Briefing Note

BENEFICIAL USE OF WOOD ASH

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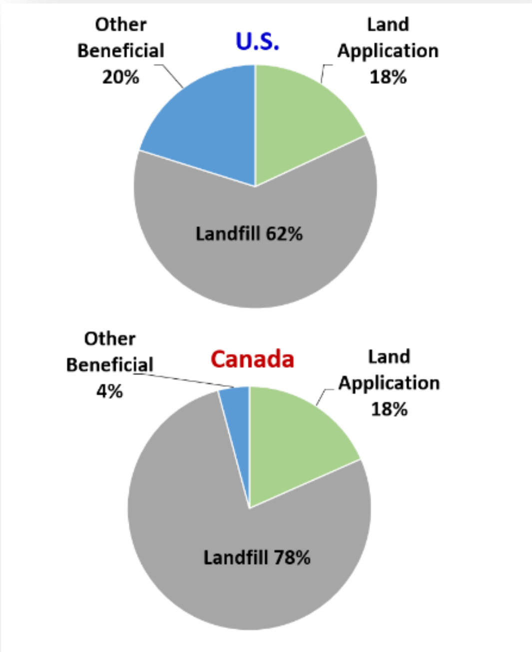
OVERVIEW

In the world of solid residual management, wood ash remains a relatively untapped resource for beneficial use. As illustrated in the charts below, most of the boiler ash generated at pulp and paper mills in North America is landfilled.



Source: 2014 North American Pulp and Paper Benchmarking data (Woody biomass residuals are not included)

While these figures reflect the difficulty involved in implementing beneficial use programs for wood ash, and possibly the lack of available local markets, they also represent an opportunity to reduce landfill disposal costs and to realize additional sources of revenue.

WHAT ARE THE MAIN CHARACTERISTICS OF WOOD ASH?

Wood ash is an alkaline material, i.e., it can neutralize acids by virtue of its chemical composition (see land application and land reclamation). The elemental composition of wood ash varies with wood fuel, combustion conditions, and ash handling practices. In general, however, ash generated from the combustion of clean wood is rich in calcium, potassium, and magnesium, all of which are present in ash in the form of oxides, hydroxides, and carbonates. Other macroelements include phosphorus, aluminum, iron, sulfur, and silicon. Carbon content varies significantly from a few percent points to over 30%, depending on combustion conditions, while nitrogen is present in negligible amounts.

Wood ash also contains microelements, primarily manganese, boron, zinc, and molybdenum, which incidentally are essential to plant growth (see land application). Heavy metal concentrations in wood ash are variable but, in general, comparable to levels found in coal fly ash, wastewater treatment sludges, and limestone, and lower than those found in sewage sludges. Volatile metals such as mercury, and to some degree selenium, are typically found at negligible levels in wood ash.

All heavy metals found in wood ash are naturally present in trees. However, when treated or painted wood is combusted, the concentrations of certain heavy metals (e.g., arsenic, chromium, copper) in the resulting ash can be significantly higher than those found in ash generated from clean wood.

Persistent organic compounds such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and dioxins and furans are present in ashes at very low levels. Nonetheless, higher levels of dioxins and furans can occur when the fuel combusted has been exposed to a source of chlorine, which is the case of salt-laden wood or wood treated with pentachlorophenol.

WHAT ARE THE KEY FACTORS AFFECTING WOOD ASH?

The characteristics and quantities of wood ash primarily depend on the type of wood burned, combustion technology and conditions, particulate matter emission controls, and on-site ash handling and collection practices.

Fuel

Soil type and climate affect the elemental uptake of nutrients by trees, and thus ash content and composition. Wood species grown in temperate climates tend to yield less ash than tropical woods.

Combustion of bark produces more ash than does the combustion of stem wood. According to literature, on average, ash makes up 8% of bark on a dry basis. On the other hand, wood residues that are primarily composed of stem wood contain about 2% of ash, on a dry weight basis. Also, it has been reported that ash from the combustion of stem wood can have greater neutralizing value than bark ash, which suggests that ash resulting from the combustion of bark would have lower alkalinity.

Ash generation rates and alkalinity are also influenced by wood species. High-density hardwoods tend to produce ash with higher alkalinity relative to ash derived from low-density hardwoods and especially softwood. The combustion of hardwood species also produces more ash than the combustion of softwoods.

When wood is co-fired with other fuels, such as coal or fuel oil, the resulting ash tends to have lower pH and neutralizing value.

Combustion

Combustion temperature also affects the proportion of oxides, hydroxides and carbonates in the ash, and thus its alkalinity.

High carbon content (>30% C) in wood ash typically suggests poor combustion conditions. High-carbon wood ash has a large active surface area, which makes it an effective adsorbent (see use of wood ash as an adsorbent and construction applications).

Ashes from circulating fluidized bed combustors generally have low carbon content (< 5%), while ashes from grate boilers often have higher carbon content (40-70%). Increases in boiler efficiency have been reported to decrease carbon content and particle size in wood ash, while increasing pH and calcium carbonate content. This finding implies that the presence of unburned carbon in ash is expected to reduce its alkalinity.

Ash Collection and Handling

There are two types of ashes collected at forest products facilities: fly ash and bottom ash. Fly ash is collected from the combustion gases by an emission control device. Bottom ash is collected from the combustion chamber. Grate and fixed-bed boilers produce more bottom ash than fly ash, while fluidized bed combustors generate more fly ash. Some facilities have segregated ash piles; others combine them for disposal.

Fly ash typically contains more carbon than bottom ash, which implies that bottom ash tends to be denser than fly ash. Ash with lower carbon content also has higher bulk density, which is more favorable from a transportation standpoint.

Both alkalinity and pH of wood ash decrease with increased outdoor storage time as oxides turn into hydroxides when in contact with water, and then into carbonates when the hydroxides react with carbon dioxide.

WHAT IS THE ELEMENTAL COMPOSITION OF FLY AND BOTTOM ASHES?

The distribution of chemical elements between bottom ash and fly ash depends on combustion technology and conditions (e.g., temperature, oxygen supply), the efficiency of particulate matter collection devices, ash particle size, and the chemical affinity of the elements for oxygen and the mineral and organic matter in the fuel.

As indicated earlier, mercury is readily volatilized and is primarily emitted with the flue gases. Metalloids such as selenium and boron partition to both gas and particulate phases. Heavy metals such as arsenic, cadmium, lead and zinc are relatively volatile at high combustion temperatures, but condense on fly ash particles in the post-combustion zone. Accordingly, these elements are often enriched in the fly ash. Less volatile metals such as cobalt, chromium, copper, molybdenum, nickel, and manganese, and macronutrients such as calcium, magnesium, potassium, sodium, and phosphorus tend to partition to both the fly ash and the bottom ash. Overall, the concentration of volatile heavy metals increases with decreasing particle size and thus, the finer fractions of fly ash or bottom ash generally contain higher concentrations of these elements.

HOW DO FACILITIES HANDLE WOOD ASH?

Several regulatory agencies provide guidelines for handling and storing wood ash prior to disposal or in preparation for beneficial use. In these guidelines it is often recommended to use ash as soon as possible to minimize the need for on-site storage. If indoor storage is not possible, ash piles can be stored outside for a few weeks and, if possible, covered with tarps to prevent removal by wind.

To minimize dust generation during handling some facilities spray the ash with water and allow it to harden. The degree to which hardening occurs depends on the amount of water added, degree of ash compaction, ash composition, ambient temperature, and time. Longer hardening times make aggregates more stable. Once hardened, ash can be crushed into grains, rolled on a rotating plate to produce granules, or pressed through a strainer to form pellets. Any of these forms is generally easier to handle, and less reactive, than dry ash. In this regard, if the intent is to apply ash on land, it should be noted that hardened ash tends to dissolve much more slowly in the soil than dry ash does. If hardening takes place at the ash generator's site, the recommendation noted in regulatory guidelines is that storage areas be implemented for both unprocessed and finished ash product.

Another recommendation of these guidelines is to place outdoor ash piles on packed soil or a pad surrounded by a small berm, silt fences, or straw bales to contain or prevent runoff from entering or leaving the surrounded area. Several guidelines also recommend the placing of these piles at a minimum distance from watercourses and animal watering areas.

Finally, most provincial guidelines recommend workers handling wood ash to wear masks and gloves, protect their eyes, and cover their skin. Covering ash during transportation is also recommended to minimize dust emissions.

WHAT ARE THE MOST COMMON BENEFICIAL USE OPTIONS FOR WOOD ASH?

Wood ash characteristics are key in determining the technical viability of the beneficial use options considered by the facility. The most widespread use involves the application of wood ash on agricultural land. In fact, most government guidelines and codes of practice in the US and Canada address primarily land application projects. As far as information on other beneficial use options is concerned, a substantial portion comes from studies conducted outside of North America. Below, the most prevalent beneficial use options are briefly described.

Land Application

Wood ash not only contains macro- and micronutrients that are good for plant growth; it can neutralize acidity in soils. These properties make wood ash an excellent soil amendment, especially if coupled with a nitrogen fertilizer. The liming ability of wood ash can, in fact, help counteract the expected reduction in soil pH caused by time and the application of nitrogen fertilizers. If the soil is acidic and low in macronutrients, wood ash tends to provide a growth response similar to, and often better than, that of limestone, provided increases in pH are progressive and do not occur beyond the intended crop's optimal pH range.

Application of wood ash to forest land is less common than agricultural land application, at least in North America. This situation is perhaps due to the uncertain response of trees to wood ash in light of growth cycles longer than those associated with agricultural crops, competing understorey vegetation, wood species, climate, soil type and pH, and complex nutrient dynamics. Available research, conducted primarily in Scandinavian countries, documents application rates that have been proved beneficial on a site-specific basis, particularly on organic soils that are poorly buffered and depleted in macronutrients, such as calcium and magnesium, due to intensive harvesting or acidic, atmospheric deposition. Recycling nutrients back to the forest through the application of wood ash is a regulated practice in Denmark, Finland, Sweden, and Austria. These countries have implemented national legislation and recommendations on ash utilization on forest land, including recommended element concentration limits in wood ash intended for forest fertilization.

Based on the review of the available literature, several key variables have been identified as significantly affecting land application projects in general. These include ash properties such as its neutralizing ability, the bioavailability of its nutrient content, and particle size and form (i.e., dry vs. hardened). Heavy metal concentrations in wood ash are expected to impose little to insignificant environmental risk, especially when application rates are based on agronomic needs. However, land appliers should check with their regulatory agencies regarding prescribed allowable concentrations or loadings for heavy metals, if any.

Soil conditions are an important consideration. Before applying wood ash, users need to test their soil for pH, organic matter, moisture, soil texture and structure, cation exchange capacity, electrical conductivity, biological activity, and elemental composition. Application rates need to consider the crop, primarily its nutrient requirements and competing vegetation, and whether it is more effective to spread ash or incorporate it into the soil.

In addition to the extensive ash characterization and monitoring programs required in North America for agricultural application approvals, ash users must overcome some practical challenges. These include dust emissions resulting from the handling of dry ash, availability of suitable storage areas, variability in ash quality, effect on herbicide effectiveness, and transportation costs. The effectiveness of wood ash relative to that of agricultural lime, and the perceived effect of wood ash on the environment, are also among the concerns typically expressed by users.

Land Reclamation

Wood ash can also be used for reclaiming and revegetating acid mine spoils, mining sites, and tailing ponds. The most beneficial property of wood ash in this context is its acid neutralization capacity. Specific applications include the revegetation of tailing ponds, where a layer of wood ash is placed below the vegetation support layer, to prevent vegetation roots from reaching the tailings; or the use of wood ash as a substitute for limestone or lime-based materials, to neutralize acid mine drainage (AMD) collected at mining sites.

Construction Applications

Wood ash can also be used as an ingredient in the manufacturing of construction materials (e.g., concrete). In this regard, one of the most relevant characteristics of wood ash is its ability to combine with siliceous, and siliceous and aluminous compounds in the presence of water to produce a material with cementitious properties.

The addition of wood ash as a partial replacement for cement in concrete mixes typically results in decreased concrete workability, longer setting times, and reduced bulk density of the hardened concrete. The effect of wood ash on material strength is variable as it changes with the amount and quality of wood ash used, and the age of concrete. In general, the proportions of silica, alumina, iron oxide, and alkaline-earth and alkali oxides in wood ash, which primarily depend on combustion conditions and wood species, affect the degree to which wood ash can be used as a substitute material for cement in concrete mixes. Other relevant wood ash properties include fineness, given its effect on pozzolanic activity (i.e., the production of cementitious materials); sulfur trioxide and alkali contents, given their influence on concrete expansion; and especially, carbon content.

The relatively high carbon content of wood ash is a critical limiting factor because carbon tends to interfere with the surfactant action of air-entraining admixtures (AEAs). AEAs are added to the concrete mix to stabilize the air bubbles intentionally entrained into the concrete mixture through mechanical agitation. A specific amount of entrained air is necessary to ensure adequate workability and cohesion of the concrete mix, and improved resistance of the set material to freeze/thaw cycles. Given that fine particulate carbon is known to adsorb water and AEAs, the addition of wood ash in concrete formulations can affect air entrainment in the concrete and water requirements. This situation does not typically apply to coal ashes, which have much lower carbon contents than wood ashes.

Concrete standards limit the carbon content in fly ash to less than 6%; however, market requirements often impose stricter limits. Given this context, it is easy to see why wood ash is, in general, not the preferred choice as a partial replacement of cement in concrete mixtures. Several options can address this issue. One involves on-site reduction of carbon content by improving combustion conditions, recirculating/re-burning ash, or changing combustion technology (e.g., fluidized bed combustors). Another option is to explore the cofiring of wood and coal. NCASI is aware of pulp mills that have used coal-wood fly ash in concrete intended for the construction of highways and bridges, and coal-wood bottom ash as an aggregate material in asphalt mixes and concrete blocks.

If the issue of high carbon content cannot be addressed, an interesting outlet for wood ash is the manufacturing of materials of low-to-medium strength. In this regard, wood ash has been successfully tested as an additive in self-compacting controlled low-strength materials (CLSM), also known as flowable fill, i.e., structural fill material that is easily poured into place. Potential uses for CLSM include fill around foundations; structural fill under pipes, concrete slabs and footings, and in dams and bridge abutments; fill for utility cuts in roads; base material for sidewalks, flexible pavements, parking areas and low-traffic roads; and for stream bank stabilization and erosion control.

Geotechnical Applications

Wood ash has been used as an aggregate material in road construction and soil stabilization applications. Moisture content, particle size, bulk density, degree of contamination, and leachability are some of the relevant variables evaluated in this context. Generally, wood ash improves soil strength and stiffness, reduces frost heave, and increases the soil's bearing capacity and workability.

Research in Canada has shown that when applied routinely to forest haul roads, wood fly ash can increase the allowable load during the winter.

Field demonstrations in Europe have used wood fly ashes, in combination with deinking residuals, to renovate unpaved roads and to stabilize the soil under low-volume paved roads.

Another application involves the use of wood ash in earthen construction, particularly in embankments, dikes, or levees, where it serves as a core or filler material, and as a lower permeability material for the outer, exposed layer. Similarly, wood ash can be used as a leveling course, or as a layer prior to temporary or permanent covering of landfills.

Finally, wood ash and green liquor dregs have also been used as ill material in lagoons and landfills to bring them up to grade.

Use of Wood Ash as an Adsorbent

A high carbon content becomes an advantage when it comes to using wood as an adsorbent material. Indeed, wood ash with a carbon content of 27-32% has been found to have sorption characteristics similar to those of commercial activated carbon. The adsorption capability of wood ash has been used to remove volatile compounds and odor-generating compounds (e.g., reduced sulfur compounds) from gaseous streams, food-processing wastes and sludge. Wood ash has also been used in combination with cement kiln dust, to scrub air emissions from coal-fired cement kilns, with the resulting slurry by-product being beneficially used as fertilizer.

Another relevant application is the removal of various water-borne contaminants present in landfill leachates, process spills, and pulp and paper mill wastewaters. For instance, wood ash has been proven effective in removing color, chemical oxygen demand (COD), and lignin from wastewaters via two mechanisms, precipitation of lignin with calcium oxide and physical adsorption on wood ash particles. The removal of relatively low heavy metal concentrations from process wastewaters relies on the fact that some minerals in wood ash, primarily calcite, quartz and potassium-alumina silicates, exhibit, under alkaline conditions, a negatively charged surface that enables the adsorption of metal cations.

Compost and Top Soil Manufacture

During composting, organic waste is biodegraded under controlled aerobic conditions to produce a relatively stable material (compost) that is useful for amending soil purposes. Because wood ash is a significant source of plant nutrients, it is an excellent ingredient in compost feedstock mixes.

Wood ash is also a beneficial source of carbon. The biodegradation of organic wastes into a fertile compost heavily relies on achieving a proper balance between carbonaceous materials and nitrogen-rich materials. This balance has been experimentally determined at a carbon-to-nitrogen (C:N) ratio somewhere between 25:1 and 30:1. The addition of high-carbon wood ash to a lower-than-optimal C:N ratio mix helps reduce the loss of nitrogen (not used by the microorganisms) to the atmosphere. Wood ash also increases the porosity of the substrate, which in turn enhances oxygen transfer within the pile; acts as an effective odor-control agent; neutralizes fruit wastes and acidic materials; and imparts an appealing dark color to the compost product.

Wood ash has also been evaluated as a component in peat-based substrates for the manufacturing of container-grown greenhouse-grown crops such as flowers and tomatoes. Results show that substrates amended with less than 20% of wood ash by weight are suitable for plants grown in the 6.5-7.0 pH range.

Other Applications

The available literature also reports less-known options for the beneficial use of wood ash. These include use as

- a binding agent in the production of charcoal;
- a filler in plywood adhesives formulations;
- a nucleating agent for the manufacturing of glass-ceramic materials; and
- a replacement of lime, clay or cement kiln dust in the solidification of hazardous wastes.

For More Information

Member companies are encouraged to use NCASI's Practical Guide for the Beneficial Use of Forest Products Residuals ("GuBu") to access detailed information on the beneficial use options outlined in this briefing note. GuBu can be downloaded from the NCASI members-only website at http://www.ncasi.org/Programs/Sustainable-Manufacturing/Resources/Guide-for-Beneficial-Use-(GuBu)/Index.aspx

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