# Alternative management of pulp and paper industry solid wastes

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*ABSTRACT: Research concerning the management of pulp and paper industry solid wastes has centered on conventional alternatives. This report focuses on nonconventional methods. It provides information on past and present research activities as well as a discussion of paper industry experience with alternative solid waste management programs. The discussion includes many sludge management alternatives including several which have recently received considerable attention and considers lime grit, green liquor dregs, wood ash, and bark.*

*KEYWORDS: Bibliographies, sludge disposal, solid wastes, waste management.*

As early as the 1940s, forest product companies, researchers, entrepreneurs, and knowledgeable individuals have sought to identify alternatives for the management of paper industry solid wastes. These efforts have resulted in a considerable volume of research and actual experience related to the efficacy of a wide variety of solid waste management techniques. Some of these techniques have proven to be viable, environmentally safe waste management alternatives. Most research in the area of solid waste management has centered on the conventional alternatives of landfilling, burning or incineration, and land application *(1)*.

The focus of this paper is the management of paper industry wastes by nonconventional methods. The information will convey the breadth of nonconventional solid waste management alternatives and identify sources of information which may have value for those wishing to pursue a particular alternative. There is not a comprehensive assessment of each solid waste management alternative. Much of the research on the various alternatives occurred when landfilling was less costly and viewed with more acceptance than it is today. Present day judgments about the feasibility of some options may therefore differ from those made at the first proposal of the concepts.

The information presented here comes from a combination of published literature and unpublished information. The volume of published literature dealing with pulp and paper industry waste management alternatives is quite large. NCASI's internally maintained information was the primary resource used to support this effort *(2)*.

## Alternative management of sludge

### Recovery of raw materials from sludge

Paper industry sludges frequently contain significant percentages of both cellulose fiber and papermaking fillers such as clay and titanium dioxide. There have been attempts to reduce sludge volume by reclaiming the fiber or filler or both for reuse.

Although reclamation of usable materials from sludge does occur, the industry more commonly uses in-mill loss control measures as the primary means of recovering raw materials. NCASI has previously documented many of these pollution prevention strategies *(3–7)*. Although the discussion of in-mill loss control strategies is beyond the scope of this paper, it is important to note that such practices can substantially reduce the fiber and filler content of sludge. The degree to which

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some mills employ these practices may affect the potential benefits of reclaiming waste material from sludge.

There are several means to recover raw materials from sludge. One of the most common is to recycle primary sludge back into the mill's fiber processing system. Recycled paperboard mills commonly use this technique *(1)*. Some manufacturers of unbleached and bleached pulp and paper have also practiced recycling primary sludge back to the mill with limited success *(8–11)*. Segregated effluents from paper machines, bleach plants, and various cleaning and screening operations can be good targets for fiber reclamation because they usually lack contaminants such as bark or causticizing waste solids.

Using some fractionation scheme for the sludge may also provide recovery of fiber alone. The complexity of fiber recovery systems varies widely and depends upon the nature of the constituents in the sludge. The final configuration of most systems results from a combination of research and trial and error *(8, 9, 11)*. Mills producing bleached pulp sometimes add recovered fiber to the unbleached pulp entering the bleach plant *(8, 9, 11)*. This strategy allows for both the reclamation of unbleached fiber and the brightening of previously bleached fiber which may have been "dirtied" by exposure to contaminants in the wastewater. Some mills have associated the reuse of fiber recovered from sludge with increased deposits of pitch on equipment.

Use of fractionation systems will recover filler. Most systems for which pilot- or full-scale data are available have employed a thermal oxidation technique for destroying the organic fraction of the sludge to yield filler in the form of an "ash." Experiments with calcination systems have revealed that controlling the kiln temperature between 816°C and 843°C helps to avoid formation of fused agglomerates which can cause the recovered filler to be excessively abrasive *(12)*.

Wet air oxidation (WAO) will also recover filler materials from sludge. At least one U.S. mill presently practices this process on a full scale. WAO is an oxidation reaction carried out in a liquid environment under high temperature and pressure. The process is capable of reducing sludge volume through oxidation of the organic fraction to yield an ash composed of inert materials, e.g., filler clay, titanium dioxide, and calcium carbonate, for reuse in the papermaking process *(13)*. Initial experience with the operation of a WAO unit for filler recovery revealed problems with calcium sulfate and calcium oxalate scale deposition *(14)*. Both pilot- and full-scale systems have demonstrated some problems with low brightness of the recovered filler *(14)*.

## Sludge use in building and ceramic materials

Perhaps the most widely researched area of alternative solid waste management has been the use of various wastes as feedstock in the manufacture of building materials such as cement, bricks, ceramics, and concrete. Some lightweight aggregate, a product contained in some of these building materials, has used sludge as a component.

Sludge use in building products has followed three general techniques. One method is the use of sludge as a feedstock to a cement kiln. Raw materials used to produce cement can include calcium carbonate, clay, silica, and smaller amounts of aluminum and iron. Some sludges contain significant quantities of these materials. At least two companies have extensively investigated this alternative, and at least one mill currently practices this full-scale *(15, 16)*. The mill sends all its primary sludge and all its coal boiler ash to the cement manufacturer. This is a combined total of approximately 100 tons/day. For the kiln involved, this amount of material represents only about 2% of the total feedstock.

Another alternative is the use of sludge in cementitious products. There has been wide study of the use of organic fibers including wood pulp in cementitious composites. Potential advantages of adding organic fibers to cementitious composites include increased durability and pumpability as well as reduced shrinkage-related cracking *(17)*. Two studies undertaken to assess the performance characteristics of composites which included paper industry sludge concluded that a composite material potentially useful in building blocks, wallboards, panels, shingles, fire retardants, and filler materials for fireproof doors could result from combining Portland cement with sludge from deinking mills *(17, 18)*. Experiments indicated that mixtures including Portland cement, ash, sand, and sludge yielded a compressive strength comparable to conventional concrete and superior flexural strength. Researchers caution, however, that the results come from short-term evaluation of test composites. Unsatisfactory experience with other cellulosic fillers requires long-term durability and dimensional stability testing of the material *(17)*.

The production of lightweight aggregate (LWA) has also used sludge. Aggregate is a term describing a collection of materials used as filler in construction materials. Aggregates find use in cementitious products such as concrete, masonry, building blocks, and asphalt. Sand and gravel or both are typical aggregate materials mixed with cement to produce concrete. LWA refers to a select group of materials which allow for reductions in final density while maintaining acceptable strength properties. Products which sometimes incorporate LWA include concrete block, architectural panels, and decorative stone.

There is little published literature on the use of paper mill sludge in the production of LWA for cementitious composites. Two organizations have conducted recent experiments using paper mill sludge to produce LWA. One process uses a proprietary mixture of paper mill sludge, ash, and other additives *(19)*. A temporary pilot facility has produced 18 tons of LWA for test marketing. Results of this effort appear positive. The company plans to construct a permanent pilot plant for product research and development.

## Pelletization of sludge

The pelletization of primary or combined sludges is not new to the pulp and paper industry. Following are some reasons for production of sludge pellets:

- Volume reduction
- Odor control
- Recovery of fuel value
- By–product applications.

The most common reason for production of pellets is for use as an alternative fuel. One mill transports dewatered sludge to an off–site pellet mill for drying and formation into pellets. The mill purchases the finished pellets as a fuel supplement. The finished pellets contain 15–20% moisture and 10% ash. They have a heating value of 14.7 x $10^6$ J/kg (6325 Btu/lb) *(20)*.

Mixtures of sludge and nonrecyclable paper (NRP) can be used to produce fuel pellets. At least two companies now manufacture such pellets *(21)*. They market these pellets as an alternative fuel compatible for use in most stoker and some pulverized coal boilers. The amount of sludge in these pellets can range between 10% and 66%. Manipulating both the sludge content and the grade of NRP used can control the fuel value of the pellets. Finished pellet fuel values are in the range of 14–23 x $10^6$ J/kg (6000–10,000 Btu/lb). Most state regulatory agencies require evaluation of alternative fuels for by–products of combustion before widespread use of the fuel. Companies involved in both production and use of sludge and NRP fuel pellets have indicated that regulatory reaction to trial burn data has generally been positive.

One organization has developed a proprietary process to convert combined sludge from a recovered paper deinking mill into a granular product. The product has use as a carrier material for agricultural as well as home and garden pesticides. It can compete with other common pesticide carrier materials composed of clay, vermiculite, diatomaceous, and cob products. Claims for the product indicate that it is superior to some of these conventional carriers because it is dust–free and attrition resistant *(22)*. The company's production facility has a capacity of 180 tons/day of the granular product.

Kitty litter, poultry litter, and large animal bedding have all used pelletized sludge. At least one U.S. mill processes all of its primary sludge into several varieties of animal litter sold to a distributor for marketing. The litter production process is proprietary. It involves sanitizing and deodorizing primary sludge followed by drying and pelletization. Kitty litter is the primary product manufactured, but other products include large animal bedding, pet bedding, and bedding for laboratory animals. Grocery stores market kitty litter, and feed stores market bedding products. Bedding sells in 25– and 50–lb bags and 1000–lb tote bins *(23)*.

Several other companies have studied the feasibility of using sludge to produce kitty or poultry litter. In these cases, they have usually demonstrated production of a quality litter product from primary sludge. Initial capital costs, distribution and marketing issues, and incompatibility with company business strategies have inhibited some companies from pursuing this by–product alternative.

## Composting and synthetic soils

Research into the feasibility and potential benefits of composting pulp and paper mill sludges was most prevalent between about 1975 and 1985. Pulp and paper sludges are usually amenable to well controlled composting techniques *(24, 25)*. Markets for compost include land application for agriculture, horticulture, land reclamation, landscaping, and individual consumer use *(24)*.

At least one mill has had considerable success with marketing its composted sludge *(26)*. This mill presently composts 50% of its sludge. The mill sells the compost to a limited number of distributors who market the material in an area within a 250–mile radius from the mill *(27)*.

Initiation of new composting operations within the industry has slowed considerably since the mid–1980s. Lack of sufficiently large, locally available markets for compost and regulatory concerns about the possible presence of chlorinated dioxins and furans in industry sludges are two common reasons for the limited utilization of this management alternative. Recent industry initiatives to reduce the presence of dioxin in sludges are likely to relieve some regulatory concerns about land application of sludges.

Recently, a mill in the northeastern United States began working with a third party company to produce synthetic topsoil using sludge *(28)*. The process involves the homogenization of sludge with varying proportions of sand, gravel, and fertilizer to produce a synthetic soil. More than a dozen landfills have used the soil as part of the final cover. It also has use in other applications requiring vegetative cover. The pulp fiber content of the synthetic soil probably allows for an increased resistance to erosion before the establishment of vegetative cover *(29)*.

### Sludge as a feedstock for ethanol production

Ethanol is a common additive in automobile gasoline. The traditional methods used to produce ethanol involve the fermentation of hexose sugars derived from starches or syrups. Efforts to reduce production costs and make ethanol more widely available have led to research into the production of ethanol from nontraditional cellulosic feedstocks such as agricultural waste, municipal solid waste, and pulp and paper mill sludge.

The production of ethanol from cellulose biomass is fundamentally different from ethanol production from starches *(30)*. Both starch and cellulose are polymers of the 6–carbon sugar, glucose. The α–1,4 linkage between glucose units in starch easily hydrolyzes in the presence of enzymes while the ß–1,4 linkage in cellulose does not undergo ready attack *(31)*. Cellulose comprises only about 45% of wood mass. The chemical structures of the other major wood constituents, hemicellulose and lignin, are not glucose polymers. Lignin does not readily hydrolyze to simple sugars and hydrolysis of hemicellulose yields a variety of nonglucose hexose and pentose sugars *(32)*. Laboratory and pilot–scale efforts to produce ethanol from wood–based feedstocks have used both acid and enzymatic hydrolysis followed by fermentation of the resulting sugars into ethanol *(30, 33–35)*. Primary sludges are a target as a feedstock for ethanol production for the following reasons:

- They are widely available in sufficient quantity.
- Sludges have little or no economic value. In some cases there can be a fee for handling them.
- When the fibrous component of sludge contains chemically pulped wood, only a small amount of lignin is present compared to unpulped or mechanically pulped wood.

Recent research conducted at the University of Florida has targeted conversion of cellulose and hemicellulose fractions of cellulose–based feedstocks into hexose and pentose sugars followed by fermentation to ethanol using a genetically–engineered strain of *Escherichia coli (36)*. Claims for this process indicate the advantage of converting sugars derived from hydrolysis of both cellulose and hemicellulose into ethanol to increase the overall yield of ethanol. Full–scale application of this technology may occur *(37)*.

### Sludge in animal feed products

There are two basic techniques for using sludges in animal feed. One is to incorporate sludge directly into animal feed mixtures. This method exploits the presence of carbohydrates which are primarily in the form of cellulose and other nutrients present in primary or combined sludges. Research in the early 1970s included experiments on the palatability and digestibility of sludge–augmented feed mixtures on goats, sheep, and cattle. The data suggest that the digestibility of sludge relates directly to the carbohydrate content and inversely to the ash and lignin content. Hardwood pulp residues tend to be more digestible than softwood residues *(38–40)*.

A second method for using sludge in animal feed involves production of cell protein. Cell protein is present in secondary sludge and derives from the fermentation of fibrous sludge. It is then possible to dry these proteins and incorporate them into feed mixtures. One U.S. mill installed a process to convert secondary sludge into a salable protein product for use in animal feed *(41, 42)*. Mechanically dewatering secondary sludge to 12% solids with further dewatering by feeding a mixture of sludge and oil to specially designed, multiple effect falling film evaporators produced a 45% protein material. Centrifugation of the evaporator discharge gave 83% dry solids, 1% water, and 16% oil. Targeted markets for the finished product included feed for cattle and poultry and use in agricultural composting *(41)*. Unfortunately, acceptance of the product in these markets was not sufficient to support continued production.

### Sludge as landfill cover barrier

Research has shown that some paper industry sludges exhibit low hydraulic conductivity (permeability). This finding has led to research by NCASI and others on the potential utilization of sludge as hydraulic barrier layer in landfill cover systems. In 1987, NCASI completed construction of 4 pilot–scale field test cells designed to allow investigation and comparison of the performance of hydraulic barrier layers made from sludge and made from clay. Data obtained from these cells during the first 5 years of operation indicate that the sludge barriers perform as well or better than the clay barriers *(43, 44)*.

Experience with the use of paper industry sludge as daily, interim, and final cover for paper industry and municipal landfills is available *(43, 45, 46)*. Worthy of special mention is the experience of one organization *(47)*. To demonstrate the utility of paper mill sludge as landfill–capping material, this recovered fiber processing mill constructed 6 test cells to compare the performance of primary sludge, combined sludge, and clay as hydraulic barriers. Data from these test cells sufficiently supported a petition to the Massachusetts Department of Environmental Protection for a full–scale demonstration project. The project involved capping a 2 hectare municipal landfill with combined mill sludge. To date, monitoring of cap performance indicates the demonstration has been successful. The company has received a "beneficial use determination" which allows use of the sludge in other landfill cover systems in Massachusetts.

### Sludge destruction by nonconventional methods

Investigators have studied pyrolysis or gasification and supercritical water oxidation (SCWO) as a way of reducing sludge volume. Pyrolysis is the gasification or liquification of organic matter by heat either in the total absence of oxygen or in the presence of a controlled amount of oxygen. By-product gases and oil-like liquids occur during pyrolysis. Both of these have some fuel value. Ash or "char," a solid by-product from the pyrolysis reactor, contains inert material and unreacted carbon complexes. There has been study of pyrolysis of cellulose-based waste materials, but there is very little published information on experience with pyrolysis of pulp and paper industry wastes *(21, 48, 49)*. There have been pilot studies on the application of this technology to wood chips, recycle mill sludge, and bleached kraft mill sludge. Research on a larger pilot-scale may occur *(50)*. There is no report on a full-scale experience with the pyrolysis of sludge.

SCWO has undergone research as a waste management technology for approximately 10 years *(52)*. The process involves the decomposition of organic and some inorganic material in the aqueous phase above the critical point of water (374°C and a pressure of 22 x $10^3$ kPa). In this state, organic materials become much more soluble in water and oxidize readily. The principle of SCWO is similar to that of wet air oxidation except that wet air oxidation maintains subcritical conditions. No full-scale SCWO units are currently in operation.

There is laboratory-scale research on SCWO of a pulp and paper mill sludge. This work used an 80 $cm^3$/min benchtop system. Operating limits for the reactor were 600°C and 25.5 x $10^3$ kPa. Residence times in the reactor ranged between 10 s and 10 min. In the experiments, a 99% reduction of total organic carbon was possible *(52)*. Some potential problems with larger-scale or full-scale systems have been suggested. These include corrosion of equipment particularly for low pH and high chloride concentration wastes and deposition of salts or pyrolitic chars which could lead to plugging or increased cleaning requirements *(51)*.

### Miscellaneous alternatives

The literature includes a variety of other sludge management alternatives. **Table I** lists these with corresponding references for obtaining additional information. Most of these have received relatively little recent investigation.

## Management of nonsludge solid waste

Most of the research on alternative management of nonsludge wastes has focused on uses for ashes and kraft mill causticizing wastes—grits, dregs, and lime mud. Most of this research has targeted various land application techniques for the beneficial use of these materials. Other applications include use of both ash and causticizing wastes in road construction and the use of ash as a filler in concrete products.

### Lime grit and green liquor dregs

At least two kraft mills in the United States use dewatered slaker grits for road construction. One mill uses the material for on-site roadways and sells it for use in construction of public roadways. This company has found that roadways constructed with lime grit are more capable of handling heavy truck traffic and need less maintenance than unpaved roads constructed of native soils. One disadvantage is that dust from the grit and sand road is finer and can migrate farther than that produced from native soil roads. The grit has better liquid-holding capacity than native soils improving the efficiency of dust suppression techniques.

### Wood ash

Wood ashes are useful geotechnical materials of construction *(62)*. Construction applications include the use of ash as a core material in dikes or levies. This application uses ash as a filler and a lower permeability material for the outer, exposed layer. Experience with using wood ash for these applications indicates that to maintain stability it is critically important to keep the ash from becoming saturated with water. Erosion and dusting may be problems with exposure of the ash surface. Ash also makes an excellent leveling course before temporary or permanent covering of landfills.

Studies have also examined the use of coal and wood ash as extenders in cement. In some cases, unacceptably high levels of unburned carbon in the ash have limited the use of this alternative. Some techniques for reducing the carbon content of ash include size fractionation, electrostatic or magnetic separation, and combustion *(63)*. Wood ash has also found use as an additive to compost *(64, 65)*. The benefits of adding wood ash to compost include color enhancement and odor control. Ash used as a bulking agent consumes less space than bark and does not need screening from the finished compost as is usually necessary with bark *(65)*.

### Bark and wood waste

Bark, particularly pine bark, is a decorative landscaping material. The market for landscaping material, however, is considerably smaller than the amount of bark produced by the forest products industry. Bark is also a bulking agent in composting operations. Like other bulking agents, bark provides the compost pile or windrow with sufficient porosity to allow aeration of the compost material *(24)*.

## Summary

Identification and evaluation of management options for paper industry solid wastes have been common research topics for more than 50 years. The pulp and paper industry has conducted or sponsored most of the research. The most attention in the literature has concerned identification of alternative management options for wastewater treatment plant sludges.

Full-scale experience suggests that the viability of alternative management strategies primarily depend upon four factors:

- Technical feasibility
- Cost
- Available markets
- Potential liability.

The relative significance of these factors varies depending on mill type, mill location, waste type, and company business strategy.

Recently there has been considerable interest in some of the solid waste management alternatives discussed in this paper. These include the following:

- Production of light-weight aggregate
- Production of granules to carry agricultural chemicals
- Pelletization of sludge and nonrecyclable paper for use as fuel
- Production of ethanol from sludge
- Use of sludge in cement kiln feedstock
- Use of sludge as hydraulic barrier material in landfill capping systems.

The interest in these particular waste management opportunities probably relates mostly to their potential for using significant amounts of sludge. With the exception of ethanol and light-weight aggregate production from sludge, full-scale operations have successfully demonstrated each of these alternatives.

I. Miscellaneous sludge management alternatives

| Alternative | Reference |
|---|---|
| Hydrolysis of secondary sludge | 53 |
| Sludge disposal in kraft process | 54, 55 |
| Binder for iron ore concentrates | 56 |
| Calcium magnesium acetate | 57 |
| Molded products | 58 |
| Wall board | 59 |
| Mushroom culture medium | 40, 60 |
| Oil absorbent | 40 |
| Filler plastics | 61 |

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