residuals were reported to contain

approximately 5 to 15% secondary sludge. Barrier thickness ranged from 18 to 49 inches with a median value of 30. A significant number of the full-scale closure applications used a blend of waste water treatment residuals (as well as fly ash) and local soils to construct the overburden, frost protection, and vegetative layers. These synthetic soils (sometimes referred to as engineered soils), while not designed for low hydraulic conductivity, were determined to have other desirable properties, making them superior to local soils for use as capping materials. Using residuals in the barrier layer of the cap was considered beneficial in two respects. First, at a relatively low unit weight, the cap would place limited bearing pressure on the waste material. Also, the residuals were considerably more flexible than compacted clay (NCASI 2005).

An American Society for Testing and Materials (ASTM) Standard Guide is being developed to define appropriate hydraulic conductivity testing protocols for paper industry residuals utilized as barrier material in landfill covers. More information on this specification is provided in Appendix 1.

The Standard Guide will proscribe the following:

- Measures to control gas should be used when testing residuals that produce gas. Gas production can be controlled effectively by (a) testing at 4°C, (b) spiking permeant with DBNPA biocide at maximum recommended concentration, and (c) applying high backpressure (> 330 kPa) while testing. Flushing lines also works but is labor intensive.
- The hydraulic gradient should be as low as practical to simulate field conditions. Hydraulic gradients more than 10 should not be used.
- Residuals specimens should be tested at the effective stress likely to exist in the field.
- Testing residuals with tap water is acceptable; however, some states may have regulations that specify other permeants.
- The termination criteria of ASTM D5084 are reasonable for residuals except that the range of acceptable outflow-inflow ratio should be increased to 0.70 to 1.3 inches (NCASI 2005).

#### 4.1.8 Absorbent and animal bedding

Primary WWTP residuals have the capacity to absorb large amounts of liquid. This desirable characteristic has been used by the animal bedding/litter and industrial sorbent industries. WWTP residuals have been successfully used as the base raw material in many industrial sorbent and animal bedding products, which are available on the market today. Two examples of companies that use WWTP residuals in their absorbent products are International Absorbents, Inc., and Complete Spill Solutions (RMT Inc. 2003).

#### 4.1.9 Lightweight glass aggregate

The mineral constituents of WWTP residuals, commonly referred to as the ash content, can be converted to aggregate material through a heat fusing process. In the production of lightweight aggregate, the WWTP residuals are typically mixed with fly ash and pelletized. The pellets are placed in a rotary kiln and heated. Once cooled, the resulting product is a lightweight aggregate that typically meets ASTM standards, and which can be used in concrete masonry, landscaping,

and geotechnical applications. In the production of glass aggregate, the mineral constituents of the WWTP residuals are melted by high temperatures and tapped off. The molten liquid is then cooled rapidly in a water quenching system, and the resulting product is glass aggregate. The glass aggregate can be used in floor tiles, abrasives, roofing shingles, asphalt and chip seal aggregates, and decorative landscaping. In the production of both lightweight aggregate and glass aggregate, the heat fusing process destroys any dioxins, furans, and other organics and encapsulates heavy metal constituents, such that the leached extracts of the resulting aggregates pass drinking water standards (RMT Inc. 2003).

#### 4.1.10 Portland cement concrete additive

WWTP residuals can be added as an admixture to concrete to serve as a source of wood fiber. Wood fibers have been shown to increase the durability and pumpability, while reducing shrink-related cracking in concrete. The addition of residuals also may provide greater freeze-thaw cracking resistance and greater salt-scaling resistance than plain concrete. However, care must be taken to not reduce compressive strength, and a higher dose of high-range water-reducing admixture may be needed to avoid a high water demand in the concrete (RMT Inc. 2003).

#### 4.1.11 Cement kiln manufacture

Those WWTP residuals with a high inorganic content can serve as feedstock in the production of cement. The basic raw materials required to make cement include limestone, clay, sand, and iron ore, which provide calcium, silicon, aluminum, and iron. WWTP residuals high in inorganics can contain significant quantities of these base materials.

#### 4.1.12 Building board

Pulp extrusion is a process for converting WWTP residuals into both structural and nonstructural solid panel and profile products. The WWTP residuals require the addition of a water-soluble polymer to alter rheological properties, such that a homogeneous pulp paste can be formed and extruded. Following extrusion, the residuals are consolidated by press drying. The resulting physical and mechanical properties of the building board are dependent upon the type of fiber used as the feed material; however, the mechanical properties of building board manufactured from WWTP residuals have been shown to be similar to the mechanical properties of traditional wet-process hardboard (Scott et al., 2000). Residuals from a deinking mill in the Netherlands have been used to manufacture commercial building board; however, the board-making facility has closed.

#### 4.1.13 Regulations and guidelines

Appendix 1 outlines WWTP by-product standards for soil amendments, compost, alternative daily cover at landfills, hydraulic barrier layers, industrial sorbents/animal bedding and lightweight glass aggregate.

4.2 Potential markets or uses for boiler ash waste

Boiler ash waste residues have increased since the 1990s. Opportunities for beneficial use of this material type range from large-scale land applications and construction use, to smaller scale applications with the wastewater treatment industry and papermaking process. Residual use of boiler ash waste can be managed by watching ash chemistry and boiler operation. It is important to note that the source of the wood fuel creates a marked difference in boiler ash nutrients. Ashes from wood and bark fuel sources vary greatly from ashes created from pulp and paper mill residuals (hog fuel and waste water treatment residue).

There is also a significant difference in dioxin and furan levels when you compare ash created from inland mills (which have very low rates) to the salt-laden coastal mill fuels (which in most cases have higher rates). Dioxin and furan concentrations may be reduced by only using the bottom ash from coastal mills, but this is a small percentage of material when compared to fly ash. If chloride levels can be reduced in the hog fuel before incineration, then the fly ash can be beneficially used. Complete combustion of the hog fuel also greatly reduces the dioxide and furan concentrations. The reduction can be completed by burning the fuel at 850 degrees Celsius for two seconds, ensuring the wood is completely dry, and allowing only small fuel particle sizes. Post-treatment of ash with exposure to sunlight, ultraviolet light and biological processes can reduce concentrations as well. And composting the ash with WWTP residuals has shown a 50% decrease in dioxide and furan concentrations (Elliott and Mahmood 2006).

Wood-fired boiler ash has fewer metals at lower concentrations (except cadmium) than coal-fired ash. These qualities make wood ash better suited for land application. Bottom ashes have higher bulk density, lower carbon content and trace amounts of dioxins and furans. Ashes from hog fuel, which are high in salt content, used primarily in coastal pulp and paper mills are regulated for dioxides and furans. But a reduction in the use of chlorinated organics can make this ash type satisfactory for land applications (Elliott and Mahmood 2006).

Table 3: Boiler Ash Waste Markets or Beneficial Uses

Market or Beneficial Uses	Description
Compost feedstock	The wood ash supplies nutrients, reduces moisture, acts as a bulking agent and imparts dark color, as well as reducing odor.
Manufactured soil component	Wood ash is more appropriate for land application. Ashes provide alkalinity to soil.
Cement and brick feedstock	Boiler ash from wood and WWTP residues is suitable for cement and brick manufacture.
Concrete additive	Coal fly ash used as additive in concrete for highways and other applications. A state DOT approved use of coal-wood fly ash for use in concrete after short and long term evaluation of product. With wood fly ash added, concrete is stronger, more durable, more resistant to water erosion in saltwater conditions, and is less expensive. Coal-wood bottom ash is used as

Market or Beneficial Uses	Description
	aggregate in concrete blocks (Thacker 2007a)
Flowable fill – Controlled Low-Strength Material (CLSM)	CLSM is a plastic soil-cement and has become a popular material for projects such as structural fill, foundation support, pavement base, and conduit bedding.
Waste stabilization	Wood ash neutralizes the acidic waste material to prevent leaching of contaminants and to bind contaminants within the waste.
Soil stabilization	Can be used as potting or liming agent.
Earthen construction	Boiler ash may increase the strength of the structure if it is cementitious.
Asphalt aggregate/road building component	Coal-wood bottom ash is used as aggregate in asphalt mixes.
Landfill daily cover	When mixed with WWTP residuals, can provide daily cover for landfills.
Activated carbon manufacture	Fly ash, with unburned carbon in ranges of 27-32%, has been found to be an effective absorbent of certain odors and colors.

#### 4.2.1 Land application

Using wood ash has become more common in re-forestation settings, using the premise that the ash helps to return nutrients to the soils. The use of coal ash is not beneficial in this instance, as the components of that particular ash are not compatible with forested soils. When adding wood ash to soils, attention must be paid to add N and water-soluble P for proper soil balance.

A North Carolina Weyerhaeuser mill applied bottom ash from a hog-fuel fired boiler at a rate of 27 tons/ha on a loblolly pine plantation to find increased rates of K, Mg and Ca compared to test plots. A newsprint mill in Oregon applied power boiler ash as a liming agent as a replacement of commercial agricultural lime. The program was successful enough to create a product called Pro-Lime Plus, utilizing the ash. Weyerhaeuser has marketed a similar product called Carolina Silvi-Ash for year-round use on timberlands. The government of Alberta, Canada in 2002 developed specifications for the use of energy recovery system wood ashes as a liming agent for cultivated agricultural lands (Elliott and Mahmood 2006).

#### 4.2.2 Soil amendment

This is currently one of the most common beneficial use applications for wood ash. Optimizing soil chemistry is a critical process in agriculture. Wood ash neutralizes the pH of acidic soil in a manner similar to the use of agricultural lime and serves as a nutrient source (fertilizer) to agricultural soil. The small particle size of wood ash may promote a more rapid change in the pH of the soil as compared to traditional agricultural lime. Wood ash has also been successfully applied as a forest soil amendment. Wood ash has been proven to raise the pH of acidic soil and serves as a nutrient source to promote the growth of trees (RMT Inc. 2003).

#### 4.2.3 Soil stabilization

Wood ash is an effective agent for the chemical and/or mechanical stabilization of soil. Soil stabilization is the alteration of soil properties to improve its chemical or engineering performance. Wood ash is used to neutralize acidic soil to prevent the leaching of contaminants, and to bind contaminants within the soil. Wood ash is also used in the same manner to stabilize waste materials, such as sludges when managed in land disposal units. The wood ash neutralizes acidic waste material to prevent leaching of contaminants and to bind contaminants within the waste (RMT Inc. 2003).

#### 4.2.4 Building products

Carbon content of 6% in the ash is the highest tolerated amount for concrete and cement production. A midwest U.S. mill has produced structural-grade concrete with wood ash as an additive. Boiler ash from wood and WWTP residues at another mill was suitable for cement and brick manufacture. At a newsprint mill, the bottom ash is separated out and used as an additive for brick, and the fly ash is used in Portland cement production (Elliott and Mahmood 2006).

Major components of Portland cement are various oxides of calcium, silicon, aluminum, and iron, with calcium being the predominant element. Depending on its chemical composition, boiler ash can be desirable in cement manufacture as a source of calcium, aluminum or silicon. Ash can improve the strength and durability of concrete, but this use normally is limited to coal fly ash because ASTM standards specify this material, and high levels of unburned carbon in ash can be detrimental (Thacker 2005).

As to earthen construction applications, boiler ash may increase the strength of the structure if it is cementitious. Otherwise, it is simply fill material. A pulp mill's ash from the combustion of bark and WWTP residuals is a major ingredient in a construction material termed "Ashcrete". It is employed in the modification of a wastewater lagoon, in a landfill closure, and as a base for a concrete pad. Mention is made that two other mills utilize a similar material to construct berms and to close lagoons (Thacker 2005).

#### 4.2.5 Road building materials

For ash to be considered in such applications as aggregate for mill site roads or publicly-owned roads, specifications in moisture content, dry density, degree of contamination and leachability must be met. An optimum addition rate is 10% wood ash in replacement of the traditional road building material. Many mills have been able to use the ash in their own roadbuilding or for sale to local communities, allowing those mills to re-classify the material from a waste product to a product.<sup>18</sup> The Florida Department of Transportation has approved a combination coal-wood ash from a paper mill to be employed in concrete road construction (Thacker 2005).

#### 4.2.6 Compost feedstock

Wood ash has widely been identified as a compost production feedstock. The wood ash supplies nutrients, reduces moisture, acts as a bulking agent and imparts dark color. Another key

component of wood ash that is valued by industry working with compost production is the ability of wood ash to reduce odor (Thacker 2007b)

The UPM-Kymmene New Brunswick mill sends its wood (primarily from clarifier agents) and oil biomass burner ash to a composting company. In turn, the company adds the ash at a 10-15% by weight to produce organic topsoil, black earth and lawn and garden mix. The ash serves to add an earthy black color, stabilize pH, and control odor and pathogens.

A mixture of certain types of wood ash with mill wastewater treatment residuals will provide an excellent soil conditioner. Blending ashes from a power boiler that primarily uses hog fuel with some waste water treatment residuals and a minor supplement of coal, with wastewater treatment residuals results in a product rich in nutrients (K, Ca, Mg) and alkalinity (from the ash) and N and P (from the residuals).

An integrated kraft mill in Maine producing 650 tons/day has been able to recycle 63% of its wastewater treatment residuals and 86% of its generated boiler ashes for use on agricultural lands as a soil conditioner. An integrated British Columbia (BC) coastal bleached kraft mill used a 1:1 composting ratio of boiler ash to wastewater treatment residuals to produce a soil conditioner meeting all safety regulations of the BC Ministry of Government. The composting cut in half the dioxin and furan concentrations (Elliott and Mahmood 2006). Finland has also used wastewater treatment residues to granulate the boiler ash before land applications, in order to minimize the airborne particulate levels of the ash.

#### 4.2.7 Activated carbon

Fly ash traditionally has high levels of unburned carbon, which has similar properties of activated carbon. Thus ash, with unburned carbon in ranges of 27-32%, has been found to be an effective absorbent of certain odors and colors.

#### 4.2.8 Regulations and guidelines

Appendix 2 outlines wood ash by-product standards for soil amendments.

#### 4.3 *Potential markets and uses for causticizing residues*

Causticizing residues such as slaker grits, green liquor dregs, and excess lime mud are among the significant by-product solids from kraft pulp mills. These materials have chemical and physical properties that can make them suitable for a number of beneficial uses (NCASI 2007).

*Table 4: Caustizing Residual Markets or Beneficial Uses*

<b>Market or Beneficial Uses</b>	<b>Description</b>
Liming agent on agricultural and forest land application	An increase in crop yield was documented to be similar to the complimentary commercially-available limestone.
Cement and brick feedstock	The basic raw materials required to make cement are calcium, silicon, aluminum, and iron. Causticizing materials have high percentages of calcium, aluminum,

Market or Beneficial Uses	Description
	and iron.
Compost feedstock	Provides lime to compost mixture.
Manufactured soil ingredient	Causticizing residuals provide lime to soil.
Soil stabilization/earthen construction	Soil stabilization is the alteration of soil properties to improve the chemical or engineering performance of the soil. Lime slaker grits have been used as an additive.
Surface mine and acid mine reclamation	Manufactured soil using causticizing and WWTP components can be used to prevent stormwater runoff on mine sites.
Gaseous sulfur-compound treatment	Can assist in the removal of a sulfur compound that contains gas, particularly an industrial gaseous effluent.
Alternative daily cover and hydraulic barrier for landfills	Lime slaker grits have been successfully used as an alternative cover material to the traditional 6 inches of daily soil cover used for active faces of a landfill.
Wastewater neutralization	Residuals provide potential alternatives for adjusting pH in wastewater to neutral levels.
pH adjustment of process water	Residuals provide potential alternatives for adjusting pH in process water.
Wastewater AOX removal	The removal of organic halogens (AOX) from wastewater can be assisted by using caustizing residuals.
Road dust control	Lime slaker grits has also been shown to be effective as a dust suppressant on unpaved roads.
Sludge bulking control	Assists in the biological treatment of sludge and providing bulking control.
Asphalt additive	Lime mud, lime slaker grits, and green liquor dregs have been used successfully as a substitute for fine aggregate in roads.

#### 4.3.1 Land application

Land application is the most commonly practiced beneficial use for causticizing materials, with lime mud being the material that is most commonly used as a soil amendment. Causticizing residuals are utilized as a replacement for agricultural limestone to increase soil pH. Soil pH is an important chemical characteristic because it affects the availability of many plant nutrients and toxic elements. The soil pH desirable for crop production is dependent both on the soil type and the crop species, but in general is in the range of 5.8 to 7.0. Soil pH levels below or above the optimum range can be detrimental to crop growth (Camberato et al. 1997).

In studies of land applications utilizing causticizing residuals, an increase in crop yield was documented to be similar to the complimentary commercially-available limestone. In many soils, periodic liming is required so that conditions are favorable for plant rooting and nutrient acquisition and to counter the effects of agricultural land acidification. Recent estimates indicate 11 million Mg of agricultural limestone are sold annually in the USA at a cost of \$58 million. Industrial residuals, particularly those from the paper manufacturing industry, provide potential alternatives for adjusting soil pH. Particle size is the main factor determining reaction rate.



Causticizing residuals generally have smaller particle sizes than agricultural limestone and therefore tend to react faster. The rapid rate of reaction of these materials compared to limestone may be an advantage if soils are planted shortly following amendment application (Camberato et al. 1997).

Based on liming needs, typical application rates are about 2.5 tons/acre for grits and dregs (mixed together) and about one ton/acre for lime mud (Thacker 2005).

#### 4.3.2 Alternative daily cover

Lime slaker grits have been successfully used as an alternative cover material to the traditional 6 inches of daily soil cover used for active faces of a landfill. The use of grits as an alternative daily cover helps to control blowing litter, animals, and insects at the landfill (RMT, Inc. 2003).

#### 4.3.3. Cement manufacturing

Causticizing materials are utilized as feedstocks in the production of cement. The basic raw materials required to make cement are calcium, silicon, aluminum, and iron. Causticizing materials have high percentages of calcium, aluminum, and iron, and if properly washed (as is the norm), they generally are low in constituents that can negatively impact the production and quality of cement, such as sulfur and sodium (RMT, Inc. 2003).

#### 4.3.4 Soil stabilization

Soil stabilization is the alteration of soil properties to improve the chemical or engineering performance of the soil. Lime slaker grits have generally been used in this application. Lime slaker grits, when mixed with sand and compacted in lifts, have been shown to handle heavy-truck traffic better than typical soil surfaces. Lime slaker grits has also been shown to be effective as a dust suppressant on unpaved roads. While the dust from the grit/sand roads is finer than that produced from native soil roads, the grit has a better liquid-holding capacity, which improves efficiency for dust suppression techniques (RMT, Inc. 2003).

#### 4.3.5 Aggregate in asphalt paving

Lime mud, lime slaker grits, and green liquor dregs have been used successfully as a substitute for fine aggregate in roads.

#### 4.3.6 Regulations and guidelines

Appendix 3 outlines caustizing by-product standards for soil amendments and alternative daily cover at landfills.

#### 4.4 *Wood yard debris and pulping/paper mill rejects*

The majority of wood wastes, also known as hog fuel, coming from pulp and paper mills are used to fuel power boilers to generate electricity, steam or both. Mills also use coal, oil, and

natural gas to supplement (Camberato et al. 1997). Woodchips, sawdust and bark residuals are also used as raw materials for chipboard and pulp production.

Wood yard debris and pulp/paper mill rejects have long established usefulness as an input for energy and straight back into the papermaking process. These materials also may be added to compost mixtures satisfactorily.

*Table 5: Debris and Rejects Markets or Beneficial Uses*

<b>Market or Beneficial Uses</b>	<b>Description</b>
Boiler fuel (energy input)	Debris and rejects useful as an energy source.
Second-grade paper production	Rejects commonly are placed back into service for lower grade papers.
Compost feedstock	Both wood debris and mill rejects are suitable as a compost additive.

### **5.0 Barriers and Challenges to Beneficial Use of Products**

Despite the emergence and growth of markets for pulp and paper mill waste by-products, there remain many barriers and challenges to more widespread use of these materials. One common barrier is a mismatch between by-product quantity and processor/market demand. Too much material can drive prices so low that it becomes economically infeasible for mills to incur the transaction costs of getting their waste materials to markets. Too little, on the other hand, makes it infeasible for buyers since there are minimum thresholds in how much material is needed to be useful. Another barrier is a pessimistic “been there, done that” attitude among mills from exposure to a number of beneficial use programs that never developed or were short-lived, resulting in reduced motivation to pursue opportunities.

In addition, mills and end users are focused typically on normal business activities, and there may be a lack of time to thoroughly investigate potential beneficial uses. None the less, waste brokers/facilitators have beneficial use as an area of focus and can be critical to the success of a project. In addition, State market development agencies can help promote beneficial uses of industrial residuals (NCASI 2001).

The decision making process for most mills is local, but with the need for expert corporate level support. Before entering into a new approach, full exploration of alternatives must occur before allocating capital. Beneficial use decisions must meet corporate environmental health and safety expectations, regulatory requirements, and return on investment/financial criteria. Drivers for beneficial use programs include resource conservation initiatives, economic forces and regulatory forces.

An example is Mead Westvaco, which had a landfill rate of 52.6%, with a 16.7% reuse rate, 8.2% recycling rate and 22.5% energy recovery rate. The company set a waste hierarchy to guide its waste management:

Mead Westvaco’s Waste Hierarchy:  
Improved Resource Utilization

Waste Source Reduction  
On-site Recycling/Reuse  
Off-site Recycling/Reuse  
On-site Treatment  
Treatment/Disposal

The company's residuals management beneficial use program elements include:

- Utilize company project review guidelines.
- All projects reviewed and approved by legal, environmental, product stewardship peer review.
- All projects must be supported by good technical, economic, legal, and business analyses.
- All residuals require rigorous testing/characterization prior to utilization.
- Residuals must go through a rigorous product stewardship screening.
- Residuals beneficial use should typically include a utilization plan.
- All proposed beneficial use projects require a rigorous legal review including contracts/agreements.
- All residuals/beneficial use projects require communication/notification to local regulatory agencies.
- All projects require follow-up monitoring to insure the project continues to meet its original merits and is used following good management practices.

The company's beneficial use project review process includes:

- Idea collection
- End use application/screening
- Testing/characterization (include agronomic value)
- Gatekeeper- peer review by residuals group, and corporate environmental/legal
- Product information
- Utilization plans
- State notification: permitting/approval
- Public notice
- Public relations
- Follow-up program (McCormick and Bryer 2002).

In addition, all by-product usage projects must also complete a feasibility analysis with costs and benefits properly weighed. Feasibility considerations include:

- Distance to market/processor: Cost of hauling must be considered, as well as weight of by-product.
- Technical experience at mill: Is the mill capable of producing the by-product as specified by the end-market?
- Cost to produce and cost savings: benefits of by-product use must include cost avoidance of landfilling, but can also include environmental benefit savings. All projects must evaluate additional costs to prepare material for by-product use as well.

- Volume consumption: will the end-market be able to consume the amount of material produced?
- Potential liability: by-products must be properly matched for use, ensuring correct chemical and pH requirements for end use (Wiegand).

These considerations must also account for mill type, mill location, waste type and company business strategy. For example, alternative uses for sludge ash, such as bricks and cement, are an excellent option if a user can be found near the mill and if long-term contracts can be acquired. New products developed from pulp and paper mill sludge, however, need to have a market to make them economically feasible. It does not make sense to develop and create products for which there is no market (Scott).

In the case of landspreading, this can be accomplished with either dewatered or nondewatered sludge. When the sludge is not dewatered, it is fluid enough to allow spray application. Transportation costs can become prohibitive, however, if the underwatered sludge needs to be transported a great distance from the mill. With dewatered sludge, the application areas can be farther from the mill. While spray application can also be used by rediluting the sludge, other application methods can also be used. Another feasibility issue with landspreading is locating enough land on which to spread the sludge (Scott).

#### *5.1 Challenges and considerations with land application of residuals*

There have been concerns about the environmental implications of trace concentrations of dioxins and furans in sludges from mills using chlorine bleaching processes. Studies of wildlife exposed to land-applied sludges from mills using chlorine bleaching have shown no adverse effects, however. As previously noted, concentrations of dioxins and furans in bleaching mill sludges have been reduced dramatically in recent years due to the implementation of new bleaching technologies. These and other chlorinated compounds should continue to decrease in significance. Studies have also shown that chlorolignin compounds formed during chlorine bleaching processes are rapidly immobilized in soil and are slowly mineralized to inorganic chloride. According to these studies, low molecular weight chlorinated deprecation products appear to rapidly decompose in soil, and do not accumulate, leach or create a toxic environment for soil bacteria (Camberato et al. 1997).

#### *5.2 Federal and state regulation of land application of paper manufacturing residuals*

Land application of paper mill sludges and other residuals are regulated primarily at the state level, although they are potentially subject to regulation under several federal statutes. Since mill residuals are not defined as hazardous wastes, they are not regulated under the Resource Conservation and Recovery Act (RCRA). Analyses of organic compounds using TCLP characterization, heavy metal concentrations and pH are generally needed to confirm this fact. As with any soil amendment, water quality standards for nutrients and heavy metals developed under the Clean Water Act must not be exceeded.

In March 1994, a Memorandum of Understanding between the U.S. EPA and the American Forest and Paper Association established voluntary dioxin/furan concentration limits, application

rates, site management practices, monitoring, record keeping, and reporting requirements for the land application, distribution and marketing of residuals from kraft and sulfite pulp and paper mills using chlorine and chlorine-derivative bleaching processes. The MOU applies to residuals with dioxin/furan concentrations greater than or equal to 10 ppt TEQ. Residuals with concentrations below 10 ppt TEQ are excluded from the Memorandum, except for monitoring, testing, distribution and reporting requirements. Maximum residuals dioxin/furan concentrations of 50 ppt TEQ (or temporarily up to 75 ppt TEQ) and maximum soil concentrations up to 10 ppt TEQ are permitted. For agricultural application, sludge may be applied at rates up to 68 dry metric tons per hectare, unless greater application rates are permitted by the individual state.

Current state regulations for land application of paper mill sludges and other residuals vary widely. Only a few states, including Maine, Ohio, and Wisconsin, have provisions which specifically regulate paper mill residuals such as sludges. As long as analyses (t.g. TCLP) show the materials to be applied are not hazardous, they are most often regulated under general state solid waste requirements or under "Beneficial Use" provisions. In the latter case, regulatory burdens and permitting requirements may be reduced if the benefits of the materials to the site can be demonstrated. Many states use the guidelines for heavy metals and management practices defined in U.S. EPA 503 standards for land application of municipal sewage sludge biosolids as a baseline for land application of paper mill residuals. Paper mill residuals easily meet the U.S. EPA 503 composition standards in most cases. Some states have more stringent standards, however, which can limit land application in some situations. Typical requirements include information on site and soil characteristics, set-back distances from surface water and wells, depth to groundwater, slope, vegetative cover, and proximity to floodplains or wetlands. A major regulatory issue for the generators and users of mill residuals is whether a general permit for residuals, site requirements and management practices is sufficient, or whether each site and practice must be individually permitted (Camberato et al. 1997).

Details on specific guidelines and regulations for WWTP, wood ash and caustizing residues are outlined in Appendices 1, 2 and 3 respectively.

### *5.3 Waste stream recycling and re-use at participating mills*

To investigate the extent to which mills participating in the IFP were engaging in the various waste stream reduction, reuse, and recycling initiatives outlined here, we conducted an informal survey. The survey, which appears as Appendix 4, was distributed in June 2008 to all five mills. The survey begins by asking mills about the annual amount of waste generated, its destination and any waste reduction initiatives mills may have undertaken, including cooperative arrangements with other entities.

Then, for each major type of waste, the survey identifies the beneficial use or end-use markets discussed by this report and asks mills to indicate which of four options applies: (1) the mill already uses waste in this way; (2) the mill plans to use waste this way; (3) the mill has determined that using waste in this manner is economically infeasible, or (4) the mill has determined that using waste in this manner is infeasible for other reasons. The reason for separating out economic infeasibility is to identify which waste utilization options may warrant further investigation as subjects of state incentive programs.

Three responses were received. To protect confidentiality of the mills, the results have been aggregated. Results for each question are summarized in Appendix 4 beneath each question. Although the survey needs to be refined to clarify unresolved questions from the respondents and sent to other Washington State mills, there are several important conclusions that can be gleaned from the three responses we received:

- Mills already are engaging in a number of important wastestream recycling and re-use initiatives.
- For WWTP residuals, these include papermaking fiber and filler, manufactured soil components, and compost feedstock.
- For boiler ash residuals, these include compost feedstock, manufactured soil components, cement kiln feedstock, soil stabilization, and landfill daily cover.
- For causticizing residuals, these include manufactured soil ingredients.
- For wood yard debris or pulping and paper rejects, these include boiler fuel and second grade paper production.
- A number of waste stream recycling and re-use initiatives are being explored, such as acid mine drainage control cover, animal bedding, roofing paper, hydroseed, engineered seed pellets, concrete additive, asphalt aggregate, materials for surface mine reclamation, and pH adjustment of process water.
- Fourteen beneficial or end market uses for waste were not undertaken by mills due to economic infeasibility. These may be appropriate targets for economic incentive programs.

## **6.0 Increasing the Use of Waste Residuals**

### *6.1 Industry efforts to foster increased use of waste products*

One of the leaders in promoting the beneficial use of by-products of the pulp and paper industry is the National Council for Air and Stream Improvement (NCASI, [www.ncasi.org](http://www.ncasi.org)). NCASI serves as an environmental resource for the forest products industry in its broadest definition, addressing a wide range of issues of importance to this industry, including the promotion of the beneficial use of the industry's by-products.

In an effort to promote beneficial use applications among its members, NCASI publishes technical reports and bulletins that address the potential beneficial use applications of pulp and paper industry by-products. In addition, NCASI has recently worked with the U.S. EPA in sponsoring the Industrial By-Products Beneficial Use Summit that brings together regulators and industry representatives, to better understand the beneficial use of industrial by-products ([www.byproductsummit.com](http://www.byproductsummit.com))

In addition to NCASI, the Technical Association of the Pulp and Paper Industry (TAPPI, [www.tappi.org](http://www.tappi.org)) provides resources to the pulp and paper industry relating to beneficial use of pulp and paper by-products. TAPPI is the leading technical association for the worldwide pulp, paper, and converting industries providing information, education, and knowledge-sharing opportunities. TAPPI's Environmental Division actively supports beneficial use through its Residuals Management Committee. Active information exchange, and training and education are

promoted at its annual meeting held in the spring each year. In addition, TAPPI hosts an active discussion board and “Ask the Experts,” which are electronic forums that allow those interested in beneficial use alternatives to network with each other and industry experts (RMT Inc. 2003).

## 6.2 *Public sector incentives and research programs to reduce industry waste*

### 6.2.1 Focus on Energy

Wisconsin provides a state-level program called Focus on Energy, which brings support to the state’s mills with project evaluation assistance and monetary incentives. Grants can be used to examine a project’s feasibility. This program is relevant to energy waste stream reduction in that fossil fuels on average account for 75% of a mill’s energy input. Finding increased ways to use the waste stream for energy provides a two-level benefit with decreased purchase of fuels and decreased waste (Wisconsin Paper Council).

The Focus on Energy program has identified spent pulping liquors as a chief alternate fuel for papermakers. When these chemicals become too weak after being used and recycled several times in the pulp manufacturing process, they are burned to recover their energy content.

Other important fuels in this category include bark and other unpulpable wood waste, with their BTU use in recent years expanded by 176%, and various types of refuse, from industrial and municipal waste to used auto and truck tires. Use of such refuse-derived fuels, or RDF, increased more than 650% at paper companies since the early 1970s, from about 0.25 trillion BTUs to more than 1.9 trillion BTUs.

### 6.2.2 The Clean Washington Center

Founded in 1991, the Clean Washington Center's focus and mission has been to develop markets, technologies, and beneficial end uses for recycled materials. The Clean Washington Center (CWC) managed and documented over ninety projects validating recycling technologies or recycled content products, and has developed Best Practices In Recycling for several recyclable commodities. The now defunct center provided research into paper mill waste stream reduction projects ([www.cwc.org](http://www.cwc.org)).

### 6.2.3 The New York State Energy Research and Development Authority

In 1995, the Authority developed a report that evaluated the New York paper mill industry in terms of the productive management and treatment of solid wastes. The report can be accessed at: [http://www.osti.gov/bridge/product.biblio.jsp?osti\\_id=119919](http://www.osti.gov/bridge/product.biblio.jsp?osti_id=119919).

### 6.2.4 The Wisconsin Department of Natural Resources

The Wisconsin DNR offers a Waste Reduction and Recycling Demonstration Grant Program, with a grant category for industrial wastes, including the paper industry. See <http://dnr.wi.gov/org/caer/cfa/EF/RECYCLE/PROJECTS/ind.htm> for details.

### 6.2.5 U.S. EPA Grants and WasteWise Program

The U.S. EPA periodically provides grants for research into paper mill and industrial beneficial use. NCASI and the Natural Resources Research Institute (NRRI) are both recipients of this grant program. WasteWise allows industry partners to enroll in the EPA program in order to reduce waste.

### 6.2.6 Beneficial Use of Industrial Materials Summit

This is an annual conference held that specifically addresses the use of industrial by-products targeting various producers, including paper mills. Information from the 2008 summit is posted at <http://www.beneficialusesummit.com/2008/index.html>.

### 6.3. *Final considerations when evaluating waste reduction costs and benefits*

In this brief report, we first identified major components of the pulp and paper industry waste stream. Wastewater treatment plant residuals, boiler ash, and causticizing residues make up the lion's share of the waste stream, however, other important waste components include wood yard debris and pulp and paper mill rejects. We then reviewed state of the art waste reduction and re-use techniques employed by industry leaders and emerging waste reduction technologies. Monitoring industry sustainability reports filed on-line through the Global Reporting Initiative's (GRI's) corporate registry is a good way for DOE and mills participating in the IFP to keep abreast of the latest methods. The most prominent ways industry leaders are re-using their waste streams are for land applications, alternative energy, construction materials, and inputs into the production process.

We then provided an overview of emerging markets for pulp and paper industry waste. Overall, we identified and discussed 46 marketable commodities that can be extracted from the waste stream and put to a wide range of beneficial uses. While there are a number of technical and economic barriers to more widespread participation in these markets, IFP mills are already implementing a number of waste stream reduction and re-use initiatives. Some additional considerations for greater participation include:

- Resource savings and resource efficiency – reducing and re-using waste can save mills money on purchased energy and material costs and reduced landfill fees.
- Substituting fossil energy sources for waste-based sources and on-site composting can be a potential source of carbon credits for mills participating in emerging carbon markets.
- Waste products can be used to support mills' infrastructure with such items as road-building components, soil amendments, fuel for electricity, and construction materials.

Future research by government and non-profit organizations as well as the industry will reveal the extent of potential cost savings associated with these options for waste stream re-use.



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## Appendices

### Appendix 1:

*Paper Industry Wastewater Treatment  
By-Product Standards/Specifications/Guidelines (RMT Inc. 2003).*

STANDARD/SPECIFICATION/GUIDELINE	DESCRIPTION
<b>Soil Amendment</b>	
<b>Planning Guide and State Regulation Summary for Land Application of Mill By-Product Solids.</b> NCASI Technical Bulletin 863. National Council for Air and Stream Improvement. May 2003.	This guideline describes practical steps for establishing a successful land application program for wastewater treatment plant residuals, boiler ash, and other alkaline by-product solids. The guideline discusses regulatory considerations, methods for evaluating feasibility, state contacts and permitting, research results, and environmental management and compliance issues.
<b>Utilizing Paper Mill By-Products as Forest Soil Amendments: Forest Responses, Recommendations, and Industry Case Studies.</b> NCASI Technical Bulletin 798. National Council for Air and Stream Improvement. February 2000.	This guideline reviews the characteristics and forest land applications of wastewater treatment residuals and boiler ash, provides a review of successful land application programs and regulatory considerations, and provides recommendations for using these byproducts successfully as forest soil amendments, while minimizing the potential for adverse effects on the environment.
<b>Compost</b>	
AASHTO MP 10-03. <b>Standard Specification for Compost for Erosion/Sediment Control (Compost Blankets).</b> American Association of State Highway and Transportation Officials.	This specification covers compost produced from various organic byproducts (including industrial residuals and biosolids) for use as a surface mulch for erosion/sediment control on sloped areas.
<b>Alternative Daily Cover at a Landfill</b>	
ASTM D6523-00. <b>Standard Guide for Evaluation and Selection of Alternative Daily Covers (ADCs) for Sanitary Landfills.</b> American Society for Testing and Materials. April 2000.	This standard provides a general set of guidelines to assist end users in assessing different options for ADCs at sanitary landfills. The standard provides key performance information on broad classifications of ADCs, and wastewater treatment plant residuals are included as a subcategory. The suitability and acceptability of ADCs are dependent on climate, operating conditions, and regulatory requirements; therefore, specific

	performance information must be evaluated on a case-by-case basis.
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*Appendix 1, continued*

<b>Hydraulic Barrier Layers</b>	
<b>Laboratory Hydraulic Conductivity Testing Protocols for Paper Mill Residuals Used for Hydraulic Barrier Layers.</b> NCASI Technical Bulletin 848. Nelson, M. and C. Benson. June 2002.	This guideline provides research-defined protocols for the determination of hydraulic conductivity of wastewater treatment plant residuals for use as hydraulic barriers in landfill covers. The guideline includes a draft of an ASTM standard guide, which is currently being balloted by ASTM through Subcommittee D18.04.
EPA/600/R-93/182. <b>Quality Assurance and Quality Control for Waste Containment Facilities.</b> Daniel, D. and R. Koerner. September 1993.	This technical guideline provides guidance for developing construction quality assurance procedures for solid waste landfills. The guideline contains a section on hydraulic barriers, which includes discussions on liner requirements, compaction requirements, construction variables that affect hydraulic barriers, and preprocessing and placement techniques. The guideline is not specific to wastewater treatment residuals, but the quality assurance procedures apply generally to all types of barrier materials.
<b>A Field Study of the Use of Paper Industry Sludges in Landfill Cover Systems: Final Report.</b> NCASI Technical Bulletin 750. National Council for Air and Stream Improvement. November 1997.	This guideline provides the research results of field-scale landfill covers that were constructed to compare the field performance of paper industry WWTP residuals and clay hydraulic barriers. The results showed that WWTP residuals had hydraulic conductivities comparable to those of clay and underwent no deterioration. BioMix® is trademarked by Allied Waste Industries and is a blend of soil and Short Paper Fiber®. The end product is a manufactured soil with a hydraulic conductivity of between 10 <sup>-7</sup> and 10 <sup>-9</sup> cm/s. The standards for selection of the wastewater treatment plant residuals and production of BioMix® are confidential.
<b>Industrial Sorbents/Animal Bedding</b>	
ASTM F726-99. <b>Standard Test Method for Sorbent Performance of Adsorbents.</b> American Society of Testing and Materials. February 1999.	This standard covers a test method that describes the performance of adsorbents in removing nonemulsified oils and other floating immiscible liquids from the surface of water. The standard provides definitions, testing procedures, and adsorbent classifications.

*Appendix 1, continued*

International Absorbents, Inc.	International Absorbents, Inc., creates trademarked animal bedding and industrial absorption products from pristine wastewater treatment residuals. International Absorbents' specifications and standards for selection and production are confidential.
Complete Spill Solutions (formerly Cellutech, Inc.)	Complete Spill Solutions creates trademarked industrial absorption products from wastewater treatment residuals. Its specifications and standards for selection and production are confidential.
<b>Lightweight/Glass Aggregate</b>	
ASTM C 331-03. <b>Standard Specification for Lightweight Aggregates for Concrete Masonry Units.</b> American Society for Testing and Materials. May 2003.	This specification covers lightweight aggregates intended for use in concrete masonry units, when a prime consideration is to reduce the density of the unit. The specification provides the general physical requirements for lightweight aggregates, the test methods, and an aggregate grading guide for concrete masonry units. The specification is not specific to WWTP residuals.
ASTM C 330-03. <b>Standard Specification for Lightweight Aggregates for Structural Concrete.</b> American Society for Testing and Materials. May 2003.	This specification covers lightweight aggregates intended for use in structural concrete in which a prime consideration is to reduce the density while maintaining the compressive strength of the concrete. The specification provides the general physical requirements and the test methods for lightweight aggregates. The specification is not specific to WWTP residuals.
<b>Lightweight/Glass Aggregate continues</b>	Minergy Corporation has a patented technology for creating glass aggregate from WWTP residuals. Minergy Corporation's standards and specifications for selection and production are confidential.

*Note: Most states require materials promoted or sold as liming agents or fertilizer to be registered with the state agricultural department. In general, the materials are required to meet a defined set of specifications (e.g., calcium carbonate equivalence) to be considered liming agents.*

## Appendix 2:

### *Wood Ash Standards/Specifications/Guidelines (RMT Inc. 2003)*

STANDARD/SPECIFICATION/GUIDELINE	DESCRIPTION
<b>Soil Amendment</b>	
<p><b>Standards and Guidelines for the Use of Wood Ash as a Liming Material for Agricultural Soils.</b> IBSN: 0-7785-2280-6. Alberta Environment, Science and Standards Branch. July 2002.</p>	<p>These (Canadian) standards and guidelines apply to wood ash recovered from energy generation systems. The standards and guidelines provide general information on wood ash, regulatory requirements for generators, and recommended practices for land managers.</p>
<p><b>Product from Residue: Standard Setting for Alkaline Mill Residues in Quebec.</b> TAPPI Proceedings, 1998 International Environmental Conference and Exhibit. pp. 779-783.</p>	<p>This standard for Quebec, Canada, covers various alkaline residues, including wood ash, for use as agricultural liming agents. The standard provides the performance requirements and includes the quality requirements for metals and specific organic contaminants.</p>
<p><b>Recommended Practices for Using Wood Ash as an Agricultural Soil Amendment.</b> Bulletin 1147. The University of Georgia, College of Agricultural and Environmental Sciences. September 2002.</p>	<p>This guideline covers a procedure for applying wood ash as a lime substitute on agricultural lands. The guideline provides general information on the methods to be used by wood ash producers and dealers, the tests to be performed on the wood ash, and the application practices for landowners.</p>
<p><b>Planning Guide and State Regulation Summary for Land Application of Mill By-Product Solids.</b> NCASI Technical Bulletin 863. National Council for Air and Stream Improvement. May 2003.</p>	<p>This guideline describes practical steps for establishing a successful land application program for wastewater treatment plant residuals, boiler ash, and other alkaline by-product solids. The guideline discusses regulatory considerations, methods for evaluating feasibility, state contacts and permitting, research results, and environmental management and compliance issues.</p>
<p><b>Utilizing Paper Mill By-Products as Forest Soil Amendments: Forest Responses, Recommendations, and Industry Case Studies.</b> NCASI Technical Bulletin 795. National Council for Air and Stream Improvement. February 2000.</p>	<p>This guideline reviews the characteristics and forest land applications of wastewater treatment residuals and boiler ash, provides a review of successful land application programs and regulatory considerations, and provides recommendations for using these by-products successfully as forest soil amendments, while minimizing the potential for adverse effects on the environment.</p>

**Appendix 3:**

*Causticizing By-Products Standards/Specifications/Guidelines (RMT Inc. 2003)*

STANDARD/SPECIFICATION/GUIDELINE	DESCRIPTION
<b>Soil Amendment</b>	
<p><b>Planning Guide and State Regulation Summary for Land Application of Mill By-Product Solids.</b> NCASI Technical Bulletin 863. National Council for Air and Stream Improvement. May 2003.</p>	<p>This guideline describes practical steps for establishing a successful land application program for wastewater treatment plant residuals, boiler ash, and other alkaline by-product solids. The guideline discusses regulatory considerations, methods for evaluating feasibility, state contacts and permitting, research results, and environmental management and compliance issues.</p>
<p><b>Product from Residue: Standard Setting for Alkaline Mill Residues in Quebec.</b> TAPPI Proceedings, 1998 International Environmental Conference and Exhibit. pp. 779-783.</p>	<p>This standard for Quebec, Canada, covers various alkaline residues, including lime mud, green liquor dregs, and slaker grits for use as agricultural liming agents. The standard provides performance requirements and includes quality requirements for metals and specific organic contaminants.</p>
<b>Alternative Daily Cover at a Landfill</b>	
<p>ASTM D6523-00. <b>Standard Guide for Evaluation and Selection of Alternative Daily Covers (ADCs) for Sanitary Landfills.</b> American Society for Testing and Materials. April 2000.</p>	<p>This standard provides a general set of guidelines to assist end users in assessing different options for ADCs at sanitary landfills. The standard provides key performance information on the broad classifications of ADCs. The suitability and acceptability of ADCs are dependent on the climate, the operating conditions, and the regulatory requirements; therefore, specific performance information must be evaluated on a case-by-case basis.</p>



**Appendix 4:**

*Waste Stream Survey of Mills Participating in the Industrial Footprint Project  
(Responses summarized in italics)*

**How many tons of wastes are generated at your mill?**

*Mills reported this in various ways. Boiler ash: 22,300 tons as is; 8320 yards/yr; 60 tons a day at 50% moisture. Treatment plan solids: 3,300 dry tons/ yr.; 150 tons per day at 70% moisture of sludge; 21,300 tons annual dry basis; Slaker grits: 1,700 tons dry basis; OCC (recycle rejects), burned: 2,800 tons dry basis; OCC (recycle) rejects, discarded: 2,200 tons as is; Hog fuel rejects: 1,500 tons as is.*

**How is this material managed?**

Percentage going to landfill and/or lagoon: *100%, 27%*  
 Percentage going to land application: *0%, 30%, 100% of treatment solids*  
 Percentage going back into production cycle: *0%, 0%, positive, but not estimated*  
 Percentage going to other beneficial uses: *23%, 50%, 100%*

**Has your facility undertaken any waste reduction initiatives? If so, please summarize.**

*Recycling  
 Re-use  
 Refuse derived fuel  
 Solid waste reduction goals  
 Byproducts synergy group  
 Boiler ash to cement kiln  
 Rechipping then reusing hog fuel rejects  
 Improved recycling of office waste*

**Has your facility worked cooperatively with any companies, landfills, agricultural lands, etc. to beneficially use mill waste stream materials? If so, please explain.**

*Initiatives reported: Orchards using compost, WA DOT using compost, agricultural fertilizer company using dyes, landscaper buying felts, TRAC buys kiln bricks and talc bags used in RDF, cartridges recycled, cores recycled, metal recycled, solid waste to fuel, using fiber rich portion of wastewater sludge for absorbents.*

Waste Water Treatment Plant Residuals

**Please fill out the table below by marking (X) the appropriate box for each beneficial use or end market (numbers indicate how many marks were received in total).**

<b>Beneficial Use or End-Market</b>	<b>Already using waste this way (X)</b>	<b>Plan to use waste this way (X)</b>	<b>Economically infeasible (X)</b>	<b>Infeasible for other reasons (X)</b>
Papermaking fiber and filler	1		1	2

<b>Beneficial Use or End-Market</b>	Already using waste this way (X)	Plan to use waste this way (X)	Economically infeasible (X)	Infeasible for other reasons (X)
Industrial absorbent			1	
Animal bedding/cat litter		1		
Manufactured soil component	1			
Compost feedstock	1			
Landfill cover or barrier cap			1	
Acid Mine Drainage (AMD) control cover		1		
Building board/fixture			1	
Brick or concrete additive				1
Glass or lightweight aggregate				1
Fine mineral product				1
Cement kiln feedstock			1	
Roof felt/tar paper		1		
Fuel pellet additive			1	
<b>Other Uses:</b>				
Hydroseed		1		
Engineered seed pellet		1		

Boiler Ash Residuals

**What type of boiler ash residuals are generated at your mill? Coal, wood or a mixture of the two?**

*Wood (all three responses), but also some non-combustible material that enters sewers, especially paper additives.*

**Have you implemented a high efficiency boiler to reduce waste residuals and to reduce amount of fly ash? Two “no” responses, one “yes.”**

**Please fill out the table below by marking (X) the appropriate box for each beneficial use or end market.**

<b>Beneficial Use or End-Market</b>	Already using waste this way (X)	Plan to use waste this way (X)	Economically infeasible (X)	Infeasible for other reasons (X)
Compost feedstock	1			1
Manufactured soil component	1			1

<b>Beneficial Use or End-Market</b>	Already using waste this way (X)	Plan to use waste this way (X)	Economically infeasible (X)	Infeasible for other reasons (X)
Cement kiln feedstock	1		1	
Concrete additive		1		1
Flowable fill – Controlled Low-Strength Material (CLSM)		1		
Waste stabilization			2	
Soil stabilization	1	1	1	
Cattle bedding				2
Earthen construction				1
Asphalt aggregate		1		
Landfill daily cover	1		1	
Activated carbon manufacture			1	
<b>Other Uses:</b>				

Causticizing Residuals

<b>Beneficial Use or End-Market</b>	Already using waste this way (X)	Plan to use waste this way (X)	Economically infeasible (X)	Infeasible for other reasons (X)
Liming agent on agricultural land				1
Cement kilns			1	
Forest land application				1
Acid mine reclamation		1		
Manufactured soil ingredient	1			
Soil stabilization/earthen construction			1	
Surface mine reclamation		1		
Clay Brick additive				1
Gaseous sulfur-compound treatment				1
Hydraulic barrier material mix neutralization				1
PH adjustment of process water		1	1	1

<b>Beneficial Use or End-Market</b>	Already using waste this way (X)	Plan to use waste this way (X)	Economically infeasible (X)	Infeasible for other reasons (X)
Wastewater AOX removal				
Compost feedstock				1
Road dust control				1
Sludge bulking control				1
Asphalt additive				1

Wood Yard Debris or Pulping/Paper Rejects

<b>Beneficial Use or End-Market</b>	Already using waste this way (X)	Plan to use waste this way (X)	Economically infeasible (X)	Infeasible for other reasons (X)
Boiler fuel (energy input)	3			
Second-grade paper production	2			1