Utilization of kraft pulp mill residuals

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ABSTRACT: Kraft pulp mills produce on average about 100 kg of solid residuals per metric ton of pulp produced. The main types of mill waste are sludge from wastewater treatment plants, ash from hog fuel boilers, dregs, grits, and lime mud from causticizing plants and lime dust from lime kilns. Of these, about half is disposed of in landfills, which highlights the need and potential for waste recycling and utilization.

Sludge is either incinerated in hog fuel boilers to generate steam and power or used in various forms of land application, including land spreading, composting, or as an additive for landfill or mine waste covers. The majority of hog fuel boiler ash and causticizing plant residues is landfilled. Alkaline residuals can be conditioned for use in land application, manufacture of construction materials, and production of aggregates for road work.

This technical review summarizes residuals utilization methods that have been applied in pulp and paper mills at demonstration- or full-scale, and therefore may act as a guide for mill managers and operators whose goal is to diminish the costs and the environmental impact of waste management.

Application: This technical review provides information about industrial-scale applications of residuals utilization, and therefore may act as a guide for mills that are seeking to implement waste reduction or utilization programs.

The global annual production of kraft pulp has been steadily increasing and is now about 145 million metric tons [1]. It is expected to continue growing for the next few years [2,3]. With an average residuals generation of 0.1 metric tons per air-dried metric ton of pulp, the waste generated at kraft pulp mills amounts to approximately 14.5 million metric tons globally. Most of the waste consists of sludge from wastewater treatment, ash from biomass combustion, green liquor dregs, lime mud, and slaker grits from causticizing (**Table I**).

Diverting waste from landfills and finding strategies for utilization have increasingly become important environmental and social considerations in kraft mill operations. Therefore, many mills are conducting residuals utilization programs in order to reduce the amount of waste disposed of in landfills. For example, UPM in Finland is currently implementing a zero-waste program with the goal to avoid any waste disposal in landfills by 2030 [9]. Other pulp and paper producing companies, such as Stora Enso and International Paper, have also implemented aggressive waste reduction programs aimed at minimizing landfill disposal [10,11].

Recent reviews have summarized numerous important scientific and engineering studies that have demonstrated

	Wastewater Treatment Plant Sludge	Wood Ash	Lime Mud	Dregs	Grits
Amount	49 (0.5–270), kg wet/o.d. metric ton of pulp[1]	34 (2.2–107), kg/o.d. metric ton of pulp[1]	12 (0.1–560), kg/a.d. ton of pulp[5]	6.6 (0.01–120), kg/a.d. ton of pulp[5]	3 (0.01–40), kg/a.d. ton of pulp[5]
pH	6.6–8.2[2]	10.4 (9.0–13.5)[4]	11.4 (8.4–13.0)[1]	10.8 (9.5–12.1)[1]	12.5 (12.2–12.7)[1]
Nitrogen, g/kg	29 (1.4–41)[3]	1.5 (0.2-7.7)[4]	1.8[1]	2.7 (1.6–4.2)[1]	2.2 (1.3–5.0)[1]
Phosphorous, g/kg	3.4 (1.2–5.8)[3]	5.3 (1-14)[4]	2.8 (1.1–5.7)[1]	0.67 (0.13–1.2)[1]	0.81 (0.23–1.7)[1]
Potassium, g/kg	1.4 (0.4–6.0)[3]	26 (1-130)[4]	0.44 (<0.2–1.2)[1]	4.6 (0.33–12)[1]	2.7 (1.3–6.0)[1]
Calcium, g/kg	30 (2.7–90)[3]	150 (25-330)[4]	380 (280–500)[1]	190 (35–320)[1]	360 (340–390)[1]
Magnesium, g/kg	0.65 (0.11–1.0)[3]	10 (1-25)[4]	6.2 (2.4–10.4)[1]	23 (5.8–43)[1]	7.2 (3.7–10)[1]

[1][4, and references therein], [2][5, and references therein], [3][6], [4][7, and references therein], [5][8 and references therein].

I. Amounts and composition of kraft pulp mill residuals. Amounts of waste are median values, and all others are mean values (except pH of wastewater treatment plant sludge). Numbers in brackets are ranges (o.d. = ovendry; a.d. = air dry).

the utilization potential of sludge, ash, and causticizing plant residues in agricultural settings and various environmental engineering applications [5,12,13]. The majority of these studies have investigated utilization methods on a laboratory or pilot scale, and the associated results cannot be directly translated to full-scale operation. Upscaling of these methods is often challenging and requires tailoring the methods to the specifics of the waste generated at a mill, as well as the market conditions for the waste.

Full-scale applications are often not reported in technical or scientific publications and can therefore not easily serve as a reference to other mills that seek to implement residuals utilization programs. Therefore, this technical review is an attempt to fill this gap, while focusing on applications that have been previously applied at pulp and paper mills on an industrial scale.

SLUDGE UTILIZATION

The median sludge production is 49 kg wet/ovendry (o.d.) metric ton of pulp [4]. The main types of sludges generated at pulp and paper mills are biosludge (waste activated sludge) and primary sludge. Primary sludge is generated when solids settle in primary clarifiers and mainly contains fibers. Biosludge is generated as a result of biological wastewater treatment and contains mainly bacterial biomass and lignocellulosic material. Only about 20% of the sludge generated in pulp and paper mills worldwide is disposed of in landfills, whereas at least 25% is beneficially used by means of land application [14,15].

Land application of sludge

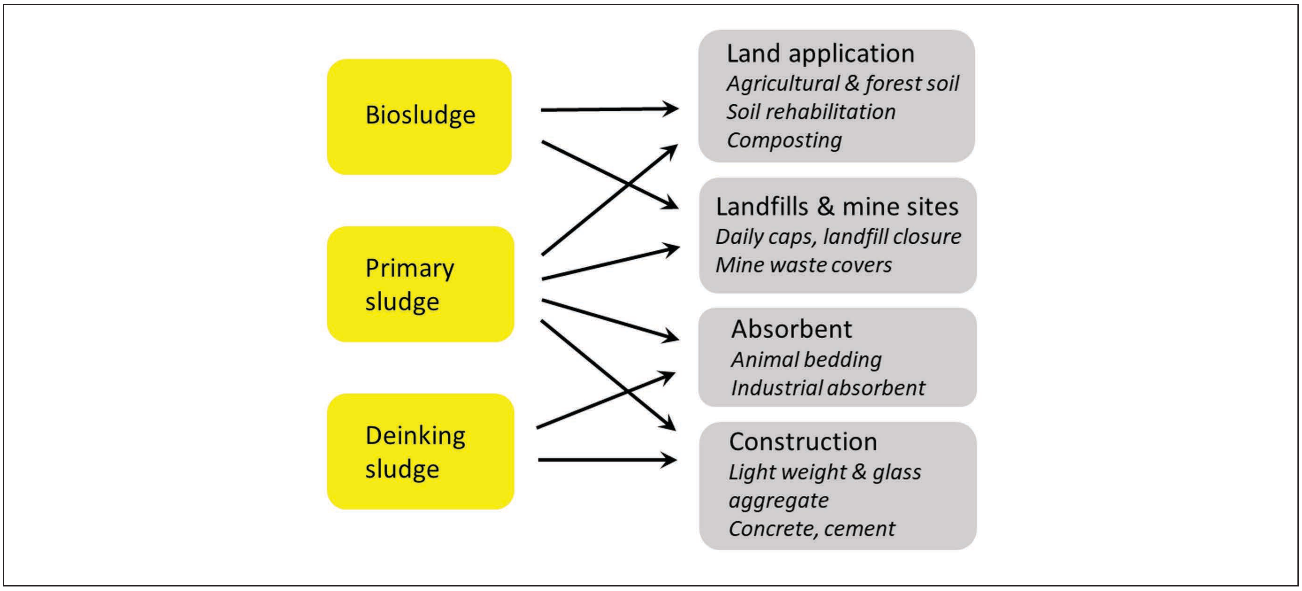
Biosludge and primary sludge are suitable for land application because of high organic matter and nutrient contents. Biosludge contains notable concentrations of nitrogen and phosphorous because these nutrients are added to the activated sludge treatment system and partially end up in the sludge. The carbon (C): nitrogen (N) ratio of biosludge usually ranges from about 5:1 to 20:1 [16], which is suitable for plant growth. Primary sludge can provide other benefits to soils, such as improving the soil structure by means of aggregate formation and enhancement of the water infiltration rate. Adding primary sludge to kaolinitic soils improves aeration and water permeability. Sandy soils benefit from the high nutrient holding capacity and the high moisture holding capacity of primary sludge [16]. Primary sludge may also be applied for erosion control and roadside vegetation growth [17].

One of the most significant challenges of land application is the high C:N ratio of the primary sludge, which can lead to nitrogen deficiency in the soil. In this case, nitrogen may become immobilized within the tissue of soil microorganisms and is therefore unavailable for plant uptake. Composting of the sludge or the addition of nitrogen can alleviate this deficiency. In order to provide a balanced nutrient supply, a Canadian mill has added 2.7 kg of nitrogen per dry ton of sludge for land application [18]. Other potential problems with sludge application are related to odor, herbicide ineffectiveness, and the stimulation of weed competition [19]. In most cases, sludge has been reported to be non-hazardous with respect to heavy metal contamination and toxicity, as determined by the Toxicity Chemical Leaching Procedure [4,20]. Also, according to a leachability study on metals in paper mill sludge, the majority of heavy metals are more tightly bound to the sludge matrix and is less likely to leach [21]. Nevertheless, heavy metal concentrations in mill sludge can vary over several orders of magnitude [4], and in some cases, high concentrations can constitute a significant environmental risk. Therefore, prior to land application, sludge composition analyses and leachability tests should be implemented.

Sludge can be land applied either as dewatered sludge with a solids content of 15%–40% or as thickened sludge with a solids content of 3%–8%. The advantage of the thickened sludge is that it can be sprayed using conventional manure spraying technology. However, due to the larger volume of thickened sludge, the transportation costs usually allow land application only within 50–100 km around the mill.

Composting mill sludge can enhance its fertilizing value by reducing the C:N ratio and increasing the nitrogen availability, as well as increasing the cation exchange and moisture holding capacity. Mill residuals including sludge have been mixed with other types of waste to produce more balanced compost, including food waste, manure, municipal biosolids, yard trimmings, and waste from the pharmaceutical and textile industries [16].

Several pulp mills in Alberta, Canada, deliver their biosludge and primary sludge to surrounding farms. The land application of sludge not only can save farmers costs for nitrogen fertilizers, but also improves soil structure and water holding capacity. The sludge only needs to be applied once every several years because the nitrogen in the sludge is present mainly in the organic form, which is released slowly [20]. Turning mill sludge into product can result in different types of benefits. For example, sludge and bark from a Chilean mill are utilized as vegetable substrates, which has led to waste disposal cost savings, decrease in landfilling, and a reduction in ash generation [22]. Several mills in Ontario, Canada, utilize most of their sludge in agriculture and silviculture, as well as for soil rehabilitation. The sludge application has shown to reduce the use of commercial fertilizer with a potential saving of $250/hectare (ha) for a crop of corn [23]. In a large-scale field study in Quebec, Canada, a combination of paper mill biosolids and alkaline residuals (calcitic lime, lime mud, wood ash) was applied on crop land over the course of nine years in various amounts and mixtures [24]. The application turned out to be beneficial to crop growth because of the nutrients contained in the waste. Adverse environmental effects were not found, unless the application of sludge exceeded



1. Mill sludges and previously applied utilization methods.

60 metric tons wet ha^{-1} yr^{-1}, which then caused significant nitrate leaching.

Landfill and mine site amendments

Mill sludge has been incorporated into manufactured soils to be used as landfill capping material and as mine site amendments (**Fig. 1**). As an example, sludge from two kraft mills in Michigan, USA, have been tested for use as covers on mining waste rock stockpiles to provide organic matter and nutrients and to help establish self-sustaining plant growth [25]. In another case, sludge from a mill was used as cover for copper uranium tailings. The sludge application provided for vegetation growth and cut the sludge disposal costs at this mill in half [26].

Similar to agricultural applications, various types of mill wastes are often mixed to improve the soil properties and fulfill engineering requirements. Mixtures consisting of biosludge, wood waste, and fly ash were used as barrier layers for the closure of two landfills at a coastal mill in British Columbia, Canada. The low hydraulic conductivity of the waste mixture led to improved erosion stabilization and at the same time provided a growing medium for plants [27]. Other advantages of using sludge in barrier layers of landfill caps are its higher flexibility compared to compacted clay and a lower bearing pressure imposed on the waste material [28].

Absorbents

Primary sludge from pulp and paper mills has been used to produce animal bedding and litter, while requiring minimal processing prior to application [29]. Sludge from several mills in New York State, USA, has been applied as bedding at cow farms. Prior to application, the sludge is amended with cement kiln dust to facilitate drying and inhibit bacterial growth. After usage, some farmers reuse the material as soil fertilizer [30]. Primary sludge has also been used for the production of cat litter, after being sanitized, deodorized, dried, and pelletized [31]. The sludge may also be used in the production of industrial oil absorbents [29].

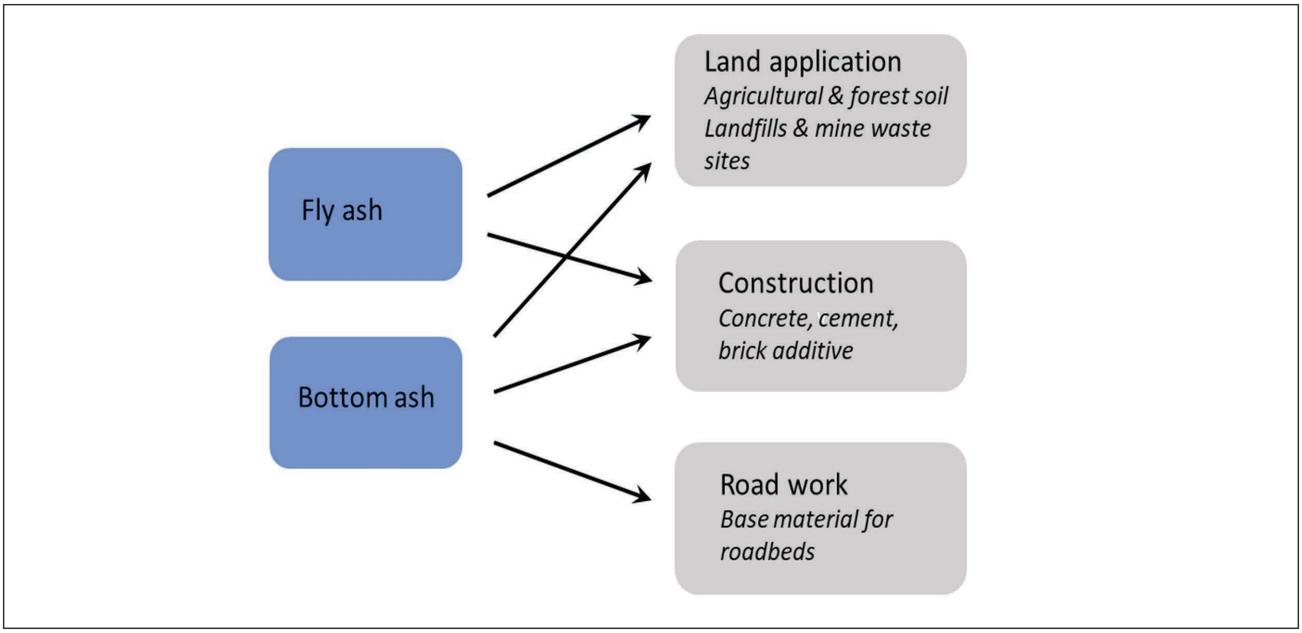
Construction material

Since sludge contains notable amounts of silicon, aluminum, and iron, it can be used as an ingredient in the production of glass aggregate. A company in Wisconsin, USA, has used sludge from several nearby paper mills to produce glass aggregate [32] that can be used in floor tiles, abrasives, roofing shingles, asphalt, and decorative landscaping [16]. Because sludge contains organic matter, the heat of combustion supplements the energy required in the glass aggregate production [32]. In a similar application, sludge and fly ash were mixed and used to produce lightweight aggregate that can be applied in concrete masonry, landscaping, and geotechnical applications [16].

Mill primary sludge can be utilized as an addition to concrete, where it can have several benefits, including improved durability, increased pumpability of the liquid concrete, and reduced shrink and freeze-thaw related cracking, as well as improved salt-scaling resistance [33].

Other applications

Sludge from mills in the Netherlands and Slovenia has been utilized to produce anti-dust material for coal-fired power plants and ore stockpiles [29,34]. Sludge storage, transport, and application can be facilitated by drying and pelletizing to reduce volume and odor. This is also beneficial in applications where mill sludge is used as an additive to produce pellets that are applied as a fuel supplement [33]. Mill sludge has also been used to produce granules that act as carrier material for plant pesticides. Because the product is dust-



2. Previously applied utilization methods for bottom ash and fly ash.

free and attrition resistant, it may have a benefit over other conventional pesticide carriers [31].

ASH UTILIZATION

Ash from biomass (hog fuel) boilers has a pH ranging between 9.0 and 13.5, and on average, about 30–50 kg are generated per metric ton of pulp. Ash usually contains high concentrations of calcium, potassium, phosphorous, and magnesium, which are important nutrients that make it suitable as a soil supplement. However, ash can also contain undesirable metals such as arsenic, cadmium, and selenium [33], which may make it unsuitable for land application. Bottom ash and fly ash are often treated and utilized separately because of their different properties. Bottom ash has a higher bulk density and a lower carbon content. It also contains less dioxin and furans compared to fly ash [35 and references therein]. The unburned carbon content in wood ash ranges between 5% and 50% [36], and a high carbon content may be detrimental to some construction-related applications such as the manufacture of concrete [36]. The composition of ash from biomass boilers depends on the type of the biomass burned and the location of the mill. Fly ash from coastal mills usually contains notably larger concentrations of dioxins and furans [35], which may prevent certain forms of land application. In North American mills, approximately two-thirds of the generated hog fuel boiler ash is disposed of in landfills, with one-third being used in land application or other beneficial ways [19].

Land application

Biomass boiler ash is suitable for land application for several reasons. It contains valuable nutrients that are important for plant growth, and its high calcium content helps stabilize the soil pH. Pulp mills that grow their own trees for use in pulping often utilize their biomass boiler ash during re-forestation. Most kraft pulp mills in Brazil apply their boiler ash on fast-growing eucalyptus trees, which require a constant nutrient supply. Due to its high pH, boiler ash can also be used as a liming agent. The challenges of land application are the high reactivity and solubility of the ash, leading to a fast release of nutrients. To address these challenges, the ash may be pelletized with a binder that can help regulate the release of nutrients [37]. Also, the application of granulated ash on a forest owned by a Finnish mill [38] has been shown to be a suitable method to reduce the amount of landfilled waste. Heavy metal concentrations in wood ash are usually considered non-hazardous [39], and detrimental effects of land application on soil health and microbial community seem to be minimal [40]. However, the metal concentrations and the leaching behavior vary, and elevated levels of some metals may pose an environmental risk. In a leachability study by Pöykiö et al. [41], cadmium appeared to be the most mobile metal in fly ash, pointing to its potential bioavailability.

Boiler ash has been used as part of manufactured soil for the application at mine waste sites, for landfill covers, and for waste solidification/stabilization [19] (**Fig. 2**). As an example, wood ash from a Swedish mill is used as hardener in filling mine cavities [42]. Mine cavities require large amounts of material; therefore, low-quality ashes that cannot be used as fertilizer are used for this purpose [37]. In another application, fly ash from a mill in Maine, U.S., is used as a stabilizing material at a landfill. Injection of limestone during boiler operation for sulfur dioxide (SO_2) emission control generates a product that is suitable for this purpose [43].

Composting additive

Wood ash is particularly suitable as feedstock for composting because it provides nutrients to the compost, it reduces moisture, acts as a bulking agent, reduces odor, and darkens the product [16]. A darker color is beneficial during spring application on agricultural land by absorbing more heat. Biosludge and ash in compost mixtures complement each other. Ash provides alkalinity and certain nutrients (calcium, magnesium, potassium), whereas biosludge provides other nutrients (nitrogen, phosphorous), as well as organic matter. Another potential benefit of composting ash-sludge mixtures is that they have shown to notably decrease the concentrations of dioxins during the composting process [44].

Construction material

Due to its high mineral content, ash has been applied as an additive for the manufacture of construction material such as concrete, cement, and bricks. Ash addition to concrete may improve its durability and saltwater erosion resistivity. However, for these types of applications, the carbon content of the ash must be below about 6% [16]. Because of the different properties of bottom ash and fly ash, the bottom ash of a Brazilian kraft mill is used for cement production, whereas the fly ash, high in potassium, is transported to nearby farmers [45]. Utilization of ash is often diversified, depending on the demand for certain applications. Ash from several pulp mills in Norway is used in the production of concrete and bricks, as well as for road construction [46]. Ash has also been used as an additive in the production of controlled low-strength material (CLSM) for structural fill, foundation support, and pavement bases [19].

Road work

Ash from mills has been used for road construction, stabilization, and embankments [19], which is beneficial when the ash is high in aluminum, iron, and silicon oxides. Because of its higher density and lower carbon content, bottom ash is commonly used as a base material in roads [37]. As an example, ash from several of a Finnish pulp and paper company's mills is utilized for forest road construction. Adding wood ash to wet soil has been shown to create a hard foundation that can substitute for crushed stone in roadwork [47]. Ash from sludge incineration at a mill in Sweden also appeared to be applicable for building of forest roads and for use as a binder in asphalt [48].

Activated carbon

Fly ash containing a relatively large fraction of unburned carbon (~30%) is suitable for the production of activated carbon. The product can be used as an absorbent of colors and odors [16].

GREEN LIQUOR DREGS UTILIZATION

Dregs are solid particles removed from green liquor by settling or filtering. They consist mostly of char (carbon) and compounds of calcium, sodium, magnesium, and sulfur. Dregs are highly alkaline, with a pH of 9.5–12.1. On average, about 5–15 kg dregs are generated per metric ton of product.

Land application

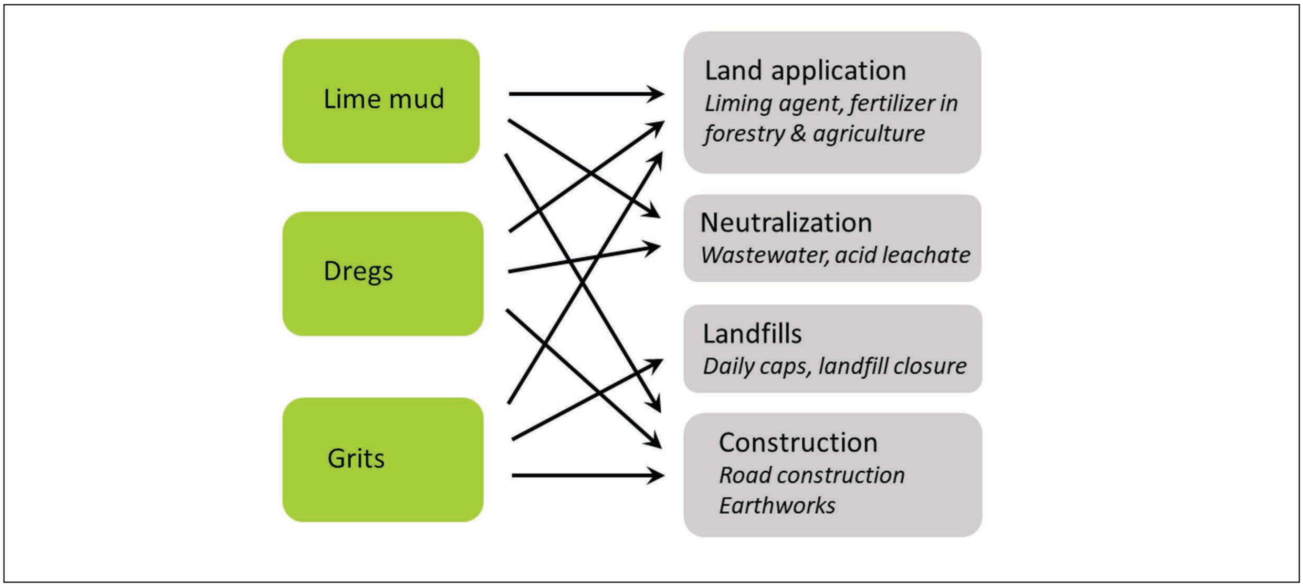
Dregs can be beneficial as a soil supplement due to their alkalinity and high calcium and magnesium contents. Dregs can have a similar liming effect as commercial limestone [49]. However, one of the main challenges of soil application is the high sodium content of dregs. The sodium adsorption ratio (SAR) is often used to assess the suitability of dregs for land application. The SAR considers the concentration of sodium on the one hand and the concentrations of calcium and magnesium on the other hand; high concentrations of the latter two elements are beneficial to the soil. In order to diminish the negative effects of sodium, mills have mixed dregs with other types of mill waste prior to soil application. Mixtures consisting of dregs and grits are typically applied at about 6 tons/ha land for liming purposes [8]. Mills transport the residuals to the farmers, and benefit from the extended lifetime of their landfills. Another potential utilization method involves drying and pelletization of dregs/lime mud mixtures, which may then be applied on agricultural land. The pellets limit the leachability of sodium due to a smaller specific surface area [50].

Dregs as mine site amendments

Long term effects of mining operations include the formation of acid mine drainage in sulfide-laden mine waste sites [51]. Dregs have been applied as part of manufactured soils for the capping of mine sites. In a large demonstration scale project, dregs from Swedish pulp and paper mills were mixed with till and applied on a mine site to prevent acid rock drainage. The mixture acts as a sealing layer while preventing oxidation of the mine waste, infiltration of water, and leaching of heavy metals [52]. Challenges of dregs application are its stickiness and low shear strength. This may prevent engineering applications that involve providing weight support for a protective layer on top of the dregs or the application in a sloped sealing layer without the risk of sliding [53].

Construction material

The relatively high calcium, silicon, aluminum, and iron contents make causticizing residues suitable as additives for cement production and as fine aggregate in hot-mixed asphalt. However, most of the sodium and sulfur need to be washed off prior to application [33]. There are numerous examples of application of dregs in earthworks. In a mill in Finland, the dregs are incinerated, and the resulting ash is utilized for soil construction projects [54]. At another mill, dregs/fly ash mixtures were utilized for the construction of a load-bearing storage field [55]. Also, dregs and ash from several kraft mills in the United States were used to produce



3. Previously applied utilization methods for causticizing residues.

"AshCrete," a product applied in various earthwork projects [56]. Pulp and paper companies increasingly implement residuals utilization programs that include causticizing residues. A European pulp and paper mill consortium has conducted demonstration projects to investigate applications of lime mud as a concrete filler and dregs and grits as aggregates for asphalt pavements, as well as dregs as a sealing layer for mine waste deposits [57].

Dregs as a neutralizing agent

Dregs are used for pH adjustment and stabilization. One mill in Finland has used its dregs for neutralization of acidic mill wastewater [42]. Another Finish mill has tested dregs utilization for the neutralization of acidic gases and to remove sulfur dioxide by the calcium carbonate contained in the dregs [54].

LIME MUD UTILIIZATION

A small portion of lime mud, typically in the form of lime dust from lime kilns, is purged from the lime cycle in order to control accumulation of non-process elements. Lime mud is alkaline (pH 8.4–13.0) and consists mainly of calcium carbonate.

The most common application of lime mud is as a soil amendment on agricultural lands (**Fig. 3**). The high pH of lime mud helps adjust the pH of crop soil, allowing for better absorption of nutrients. It has shown to provide a better yield for the forage crop alfalfa used in dairy farming [58]. The calcium carbonate equivalence (CCE) of lime mud is higher than that of dregs/grits mixtures. In agriculture, lime mud is usually applied at a rate of 2.5 tons/ha land [8]. This type of waste is also applied in forestry. Mixtures of lime mud and ash from a mill in Portugal are utilized as fertilizer in oak, pine, and eucalyptus forestlands [48].

Other applications include the usage as an additive for the construction of roads and for soil stabilization. Lime mud from several U.S. mills was used as an additive to manufactured soil to improve the soil bearing capacity, which is beneficial for the construction of roads and parking lots [8].

Also, a variety of other different utilization methods have been reported, including use as an additive for the production of topsoil or potting mix and as a constituent for cement production [8]. Similar to dregs, lime mud has been shown suitable for pH control of mill wastewater. Mahmood and Paice [59] refer to several Canadian kraft mills that add lime mud to their aerated stabilization basins for pH adjustment.

One of the challenges of using lime mud is related to the recovery and the conditioning of the lime mud prior to utilization, i.e., the dredging from mill holding ponds and the drying and pulverization in order to enable distribution with conventional dry lime spreaders. Another challenge may be the relatively low concentration of magnesium in lime mud and grits. Therefore, long-term application as a liming agent may cause magnesium deficiencies in the soils [4].

SLAKER GRITS UTILIZATION

Grits constitute the settleable material in the slaker, and they consist mostly of calcium carbonate with some calcium hydroxide, sodium, magnesium, and aluminum compounds. On average, about 5 kg of grits are generated per metric ton of pulp.

Grits are alkaline (pH 12–13), and therefore have been utilized for liming purposes on agricultural and forest land. As an example, grits, dregs, and sludge from a Brazilian

Type of Residual	Application	Potential Benefits and Requirements
Sludge	Land application	Biosludge: adds nitrogen, phosphorous, and organic matter to soil; cost savings for sludge dewatering/disposal. Primary sludge: enhanced soil structure, water infiltration, and moisture and nutrient holding capacity (depending on the type of soil). Composted sludge: lower carbon (C): nitrogen (N) ratio, higher nitrogen availability, and larger cation exchange and moisture-holding capacity. Low C:N ratio, odor, and heavy metal concentrations are required.
	Landfills and mine sites	Adds organic matter and nutrients for self-sustaining plant growth.
Ash	Land application	Adds soil nutrients, including calcium, potassium, phosphorous, and magnesium; pH stabilization. Composting additive: ash reduces moisture/odor and acts as a bulking agent. Low heavy metal and dioxin/furan concentrations are required.
	Construction material, road work	High mineral content is beneficial for concrete, cement, and brick production; bottom ash (high density, low carbon content) is suitable as a base material in roads — creates hard foundation in combination with soil. Low carbon content is required.
Dregs	Land application	Adds calcium and magnesium to soils; used as a liming agent. Low sodium adsorption ratio is required.
	Construction material	High mineral content is beneficial for cement and fine aggregate production; dregs/ash mixture is suitable as a base material for earthworks. Low sodium and sulfur content is required.
Lime mud	Neutralizing agent	Stabilizes pH of agricultural and forest soil due to high alkalinity (liming agent); pH control in mill wastewater treatment systems.
	Road construction	Improves road stability and bearing capacity.
Grits	Land application and landfills	pH stabilization of agricultural and forest soil (liming agent); suitable as an additive for landfill covers.
	Road construction	Grits/sand mixtures are beneficial for roadbed stabilization, particularly when affected by heavy truck traffic.

II. Summary of the main benefits and requirements of residuals utilization.

mill are used for soil fertilization and pH control in forestry [60]. Grits are also suitable as a soil additive for daily landfill covers, where it helps to control blowing litter, animals, and insects [33]. In another reported application, lime mud, grits, and dregs from a mill in the United States were marketed for various uses, including strip mine reclamation [8]. Because of the potential leaching behavior of sulfur, alkali metals, and alkaline earth metals from grits, a leachability assessment might be necessary prior to application on soil [61].

Grits are particularly suitable for application in road construction. Mixtures consisting of sand and grits from a kraft mill were used for the construction of roads affected by heavy-truck traffic. As a result, the roads require less maintenance than unpaved roads using native soils. Also, grits have a better liquid holding capacity, which makes certain dust suppression techniques more effective [33]. Other examples include the application of grits from a U.S. mill in roadbed underlayment [58] and the utilization of sand/grits mixtures as a road stabilizer at a mill in Chile [22].

CHALLENGES OF MILL RESIDUALS UTILIZATION

There are several challenges related to the utilization of mill residuals. One of the main challenges is the large day-to-day variations of the physical and chemical properties of the waste. In particular, applications of mill waste for the manufacture of construction material require a consistent quality in terms of mineral and organic matter content. Markets must be available for the mill waste that are reliable on a longer-term basis in terms of the required quantity and cost. Also, the geographical vicinity to the companies that utilize the waste is important to keep transport costs at a minimum.

Potential long-term liabilities related to waste utilization programs are often a concern to mills. Future changes of environmental regulations may lead to the shutdown of a beneficial use program or a liability for cleanup of a site where mill wastes were previously applied.

The implementation of mill residuals utilization programs must comply with environmental health and safety regulations at the mill and must be economically viable. If the utilization method is more costly than the conventional method of disposal, an implementation will likely not take place.

Contamination of waste, such as heavy metals and organic contaminants, in sludge or ash can also prevent utilization.

Regulations for the beneficial use of mill residuals vary widely among countries and local governments. In Canada and the United States, some of the parameters analyzed for consideration of land application of residuals are metal concentrations, pH conditions, pathogens, vector attractiveness, dioxin/furan concentrations, C:N ratio, sodium adsorption ratio, and odor. Also, the permit process often requires the investigation of site-specific parameters related to various soil properties and the distance to surface water and groundwater.

SUMMARY

Currently, about half of all residuals generated in kraft pulp mills are landfilled. Mill waste is most suitable for land application, road building, earthworks, and construction (**Table II**). However, every utilization strategy has to be tailored to the specific conditions at the mill, including waste type and amount and the quality and variations in waste composition. Further, long-term residuals utilization programs require reliable market conditions in terms of supply and demand.

A substantial portion of the sludge generated in pulp and paper mills is put to some use, either by incineration or various forms of land application, including land spreading, composting, or adding to landfill or mine waste covers. However, the majority of the alkaline wastes (ash and causticizing residues) are currently landfilled. Wood ash is suitable for land application in agriculture and forestry because it is rich in nutrients such as potassium, calcium, and phosphorus, and because it provides alkalinity for pH stabilization. Ash can also be used for the manufacture of building material such as concrete, cement and bricks, as well as for road and earth construction. The alkalinity of lime mud, dregs, and grits has been harnessed for the purpose of neutralizing acidic effluents or acid leachate. The combination of alkalinity and nutrients has led numerous mills to apply their lime mud and dregs in agricultural settings. Grits have been shown to be useful as an additive for construction and road building material, as well as for landfill covers.

Some of the challenges to utilize mill waste are large day-to-day variations in the amount and composition. Also, the transport and the geographical vicinity to the waste recipients are important aspects of feasibility. Potential utilization as a soil amendment requires long-term toxicology and leachability assessments. Other challenges may be related to the chemical composition of the waste, such as low nitrogen content in sludge or high sodium content in dregs. **TJ**

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ABOUT THE AUTHORS

This topic was selected for study because mills are increasingly interested in diverting residuals from landfills and establishing beneficial use programs. The most difficult part of this work was to find information about current and previous applications of mill waste utilization, because these are usually not reported in technical and scientific publications. This challenge was addressed by searching for reports from organizations that support the forest products industry, reading sustainability reports from pulp and paper companies, and having personal communications with mill personnel.

The most surprising part of this study was to learn that there is a wide variety of utilization methods that have been applied by mills, and that there is often not much known about the successes or failures of these programs. Mill personnel will find this review helpful when considering options for diverting residuals from landfills.

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