# Recycling and disposing of wood ash

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*Land application appears to be a safe, relatively simple, and economical method of ash disposal.*

The United States obtains approximately 2.7 quads of energy per year from biomass while producing 1.5-3.0 million tons of ash. In the future, energy from biomass should increase to 4 quads, and perhaps it will go as high as 10-20 quads (*1*). Most of this energy comes from paper mills, saw mills, and electrical generating plants that burn large quantities of wood residues to produce steam and electricity. The ash residue, generated at rates of 1-100 tons/day/site, is becoming a significant disposal problem as environmental regulations become more stringent and landfill sites become less available and more expensive. To date, the extent of the ash generation and disposal problem has not been fully recognized since biomass is viewed as a clean-burning, environmentally benign fuel.

## Wood ash

Wood ash is the inorganic and organic residue remaining after the combustion of wood. Ash content and chemical composition are variable among tree species and also depend on soil type and climate. Temperate-climate woods yield 0.1-1.0% ash, while tropical and subtropical woods yield up to 5%. Hardwoods, in general, contain more ash than softwoods.

Ash content is highly variable within the tree, being highest in the foliage and then decreasing in the bark, twigs, roots, branches, and stem. Within the stem, ash is highest in the pith, early wood (spring wood), and juvenile wood. Bark contains a much higher ash content than wood, as indicated by the 1-3% ash content in hog fuel.

Literature comparisons among industrial wood ashes are difficult since the moisture content, carbon content, and type of ash are not commonly mentioned. The physical and chemical properties of ash collected from combustion systems vary significantly depending on the temperature of combustion, the type of fuel (species of wood and amount of bark), and where it is collected in the combustion system.

Ash has a small particle size and low density. Density varies with the carbon content; the greater the carbon content, the lower the density of the ash and the lower the concentration of elements in the ash. The carbon content can vary from 1% in fluidized-bed combustion systems to 70% in inefficient burners, with 5-30% being a typical range (*2*).

The moisture content is also highly variable. Many ash collection systems commonly add water to cool the ash and reduce fugitive dust problems. Other ash collection systems use a wet-bottom furnace where the hot ash is dumped into recirculated water, and the suspension is sent into a settling pond or waste treatment system. The leached ash residue is ultimately dredged from the settling pond, dewatered, and then landfilled.

Ash is composed of major and minor elements needed by the tree for growth as shown in **Table I**. The major elements are calcium (7-33%), potassium (3-4%), magnesium (1-2%), phosphorus (0.3-1.4%), manganese (0.3-1.3%), and sodium (0.2- 0.5%). Essential trace elements for plant growth include zinc, boron, copper, molybdenum, and others at parts per million levels. Heavy-metal concentrations are typically low. With the concern over heavy metals, note that the total metal concentration in the ash is quite different from the extractable or available concentration. Also, wood ash is substantially different from coal ash, which has a lower alkalinity but higher silicon, aluminum, iron, and heavy-metal content.

The combustion temperature directly affects the total yield and chemical composition of ash. Some elements, particularly potassium, are volatilized at high combustion temperatures, thereby lowering their content in the ash.

The alkali metal and alkaline earth elements in the wood ash are present mainly in the form of oxides, hydroxides, and carbonates such as potassium oxide, calcium oxide, potassium carbonate, and calcium carbonate (**Table II**). The oxides react exothermically over time with moisture and carbon dioxide to form hydroxides and carbonates. These components produce a highly alkaline ash with a typical pH range of 11 to 13. The soluble potassium hydroxide and potassium carbonate react rapidly with acids, while the less soluble calcium hydroxide and calcium carbonate react more slowly.

## Potash production from wood ashes

From the 1700s through the early 1900s, wood was combusted in the United States to produce ash for chemical extraction. The wood ash industry in the Northeast actually generated $2 million in 1810. The ash was mainly used to produce potash for fertilizer, but some also went into soap and glass manufacture and into potassium cyanide used in the recovery of gold from tailings and low-grade ores (*3*).

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I. Elemental composition of five industrial wood ash samples and a ground limestone

| | Concentration, % | | | | | | |
|---|---|---|---|---|---|---|---|
| *Macroelements* | *Ash 1* | *Ash 2* | *Ash 3* | *Ash 4* | *Ash 5* | *Ash 6* | *Limestone* |
| Phosphorus | 1.36 | 0.69 | 0.33 | 0.79 | ... | 0.90 | 0.06 |
| Potassium | 4.17 | 2.86 | 1.66 | 3.08 | 2.60 | 3.00 | 0.13 |
| Calcium | 33.14 | 10.94 | 12.80 | 27.00 | 7.35 | 13.60 | 31.40 |
| Magnesium | 2.24 | 1.62 | 0.81 | 1.55 | 0.71 | 1.39 | 5.09 |
| Sodium | 0.30 | 0.16 | 0.20 | 0.27 | 0.54 | 0.15 | 0.07 |
| Aluminum | 2.43 | ... | 1.59 | 1.59 | 3.20 | 2.00 | 0.21 |
| Iron | 1.91 | 0.33 | 1.32 | 1.11 | 1.70 | 2.10 | 0.29 |
| Manganese | 0.67 | 0.35 | 0.66 | 1.27 | 0.33 | 0.91 | 0.05 |
| *Microelements* | | | *Concentration, ppm* | | | | |
| Arsenic | ... | 10 | ... | ... | ... | 3 | ... |
| Boron | 8 | 127 | ... | ... | 55 | 290 | ... |
| Cadmium | 26 | 3 | 4.2 | 7.9 | 4.4 | 16 | 0.7 |
| Chromium | 92 | 14 | 9.1 | 21.1 | 27 | 25 | 6.0 |
| Copper | 140 | 78 | 40 | 90.3 | 120 | 70 | 10 |
| Molybdenum | 123 | ... | ... | ... | ... | 3.0 | ... |
| Nickel | 50 | 12 | 11.6 | 49.1 | 47 | 50 | 20 |
| Lead | 127 | 66 | 38 | 72.2 | 59 | 70 | 55 |
| Sulfur | 4354 | 6800 | ... | ... | ... | ... | ... |
| Zinc | 692 | 794 | 200 | 381 | 370 | 560 | 113 |
| Mercury | ... | <4.9 | <0.1 | ... | <0.84 | ... | ... |
| Selenium | ... | <0.25 | ... | ... | 11.0 | ... | ... |
| Cobalt | ... | 4 | ... | ... | ... | 20 | ... |
| Antimony | ... | ... | ... | ... | <2.1 | ... | ... |
| Barium | ... | ... | ... | ... | 910 | 0.5 | ... |
| Vanadium | ... | ... | ... | ... | 79.0 | 27 | ... |
| Total nitrogen 600 | ... | ... | 500 | 500 | ... | 800 | 100 |
| *Chemical properties* | | | | | | | |
| $CaCO_3$ equiv. | 92.4 | 35.70 | 35 | ... | ... | ... | ... |
| pH | 13.1 | 12.94 | 11.9 | 12.7 | 11.7 | ... | 9.9 |
| Electrical conduct. | 160 | ... | ... | ... | ... | ... | ... |
| Combustibles | <5% | 32.18 | ... | ... | ... | ... | ... |
| Total solids, % | ... | ... | 72.4 | 99.71 | ... | ... | 100 |

Sources: Ash 1(*10*), Ash 2 (*18*), Ash 3 (*11*), Ash 4 (*12*), Ash 5 (*23*), Ash 6 (*2*), and Limestone (*12*).

The potash production process was unsophisticated and labor intensive (*4*). The soluble potash was leached from a battery of 18-24 leach vats containing 1.5-2 tons of wood ash per vat. Approximately 10 gallons of water were added three times a day to each vat for approximately 10 days. The weak lye solution was evaporated in pans and purified in melting kettles to yield a crude potash that might contain 44% potassium hydroxide, 19% potassium carbonate, 16% potassium sulfate, 6% potassium chloride, and 8% sodium carbonate (*3*). The yield from the ash was typically 4% potash.

Carson and Weeter (*5*) recently evaluated a more sophisticated continuous-flow ash extraction system, but problems with ash settling deterred further development. They also considered using rain to leach potash from an ash landfill into a liner and leachate control system. Problems with clogging, soil solubilization, and corrosion may limit this approach. Even though these ash extraction processes failed, other variations might yield a valuable potash product and also reduce the alkalinity of the ash, making it more acceptable for landfilling. On the other hand, the relatively low ash volumes available at particular sites, e.g. 10,000 tons/year from a 50-MW power plant, could make a potash extraction process impractical from an economic standpoint.

II. Typical reactions of wood ash components

| | | |
|---|---|---|
| $Wood + O_2$ | $\longrightarrow$ | $Charcoal + CaO + K_2O + M_xO_y + CO_2 + H_2O$ |
| $CaO + H_2O$ | $\longrightarrow$ | $Ca(OH)_2$ |
| $Ca(OH)_2 + CO_2$ | $\longrightarrow$ | $CaCO_3 + H_2O$ |
| $CaCO_3 + H_2O + CO_2$ | $\longrightarrow$ | $Ca(HCO_3)_2$ |
| $K_2O + H_2O$ | $\longrightarrow$ | $2\ KOH$ |
| $2\ KOH + CO_2$ | $\longrightarrow$ | $K_2CO_3 + H_2O$ |

## Disposal and utilization

Until recently, ash was a valuable raw material, but today ash wastes have a negative value due to their disposal costs. For the most part, ash is either landfilled (90%) or land applied. In the Northeast, approximately 15% of wood ash is landfilled, 80% is land applied, and 5% is disposed of in some other way, mainly as a sewage sludge composting

agent (*2*). Most other areas of the country landfill wood ash. In Europe, ash is used as a feedstock for cement production, a soil amendment on forest lands, and a road-base material (*2*).

Several ash disposal and utilization methods were evaluated in the late 1980s as environmental concerns increased. The research has used the high alkalinity and the absorbent nature of the ash to neutralize acidic wastes. Gray *et al.* (*6*) evaluated the treatment of landfill leachate with wood-coal ash. Ash columns were prepared in the laboratory, and landfill leachate was passed through them at a loading rate of 1 gal/day/ft$^2$. Approximately 33% of the BOD and COD and 88% of the total suspended solids were removed. In addition, the ash column removed 80-100% of the heavy metals. This study suggested that ash could be used to cover landfills or added to landfill leachates to reduce metal and organic content of leachate.

Ash has been used effectively in four Northeastern towns as a bulking and odor control agent in composting of municipal sewage sludge in aerated static piles (*7, 8*). In addition, ash has been granulated to yield a fertilizer and liming agent (*9*). Land application appears to be one of the best methods for ash disposal, recycling the nutrients taken from the land during harvest back to the land.

## Land application

Wood ash can be used to lime acidic agricultural and forest soils and replace micro- and macroelements removed during plant growth and harvesting (*10-16*). Ash has a low fertilizer equivalent (NPK ratio of 0:1:2), but it can be used as an excellent substitute for lime and limestone to neutralize acidic soils and to add calcium, potassium, and magnesium. Liming with wood ash may also reduce the toxic effect of aluminum and manganese in acidic soils (*5*). Ash will probably be sold in the future as a liming agent and soil amendment.

Land application of ash is presently being practiced in Maine, New Hampshire, Vermont, New York, and Oregon, and it appears to be a safe, cost-effective disposal method, assuming transportation distances are relatively short. The application rate should be limited to a level that maintains the soil pH within acceptable ranges for plant growth.

### Agricultural land application

Naylor and Schmidt (*12*) evaluated wood-ash liming characteristics and macro- and microelement availability in soil. An industrial wood ash, equivalent to a 0-1-3 NPK fertilizer, was mixed with two soil types in pots at application rates of 0, 2.24, 4.5, 9.0, 17.9, and 35.9 metric tons/ha. After two months of incubation, the extractable phosphorus, potassium, and calcium and the pH of the ash were linearly related to the rate of ash application.

Naylor and Schmidt (*11*) also conducted a field study on the growth of alfalfa, applying ash at 0, 9.4, 11.7, 17.3, 22.6, 31.2, and 49.8 metric tons/ha. The wood ash was equivalent to a 0-1-2 NPK fertilizer and had a total neutralizing value (TNV) of 35, compared to limestone as a standard with a TNV of 100. The ash increased the exchangeable concentration of potassium, calcium, manganese, and magnesium. The exchangeable iron and aluminum decreased because of the rise in soil pH. Hay yields and protein content increased at all application rates compared to the control. The application rate had little impact on the trace metal composition of the alfalfa. In general, the ash appeared to be a good soil amendment and liming material, even at high application rates.

Lerner and Utzinger (*14*) performed a field study using ash from four different wood species, plus a species mix. The ashes had an average composition of 26% Ca, 7% K, and 1% P and an effective calcium carbonate equivalent range of 83-116%. In a field study using application rates of 2.4-9.7 metric tons/ha, the ash increased the soil pH but had no net effect on snapbean growth and yield.

Research by Etiegni *et al.* (*10*) evaluated wood ash at high and normal application rates as an agricultural soil supplement and liming material in a greenhouse study. Wheat and poplar were grown on six different Idaho soils amended with different ash concentrations (0, 40, 80, 160, 320, and 640 metric tons/ha). In addition, wheat was grown at 0, 2.5, 5, 10, and 20 metric tons/ha. No detrimental effects were observed at ash levels equal to or lower than 40 metric tons/ha. In fact, the biomass of the wheat and the caliper and height of the poplar cuttings increased more at 40 metric tons/ha than with the control soil, probably because of the increase in soil pH and availability of soil nutrients.

A second greenhouse study examined the phytotoxicity of wood ash at high application rates on snapbean growth and yield (*17*). The alkalinity, potassium content, and boron content of the ash were examined as potential toxicants. The experiments demonstrated that the alkalinity was the most important growth limiting component in ash, but potassium was also an important limiting element. Research in progress is evaluating the response of spring wheat in a field study to different application rates of wood ash as compared to limestone (*18*).

Magdoff *et al.* (*15*) evaluated land application of wood ash in a greenhouse and laboratory research project. Two soils were mixed with wood ash, limestone, and a limestone-ash mix (90:10). Plant growth, nutrient uptake, and soil chemical changes were measured during the growth of corn and alfalfa. Ash gave better growth responses than limestone. The effect of over-liming was reduced when ash was added with the limestone, probably due to the extra nutrients in the ash. The study demonstrated that wood ash could be used as an effective liming material by following the currently recommended guidelines for limestone. Magdoff recommended that crops should not be planted immediately after ash application, as ash absorbs herbicides and pesticides and could cause concentrated alkaline conditions before neutralization by the soil. Magdoff also recommended that because of ash variability the calcium carbonate equivalent should be measured routinely.

Zibiliske and Clapham (*19*) evaluated wood ash as a liming agent and soil amendment in a greenhouse experiment with spinach, a pH-sensitive plant. Spinach yield per pot increased linearly with the ash application rate up to the target pH.

Gray and Rock (*16*) simulated the effect of precipitation on the leaching of ash components after land application. A loamy sand and a silt loam soil were mixed with wood ash at a loading rate of 27 metric tons/ha, and then water at a pH of 5.6 was added to the column at a rate of 90

$cm^3$/day. The study concluded that ash could be applied to the loamy sand at 12 metric tons/acre but should be applied at a lower rate on the silt loam.

In summary, wood ash is a valuable liming agent and soil amendment that enhances agricultural productivity. Ash can be used as a substitute for agricultural lime, and it also provides supplemental macro- and microelements needed for plant growth. Land application appears to be a safe method for disposal and utilization of ash.

### Forest land application

Weber *et al.* (*20*) studied the effect of wood ash and NPK fertilizers on microbial activities over a three-year period in an intensively cultivated, acidic, nitrogen-rich peat soil planted with *Salix sp.* The wood ash increased all microbial activities that were examined: nitrogen availability, mineralization, cellulose decomposition, nitrogen fixation, and denitrification.

Lumme and Laiho (*21*) examined the effects of conifer bark ash on the growth of fast growing willow (*Salix aquatica*). The ash was considered to be a good phosphorus, potassium, and magnesium fertilizer and liming agent. The elements in the ash were released more slowly than those in the fertilizer, showing a higher release in the second growing season. No significant increase in microbiological activity was observed. The study suggested that ash application rates of 5–10 metric tons/ha were beneficial, while at higher rates (10–20 metric tons/ha) the ash may interfere with plant nutrient uptake.

Forest land spreading will probably grow in importance because forest land is available and close to ash producers. In addition, forest nutrients will have to be replaced, particularly with more intensive forest growth and harvesting practices. The application of ash to forest land is more difficult than to agricultural land, but mechanical equipment is improving. One problem with forest land spreading is that the pH requirements for forest trees are not fully established, and there are fears that ash could increase soil pH and thereby favor the growth of undesirable hardwoods over softwoods.

### Commercial land spreading

Resource Conservation Services (RCS), a private marketing company in the Northeast, is presently land spreading wood ash from several wood-fired plants (*22*). RCS has placed a positive value on the ash based on its potassium, phosphorus, magnesium, lime, and micronutrient content. The heavy-metal content is typically below the minimum state standards of Maine and New Hampshire (**Table III**), but the cadmium content can sometimes exceed the strict state limits of 10 ppm. Table III also compares the metal content of ash, limestone, and a typical soil. Land spreading of ash is regulated in Maine and New Hampshire, but ash is licensed like limestone in New York.

Ash is applied based on the calcium carbonate content of the ash and the equivalency needs of the particular soil. For example, if two tons of lime are needed per acre and the ash has a 50% lime equivalency, then four tons of ash would yield the proper liming rate. Ash can be spread with conventional manure spreading equipment and is either top-dressed or incorporated. Ash is also applied as a mixture with limestone and paper mill sludge (*23*). During the winter, ash is stockpiled to avoid runoff problems that could contaminate groundwater.

**III.** A comparison of the maximum heavy metal standards allowed in Maine and New Hampshire with the concentration in an average ash (22), limestone, and soil

| | Concentration, ppm | | | |
|---|---|---|---|---|
| *Metal* | *Maine and N.H. standards* | *Ash* | *Ground limestone* | *Average soil* |
| Cadmium | 10 | 3.5 | 0.04 | 0.06 |
| Chromium | 1000 | 26.1 | 11 | 100 |
| Copper | 1000 | 123 | ... | 20 |
| Lead | 700 | 28 | 9 | 10 |
| Nickel | 200 | 75.5 | ... | 40 |
| Zinc | 2000 | 521.6 | ... | 50 |

**IV.** The concentration of total and extractable metals in an industrial Northwest wood ash as compared to the maximum extractable metal concentrations allowed in the EP toxicity test before classification as a hazardous waste

| *Metals* | *Total metal conc., ppm* | *Soluble metal conc., mg/L* | *Maximum metal conc., mg/L* |
|---|---|---|---|
| Aluminum | 11,000 | <2 | ... |
| Antimony | <300 | <3 | ... |
| Arsenic | <20 | <0.2 | 5.0 |
| Beryllium | 0.3 | <0.01 | ... |
| Barium | 1,100 | 0.7 | 100 |
| Boron | 110 | 2.0 | ... |
| Cadmium | 6.9 | 0.04 | 1.0 |
| Chromium | 14 | <0.1 | 5.0 |
| Cobalt | 5 | <0.1 | ... |
| Copper | 54 | <0.1 | ... |
| Iron | 8,500 | 3 | ... |
| Lead | 28 | <0.1 | 5.0 |
| Magnesium | 14,000 | 110 | ... |
| Manganese | 3,300 | 13 | ... |
| Mercury | <0.2 | <0.005 | 0.2 |
| Molybdenum | 4 | <0.1 | ... |
| Nickel | 14 | <0.1 | ... |
| Selenium | <50 | <0.3 | 1.0 |
| Silver | <2 | <0.1 | 5.0 |
| Strontium | 470 | <0.2 | ... |
| Thallium | <200 | <2 | ... |
| Tin | <10 | <0.2 | ... |
| Titanium | 450 | <0.1 | ... |
| Zinc | 570 | 0.7 | ... |

pH = 13.4 at 1:2 dilution.

In Maine, wood ash is classified as a specified waste, which requires regulatory approval prior to land spreading. The first step requires the landowner to prepare an application for land spreading. The site is examined using soil and topographic maps to determine its suitability. A soil scientist then collects soil samples and recommends loading rates based on desired crops and specific soil

characteristics. The company generating the ash then reviews the application and sends copies to the Maine Department of Environmental Protection (DEP), town officials, and the landowner. The Maine DEP then sends copies to various agencies for review and comment and also re-examines the suitability of each site. The approval process takes approximately six months.

Agri-Tech, another private marketing company, operates a similar program in western Oregon (*24*). The ash is managed as an industrial by-product in a beneficial use program under Oregon law. The State of Oregon Department of Environmental Quality (DEQ) does not require permits for each individual property but does require quarterly and annual reports identifying which properties are involved. County governments regulate ash utilization to the extent that they are responsible for land use issues and solid waste disposal. Some counties require that every adjacent property owner be notified by mail that the ash is to be applied on a given site.

The Agri-Tech program uses modified manure spreaders with light four-wheel-drive tractors. This equipment increases the length of the spreading season, but stockpiles are required during the wet months. Application rates are limited to a maximum of three tons of lime equivalent per acre, which matches the agronomic rate used in local farm operations. Soil samples are collected and analyzed before and after the ash application.

## Disposal costs

With more strict landfill regulations and a decreasing number of acceptable sites, the cost for landfilling has increased abruptly and is certain to continue. Landfill costs vary widely. Based on 1989 costs in Maine and New Hampshire, the tipping fee at a "secure" landfill, with a liner and leachate collection and control system, was $55–75 per ton (*22*). A wood burning facility producing 5000 tons of ash per year (14 tons/day) would have annual tipping costs of $275,000–$375,000 plus transportation costs. Landfill costs in other sections of the country are lower because landfill regulations are not as strict. Land application of ash is approximately 33–66% less costly than landfilling in the Northeast (*2*).

## Regulatory questions

Many regulatory agencies have difficulty in classifying wood ash. Under the Resource Conservation and Recovery Act, ash is not characterized as a hazardous waste because there are no pH criteria for a solid. But the State of Washington classifies wood ash as a dangerous waste when its pH exceeds 12.5. This classification necessitates special handling and disposal procedures which have caused major problems for several ash generating facilities. For example, a pulp and paper mill in Washington attempted to neutralize its ash for three months with sulfuric acid, but the cost was prohibitive.

Heavy-metal concentrations in ash do not appear to be a significant problem. As shown in **Table IV**, the extractable metal concentrations of a Northwestern wood ash did not exceed the limits of the EP Toxicity Test (*25*) for classification as a hazardous waste. Ash produced from mixed fuels such as wood, coal, and municipal waste may have higher heavy-metal concentrations.

Zinc at 200–800 ppm will probably be the rate-limiting metal component in land application of wood ash. Cadmium, averaging 6–15 ppm, does not appear to be a problem when ash is applied at reasonable application rates. For example, the maximum annual cadmium loading is 0.5 kg Cd/ha/year (*26*), and the maximum cumulative loading is 5 kg Cd/ha on a soil with a cation exchange capacity of less than 5 meg/100 g and a pH of less than 6.5. The pH and potassium thresholds for the land will be exceeded long before the land is limited by cadmium and zinc. From past and current research, it appears that application rates based on the liming requirements of the soil pose little risk to the environment.

## Conclusions

Wood ash should not be viewed as a problem but as a valuable raw material containing elements concentrated by plants and the combustion process. The recycling of ash back to agricultural lands can help improve soil productivity and also conserve valuable landfill space. Land application appears to be a safe and economic method for disposing of and utilizing wood ash.□

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1 quad = $10^{15}$ Btu.

1.0 ton/acre = 0.91 metric ton/ha.