Industry Residuals: How They Are Collected, Treated and Applied

August 2006

Prepared by

Ashley Corker
Environmental Careers Organization Grantee

for

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation and Field Services Division
Washington, DC
www.epa.gov
www.clu-in.org

NOTICE

This document was prepared by an undergraduate student during an internship with the U.S. Environmental Protection Agency (EPA), sponsored by the Environmental Careers Organization. The report was not subject to EPA peer review or technical review. The EPA makes no warranties, expressed or implied, including without limitation, warranty for completeness, accuracy, or usefulness of the information, warranties as to the merchantability or fitness for a particular purpose. It does not create or impose any legally binding requirements or reflect the policy or views of the U.S. EPA. Moreover, the listing of any technology, corporation, company, person, or facility in this report does not constitute endorsement, approval, or recommendation by the EPA.

The report is intended to provide an overview of industry residuals that are normally considered a waste but may be extremely useful in the remediation of disturbed soils. In deciding which soil amendments to research, experts in the remediation field were consulted. After the amendments were chosen, a variety of technical documents, books, and Web pages were consulted. As a general rule, every attempt has been made to use peer-reviewed information and technical documents from authoritative sources. These include technical papers/reports, books, research articles and abstracts, U.S. EPA and other agency documents and commercial database searches.

The report is also available on the Internet at www.clu-in.org/studentpapers/.

About the National Network for Environmental Management Studies

The National Network for Environmental Management Studies (NNEMS) is a comprehensive fellowship program managed by the Environmental Education Division of EPA. The purpose of the NNEMS Program is to provide students with practical research opportunities and experiences.

Each participating headquarters or regional office develops and sponsors projects for student research. The projects are narrow in scope to allow the student to complete the research by working full-time during the summer or part-time during the school year. Research fellowships are available in Environmental Policy, Regulations and Law; Environmental Management and Administration; Environmental Science; Public Relations and Communications; and Computer Programming and Development.

NNEMS fellows receive a stipend determined by the student's level of education and the duration of the research project. Fellowships are offered to undergraduate and graduate students. Students must meet certain eligibility criteria.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1. Purpose

This report is intended for remedial project managers (RPMs), field personnel, others in the remediation sector, and anyone else who is interested in learning about the beneficial use and possible application of industry residuals as soil amendments. These materials are too often considered waste and disposed of as such. Application on land of the residuals not only provides remedial advantages, but also decreases pollution and the need for landfill space. This document is not intended to act as regulatory guidance, but simply to give an overview of alternate solutions to the reclamation of contaminated lands by providing information on:

- The processes that generate certain residuals;
- The quantity of each residual generated each year;
- What is currently being done to dispose of each residual;
- Possible uses for remediation;
- Advantages and disadvantages of residual use on land; and
- Examples of the use of residuals.

1.2. Methodology

A soil amendment, for purposes of this project, is any industry residual that is normally considered a waste but may be extremely useful in the remediation of disturbed soils. In deciding which amendments to research, experts in the remediation field were consulted. The residuals that had the most promising outlook for use on land were selected:

- Biosolids from municipal water and wastewater treatment
- Concentrated animal feeding operations (CAFOs) manure
- Coal combustion by-products: fly and bottom ash, flue gas desulfurization (FGD) gypsum
- Pulp and paper wastes: lime-based residues, fiber sludge, water treatment plant (WTP) residuals
- Red mud
- Sugar beet lime
- Wood ash
- Yard waste and wood trimmings

After the amendments were chosen, a variety of technical documents, books, and Web pages were consulted. As a general rule, every attempt has been made to use peer-reviewed information and technical documents from authoritative sources. These include technical papers/reports, books, research articles and abstracts, U.S. EPA and other agency documents and commercial database searches. (See section 5.)

To summarize this information, two tables were created. Table 1 concentrates on the beneficial use (applications) of each residual, as well as the quantity produced each year, and Table 2 focuses on the current disposal methods (use), as well as case studies.

Generally, amendments provide either an alkaline pH for remediation of acidic soils, such as sugar beet lime, or are rich in organic matter and nutrients with the ability to complex metals, such as manure and biosolids. Many of the materials chosen are not well-documented in the remediation field. This report hopes to influence a change in that. However, information concerning other types of land application (i.e. agriculture) was available.

Table 1: Amendment Applications

Amendment	Location (see appendices)	Remediation Use	Quantity Generated/ Year	Advantages	Disadvantages
Biosolids		Compost	About 12 million dry tons (2006)	Increasing landfill costs; neutral pH	High transportation costs
Waste-water	All populated areas	Improve soil characteristics; provide C, N, other macro- and micronutrients; improve water-holding capacity and infiltration	6.9 million dry tons (1998)	Complexes heavy metals; dewatered for easier handling; similar to finely textured soil	Public has "fecal phobia;" may leach into water sources; unpleasant odor
Raw water	Near sources of surface water, groundwater, and people	Decrease P runoff; provide Al, Fe		Low in trace elements of concern	Highly variable composition
CAFO	Everywhere in U.S.	Provide C, N, P, K, Ca, Mg, S; stimulate microbial activity; increase water-holding capacity		High C:N; neutral pH; high in organic matter; high water-holding capacity; high availability; lower cost than fertilizer	Low bulk density; needs large application rate; may release VOCs into air; unpleasant odor; "fecal phobia"
Chicken	Centered in AL, AR, CA, DE, GA, MD, MS, NC, TX, VA	C:N = 9-10; compost with bedding to increase C content and to decrease moisture and odor	63.5 million tons (2002)		Given As to kill parasites, promote growth- evident in manure
Cow	CA, IA, KS, KY, MO, MT, NE, OK, SD, TN, TX,	C:N = 18-19; high in Ca; low moisture good for composting	663 million tons (2006)		May excrete excess P
Pig	IA, IN, NC	C:N = 13; high protein	102.9 million tons (2005)		May excrete excess N

Amendment	Location (see appendices)	Remediation Use	Quantity Generated/ Year	Advantages	Disadvantages
Coal Combustion by-Products	Nationwide (Except in ID, RI, VT)		1.28 million tons from pulp and paper industry (1995)	Widespread location	
Bottom ash		Use in concrete; raise soil pH; provide C, Ca, K, other micronutrients; decrease soil permeability and erosion; reduce	17.2 million tons (2004)	Coarser texture (good for drainage); less trace metals than fly ash	Contains trace elements (but not harmful to health); dusty and hard to transport
Fly ash		compost odor	70.8 million tons (2004)		
FGD Gypsum		Improve soil texture and drainage quality; raise soil pH; provide Ca, S; keep some crops free of disease; mix with lime and fly ash to reduce acid mine drainage	11.95 million tons (2004)	Low cost (compared to agricultural lime); high B is optimal for peanuts, cotton, potatoes and some fruit trees	May cause B contamination if applied in excess or to B-sensitive crops
Pulp and Paper	Eastern and Northwest U.S.				
Lime mud, slaker grits, green liquor dregs		Raise pH; seal landfills; provide Ca, Mg, Fe; liming capability	Over 1.3 million dry tons (1995)	Cheaper than commercial lime	Often reused at mill; may be unavailable for purchase

Amendment	Location (see appendices)	Remediation Use	Quantity Generated/ Year	Advantages	Disadvantages
WPT residuals (wood fiber, non-organics)		Provide macronutrients, micronutrients and microbial mass	Over 5.83 million dry tons (1995)	Rarely hazardous	Small traces of metals; variable composition
Fiber sludge		Seal landfills; reduce soil erosion; carbon source	Over 1.26 million dry tons (1995)	Will not leach heavy metals; odorless	Does not decompose easily; low pH (~5)
Red mud	LA, TX	Raise pH; improve soil structure; reduce P leaching; decrease eutrophication	6.3 million dry tons (2006)	Contains Fe, Ti, Na, Si, Al; non-toxic	Contains high As levels; slightly caustic
Sugar beet lime	CA, CO, ID, MI, MN, MT, ND, OR, TX, WS, WY	Raise pH (agricultural lime substitute); Ca	Over 98,000 tons (1997)	Location; cheaper and less dusty than pelletized lime	May only be available to sugar beet growers
Wood ash	Everywhere, concentrated in the Eastern and Northwest U.S.	Raise pH; provide P, K, Ca, Mg; improve soil texture; reduce odor of biosolids in composting; lime substitute	About 3 million tons (1998) - 1.05 million dry tons from pulp and paper industry, 1995)	Very organic; finely grained; low in heavy metals and toxins	May have overly alkaline pH; little N value; hard to spread uniformly; regulatory issues
Yard waste	Everywhere (not as common in desert and city areas)	Burn for energy; reduce N leaching; carbon source; use in compost	Over 27.7 million tons (1999)	Increasingly hard to landfill	High transportation costs

Table 2: Amendment Use

Amendment	**Current Disposal Method**	**Case Examples** (See section IV for more details)
<u>Biosolids</u>		
Wastewater	41 percent land-applied 12 percent treated (compost) then land-applied 7 percent misc. beneficial use 17 percent landfilled 22 percent incinerated 1 percent other disposal	1997-99: Bunker Hill, ID. The EPA, USDA, University of WA and others set up test plots (33 x 33 m) on the high-metal soil and treated with a mixture of biosolids sources, wood ash and log yard waste (except one blend). A native grass seed mix was planted with biosolids application. The effect of the biosolids was a decrease in extractable Zn and increases in pH as well as vegetation (grasses). See www.epa.gov/region10/.
Raw water	Like biosolids from the wastewater process, raw water treatment residuals are often land applied, but are also incinerated and landfilled.	1994-99: Poland. A team of EPA, USDA, VA Polytechnic, and Polish scientists incorporated digested, dried biosolids (w/ lime on smelter site) into the top 20 cm of the mining and smelter waste sites. The grass yield on the mine site was uniform, and there was an average 80 percent vegetative cover on the smelter sites by 1996, as well as a significant reduction in toxicity. See www.epa.gov/owm/mtb/biosolids/polabroc.pdf.
<u>CAFO</u>	*Much of the manure from CAFOs is land-applied; however, excess manure may be incinerated or landfilled if necessary.	
Chicken	Dry manure is normally composted or surface applied, and semi-solid liquid is also usually applied to land after a storage period.	1996-00: Coastal Plain Experiment Station, Tifton, GA. Gary Gascho et al. applied various rates of broiler chicken litter to cotton, peanuts, grain and wheat. Although the composition of the litter varied, results show that higher application rates of the litter correspond to higher crop yields.
Cow	Dairy manure is a solid or slurry, and is commonly stored before applied to land, although it may be applied directly after collection. Beef cattle manure in solid form may be applied directly to land after collection, although liquid or slurry must be stored before land application.	1994-95: CA. In a study to monitor the nutrients in soil after dairy manure application, Deanne Meyer and Lawrence Schwanki irrigated six large dairy farms in CA with fresh water and liquid dairy manure. Results show that dairy manure is an effective source of nutrients for corn, grain, cotton and alfalfa, especially when applied uniformly.

Amendment	**Current Disposal Method**	**Case Examples** (See section IV for more details)
Pig	Liquid manure is typically stored in a lagoon or a tank under the animals' holding area and eventually applied to land. Bedding may be added to solid manure where it falls. This forms a sort of compost and is collected every few months, usually for land application.	2000-01: IA. Dr. John E. Sawyer et al. performed a project meant to spread awareness about the use of swine manure on land. Some 23 field demonstrations were conducted throughout Iowa, applying liquid pig manure to corn and soybeans. Results show that N and P in manure are extremely plant available, as soil concentrations of both elements increased significantly with increased applications of swine manure.
<u>Coal Combustion by-Products</u>*	*Remaining percentage of products is disposed of in landfills or other permanent, non-beneficial fashions	
Bottom ash	4.6 percent in concrete 3.4 percent in cement .12 percent as a soil modified/stabilizer .23 percent in mining applications .11 percent in agriculture 38.94 percent in other beneficial use	2004: Allentown, PA. John Buck and Larry LaBuz used bottom ash (or "sand fines") from two steam electric stations, mixed with various percentages of soil, on test plots and compared them to the site's control soil and normal soil. All test cylinders (80 x 80 cm) were also amended with spent mushroom compost and pelletized poultry manure before seeding with ryegrass. The bottom ash proved to increase drainage and pH. It was concluded that adding the nutrients bottom ash normally lacks makes it a soil equivalent.
Fly ash	19.9 percent in concrete 2.2 percent in cement .7 percent as a soil modifier/stabilizer 1.6 percent in mining applications .07 percent in agriculture 14.08 percent in other beneficial use	1988: Palmerton, PA. EPA and the Zinc Corporation of America applied combination of fly ash, biosolids, limestone and potash to 1,000 acres of the smelting waste site on Blue Mountain. Fly ash improved the handling of the biosolids by reducing moisture, and also reduced surface temperatures and increased infiltration. After 100 days, the roots of 11 out of 12 plant species had penetrated the contaminated soil. See http://www.epa.gov/reg3hwmd/npl/PAD002395887.htm.
FGD Gypsum	2.4 percent in concrete 3.8 percent in cement 68.2 percent in wallboard 1.1 percent in agriculture .2 percent in other beneficial use	

Amendment	**Current Disposal Method**	**Case Examples** (See section IV for more details)
<u>Pulp and Paper</u>		
Lime mud, slaker grits, green liquor dregs	80 percent landfilled/lagoon-stored 6.4 percent land applied 12.6 percent misc. beneficial use 1 percent recycled/reused (1995)	
WPT residuals (wood fiber, non-organics)	51 percent landfilled/lagoon-stored 12 percent land applied 26 percent burned 5.5 percent misc. beneficial use 5.5 percent recycled/reused in process (1995)	1985: New Augusta, MS. Georgia-Pacific's Leaf River Mill began its land application program and has since beneficially used all of its WTP residuals. 80 percent of the residuals are applied to company-owned forest land, with the remaining percent applied to farms within a 25-mile radius.
Fiber sludge	48.1 percent landfilled/lagoon-stored 1.3 percent land applied 22.2 percent burned 13.6 percent misc. beneficial use 14.8 percent recycled/reused (1995)	
<u>Red mud</u>	Typically disposed of in land-based storage area such as landfills and monofills.	2006: Italy. P. Massanisso et al. used a mixture of red mud and municipal sludge waste on mine tailings. Red mud raised the pH, improved the soil's structure and reduced the mobility of heavy metals and plant toxicity.
<u>Sugar beet lime</u>	The lime residue from the Michigan Sugar Company (MSC) is applied back on the fields of their growers as a soil enhancement, and about 90% of the Southern Minnesota Beet Sugar Cooperative's (SMBSC) lime is applied back on to farmers land each year. American Crystal Sugar Co. disposes of most of its lime in onsite landfills, although a small portion is used by farmers.	1993: Bay City, MI. Monitor Sugar Company created a test site on which they applied four different rates of the lime waste from its processing plant to corn, navy beans and sugar beets. N, P and K were added, although no micronutrients were applied. Results illustrate that no adverse effects occur to any of the crops with an application rate up to five tons per acre every three years and that yields of sugar beets are slightly increased with the addition of waste lime.

Amendment	Current Disposal Method	Case Examples (See section IV for more details)
Wood ash	Roughly 70 percent landfilled, 20 percent land applied; remaining 10 percent has miscellaneous uses. (2003)	1990: Mansfield, LA. International Paper began to investigate used of its boiler bark ash by applying a 5:1 mixture of the ash and paper fiber to ryegrass crops. pH and crop yield were significantly increased over control plots. P, K, Ca, S and B concentrations increased, and those of Mn and Al decreased.
Yard waste	There has been a recent effort in communities to recycle yard waste, mostly by composting. Waste is collected periodically, more often during the fall when leaves are present and taken to a composting site. If it is not recycled, yard waste is incinerated or landfilled.	2001: New York City, NY. Department of Sanitation provides separate collection for fall leaves and yard waste. Collected items are taken to "parks" (large, undesirable vacant lots) for composting. Leaves are removed from plastic bags and placed in 12' x 8' x 100' windrows and periodically watered and aerated. Most of the finished compost is used by the city's Parks Department for reclamation. 2,000 cubic yards is given to residents and another 1,000 cubic yards is given to community gardens/groups.

2. AMENDMENTS

2.1. Biosolids

Biosolids are stabilized residuals that result from the treatment of water and wastewater. Through the various treatment processes (outlined below), matter filters out and settles to the bottom, and is eventually treated to destroy pathogens. This material is usually about 50 percent organic and contains several nutrients, which makes it and excellent soil conditioner.

2.1.1. Municipal Wastewater Treatment

2.1.1.1. Introduction

Although it is assumed that the "raw" and wastewater treatment processes are very similar, they have two major differences: 1) Raw water has a much higher pre-treatment quality, and 2) The goal of wastewater treatment is not to make it potable. The vast majority of water that comes out of sewage treatment plants is released back into a water source (Hopkins, 2005).

2.1.1.2. Generation and Collection Processes

Primary Treatment and Grit Removal. As water enters a treatment plant, it passes through a screen that is mechanically raked and catches large debris. This debris is not part of the residual sludge. Next, the velocity of the water is carefully controlled to catch heavier particles as it passes through a sand and grit-removal system (Jenness, 2000). The larger, inorganic solids that result from this process are not considered biosolids and are normally landfilled. Then the sewage passes into a large tank where most of the organic matter sinks to the bottom (sedimentation) (Jenness, 2000), and other wastes (such as grease and plastic) float to the top where they can be skimmed off. The sludge at the bottom of the tank is scraped towards and pumped to the next stage of treatment. Forty to fifty percent (Cornell, 1996) of solids are removed during primary treatment, and most of the sludge produced is organic matter.

Secondary Treatment. During secondary treatment, a variety of processes (depending on the plant) are used to break down the leftover organic contents of the wastewater. In all systems, however, the water goes into an aeration tank (Cornell, 1996). Here microorganisms are used to remove most of the remaining solids (up to 97 percent) and reduce the biochemical oxygen demand (a measure of the oxygen required by microbes to decompose organic matter) (Hopkins, 2005). After this step, the water undergoes secondary sedimentation, and the newly formed sludge is pumped out. The remaining water contains very little organic content and suspended matter (Cornell, 1996). This is the minimum treatment required under the Clean Water Act of 1972 (Jenness, 2001).

Tertiary Treatment. The purpose of the tertiary stage, also known as "effluent polishing," is to raise the quality of the water before it is replaced into the water source. Metal and pathogen content are the focuses of this stage. Chlorine is usually used to kill pathogens (disease-producing organisms) (Hopkins, 2005). A variety of other chemicals, such as iron, lime and salts, are used to lower metal concentrations. Qualities of the sludge produced depend on the chemicals used (Jenness, 2001), but residuals from this treatment stage are not suitable for land application.

Sludge Treatment. Sludge that is land applied must meet certain requirements as outlined by the EPA in the 40 CFR Part 503 rule (Jenness, 2001). Class A biosolids have undergone such a rigorous treatment that pathogens are virtually eliminated. Class B biosolids still contain pathogens, so several restrictions apply to their use. These restrictions include the maximum level of pathogens in the material, maximum application rates, time between applications, etc.

There are several sludge-treatment options available, and plants may use one or more of the following. Alkaline stabilization involves using lime or another alkali substance to raise pH, which decreases pathogens and immobilizes heavy metals. Aerobic (with oxygen) and anaerobic (without oxygen) digestion stabilize sludge through biological conversion (turning organic matter into water, methane, etc.) In the digestion process, the sludge is simply held in a tank (a closed tank if anaerobic) of some sort and left alone. Composting biosolids (especially with a high-carbon source) produces a product with excellent soil conditioning ability. There are several ways to compost: sludge can be set in piles and either left alone or occasionally aerated, or placed in windrows (Brown and Henry, 2006). Heat drying kills pathogens and is a good way to reduce both volume and odor. Many biosolids are dewatered, or separated from water by force, because this process reduces transportation costs. Also, if the biosolids are to be incinerated, they must have as little water content as possible.

2.1.1.3. Location, Quantity and Current Disposal Methods

Wherever there are people, there are biosolids. In 1998, 6.9 million *dry* tons (USEPA, 1999) (wet tonnage would be a significantly larger number) of biosolids were produced across the 50 states. As the population has increased in the past eight years, wastewater sludge production has grown accordingly. Using EPA Office of Water's Permit Compliance System, or PCS (see Appendix 1), it was estimated that roughly 12 million dry tons of sludge will be generated in 2006. Because cities have more people, they also generate the most biosolids. Ironically, they also have the least amount of space to be used for the disposal of biosolids, whether for land application or otherwise. Before the Ocean Dumping Ban Act, harbor cities such as New York and Boston used to carry biosolids via barge into the ocean for disposal. The 1998 Act prohibits the disposal of municipal sewage sludge in oceans (USEPA, 1988). Now the options for sludge discarding are landfilling, land applying, incineration, or some other beneficial use.

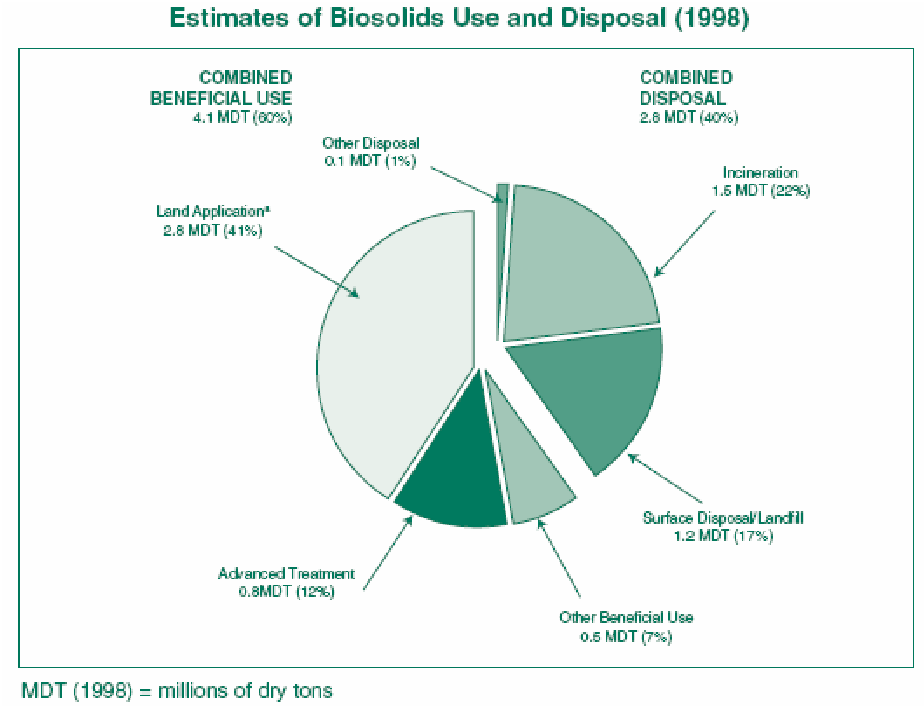

Figure 1: Biosolids generation, use and disposal in the U.S., 1998 (adv. treatment = composting)

In recent years, land application has become more common due to increased tipping fees at landfills, high energy requirements for incineration, and rising transportation costs, as well as concern for the environment. Sixty percent of biosolids generated in 1998 (see Figure 1) were somehow reused, with 17 percent land filled and 22 percent incinerated (USEPA, 1999). Although municipalities, especially those in cities, must still pay high transportation costs, they normally receive compensation for biosolids used on land. Another sensible reason for using sludge for land application is that the time and money must be put into the treatment of sludge no matter what is done with it afterwards. A benefit should be associated with that cost.

2.1.1.4. Beneficial Reuse

Biosolids have an amazing ability to remediate several potential problems in disturbed soils. They have an ideal pH, a number of necessary nutrients, and are about 50 percent (Brown and Henry, 2006) organic matter. In addition, sludge tends to contain a very low amount of trace metals. Rarely are biosolids deemed hazardous.

Although biosolids have an ideal pH for growing conditions, the addition of a liming material is normally needed to increase the pH of the soil after biosolids incorporation. Agricultural lime has been most often used previously, but residuals such as coal ash, flue gas desulfurization (FGD) gypsum, sugar beet lime, and wood ash have the same alkaline quality. Using these industry residuals should be preferred because they are all materials that would otherwise end up in landfills.

Biosolids contain all of the macronutrients, but the most plant-available are nitrogen (N) and phosphorous (P). Almost contradictorily, biosolids also help soil retain these nutrients so that leaching to water sources is less likely. As well as having noticeable macronutrient deficiencies, soil can have less significant micronutrient deficiencies. Normally biosolids contain enough micronutrients to correct any of these minor problems.

The organic matter contained in biosolids provides a better growing medium for plants. It helps aggregates form in the soil, which increases the soil's water infiltration properties. Organic matter will also increase the water-holding capacity, decreasing the chances of drought-like conditions in the soil, which is extremely important in areas that tend to get sparse rainfall.

While it is true that biosolids are rarely considered harmful, much research has been done on the amount of trace and heavy metals that they contain. A particular element of concern is cadmium (Cd) because the negative effects of the element are seen in humans before they are shown by plants (Brown and Henry, 2006). Fortunately, biosolids have the ability to complex trace metals (Sopper, 1993), making them unavailable to both plants and animals.

One of the more popular sludge treatment techniques mentioned in section 2.1.1.3. is composting. By mixing biosolids with a material that has a high carbon to nitrogen ratio (C:N), a wonderful soil-like substance is created. Because of the general need for high application rates of biosolids, composting will normally reduce the chance of excess N being added to the soil, also decreasing the likelihood of N leaching to groundwater (Brown and Henry, 2006). Composting significantly reduces what some in the biosolids industry refer to as "fecal phobia," or the general public dislike of using biosolids on land. Compost, however, is readily accepted and sold in garden centers everywhere as a fertilizer.

2.1.2. Municipal Water Treatment

2.1.2.1. Introduction

Water that is distributed to homes by municipalities must be treated. In some scarcely developed places, no treatment may be needed because of a lack of pollution. In these cases, water may be collected directly from wells or streams near residences. For example, the melting snow runoff is filtered as it trickles down Mount Rainier in Washington in small streams and is perfectly safe for a thirsty hiker to refill his or her water bottle with. The vast majority of drinking water, however, must be purified to standards set by the federal government.

2.1.2.2. Generation and Collection Processes

All "raw" water, or water that comes from a surface or groundwater source, that is pumped by a municipality into a home must be treated. The location of the water source, such as a mountain stream versus a river next to a large city, determines the quality of the water, and therefore the extent to which the water must be treated. The purification process may consist simply of a single filtration or chlorination, or it may contain variations of the following:

Initial filtration: A course screen is used to remove larger debris, such as fish, bugs, and twigs.

Coagulation/Flocculation: A chemical substance, such as an alum or lime, or a substance containing microorganisms is added to the water. These substances bond smaller particles together and then form a sticky, fluffy-looking mass (State of Utah, 2005).

Sedimentation: The flocculent particles are now dense enough to be separated from liquid. The most commonly used form of sedimentation is simply to allow the mass to settle to the bottom of the tank, while the liquid is pumped out (City of Toronto, 2006). More recently, however, plants have been using a method in which clarified water is injected into the bottom of the tank, which causes air bubbles to rise to the top. As they ascend, they attach to floc, so that there is a "blanket of sludge" created on the top of the water that can be removed periodically with mechanical scrapers (State of Utah, 2005).

Secondary filtration: Sometimes, to catch tiny particles remaining after sedimentation, water is filtered through sand or gravel, which will allow most of the liquid to pass through undisturbed but catch other particles (City of Toronto, 2006).

Aeration: Air bubbles are forced though the water to release gases that may smell or taste unpleasant. This process provides oxygen to micro-organisms which eat the majority of remaining organic matter in the water (City of Toronto, 2006).

Disinfection: A chemical, normally chlorine, is carefully added to the water to kill germs (State of Utah, 2005). Sometimes sodium or lime is used to "soften" the water, and some municipalities add fluoride to their water to help prevent tooth decay.

2.1.2.3. Location, Quantity and Current Disposal Methods

The sludge that is removed during sedimentation is normally sent to a digester, where microorganisms are added to convert organic material into gases (such as methane) and water, and a tremendous reduction in pathogens occurs (City of Toronto, 2006). Sometimes filter presses or centrifuges remove the water (dewatering) before the sludge is sent to be landfilled, incinerated, or in some cases land applied. The liquids are usually sent to evaporation pools.

2.1.2.4. Beneficial Reuse

Water treatment residuals are good candidates for land application because of their high organic content, and their innate similarity to finely textured soil (*Grounds Maintenance* Magazine, 2001). While the residuals contain some trace metals, the concentrations of those that may be dangerous in excess are low enough not to cause a hazard. The residuals can drastically reduce phosphorus runoff (*Grounds Maintenance* Magazine, 2001), and because of this, they are beneficial for use on soils with excess phosphorus (P), which also protects surface water from contamination. On the other hand, it is to a disadvantage to use residuals on P-deficit soils because too little P doesn't support optimal growth.

In addition to the benefits described above, water treatment residuals may be used for many of the same purposes as wastewater treatment biosolids, especially composting. The composition does tend to differ, though, so testing should always be performed before application. In light of stricter water quality standards, the quality of sludge has decreased over the years. Since more impurities are removed from water, more impurities are found in sludge. So far, however, this hasn't seemed to affect the benefits of its use.

2.2. Concentrated Animal Feeding Operations (CAFOs) Manure

2.2.1. Introduction

A CAFO is a subcategory of animal feeding operations (AFOs). An AFO is any facility where animals "have been, are, or will be kept" for a total of 45 days (not necessarily consecutive) in a period of 12 months. The 12 months *are* consecutive, but the animals do not need to be the same animals for all 45 days. A CAFO fits the same description, except that it is larger. The number of animals that qualifies for a CAFO depends on the type of animal, as well as the type of manure handling system. A facility is also considered a CAFO if the EPA has designated the area as such according to standards set in the 40 CFR 122 rule (USEPA, 305-F-03-009).

2.2.2. Collection Processes

Due to the huge variations in the sizes of animals (chickens and cows), the facilities used to house different types of animals must be different, and the methods for collecting manure must also differ. All types of animal manure may be stored in the same types of systems, depending on the solids content of the material.

2.2.2.1. Chickens

Chicken centers may have collection gutters underneath the cages that range from six to 12 inches in depth with a "slick" concrete finish. PVC pipe is used to pump liquid through each gutter and then into an outside collection box. If it is not pumped directly into the storage site, the manure is then moved to the proper area (Barker, #131-88, March 1996) A belt-collection technology system consists of a belt that moves underneath the cage inside a tank to catch manure as it drops. The belt is slightly convex, and there are gutters on either side to catch any liquids as they run down. The solids remain on the belt and are carried to the end of the facility to be transferred to a storage location (University of Missouri, 2004). For free-ranging chickens, bedding is placed in the pens to absorb liquid. Periodically this bedding/manure mix is removed and replaced with fresh bedding. This material is excellent for composting, but also may be applied directly to land.

Liquid and semi-solid liquid manure can be stored in lagoons. Lagoons are excellent for places that have a relatively high yearly rainfall. Anaerobic lagoons are very deep, with very little surface area required. Aerobic lagoons require much more land because a large surface area is needed for adequate oxidation. Mechanically aerated lagoons require less surface area and can be much deeper, like anaerobic ones, but they have high power costs because of the need to run the machines consistently (Barker, #040-77, March 1996) Tanks are also used to store manure and are frequently anaerobic.

Manure is often sorted into its solid and liquid components. In this case, the solids are sent to a tank to be composted and the piqued liquid is sent to a lagoon for digestion.

2.2.2.2. Cows

Cows spend their time in pastures, holding pens and feed stalls. Manure that is excreted in the pasture is left there to act as fertilizer. Anywhere else, manure is collected and moved to a treatment and storage area. Stalls will have either concrete, slatted, or partially slatted floors (*Manure Management Program,* 2004). In concrete stalls, the manure must be scraped out daily.

Sometimes gravity is used to an advantage by building the storage tank or lagoon on a downhill slope. Partially or slatted floors have a tank underneath that can provide longer term storage. These tanks can either be scraped or flushed out with recycled lagoon water (Barker, #103-83, March 1996). Lagoons (both aerobic and anaerobic) are commonly used at plants that have flush systems.

Lately, “honey vacs” (*Manure Management Program,* 2004) have become a common way to remove manure from stalls. A honey vac is a tanker with a high powered vacuum, capable of suctioning up fresh manure, whether solid or slurry. The tankers then take the manure to the storage or processing area, or sometimes apply the manure immediately to land. Most often the manure is kept in a lagoon or tank, but recently a “weeping wall” basin has been used (*Manure Management Program,* 2004). These basins remove 60 percent of the solids content (*Manure Management Program,* 2004), produce high quality manure, and can be large enough to hold a year’s worth of manure.

Other techniques that can be used but are less common are the constructed wetlands and methane digester approaches. Constructed wetlands involve aerobically digesting the manure while plants absorb nutrients. Land application is still required of the water used in a constructed wetland. Methane digesters are closed containers where manure is being anaerobically digested, and the methane gas produced in that process is collected and converted to energy. Due to increased cost and/or labor of these techniques, none of them have been widely used (“Environment,” 2006).

2.2.2.3. Pigs

Manure-collection systems used for pigs in stalls are very similar to the traditional scraping and flushing methods used to clean the under-stall tanks for cows, as well as the belt-collection technology originally developed for chickens. A “high rise” approach is sometimes used, although not very often, because of higher cost and labor. The living area in a high-rise has a slatted floor and is above a storage area that contains a carbon source (i.e., sawdust). The materials are mixed periodically, and composting occurs (“Environment,” 2006). Liquid manure is also stored in aerobic and anaerobic lagoons.

2.2.3. Location, Quantity and Current Disposal Methods

According to a survey done by the Economic Research Service for the USDA, CAFOs comprise only 4.5 percent of the total feeding operations in the United States. But they are responsible for 47 percent of the 499.31 million tons of manure produced in 2005 (USDA, ERR-9).

2.2.3.1. Chickens

Poultry operations are centered in the top ten poultry production states of Alabama, Arkansas, California, Delaware, Georgia, Maryland, Mississippi, North Carolina, Texas and Virginia, although they may be found throughout the continental United States. In only one year, chickens alone in the U.S. can produce up to 63.5 billion tons (USDA, *Census of Agriculture, Table 27,* 2002; USDA, 2000, nps00-0579) of manure* (2002). Much of the collected chicken manure is disposed of beneficially, either by land application, reuse as bedding, or even as feed supplements in animal diets. A good deal, however, is still sent to a landfill or incinerated.

2.2.3.2. Cows

States that dominate dairy production are California, Nebraska and Texas. Nebraska and Texas are also major beef producers, along with Missouri, Oklahoma, South Dakota, Montana, Kansas, Iowa, Kentucky and Tennessee. In 2006, it was estimated that the cows in the U.S. will produce 663 million tons (USDA, 2000, nps00-0579; USDA, *United States and Canadian Cattle,* 2006) of manure*. Much of this manure, like that of chickens, is largely reused on land, although it is also incinerated and landfilled.

2.2.3.3. Pigs

The swine industry is greatest in Iowa, Indiana and North Carolina. Manure produced by all swine facilities throughout the U.S. is estimated to be 102.9 million tons (USDA, 2000, nps00-0579; USDA, *United States an Canadian Hogs*, 2006) (2005)*. As for cows and chickens, a large amount of pig manure is land applied (often after composting), with the remaining sent to landfills or incinerators.

*Quantities of manure produced by individual animals are for all animals, not just those in CAFOs.

2.2.4. Beneficial Reuse

Because manure is mostly organic material, and often high in nitrogen (depending on animal diets and storage conditions), it can be a good source for macronutrients (N, P, K, Ca, Mg, S) (Edwards and Someshwar, 2000). However, a significantly larger amount of manure is needed to provide soil with the same amount of nutrients that commercial fertilizer can provide. Yet because of the availability and reduced cost of animal manure or compost, it may still be the better solution for farmers. In addition to providing nutrients, animal manure helps stimulate microbial activity and increases water-holding capacity (Edwards and Someshwar, 2000).

Some disadvantages to land application of manure, besides the quantity required, include possible P or NO3-N contamination of surface and groundwater sources, storage difficulties, and the large amount of additives added to feed. Such additives are As, Co, Cu, Fe, Mn, Se, and Zn. Most of these pass through the animal, making them evident in manure. However, the amounts are usually not enough to have adverse health effects (Edwards and Someshwar, 2000).

2.2.4.1. Chickens

The ideal carbon to nitrogen ratio (C:N) for soil is 15-40:1. Chicken manure has a C:N equal to about 9 or 10 (Edwards and Someshwar, 2000), and when it is mixed or composted with bedding or another high-carbon source, such as wood chips and yard waste, the ratio is much higher. In addition to providing more carbon, the bedding decreases the moisture content and drastically reduces odor. Some growers give the chickens arsenic to kill parasites and promote growth, which is evident in the manure, but this practice is now less accepted, and therefore being phased out of the chicken industry.

2.2.4.2. Cows

The carbon-nitrogen ratio for cow manure is typically 18 or 19. Calcium concentrations (an essential nutrient for plant growth) tend to be higher, and usually there is a relatively low moisture content. Besides having a high Ca content, cow manure also has an increased phosphorous level. This could cause leaching of P if applied in excess.

2.2.4.3. Pigs

The manure produced by pigs normally has a C:N of roughly 13. It is high in protein, so there is the potential for the manure to leach excess N when applied to land.

2.3. Coal Combustion by-Products (CCPs)

2.3.1. Bottom and Fly Ash

2.3.1.1. Introduction

Given the large number of coal-fired power producing facilities in the United States, it is no wonder that there is so much coal ash being sent to landfills. While a decent percentage of bottom and fly ash is used in construction materials, only a tiny percent is finding its way back to the land.

2.3.1.2. Generation and Collection Processes

Coal ash results from the combustion of coal, a common source of energy. Two kinds of ashes result from this process: fly ash, which, as its name suggests, rises up from the fire into the air; and bottom ash, which sinks to the ground during combustion. After fly ash leaves the boiler, it is caught in some sort of collection device, usually an electrostatic precipitator (ESP) to prevent it from leaving the atmosphere. An ESP uses magnetism to separate and remove the fly ash from the rest of the flue gases. Bottom ash is simply scraped from the bottom of the boiler after combustion is finished.

2.3.1.3. Location, Quantity and Current Disposal Methods

While coal mining is only in certain areas of the U.S. (see Figure 2), coal is used for energy in all of the 50 states except for Idaho, Rhode Island and Vermont, according to Annely Nobel of the American Coal Ash Association.

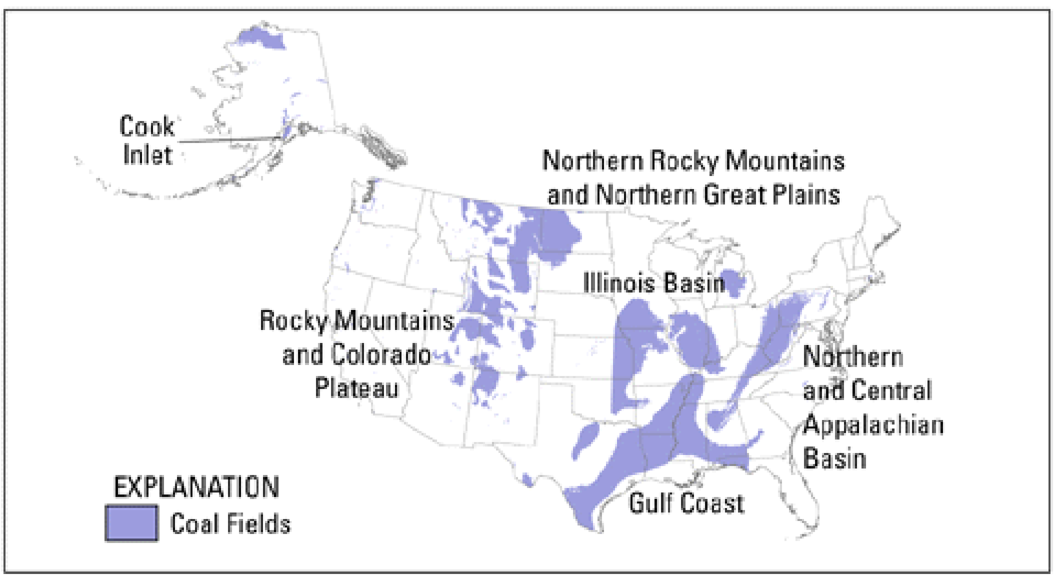

Figure 2: Naturally occurring coal fields in the U.S.

In the U.S. alone, 70.8 million tons (American Coal Ash Association, 2004) of coal fly ash and 17.2 million tons[2] of bottom ash were produced in 2004. According to a 2004 survey (American Coal Ash Association, 2004), only .07 percent of fly ash and .11 percent of bottom ash were used in agriculture, with similarly small amounts reused for mining applications and as soil stabilizers. About 22.1 percent of fly ash and 8 percent of bottom ash were used in cement, and another 14.08 percent of fly ash and 38.94 percent of bottom ash were disposed of in some beneficial way. That leaves 61.45 percent of fly ash and 52.6 percent of bottom ash sent to a landfill or other permanent, non-beneficial facility. (Not all percentages of beneficial reuse could be reported here. See the 2004 ACAA survey for complete statistics.)

2.3.1.4. Beneficial Reuse

While both bottom ash and fly ash are used in cement, fly ash is preferred because it has a pozzolanic reaction (Pennington and VanDevender). This reaction occurs with the addition of water to some ashes (particularly those with high amounts of Si and Al), causing them to set up similar to concrete, although more slowly. Coal ash, when mixed with an organic material such as biosolids, acts as a wonderful soil amendment. The ash not only reduces odor and moisture in the biosolids (Electric Power Research Institute, 2003), but also helps to prevent erosion of soil, decrease permeability, and raise an acidic pH (Garvey, 2006).

Fly ash is divided into two categories, depending on the type of coal burned to produce it. Class F fly ash comes from the combustion of bituminous and anthracite coals, and Class C is produced from sub-bituminous and lignite coals. Class F ashes are sometimes called “low calcium” because of their low lime content, yet they are very good at promoting drainage. Class C, also “high calcium,” contains a sufficient amount of lime to make it a good acid neutralizer. Both classes contain several essential nutrients, including B, Ca, Co, Cu, Fe, K, Mg, Mn, Mo, Ni, and Zn, and have a small capability to trap metals. Bottom ash has a coarser texture than fly ash, which makes it even better than Class F in improving drainage in soils. Also, bottom ash tends to have lower concentrations of trace elements (Electric Power Research Institute, 2003).

The adverse quality of these types of ashes is that they contain trace metals. In the vast majority of cases, the concentrations are not at levels that prove harmful to human or animal health. Another disadvantage of fly ash is that it is fluid-like, dusty and hard to transport (Pennington and VanDevender).

2.3.2. FGD Gypsum

2.3.2.1. Introduction

In addition to fly and bottom ash, CCPs include a variety of other by-products, such as flue gas desulfurization (FGD) by-products, which contain gypsum. The largest industry for gypsum is in the production of wallboard, but it can also be used to remediate troubled land.

2.3.2.2. Generation and Collection Processes

FGD material is the residue that results from the removal of sulfur dioxide from the flue gases emitted at coal-fired power plants (American Coal Ash Association and Ohio State University, 1999). There are two different processes used to convert SO_2 to safe sulfur compounds, which produce different by-products, characterized as wet or dry. Wet scrubber systems inject a slaked lime or limestone solution into the flue gas after fly ash has been removed. The SO_2 is oxidized into a wet, cement-like material called "scrubber sludge" (Electric Power Research Institute, 1999). To stabilize the sludge, fly ash and quick lime may be added (American Coal Ash Association and Ohio State University, 1999). In a dry system, fly ash is not separated from the flue gas before slaked lime slurry or a dry "sodium sorbent" is sprayed into the flue. The by-product is dried by heat and collected in a "particulate control device" (Electric Power Research Institute, 1999) along with fly ash.

2.3.2.3. Location, Quantity, and Current Disposal Methods

As mentioned in section 2.3.1.3., FGD Gypsum is found in all of the states except Idaho, Rhode Island, and Vermont. In the remaining 47 states, over 11.95 million tons of FGD gypsum was generated in 2004 (American Coal Ash Association, 2004). Of that amount, 68.2 percent was reused in wallboard, with 6.2 percent used in cement or concrete and only 1.1 percent used in agriculture. A tiny .2 percent was used in some other beneficial way, which still leaves 25.4 percent, or over 3 million tons, of gypsum gone to waste. Much of this waste could be used to replace the need for natural gypsum, which would not only reduce the amount of FGD by-products landfilled, but also the adverse effects associated with gypsum mining. (See ACAA 2004 survey for complete statistics.)

2.3.2.4. Beneficial Reuse

The FGD gypsum (calcium sulfate, or $CaSO_4$) produced in this process has several useful commercial uses. It provides calcium and sulfur, which are macronutrients to soil, thereby making it a good fertilizer (Norton and Ramsier, 2006); gypsum is a good soil conditioner because of its high permeability (Electric Power Research Institute, 1999) and its ability to prevent soil from crusting over (Norton and Ramsier, 2006); it has a high pH, which makes it an effective liming agent or disinfectant (Electric Power Research Institute, 1999); and FGD gypsum can be mixed with fly ash and lime to form fixated scrubber sludge, which reduces acid mine drainage by filling in mine voids (Electric Power Research Institute, 1999). Also, this material can improve the texture and drainage quality of soil. It contains boron (American Coal Ash Association, 1995), which may provide optimal growing conditions for peanuts, cotton, potatoes and some fruit trees by keeping them disease-free (Electric Power Research Institute, 1999). Unfortunately, gypsum may be hard to apply to land unless added conservatively to another amendment, because direct contact causes eye and skin irritation (Stout, Korcak and Carlson, 1988). Also, if applied in excess to crops that are sensitive to boron, the FGD gypsum will cause boron contamination.

Dry FGD products tend to be higher in heavy metal concentrations because of the presence of fly ash, but these increased levels rarely categorize the waste as hazardous (Solem, 1992). While some of these products are used beneficially in construction and agricultural applications, they are not as commercially valuable because of their lack of calcium sulfate, so the majority of them are landfilled (Electric Power Research Institute, 1999).

2.4 Pulp and Paper Wastes

2.4.1. Introduction

The same process is used to make all kinds of paper. This, of course, includes office paper, facial tissues, newspapers and magazines, but it also includes toilet paper, sandpaper, masking tape, camera film, and even some cat litter (American Forest and Paper Association, 2002).

2.4.2. Generation and Collection Processes

Pulp production. Before the pulping process can get started, a tree must be stripped of all its bark. Once that is done, there are three different kinds of pulping: mechanical, semi-chemical, and chemical. Mechanical pulping uses steam, pressure, and increased temperature to tear the wood fibers apart. The pulp produced from this is known as "groundwood pulp," and still contains lignin, the substance that holds fibers together and hardens cell walls. Paper that contains lignin becomes yellow when exposed to air and light over time, so this pulp is used to make non-permanent products, such as newspaper. Semi-chemical pulping uses a weak sodium solution to dissolve lignin, but still uses mechanical techniques to separate the fibers. In chemical pulping, chemicals known as white liquor (either sulfites or sulfates, as in the Kraft Process) are used to remove lignin and produce long fibers (Brongers and Mierzwam 2006).

Pulping process/chemical recovery. To recycle the chemicals used in chemical pulping only, the pulp "liquor" is put though a series of washes. These washes remove the "black liquor," or the chemicals added during pulping, to prevent the liquor from binding to bleach (the next step in the process). Directly after treatment, most pulp mills filter the fiber though an on-site water treatment plant, where they undergo primary and secondary treatment (see previous section on municipal water treatment).The organic materials removed from the solution are burned for energy (Marshall, 2006), and the rest of the black liquor is recausticized for reuse. This means that it is transformed back into the way it was before it was used in pulping. For Kraft pulping only, the black liquor enters a boiler or lime kiln, which is a long cylindrical drum (Marshall, 2006). In a boiler, the chemicals fall to the bottom as smelt, and in the lime kiln, the drum rotates so that the lime "grits" are worked out on their own and down the slight incline. This smelt from the boiler/kiln is dissolved in water, which forms "green liquor." Any insoluble materials in the smelt are considered waste and referred to as green liquor dregs. Lime (CaO) is added to the green liquor to convert sodium carbonate to sodium hydroxide, which is reused as white liquor. The resulting lime product can sometimes be reused, but often it is also considered waste. By reusing the chemicals over and over, no chemicals are emitted from the system.

Bleaching. Bleaching the pulp is not necessary to make paper. It increases the brightness of the paper and turns the pulp white. To do this, there are several cycles of acidic and alkaline conditions. In the acidic stage, the bleach and lignin react, making the pulp a lighter color. In the alkaline phase, the products of this reaction are removed (Brongers and Mierzwa, 2006).

Stock preparation. The pulp can be diluted into more of a liquid stock in a variety of different ways. Sometimes it is simply blended with another pulp, or it could be beaten and refined. The pulp could also be dissolved in water or mixed with a substance such as resin or wax. This is also the stage where any dyes are added, to make blue or red colored products, for example. If the end product is to be glossy, kaolin is also added. The solution is then ready to be transferred to a paper mill (Brongers and Mierzwa, 2006).

Paper manufacturing. Many pulp mills have a paper mill onsite or nearby, so transportation does not cost much. Wet-end operations consist of putting the pulp slurry onto a very fast-moving belt which, in a sense, suctions out the water. The belt then moves through rollers to compress the fibers and remove remaining water. There is little to no recycling of this water.

Dry-end production involves compressing the sheet with steamrollers so that the fibers bond together again. If necessary, a coating is applied and then the paper is rolled onto spools for storage (Brongers and Mierzwa, 2006).

2.4.3. Location, Quantity and Current Disposal Methods

The forest industry is concentrated in the eastern and northwestern United States, as the dry conditions in the south- and midwestern areas are unsuitable for large-scale growth of trees (see Figure 3).

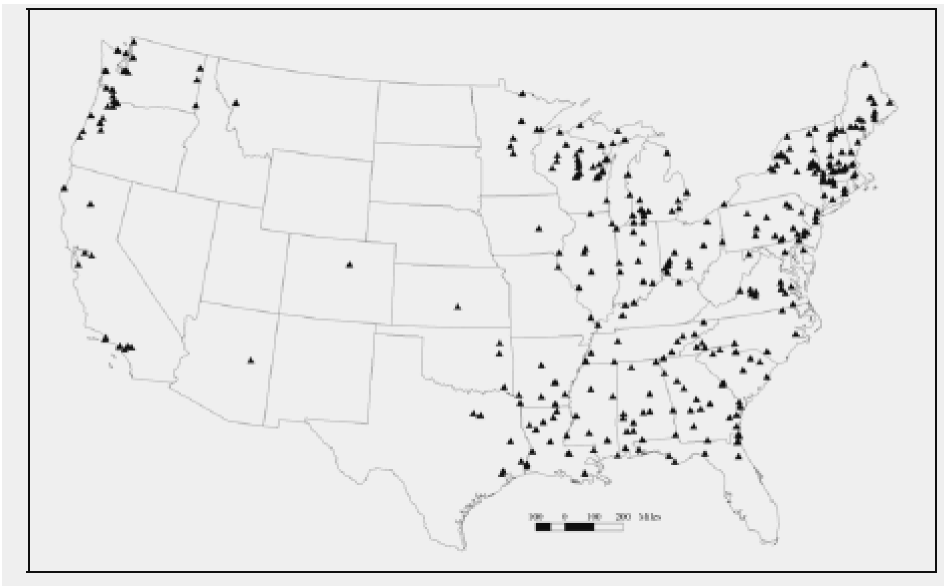

Figure 3: Geographic distribution of pulp, paper, and paperboard mills in the continental U.S.

2.4.3.1. Lime Mud, Slaker Grits and Green Liquor Dregs

These residuals are only produced by the Kraft chemical pulping process. They result from the recausticizing, or recovery process that separates the "white liquor" from the pulp for reuse. More than 1.3 million dry tons of these various lime wastes were generated in 1995 in the U.S. (National Council for Air and Stream Improvement, 1999). Of this total, over 1 million tons (80 percent) were landfilled or lagoon-stored, with only 20 percent being disposed of in a valuable manner (National Council for Air and Stream Improvement, 1999).

2.4.3.2. Water Treatment Plant (WTP) Residuals

Not all mills have onsite WTPs, but those that do produce residuals from the primary and secondary treatment stages. Primary waste consists of wood fiber and some inorganic material such as clay and calcium carbonate, while secondary residuals are mostly microbial mass. Some 5.83 million tons of water treatment plant residuals were produced by the paper industry in 1995 (National Council for Air and Stream Improvement, 1999). Fifty-one percent of this amount was landfilled or lagoon stored, with another 26 percent burned. The remaining 23 percent was used beneficially, mostly by land application (National Council for Air and Stream Improvement, 1999).

2.4.3.3. Fiber Sludge

The fiber deemed unfit for paper production (i.e. small fibers and pulper rejects, which are unique to recycled papermaking) during screening is separated and collected in a tank and eventually dredged. Over 1.26 million dry tons of fiber sludge was produced in 1995, and 14.8 percent of this was somehow recycled in the pulping process (National Council for Air and Stream Improvement, 1999). Another 14.9 percent was beneficially reused (only 1.3 percent on land), and the remaining 70.3 percent was landfilled or stored in a lagoon.

2.4.4. Beneficial Reuse

Most pulp and paper mills landfill their sludge (Edwards and Someshwar, 2000), and more recently, mills have been collecting their residuals and burning them for energy in hog-fuel boilers (Marshall, 2006) – an excellent renewable energy source.

2.4.4.1. Lime Mud, Slaker Grits and Green Liquor Dregs

Used in the past as a substance to seal landfills, these residuals all contain decent amounts of calcium carbonate, the active ingredient in agricultural lime. Because of this property, these materials all have value as a liming material. In addition to providing lime, they also contribute magnesium and iron to the soil. A benefit of using pulp and paper liming material instead of agricultural lime is the significantly reduced cost. However, there will be some cost associated with transportation from the mill to the site. Also, different mills produce extremely different qualities of lime residuals, so testing should be done on all material before it is considered for land application. Sometimes mills perform this testing themselves to make sure the material is truly a waste before sending it to a landfill (Marshall, 2006).

2.4.4.2. Water Treatment Plant (WTP) Residuals

Paper mills produce significantly different WTP residuals than municipalities. Pulp and paper WTP residuals, although lower in most nutrient concentrations, are much higher in carbon than municipal WTP residuals. While the levels are lower, pulp and paper WTP residuals still contain all six macronutrients (N, P, K, S, Ca and Mg) as well as several micronutrients, including Cl, Fe, B, Mo, Mn, Cu and Zn. However, the composition of WTP residuals varies not only from mill to mill, but also with each “batch” of sludge. Therefore the concentrations of each nutrient will vary, making some residuals better than others for land application, depending on the needs of the site. Due to the organic nature of these residuals, they also provide an excellent source of microbial mass to soil.

2.4.4.3. Fiber Sludge

Also used occasionally in sealing landfills, fiber sludge is a wonderful source of carbon. Mixing or composting the sludge with a nutrient-rich source, such as biosolids or manure (Edwards and Someshwar, 2000) makes a superb material that is ideal for application to soil because of the balanced C:N (Edwards and Someshwar, 2000). In addition to providing organic matter, fiber sludge also helps to reduce soil erosion. The negative aspect of fiber sludge is that it has a low pH of about 5. Because of this, fiber sludge would also do well when mixed with an alkaline material.

2.5. Red Mud

2.5.1. Introduction

Red mud, known also as bauxite residue, is a product of the Bayer Process, which produces pure alumina for the manufacturing of aluminum. The properties of red mud, both chemical and physical, depend on the quality of the bauxite used and the exact process through which the alumina is extracted.

2.5.2. Generation and Collection Processes

There are three stages to the Bayer Process. From the mine, bauxite is sent through a crusher and washed before the process begins (International Aluminium Institute (1) 2000).

Extraction. Alumina contains the minerals gibbsite, böhmite and diaspore (Al(OH)3, AlO(OH), and AlO(OH), respectively). These minerals are dissolved in a sodium hydroxide solution known as "caustic soda." This solution helps separate the minerals from insoluble compounds like iron oxide, silicon dioxide, and titanium oxide. After being combined with the soda, the mixture is sent in its slurry form to a heated digester. The properties of the bauxite determine the temperature used; a substance containing large amount of gibbsite is heated to a considerably lower temperature than a diaspore-rich material. After digestion, the solution is sent through a filter, where the insoluble compounds as well as the sodium hydroxide solution settle to the bottom. The resulting mud (the red mud) is then washed so that all of the caustic soda can be removed and recycled. After this red mud is separated, it is routed to an on-site "mud lake" or storage tank. Here, as much water as possible is removed so that the mud can dry (International Aluminium Institute (2) 2000). This resulting red mud is chemically stable and non-toxic (International Aluminium Institute (3) 2000).

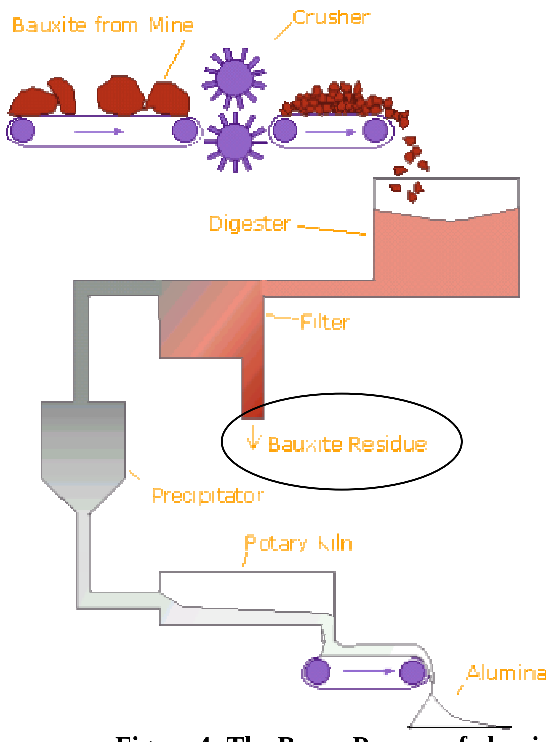

Figure 4: The Bayer Process of alumina refining

Precipitation. The minerals extracted during digestion are next precipitated from the remaining "digestion liquor." This involves cooling the solution, and is a very carefully controlled process. The precipitated hydrate crystals are then inspected. Those that are large enough are sent to the final stage, and those that are not are re-precipitated (International Aluminium Institute (2) 2000).

Calcination. These hydrate crystals are once again heated, to just below the melting point. This is done to "drive off" water and form the pure alumina product ($2Al(OH)_3$ + heat $\rightarrow$ Al_2O_3 + $3H_2O$). Again, this process is carefully monitored because it decides the properties of the alumina, and therefore its quality (International Aluminium Institute (2) 2000).

2.5.3. Location, Quantity and Current Disposal Methods

In the United States, there are only four alumina refineries, located in Texas and Louisiana (see Appendix 5). The average alumina to residue ratio tends to be about 1:1, and can range from 1:0.3 to 1:2.5 (International Aluminium Institute (3) 2000), depending on the quality of the bauxite being processed. For 2006, the alumina capacity of the four Bayer refineries in the United States is over 6.3 million tons (Plunkert, 2006). The estimated amount of waste to be produced this year is around the same number, maybe greater. The amount of residue generated per ton of alumina also varies greatly depending on the bauxite quality.

Most of the bauxite residue generated is disposed of in mono-fills, landfills, and the "mud lakes" mentioned in section 2.5.2. Sometimes, once this land is decommissioned (no longer taking in more residue), vegetation, including crops, may be grown on it (International Aluminium Institute (3) 2000). Red mud has also been used to salvage land off of seashores without causing any negative environmental consequences (International Aluminium Institute (3) 2000).

2.5.4. Beneficial Reuse

The principal use of red mud is to raise an acidic pH, since the pH level of red mud is normally around 9. Red mud has a very high phosphorous retaining capacity (Massanisso, 2006). Because of this ability, even small amounts are very useful on soils with excess P. It also has a very fine particle size to fill in gaps in the soil and improve its structure (Massanisso, 2006). In addition, it reduces eutrophication (Massanisso, 2006). Eutrophication is the condition of water being too high in nutrients that promote certain plant species, reducing the dissolved oxygen content in the water. This reduced dissolved oxygen content then causes the death of other organisms.

2.6. Sugar Beet Lime

2.6.1. Introduction

When handled the right way, sugar beets can be made into pure white sugar. The residual produced in this process is lime-based, and with an 80-90 percent $CaCO_3$ equivalency, it is extremely useful for acidic soils (Vossen, 2006).

2.6.2. Generation and Collection Process

The first step in making sugar from beets is to wash the beets free of dirt and gravel, and anything else that might have gotten mixed in. This rock/soil mixture is often sold to landscapers to use in making "crushed gravel roads" (Bennett-Kimble and Schaetzl, 2006). Next, the beets are sliced, allowing the sugar to be readily extracted in a diffuser. Hot water is added to dissolve the sugar from the beet slices (*Manufacturing,* 2006). In the diffuser, the beets go one way, and the water goes the other. To enable this, either the entire diffuser rotates, or it contains rotation drums/chambers for the beets or water to pass through. Another, older method used is to merely place the beets in hot water and allow the sugar to dissolve. This technique, however, not only takes longer but also uses more water (Bennett-Kimble and Schaetzl, 2006).

The beets come out of the diffuser with a 90-92 percent water content, which is then reduced to somewhere between 72-78 percent by squeezing (*Manufacturing,* 2006). This unneeded pulp is dried and sold as feed. The sugar-water is treated with a lime "milk" (calcium hydroxide solution) from a lime kiln (*Manufacturing,* 2006) to remove impurities. The lime "cake" is separated from the juice and pumped into a lime pond on the factory grounds. The sugar beet juice is treated once again with a lime substance, boiled, and separated from the lime mud. This mud is also sent to the lime pond (Bennett-Kimble and Schaetzl, 2006).

At this point in the procedure, the sugar is in a thick syrup form. It is boiled under vacuum (to separate the sugar from water), filtered once more, and then sent to the crystallizers. Here, the syrup is boiled, cooled, and stirred. This part is repeated a few times, and eventually the syrup-crystal mixture is put in a centrifuge, where it is spun at very high speeds to allow the syrup to drip out, and the crystals are dried. The sugar is pure white sugar, and the syrup that has been removed is molasses (Bennett-Kimble and Schaetzl, 2006; *Manufacturing,* 2006).

2.6.3. Location, Quantity and Current Disposal Methods

The only states that grow sugar beets are California, Colorado, Idaho, Missouri, Minnesota, Montana, North Dakota, Oregon, Texas, Wisconsin, and Wyoming (see Figure 5). Because it is difficult to transport large amounts of sugar beets, the processing plants that actually turn the beets into sugar are located relatively near the growing fields.

The residuals from the sugar-making process are all lime-based materials, mainly $CaCO_3$. At least 98,000 tons of sugar beet lime is produced every year in Minnesota (vonLehe, 2000) but no other estimates of the amount of lime generated yearly are available.

The fate of sugar beet lime varies from company to cooperative. According to Julie Perry of the Michigan Sugar Company, lime residue from the various plants is applied back to the growers' fields as a "soil enhancement." Members of the Southern Minnesota Beet Sugar Cooperative (SMBSC) land apply roughly 90 percent of their lime each year, according to an SMBSC representative, while the remaining 10 percent is wasted. The American Crystal Sugar Company, on the other hand, sends the majority of its lime to landfills, according to Joel Smith, a company representative.

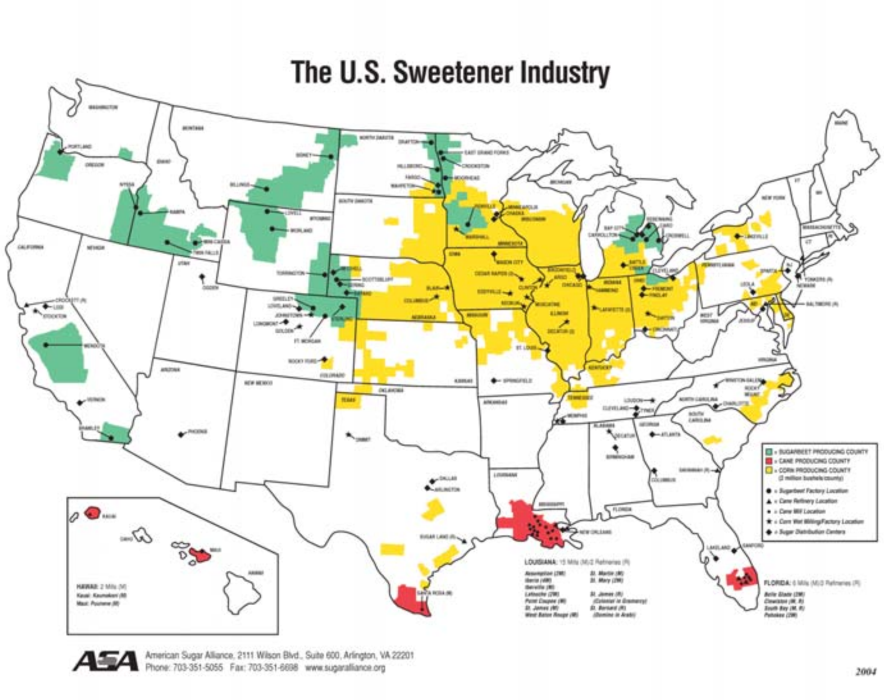

Figure 5: Locations of sugar beet producing counties are shown in green

2.6.4. Beneficial Reuse

Lime, which is mainly calcium carbonate, is very efficient at raising the pH of acidic soils, and having a calcium carbonate equivalency of 80-90 percent makes sugar beet lime residue an excellent substitute for agricultural lime. This sugar beet lime is significantly cheaper, as well as less dusty than commercial pelletized lime (Bennett-Kimble and Schaetzl, 2006). The only obstacle to using sugar beet lime is that some companies, as mentioned above in section 2.6.3., sell the lime only back to their sugar beet farmers.

2.7 Wood Ash

2.7.1. Introduction

Wood is a very good source of renewable energy, as said in section 2.4.4., where it was also mentioned that some pulp and paper mills burn their residuals. This combustion of wood and wood-based materials (such as fiber sludge) results in the production of ash. In the coming years, as nonrenewable energy resources become fewer, it is expected that a much larger amount of wood ash will be generated, as more and more people come to rely on wood for their energy needs.

2.7.2. Generation and Collection Processes

Wood-fired power plants, paper mills, and other wood-burning facilities produce both bottom ash and fly ash (Kraus, Naik and Siddique, 2003), similar to coal ash. Bottom ash is heavier, so it settles to the bottom of the boiler (hence its name), and fly ash, being lighter, becomes part of the gas exhausted from the flames. Smoke ash can easily be scraped from the bottom of the boiler, but fly ash is slightly trickier. As it rises, the smoke passes through a large compartment. This is most often an electrostatic precipitator (ESP) (Gru.com, 2004), which is a device that magnetically attracts and removes the fly ash.

2.7.3. Location, Quantity and Current Disposal Methods

Wood ash tends to be located in areas that are in the forest and paper industry (see Figure 3 in 2.4.3.), although it may be slightly more widespread. It is estimated that about three million tons (Harris and Risse) of wood ash were generated in the U.S. in 1998, about 1.05 million (National Council for Air and Stream Improvement, 1999) of which were from the pulp and paper industry. The vast majority of wood ash is landfilled (about 70 percent [Kraus, Naik and Siddique, 2003]), and 20 percent (Kraus, Naik and Siddique, 2003) of it is land applied. The remaining 10 percent (Kraus, Naik and Siddique, 2003) has various uses, possibly in construction (when mixed with water, wood ash is an excellent bonding agent to use in concrete and cement [Kraus, Naik and Siddique, 2003]).

2.7.4. Beneficial Reuse

The composition of wood ash reflects not only the composition of the tree species, but also the soil type it was grown in, the climate, and the combustion method used (Mitchell and Vance, 2000). All wood ash, however, has a high carbon content and fine texture, making it a great soil amendment. It also has a very alkaline pH, making it capable of raising low pH extremely quickly (though there must be another way of keeping the pH neutral over time, as this effect wears off).

The nutrient content of wood ash is very dependent upon the tree composition. Typically, the ash will contain large concentrations of potassium and phosphorous (Mitchell and Vance, 2000), as well as some amount of available nitrogen, calcium, magnesium, and several micronutrients (Mitchell and Vance, 2000). Wood ash is also generally low in heavy metals and toxic organic compounds. Furthermore, wood ash is good at reducing odor of biosolids and in compost (Grey, Rosenfeld and Suffet, 2002). Standing in the way of land application of wood ash are certain regulatory issues, as well as the challenge of spreading it uniformly (Mitchell and Vance, 2000).

2.8. Yard Waste and Wood Trimmings

2.8.1. Introduction

Yard waste includes wood, leaves, bark, flowers and other plants, grass clippings (Florida's Online Composting Center, 2006), and even some food scraps, and is possibly the easiest amendment for individuals (such as home gardeners) to obtain. Usually people throw all their food, leaves, and grass away, although some homeowners build their own composting piles, which can eventually be used as a topsoil replacement.

2.8.2. Generation and Collection Processes

There are several different sources of wood waste: pulp mills, paper mills, plywood plants, construction sites, lumber yards, and even backyards. Lumber yards and some pulp and paper mills, or any place where debarking occurs, generate log waste consisting of wood chips and bark that are mixed with soil, logs containing metal scraps (such as wire or nails), and mold-damaged trees. All these materials are unfit to be made into a paper product and considered waste. Logs that are too large for the debarker and even undersize limbs are also turned away (North Carolina Division of Pollution Prevention and Environmental Assistance, 2006).

Neighborhoods also generate yard waste, especially during the fall when trees shed their leaves. Many cities have programs that pick up yard waste. Yard waste pick-up is normally not as frequent as regular garbage collection, and some programs pick it up only every few weeks or every month. Many places have additional yard waste collection only in autumn because many people will have leaves to rake and dispose of. Several, but not all, communities with yard waste pick-up then compost it for use on parks or for community organizations and residents.

2.8.3. Location, Quantity and Current Disposal Methods

Some of the larger logs can be sold to "specialty" companies that own larger debarkers, and there are also smaller debarkers for modest and strangely shaped limbs. Sometimes, if it is beneficial to the company, the metal-containing portion of a log can be separated and used as boiler fuel while the remaining, uncontaminated portion is sent for processing. A simple way to reduce waste because of soil contamination is to pave log yards – no soil means no soil contamination (North Carolina Division of Pollution Prevention and Environmental Assistance, 2006).

Yard waste is located in almost all residential areas, especially in places that have lots of deciduous trees. This material is normally landfilled, or often it is used as a landfill cover. In 1999, about 27.7 million tons of yard waste were generated in the United States. 12.6 million tons of this was composted, but that leaves another 15.1 million tons simply wasted (USEPA, 1999).

2.8.4. Beneficial Reuse

Since wood and other grass clippings are organic materials, they are very good sources of carbon and nitrogen, respectively. Wood and leaves have very high carbon to nitrogen ratios, which helps limit the release of excess N into soils (Henry, 2006). Combining these materials for composting, especially with biosolids (Brown and Compton, 2006; Florida's Online Composting Center, 2006) creates an invaluable amendment for reclaiming soil. Although transportation of yard waste and wood trimmings may be expensive, it is also increasingly harder and more costly to landfill these materials, which means that municipalities would also greatly benefit from use of yard wastes on land.

If not land applied, wood waste could be a valuable source of energy. Not only is burning wood less expensive than fossil fuels, it is a renewable resource (as mentioned previously) and emits somewhere around 90 percent less carbon dioxide – an all-around better choice of fuel (North Carolina Division of Pollution Prevention and Environmental Assistance, 2006).

3. CASE STUDIES

3.1. Biosolids

3.1.1. Bunker Hill, Idaho (Henry, 2006; Jenness, 2001)

The Bunker Hill site is the nation's second largest Superfund site and comprises over 600 hectares (over 2.3 square miles) of the Coeur d'Alene River Basin. Sixty years of mining lead, zinc, cadmium, arsenic, and other metals have left the area's soil eroded, acidic, and with hardly any microbial growth or water-holding capacity.

Figure 6: Bunker Hill before restoration

To reduce the high metal concentrations and enable the growth of vegetation on the soil, experts from the U.S. EPA, U.S. Department of Agriculture, University of Washington, University of Idaho, the Northwest Biosolids Management Association, and Washington Water Power used a mixture of biosolids with other amendments. To establish a self-sustaining and healthy ecosystem on the land, the biosolids mixture had to reduce erosion, surface metals, and metal phytoavailability.

Pilot-scale demonstration plots were created on-site in 1997 to determine the effect various mixtures of biosolids, fly ash, and wood trimmings would have on the contaminants. These first plots had applications of high nitrogen biosolids and low nitrogen biosolids, applied at rates of 55 and 110 mega-grams per hectare (Mg/ha, dry weight). High N biosolids were produced by anaerobic digestion while low N biosolids were stabilized in a lagoon. Before application, the biosolids were mixed with 220 mg/ha (wet weight) of wood ash to provide calcium and a 1:5 fixed ratio of log yard waste, both of which were provided by local companies.

The low N biosolids proved to establish vegetative cover very quickly after seeding with both native and volunteer plant species. High N biosolids had an initial toxicity from the volatilization of ammonia, but with re-seeding also produced healthy plant life. Metal concentrations in the soils of all plots were similar to those of samples taken from uncontaminated areas.

A second phase of test plots was created later in 1997. The test plots were amended with several different combinations of biosolids, ash, wood waste, pulp and paper sludge, and compost. The intent was to determine the best mixtures of amendments, but by the spring after application, all test plots showed "vigorous growth" and much higher biomass levels than the control plot.

It was concluded that biosolids and ash make a very effective and adhesive soil amendment, and that to avoid lack of growth due to high ammonia, seeding should be delayed some time after application. The average cost of applying biosolids to the plots was estimated at roughly $35 per wet ton.

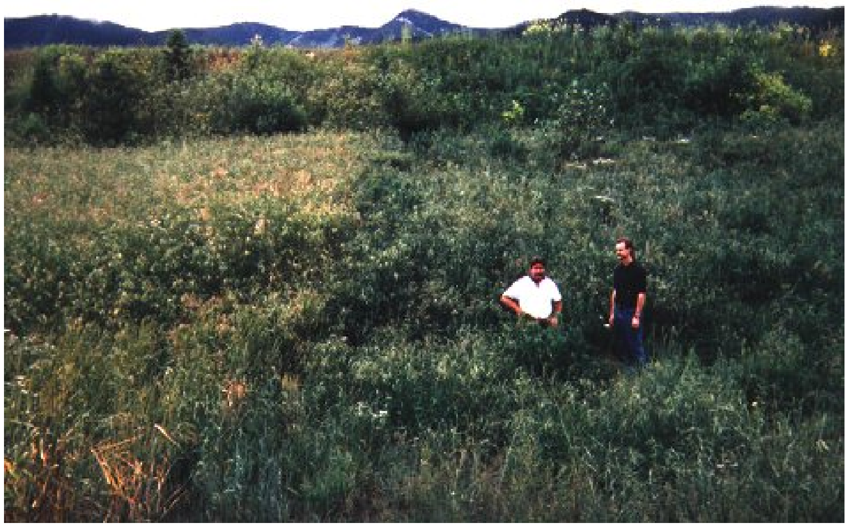

Figure 7: Bunker Hill after restoration

3.1.2. "Project Silesia," Poland (USEPA, 832-R-00-009, 2000)

From 1994 to 1999, the U.S. Agency for International Development coordinated and sponsored a project that brought together scientists from EPA, the U.S. Department of Agriculture, Virginia Polytechnic Institute, and various Polish companies to work on the remediation of a two-hectare (ha) parcel of land in the Upper Silesia region of Poland. The region contains 14 cities and over six million people. An estimated 96 million tons of waste from the mining of coal, zinc, and lead were deposited on the site. These waste piles were a major health risk to those living in close proximity, and several children were found to have elevated levels of lead in their blood.

Due to the rapidly increasing amount of biosolids being produced in the area (the numbers doubled in only one year) and previous biosolids work done in Palmerton, Pennsylvania, it was decided that biosolids would be used as an effective and cost-efficient way to remediate the waste piles. The sites chosen for reclamation were two smelter waste piles: one from a Doerschel furnace, and the other from a Welz smelting process. This area was roughly two hectares large and had no vegetation whatsoever.

To reduce metal mobility and solubility, lime was needed in addition to the biosolids. Calcium oxide (CaO) was needed in addition to calcium carbonate ($CaCO_3$) because it is more effective at raising pH. Both the sites received 30 mega-gram/hectare (Mg/ha) of $CaCO_3$, but the Welz site, having lower metal concentrations and a higher pH, received 1.5 Mg/ha of CaO while the Doerschel site received 15 Mg/ha CaO. The plots were divided into thirds, with biosolids applied at rates of 0, 150 and 300 Mg/ha to each. The amendments were then incorporated into the soil with a chisel plow and seeded in the fall of 1994.

By the spring of 1995, the Welz site had an 85 percent vegetation cover established. The Doerschel site, however, had no vegetation because of the high metal levels and excess salinity. Scientists decided that the lack of plant life was due to too-low application rates of lime. In the fall of 1995, a 300 Mg/ha application of biosolids along with a cover of 15 cm of lime was added to the soil at the Doerschel waste pile. A cover of 75-80 percent vegetation was produced by the spring of the following year.

The project was extremely successful in remediating the barren sites. It was concluded that a mixture of lime and biosolids applied to highly toxic smelter waste is very effective in revegetating the land and reducing soluble metal content.

Figure 8: Project Silesia land before (right) and after (left) restoration

3.2. Concentrated Animal Feeding Operations (CAFOs) Manure

Although manure can be used in the remediation of land, no data was available regarding its application on contaminated soils. Tests and studies recorded about manure pertain to its use in agriculture as a fertilizer.

3.2.1. Coastal Plain Experiment Station, Tifton, Georgia (Gascho, 2001)

At the Coastal Plain Experiment Station, Gary J. Gascho of the University of Georgia's Department of Plant Pathology and five others conducted a study from 1996-2000 to determine the economic benefits and best application rates of broiler chicken litter. Three double-cropped cycles of cotton, peanuts, millet, wheat, and grain were tested. Plots that grew cotton were fallowed after harvest, during the winter rotation.

Before application of litter, the soil pH was about 6.1. The soil was tested for P, K, Ca, Mg, Cu, Zn and Mn. P and K levels were good, and the concentrations of Ca and Mg were "adequate." Broiler litter was obtained from the same stack houses for the duration of the study, one to three weeks before each new rotation, and was applied at rates of 0, 4.5, 9.0 and 13.5 Mg/ha. Initially the litter was "broadcast" on fallow soil, and every application was incorporated by disking. The crops were irrigated as needed and grown with best management practices.

Samples of the soil were taken after each treatment and tested for the same nutrients listed above. The concentrations of all these nutrients increased with broiler litter addition, but the pH of the soil was not affected.

Cotton and millet yields were greatest with the highest application rate for the first year, yet in subsequent years, rates greater than 4.5 Mg/ha did not increase yield. There was a positive linear relationship between application rates and yield for both canola and wheat, with the 13.5 Mg/ha treatment yielding the most. Peanuts were negatively affected by the broiler litter, except in 1999. By analyzing yields, it was determined that broiler litter is very valuable for cotton; semi-valuable for millet, canola, and wheat; and harmful to peanuts.

3.2.2. California Diary Farms (Meyer and Schwanki, 2000)

In March 1994, six dairies in California enrolled in a two-year study to monitor crops irrigated with liquid dairy manure. The data presented are from one of the dairies, which grew corn during the first summer, cotton the next year, and grain in the second winter. The size of the crop check was 350 by 24 m, and monitoring began in May 1994.

The average total nutrients applied in the pre-planting irrigation and the four irrigations after planting totaled 498, 96, and 349 kilograms/hectare (kg/ha) of N, P and K respectively. Total amount of water applied was 498 cm. The average nutrient values in the harvested corn were 212, 31, and 229 kg/ha. It was kept in mind during the study that since the irrigation water was not applied uniformly (the irrigation valve was on one end of the check), neither were the nutrients. Even so, it was found that adequate amounts of each nutrient were applied.

During the summer of 1995, cotton was grown and irrigated four times, as the corn had been. Total water applied to the cotton, though, was about a fifth of that applied to corn at 104 cm. This amount of water provided average amounts of N, P and K that were 638, 71, and 418 kg/ha, respectively.

It was found that irrigation with liquid dairy manure is an effective source of macronutrients for crops, but the process must be closely monitored at all times. While differences in crop yield can be seen from season to season, it is impossible to tell without testing the amount of nutrients being leached. At the time of writing, few laboratories analyzed liquid manure, thus making the application of liquid manure a guessing game of sorts for farmers.

3.2.3. State of Iowa (Sawyer, 2006)

Dr. John E. Sawyer, Dr. Antonio Mallarino, and John Lundvall from Iowa State University conducted on-farm field demonstrations from 2000 to 2003 throughout the state of Iowa. The purpose of the study was not only to gain knowledge about nitrogen and phosphorous availability in swine manure, but also to spread awareness about the uses of swine manure on land. In 2000 and 2001, there were 23 demonstration sites in nine counties where swine manure was applied to fields before planting corn and soybean. Soil and plants were then tested for total N and P.

For corn, there were three strips of land that received manure applications at 0, 75 and 150 pounds(lb) total N/acre. To test the effects of commercial fertilizer N, it was hand-applied to small blocks of each of the manure strips at rates of 0, 40, 80, and 120 lb N/acre. Superimposed on the fertilizer N plots was 60 lb P_2O_5/acre and 60 lb K_2O/acre. Also tested was commercial P fertilizer. This too was applied by hand to small blocks of each manure strip at rates of 0, 20, 40, and 60 lb P_2O_5/acre. Added on top of this was 100 lb N/acre and 60 lb K_2O/acre.

The process for the soybean plots was very similar to that of corn, except that manure was applied at rates of 0, 100, and 200 lb N/acre. Fertilizer P was tested in the same method described above except that no fertilizer N was superimposed.

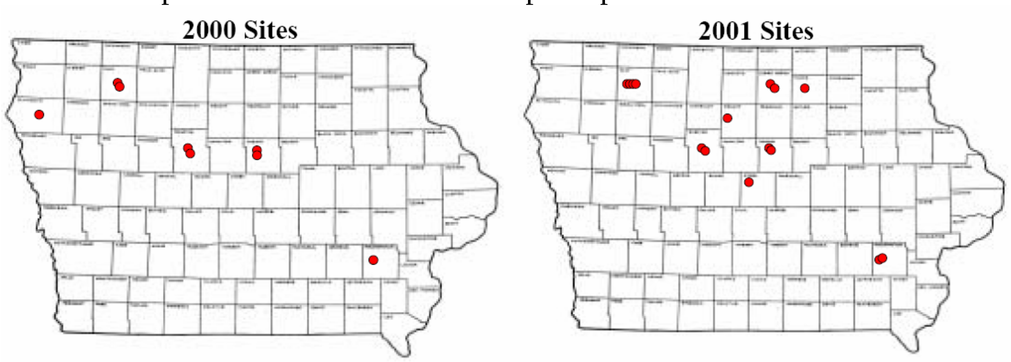

Figure 9: Swine manure nutrient utilization demonstration sites

Figure 10: Treated and untreated strips at the 2001 site in Wright Co.

Soils and plants were sampled and analyzed for N and P concentrations. Plant concentrations of both N and P increased with manure application. It was also found that the manure treatments tended to increase corn yields, although additional application of fertilizer N did not increase yields any further. Likewise, it was shown that fertilizer P applied in addition to manure on soybeans plots did not increase season yield. Results suggest that both N and P in swine manure are highly available for plant uptake.

3.3. Coal Combustion by-Products (CCPs)

3.3.1. Allentown, Pennsylvania (Buck and LaBuz, 2005)

In May 2004, Larry LaBuz and John Buck began a study investigating the uses of bottom ash, also known as sand fines, on soil for turfgrass. The sand fines used came from two PPL Generation LLC facilities – Brunner Island and Montour Steam Electric Station. The bottom ashes and soil were sampled alone and then mixed at various rates for testing. Both the bottom ash and the soil were characterized by chemical and physical properties, such as pH and texture. The soil from the site had a pH of 6.2, with a high N content, normal P and K concentrations, and lower Ca and Mg levels. The bottom ashes had pH levels of 7.6 and 8.4, with medium levels of N, P and K, and higher levels of Ca and Mg.

Test plots were created in cylinders with an 80 cm diameter and 80 cm height. The control plot was 60 cm of soil from the site, and there was one 20 cm deep plot of healthy soil atop 40 cm of a 75 percent ash and soil mixture. The remaining plots were each 20 cm deep and comprised of 25 percent, 50 percent, and 75 percent ash that were mixed by bucket blending with soil. These three plots were also set on top of 40 cm of a 75 percent ash-soil mixture.

All treatments were amended with 100 m^3/ha of spent mushroom compost and pelletized poultry manure before they were seeded with ryegrass. Fungicide was applied to the plots before the first irrigation to avoid "damping off" in the expected hot and humid weather. Plots were irrigated as needed (enough to saturate the soil) by site personnel.

The pH of the soil (control) was 6.2, with the pH levels of the amended soils ranging from 6.9 to 8.3 and averaging 7.5. Calcium and magnesium concentrations were significantly increased with application of bottom ash, although P and K were not affected. Results show that bottom ash is not phytotoxic, and that the growth it supports is comparable to that sustained by normal soils. It was concluded that once the nutrient deficiencies of bottom ash are eliminated by adding an organic material, such as poultry manure, it could act as a soil-equivalent.

3.3.2. Palmerton, Pennsylvania (Jenness, 2001)

Two smelters on Blue Mountain deposited roughly 33 million tons of zinc, lead, cadmium, and sulfur dioxide wastes in Carbon County, Pennsylvania. The Palmerton site covers 1,000 acres, making it the largest Superfund site. In 1988, the Zinc Corporation of America and the EPA began efforts to redevelop the site using innovative *in-situ* technologies.

Much testing was done to determine the best amendment to be applied to the land, and it was decided that a mixture of fly ash, biosolids, limestone and potash fit this position. The fly ash added to the mixture contributed heavily because it improved handling of the biosolids, reduced the soil surface temperature, increased porosity and infiltration, and made it more likely that the amendment would stick to the rocky slopes.

The ratio of biosolids to fly ash in the mixture varied from 1:1 to 3:1, with about 10 tons/acre of limestone and 132 lb/acre of potash added. The 2,000 lb/acre of nitrogen required from the biosolids determined the rate of application of the mixture. Twelve species of plants were selected for a 100-day study on growth in amended soil from the Palmerton site. After the 100 days, 11 of the plants had root structures penetrating the contaminated soil. The most successful of these 11 plants were chosen for further testing in the field.

Ten one-acre plots were created near an access road on the site. Biosolids were applied at a rate of 21 dry-tons/acre, with the varying additions of fly ash. To raise the very acidic pH and immobilize metals, limestone was applied at double the rate that was deemed necessary.

Results show that plots treated with a 1:1 biosolids to fly ash ratio had the greatest decrease in metal concentrations. This is due to the $Ca(OH)_2$ contained in fly ash, which, like biosolids, is able to precipitate heavy metals, therefore making them less phytoavailable. After suppliers of the necessary amendments for remediation were granted the lack of liability, full-scale reclamation began in 1991, and by 1995, almost the full original 1,000 acres had been revegetated.

3.4. Pulp and Paper Wastes

3.4.1. New Augusta, Mississippi (Vance, 2000)

In 1985, Georgia-Pacific began its land application program at the Leaf River Mill. At first, the 54 dry Mg per day of water treatment residuals were applied to agricultural land within a 25-mile radius of the mill. In 1989, it also began being applied to forest land owned by the company.

Currently, 80 percent of the WTP residuals generated by the mill are applied to the forest land, and the remaining 20 percent are given to local farmers. One farmer who had applied residuals from the mill to his land four months before planting won the National Corn Yield Contest Award in 1993.

An eight-year study at the mill illustrated the benefits of WTP residuals in forest application. While it was shown that there is a lower survival rate of pine seedlings on land amended with WTP residuals (likely due to greater competition from weeds), there is an overall increase in growth over subsequent years. It is suspected the elevated amount of phosphorous is the cause of the lower survival rate of the seedlings.

3.5. Red Mud

3.5.1. Italy (Massanisso, 2006)

At Bosicon 2006, an international conference for the remediation of polluted sites, P. Massanisso and others presented a project they had worked on involving the use of red mud and treated municipal solid waste (MSW) in reclaiming mine tailings. Massanisso is affiliated with ENEA, which in English translates to the Italian National Agency for New Technologies.

The mine tailings and soils from the study were characterized by a low pH, elevated levels of heavy metals, and a low amount of organic carbon. Remediation of this toxic metal contamination is difficult and possibly very expensive. To try and minimize efforts and cost, the *in-situ* technology of metal trapping was chosen for this particular site. Treated red mud would be used for its ability to immobilize metals and to raise the acidic pH. Additionally, the finely-grained texture of red mud would be used to improve the soil structure. Source-separated municipal solid waste (SS-MSW) would be used to improve soil structure and return organic matter to the tailings.

Six variables were studied: 100 percent abandoned mine toxic soil (MT soil), 80 percent MT soil + 20 percent Bauxsol™ (treated red mud), 80 percent MT soil + 10 percent compost + 10 percent Bauxsol, 80 percent MT soil + 20 percent compost, 60 percent MT soil + 20 percent compost + 20 percent Bauxsol, and a commercially designed soil. Barley seeds were grown in these various soils and were studied for biomass, protein content, and peroxidases (enzymes that catalyze oxidation by peroxide).

It was found that the 20 percent compost + 20 percent Bauxsol combination was most effective at raising pH and reducing metal concentration. While the 20 percent compost mixture had the greatest increase in organic carbon, the barley produced from the 20 percent compost-20 percent Bauxsol mix was close behind in amount of organic material. Biomass was significantly increased in all amendments containing compost, although plants grown in the commercial soil did have the greatest biomass.

Scientists concluded that the addition of Bauxsol to disturbed soils will deliver the following benefits: raise soil pH to almost neutral, greatly reduce toxicity, and increase the soil's ability to absorb and store water. When combined with a material rich in organic matter, Bauxsol can be used to reclaim larger areas of mine contamination.

3.6. Sugar Beet Lime

3.6.1. Bay City, Michigan (Christenson, Hubbell and List, 2006)

For over 90 years, the waste lime at Monitor Sugar Company's plant in Bay City, Michigan, had build up into a "mountain" of a problem. One solution proposed for the disposal of the lime was that farmers would take one ton of lime for every acre of sugar beets they grew for the processing at the plant. There were still uncertainties about the effect sugar beet lime would have on soils and crops, so Lee A. Hubbell and Richard R. List of Monitor Sugar Company (now Michigan Sugar Company), in cooperation with Don R. Christenson from Michigan State University organized a study to investigate the effects of lime on crops yields.

The site was created in the fall of 1993 near Bay City. There were three areas at the site, divided into blocks of 20' by 50' with rows 8-30" wide. Five different rates (per acre) of lime were applied to each of the three areas: one ton of lime every year, one ton every three years, three tons every three years, five tons every three years, and a control (no lime). One ton of lime was applied to all sections (except the control plot) in the spring of 1994 and the fall of 1996. A moldboard plow was used to incorporate the lime, and then corn, navy beans, or sugar beets were planted. These crops were rotated every year, and regular farming practices were performed throughout the growing season. The 30 feet of crops in the middle four rows of each area were harvested every fall.

Lime applied at the Monitor site was 30 percent calcium, 30 percent moisture, and had neutralizing value between 80 and 90 percent. The soils receiving the lime treatments had alkaline pH levels around 8.0 and also received N, P, and K fertilizer. During 1996 and 1997, the field was flooded, causing the majority of data from those years to be lost. After harvesting, plants were washed, ground, and tested for P, K, Ca, Mg, Zn and Mn.

The yield of sugar from sugar beets and corn yields were not significantly affected by the lime treatments. Navy beans were also not affected greatly, except for the plots receiving one ton of lime every three years. Calcium concentrations increased in all applications over one ton every year, although there was a downward trend in magnesium for all treatments. Results suggest that lime can be applied to crops at rates of up to five tons per acre every three years, yet it was advised that consistent testing be done on the nutrients in soil and plant tissue.

3.7. Wood Ash

3.7.1. Mansfield, Louisiana (Mitchell and Vance, 2000)

International Paper first began investigating beneficial disposal methods for the boiler ash produced at the company's mill in Mansfield, Louisiana, in 1990. Inspiration for the research derived from low-income farmers in the area who didn't apply agricultural limestone to their fields because of its high cost, although soils tended to be acidic and infertile. After receiving permission to apply its wood ash to land, the mill coordinated with the county's Agricultural Extension Service to find a farmer willing to allow his land to be used as a test plot.

Bark ash and reclaimed (recycled) paper fiber was blended in a 5:1 ratio and applied at rates of 0, 6.7, 11.2, and 22.4 Mg/ha to a two-ha test area. Ten days after the ash was incorporated by disking, ryegrass was seeded, and the plots were fertilized with N, P and K. In the next January and April, additional N fertilizer was added. The grass was harvested three times in December, February and May.

Soil pH levels were greatly increased on ash-amended plots, up to 6.9 (from about 4.8) for the 22.4 Mg/ha treatment. At the second harvest, yields from all plots treated with ash were considerably greater than the plot with no ash applied. Treatments of ash also generally increased concentrations of P, K, Ca, S and B in plant tissue, while decreasing Al and Mn levels. Positive test results enabled the mill to develop an "operational ash application plan" with three other farmers in the area, and by 1993 the Louisiana Department of Agriculture and Forestry approved a best management practices (BMP) plan for an ash application program at the mill. Since the start of the program, 44,000 tons of ash have been applied to local farmland (as of the year 2000).

3.8. Yard Waste

3.8.1. Department of Sanitation for New York City, New York (New York City Bureau of Waste Prevention, Reuse and Recycling, 2001)

The composting program in New York City is source-separated, with separate collections in the fall for leaves, small brush waste, and pumpkins in 35 out of 59 districts in the city. It began in 1990 on Staten Island with the opening of the Fresh Kills landfill. About 3,200 tons of leaves from Staten Island and 7,500 tons of yard waste from private landscapers were collected and composted at the facility.

Expansion of the program to five districts in the Bronx occurred in 1997 due to a recommendation from a Mayor's Task Force Report. In that first year, 1,200 tons of leaves were collected from participating Bronx districts. The program expanded again in 1998, this time to Brooklyn, where 12 districts contributed 1,900 tons for composting. By 2000, the program also included all 14 districts in Queens and one more district in Brooklyn, and over 19,000 tons of waste were collected throughout the city.

In order to provide compost from multiple decentralized areas, the Department of Sanitation began working with the Parks Department to find large areas of land - "parks" – that were mostly unwanted and vacant, and could be used for additional composting sites. In exchange for using these parks, the Department of Sanitation agreed to use finished compost for restoration, maintenance, and beautification projects in the city. Three more composting sties were created in Ferry Point Park in the Bronx, Canarsie Park in Brooklyn, and in Idlewild. A composting site was also established in Soundview park with the closing of the facility at Ferry Point.

Leaves generally arrive at the sites in plastic bags and must be removed from them using a bladed trammel screen before being placed in composting piles. These windrows are roughly 12' x 8' x 100,' and are watered and turned periodically to expedite the process. Temperatures in the piles reach up to 140°F as microorganisms digest the materials. Some of the finished compost is distributed to residents (2,000 cubic yards) and community groups (1,000 cubic yards), but the majority is used for soil remediation and landscaping in the city.

Figure 11: Piles of finished compost (left) and the turning of windrows at Fresh Kills compost facility

4. CONCLUSION

As exemplified above, waste materials don't have to be wasted. There are several residuals that can and *are* being used on land for remediation and agriculture. Unfortunately, there are regulatory, cost, and technical performance-based issues that get in the way of using such residuals as soil amendments, as well as lack of widespread knowledge about these alternative possibilities. Yet in the past few years, there has been a great increase in the use of residuals as amendments, and current efforts are resolving issues with more and more speed. Hopefully, as landfill space becomes even less available, land application will be an easy and economical choice for the disposal of these industry leftovers.

5. REFERENCES

5.1. Biosolids

5.1.1. Municipal Wastewater Treatment

1. Brown, Sally and Chuck Henry. "Using Biosolids for Reclamation/Remediation of Disturbed Soils." DRAFT. University of Washington. 12 Jul 2006. http://faculty.washington.edu/clh/whitepapersa.html

2. Hopkins, Pat. "Wastewater Treatment Process." *Gillette, Wyoming Official Website*. 15 Jun 2005. City of Gillette, Wyoming. 12 Jul 2006. http://www.ci.gillette.wy.us/util/process.html

3. Jenness, Nathan. "Mine Reclamation Using Biosolids." Aug 2001. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response.

4. Sopper, William E. *Municipal Sludge Use in Land Reclamation*. Ann Arbor: Lewis Publishers, 1993.

5. "The Production of Biosolids/Sludge." Cornell Waste Management Institute. 1996. Cornell University. 11 Jul 2006. http://cwmi.css.cornell.edu/Sludge/Production.pdf

6. U.S. Environmental Protection Agency Press Release, 21 Nov 1988. http://www.epa.gov/history/topics/mprsa/02.htm

7. U.S. Environmental Protection Agency (1999) *Biosolids Generation, Use and Disposal in The United States.* Office of Solid Waste and Emergency Response; EPA530-R-99-009.

5.1.2. Municipal Water Treatment

1. "Drinking Water." *Utah.gov*. 2005. 10 Jul 2006. http://www.watereducation.utah.gov/WaterInUtah/Municipal/default.asp

2. "Research Update: Water Treatment Residuals." *Grounds Maintenance.* 1 June 2001. Grounds Maintenance Magazine. 20 Jun 2006. http://grounds-mag.com/mag/grounds_maintenance_research_update_water/index.html

3. "Wastewater Treatment Process." *Living in Toronto.* 19 Jun 2006. http://www.toronto.ca/water/wastewater_treatment/process.htm

5.2. Concentrated Animal Feeding Operations (CAFOs) Manure

1. Barker, James C. "Dairy Manure Flush/Lagoon Treatment System, Rand Leigh

Dairy Farm." EBAE 040-77; *North Carolina Cooperative Extension Service*. Mar 1996. 11 Jul 2006. http://www.bae.ncsu.edu/programs/extension/Publicat/wqwm/ebae040_77.html

2. Barker, James C. "Lagoon Design and Management for Livestock Waste Treatment and Storage." EBAE 103-83; *North Carolina Cooperative Extension* Service. Mar 1996. 11 Jul 2006. http://www.bae.ncsu.edu/programs/extension/Publicat/wqwm/ebae103_83.html

3. Barker, James C. "Poultry Layer Production Facility Manure Management: High Rise, Deep Pit." EBAE 131-88; *North Carolina Cooperative Extension Service*. Mar 1996. 11 Jul 2006. http://www.bae.ncsu.edu/ptograms/extension/publicat/Wqwm/ebae131_88.html

4. "Comparison of New Swine Manure Collection Techniques for Improved Utilization and Environmental Quality Protection." *University of Missouri.* 2004. 11 Jul 2006. http://cafnr.missouri.edu/research/consortium/2001-04nc.pdf

5. Edwards, J.H. and Arun V. Someshwar. "Chemical, Physical, and Biological Characteristics of Agricultural and Forest By-Products." *Land Application of Agricultural, Industrial, and Municipal By-Products.* Ed. Warren A. Dick and James R. Power. Madison, WI: Soil Science Society of America, 2000. 2-17.

6. "Environment." Illinois Pork Producers Association. 11 Jul 2006. http://ilpork.com/new.info_page/Environment.pdf

7. *Manure Management Program*. 2004. Cornell University. 11 Jul 2006. www.manuremanagement.cornell.edu

8. U.S. Department of Agriculture (2002) *Census of Agriculture-Table 27*. National Agricultural Statistics Service.

9. U.S. Department of Agriculture (2005) *Managing Manure to Improve Air and Water Quality*. ERR-9; Economic Research Service. http://www.ers.usda.gov/publications/err9/err9d.pdf

10. U.S. Department of Agriculture (2000) *Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trends for the United States.* nps00-0579; Natural Resources Conservation Service.

11. U.S. Department of Agriculture (2006) *United States and Canadian Cattle*. National Agricultural Statistics Service.

12. U.S. Department of Agriculture (2006) United *States and Canadian Hogs*. National Agricultural Statistics Service.

13. U.S. Environmental Protection Agency and the Agricultural Center. *CAFO - Livestock Operation Inspection.* EPA 305-F-03-009; Office of Enforcement and Compliance Assurance.

14. U.S. Environmental Protection Agency. "Ag 101." 7 Mar 2006. *EPA.gov*. 8 Aug 2006. http://www.epa.gov/agriculture/ag101/index.html

5.3. Coal Combustion by-Products (CCPs)

1. American Coal Ash Association (1995) *CCP Applications in Agriculture*.

2. "2004 Coal Combustion Product CCP Production and Use Survey." *American Coal Ash Association.* 10 Jul 2006. http://www.acaa-usa.org/PDF/2004_CCP_Survey(9-9-05).pdf

3. Stout, W.L., J.L. Hern, R.F. Korcak, and C.W. Carlson (1988) *Manual for Applying Fluidized Bed Combustion Residue to Agricultural Lands.* U.S. Department of Agriculture, Agricultural Research Service, ARS-74.

4. Solem, Jody K. (1992) *Characterization of Atmospheric Fluidized Bed Combustion (AFBC) Residues and Their Use in Agriculture.*

5. American Coal Ash Association and Ohio State University (1999) *Construction of Livestock Feeding and Hay Bale Storage Pads Using FGD Material*. AEX-332-99; The Ohio State University Extension Fact Sheet.

6. Pennington, Jodie and Karl VanDevender. *Reducing Mud Problems in Cattle Heavy Use Areas with Coal Combustion By-Products (Fly Ash),* University of Arkansas Cooperative Extension Service Printing Services. 11 Nov 2006.

7. Garvey, Diane (2006) "Benefits of Coal Ash and Biosolids Blending." 3 Jul 2006. http://proprecycles.org. Path: (Manufactured Soils Conference) Presentations now posted; Diane Garvey…

8. Norton, Darrell and Cliff Ramsier. "A Win/Win Solution for FGD-Gypsum." *Ash at Work* Issue 1 (2006): 10-15.

9. Electric Power Research Institute (1999) Environmental Focus BR-114239: *Flue Gas Desulfurization By-Products.*

10. Electric Power Research Institute (2003) Resource Paper 1004852: *Combustion By-Product Use.*

5.4. Pulp and Paper Wastes

1. American Forest and Paper Association. 2002. *AF and PA.* 10 Jul 2006 http://www.afandpa.org

2. Brongers, Michiel P.H. and Aaron J. Mierzwa. "Pulp and Paper." 10 Jul 2006. http://www.corrosioncost.com/pdf/pulppaper.pdf

3. Edwards, J.H. and Arun V. Someshwar. "Chemical, Physical, and Biological Characteristics of Agricultural and Forest By-Products." *Land Application of Agricultural, Industrial, and Municipal By-Products.* Ed. Warren A. Dick and James R. Power. Madison, WI: Soil Science Society of America, 2000. 17-54.

4. Marshall, Kristen. Personal Interview. 12 and 22 Jun 2006.

5. National Council for Air and Stream Improvement (1999) *Solid Waste Management Practices in the U.S. Paper Industry-1995*. Technical Bulletin No. 793.

5.5. Red Mud

1. "Alumina Refining." *World-aluminium.org*. 2000. The International Aluminium Institute. 10 Jul 2006. http://www.world-aluminium.org/production/refining/index.html

2. "Bayer Process Chemistry." *World-aluminium.org.* 2000. The International Aluminium Institute. 10 Jul 2006. http://www.world-aluminium.org/production/refining/chemistry.html

3. "Environmental Challenges." *World-aluminium.org.* 2000. The International Aluminium Institute. 9 Aug 2006. http://www.world-aluminium.org/environment/challenges/index.html

4. Massanisso, P., et al. "Recycling and Use of Treated MSW and Industrial By-Products (Red Mud) Recovery of an Abandoned Mine Contaminated Soil." Rome, Italy, 14-15 Feb 2006.

5. Plunkert, Patricia A. "Bauxite and Alumina." *U.S. Geological Survey*. Jan 2006. 10 Jul 2006. http://minerals.usgs.gov/minerals/pubs/commodity/bauxite/Bauximcs06.pdf

5.6. Sugar Beet Lime

1. Bennett-Kimble, Laura and Randall J. Schaetzl. "The Sugar Beet Industry in Michigan." 2006. 11 Jul 2006. http://www.geo.msu.edu/geo333/beetindustry.html

2. "Sugar Beet Processing." *Manufacturing*. The Western Sugar Cooperative. 11 Jul 2006. http://www.westernsugar.com/manuf_beet.asp

3. von Lehe, Cathleen. "Southern Minnesota Beet Sugar Co-op Reduces Waste and Saves Over $500,000." *Minnesota Technical Assistance Program*. Nov 2000.

University of Minnesota. 11 Jul 2006.
http://www.mntap.umn.edu/intern/projects/SMNSugarbeet97.htm

4. Vossen, Paul. "Changing pH in Soil." University of California Cooperative Extension. 11 Jul 2006. http://cesonoma.ucdavis.edu/hortic/pdf/changing_soil_ph.pdf

5.7. Wood Ash

1. "Fly Ash Recycling." *Gru.com*. 2004. 9 Aug 2006. http://www.gru.com/OurEnvironment/CorporateRecycling/flyash.jsp

2. Grey, Mark, Paul Rosenfeld and Mel Suffet. "Controlling Odors Using High Carbon Wood Ash." *Biocycle* March 2002, page 42.

3. Harris, Glen and Mark Risse. "Best Management Practices for Wood Ash Use as an Agricultural Soil Amendment." *Clemson Extension*, Clemson University. 11 Nov. 2006. http://hubcap.clemson.edu/~blpprt/bestwoodash.html

4. Korcak, R.F. "Agricultural Uses of Phosphogypsum, Gypsum, and Other Industrial By-Products." Agricultural Uses of Municipal, Animals, and Industrial By-Products. U.S. Department of Agriculture (1998), Agricultural Research Service; Conservation Research Report 44.

5. Kraus, Rudolph, Tarun R. Naik and Rafa Siddique. "Use of Wood Ash in Cement Based Materials." University of Wisconsin at Milwaukee, Center for By-Products Utilization; CBU-2003-19 Abstract. 2003.

6. Mitchell, Charles C. and Eric D. Vance. "Beneficial Use of Wood Ash as an Agricultural Soil Amendment: Case Studies from the U.S. Forest Products Industry." Land Application of Agricultural, Industrial, and Municipal By-Products Ed. Warren A. Dick and James F. Power. Madison, WI: Soil Science Society of America, 2000. pp. 571-72.

7. National Council for Air and Stream Improvement (1999) Solid Waste Management Practices in the U.S. Paper Industry-1995. Technical Bulletin No. 793.

5.8. Yard Waste and Wood Trimmings

1. Brown, Sally and Harry Compton. Personal Interview. 7 Jun 2006

2. Henry, Chuck L. "West Page Swamp Wetland Restoration Project." University of Washington. 11 Jul 2006. http://faculty.washington.edu/clh/wet.html

3. "Log Yard Waste Reduction." North Carolina Division of Pollution Prevention and Environmental Assistance. 11 Jul 2006. http://www.p2pays.org/ref/09/pulp/page10.html

4. U.S. Environmental Protection Agency (1999) *RCRA Solid Waste Programs*. EPA/530-K-02-019I; Office of Solid Waste and Emergency Response.

5. "What Can Be Composted?" *Florida's Online Composting Center*. 11 Jul 2006. http://www.compostinfo.com/tutorial/GreensAndBrowns.html

5.9. Case Studies

1. Buck, John K. and Larry L. LaBuz. "Bottom Ash Fines as a Soil Amendment for Turfgrass and Site Closure- Laboratory and Mesocosm Studies at PPL Brunner Island and Montour Steam Electric Station." *Ash Library*. 2005. University of Kentucky. 26 Jul 2006. http://www.flyash.info/2005/201buc.pdf

2. Christenson, Donald R., Lee A. Hubbell and Richard R. List. "Applying Different Rates of Lime to Alkaline Soils and the Effects on Corn, Navy Beans and Sugar Beets." Michigan State University and Monitor Sugar Company. 28 Jul 2006 http://www.michigansugar.com/documents/research/2001/assbtpaper01.pdf

3. Gascho, Gary J. et al. "Effects of Broiler Litter in an Irrigated, Double-Cropped, Conservation-Tilled Rotation." Agronomy Journal. 2001. 93: 1315-1320. http://agron.scijournals.org/cgi/content/full/93/6/1315

4. Henry, Chuck. "Bunker Hill, Idaho. Ecological Restoration Demonstration." Chuck Henry, University of Washington. 10 Aug 2006. http://faculty.washington.edu/clh/bunker.html

5. Jenness, Nathan. "Mine Reclamation Using Biosolids." Aug 2001. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response.

6. Massanisso, P., et al. "Recycling and Use of Treated MSW and Industrial By-Products (Red Mud) Recovery of an Abandoned Mine Contaminated Soil." 14-15 Feb 2006.

7. Meyer, Deanne and Lawrence Schwanki. "Liquid Dairy Manure Utilization in a Cropping System: A Case Study." Land Application of Agricultural, Industrial, and Municipal By-Products Ed. Warren A. Dick and James F. Power. Madison, WI: Soil Science Society of America, 2000. pp. 413-18

8. Mitchell, Charles C. and Eric D. Vance. "Beneficial Use of Wood Ash as an Agricultural Soil Amendment: Case Studies from the U.S. Forest Products Industry." *Land Application of Agricultural, Industrial, and Municipal By-Products* Ed. Warren A. Dick and James F. Power. Madison, WI: Soil Science Society of America, 2000. pp. 571-72

9. New York City Bureau of Waste Prevention, Reuse and Recycling. "Composting in New York City: A Complete Program History (Part 2)." Aug 2001. New York City

Department of Sanitation. 28 Jul 2006
http://www.nyccompost.org/resources/publications.html

10. Sawyer, Dr. John E. "Swine Manure Nutrient Utilization, Crop Year 2001." Department of Agronomy, Iowa State University. 25 Jul 2006.
http://www.agriculture.state.ia.us/iflm/swinemanurerep.pdf

11. U.S. Environmental Protection Agency. *Poland Biosolids Smelter Waste Reclamation Project*. Office of Water; EPA 832-R-00-009. 2000.
http://www.epa.gov/owm/mtb/biosolids/polabroc.pdf

12. Vance, Eric. "Utilizing Paper Mill By-Products as Forest Soil Amendments: Forest Responses, Recommendations and Industry Case Studies." National Council for Air and Stream Improvement; Technical Bulletin no. 798, 2000.

5.10. Figures

1. U.S. Environmental Protection Agency (1999) *Biosolids Generation, Use and Disposal in the United States.* Office of Solid Waste and Emergency Response; EPA530-R-99_009.

2. United States Geological Survey. “Coal Fields of the United States.” 20 Jul 2005. *USGS.gov.* 8 Aug 2006. http://www.usgs.gov/themes/factsheet/094-99/coal_field.html

3. U.S. Environmental Protection Agency (2002) *Profile of the Pulp and Paper Industry.* Office of Compliance; EPA/310-R-02-002.

4. “Alumina Refining.” *World-aluminium.org*. 2000. The International Aluminium Institute. 10 Jul 2006. http://www.world-aluminium.org/production/refining/index.html

5. “The U.S. Sweetener Industry.” *Frequently Asked Questions.* 2005. American Sugar Alliance. 14 Aug 2006. http://www.sugaralliance.org/desktopdefault.aspx?page_id=98

6. Henry, Chuck. “Bunker Hill, Idaho. Ecological Restoration Demonstration.” Chuck Henry, University of Washington. 10 Aug 2006.
http://faculty.washington.edu/clh/bunker.html

7. Henry, Chuck. “Bunker Hill, Idaho. Ecological Restoration Demonstration.” Chuck Henry, University of Washington. 10 Aug 2006.
http://faculty.washington.edu/clh/bunker.html

8. U.S. Environmental Protection Agency. *Poland Biosolids Smelter Waste Reclamation Project.* Office of Water; EPA 832-R-00-009. 2000.
http://www.epa.gov/owm/mtb/biosolids/polabroc.pdf

9. Sawyer, Dr. John E. "Swine Manure Nutrient Utilization, Crop Year 2001." Department of Agronomy, Iowa State University. 25 Jul 2006. http://www.agriculture.state.ia.us/iflm/swinemanurerep.pdf

10. Sawyer, Dr. John E. "Swine Manure Nutrient Utilization, Crop Year 2001." Department of Agronomy, Iowa State University. 25 Jul 2006. http://www.agriculture.state.ia.us/iflm/swinemanurerep.pdf

11. New York City Bureau of Waste Prevention, Reuse and Recycling. "Composting in New York City: A Complete Program History (Part 2)." Aug 2001. New York City Department of Sanitation. 28 Jul 2006 http://www.nyccompost.org/resources/publications.html

APPENDICES

NOTE: All appendices citing specific locations of residuals contain limited information on each source, and are not meant to be comprehensive.

LISTS ARE NOT MEANT TO BE COMPREHENSIVE

Appendix 1: Biosolids Locations

~Please see www.biosolids.org for a list of both state and regional biosolids contacts.
~For other biosolids-related organizations:

Mid-Atlantic Biosolids Association – www.mabiosolids.org/
National Association of Clean Water Agencies – www.nacwa.org/
New England Biosolids and Residuals Association - www.nebiosolids.org/
Northwest Biosolids Management Association – www.nwbiosolids.org
Southern California Alliance of Publicly Owned Treatment Works – www.scap1.org/
Water Environment Federation – www.wef.org/Home

~To search for Publicly Owned Treatment Works (POTWs) in your area, please do the following:

- Go to http://www.epa.gov/enviro/html/pcs/adhoc.html to access the Permit Compliance System, also known as "PCS."
- Click "Facility Information"
- Click "Step 2: Retrieve Table for Selected Subjects"
- Check the box for "v_pcs_permit_facilities" then click "Step 3: Select Columns"
- When selecting columns, it is recommended that you check the boxes for "NPDES" (first row), "Location Telephone Number," "Mailing Name," "Mailing Street 1," "Mailing City," "Mailing State," "Mailing ZIP Code," "Name 1," and "Flow Rate"
- Click "Step 4: Enter Search Criteria"
- Under "Geography Search," enter the parameters you wish to use to locate a POTW (ZIP code, City, County, State)
- Under "Standard Industrial Classification (SIC) Code Search," you MUST enter the code 4952. Failure to do this will return more than just the POTW information.
- To save the output file as a document that can be opened in Microsoft Excel, Click "Output to CVS File" then follow the instructions given that the bottom of the results page and click on the blue, underlined number.
- To view the search results just in a table on the webpage, click "Search Data Base"

Appendix 2: CAFO Locations

Chickens

~Foster Farms
For WA and OR: Foster Farms Consumer Affairs
P.O. Box 52, Kelso, WA 98626
All others: Foster Farms Consumer Affairs
P.O. Box 306, Livingston, CA 95334
1-800-255-7227
htttp://www.fosterfarms.com/

Hatcheries in: Modesto, CA; Fresno, CA; Lyons, OR; Oregon City, OR

Grow-out Ranches in: Livingston, CA; Fresno, CA; Turlock, CA; Creswell, OR

~Gold Kist Inc.
P.O. Box 2210
Atlanta, GA 30301
(770) 393-5000
http://www.goldkist.com/index.asp

~Perdue Farms
P.O. Box 1656
Horsham, PA 19044-6656
1-800-4-PERDUE® (1-800-473-7383)
http://www.perdue.com/util/contact.html

Farm in: Salisbury, MD

~Pilgrim's Pride Corporation
P.O. Box 93,
Pittsburg, TX 75686
1-800-824-1159
http://www.pilgrimspride.com/

Hatch/Grow-out Facilities:

Athens, GA	Athens, AL
Broadway, VA	Batesville, AR
Center, TX	Canton, GA
Clinton, AR	Chattanooga, TN
Dalton, GA	Concord, NC
El Dorado, AR	DeQueen, AR
Farmerville, LA	Enterprise, AL
Harrisonburg, VA	Gainesville, GA
Mayfield, KY	Hope, AR
Nacogdoches, TX	Moorefield, WV
Nashville, AR	Natchitoches, LA
Sulphur Springs, TX	Pittsburg, TX

~Tyson's

Poultry complexes in: Temperanceville, VA

Cows –Beef/Dairy

~Certified Angus Beef LLC
1107 Hylton Heights Rd.
Manhattan, KS 66502-2822
(785) 539-0123

Located in: CO, IA, KS, MT, NE, NM, OH, OK, OR, SD, TX, WA, WI, WY

See http://www.cabpartners.com/feedlots/feedlots.php for feedlots and contact information

~Clover Farms Dairy P.O. Box 14627 Reading, PA 19612-4627 (610) 921-9111 http://www.cloverfarms.com/	Located in NJ, Southeast PA and Southern NY
~Cloverland/Green Spring Dairy (410) 235-4477 cloverlanddairy.com webmaster@cloverlanddairy.com	Located in Baltimore, MD
~Cumberland Dairy 899 Landis Ave. Rosenhayn, NJ 08352 1-800257-8484 http://www.cumberlanddairy.com/	**Contact for dairy farm locations (Along eastern seaboard)
~Dean Foods Company Attn: Corporate Communications Dept. 2515 McKinney Ave., Suite 1200 Dallas, TX 75201	**Contact for dairy farm locations
~Farmland Dairies LLC Attn: Consumer Affairs 520 Main Ave. Wallington, NJ 07057 1-888-727-6252 http://www.farmlanddairies.com/	**Contact for dairy locations (Eastern U.S.)
~Horizon Organic P.O. Box 17577 Boulder, CO 80308-7577 http://www.horizonorganic.com/site/forfarmers/meet.html	Farms in: Bonanza, OR Sidney, ME Deford, MI
~Land O'Lakes, Inc. P.O. Box 64101 St Paul, MN 55164-0101 1-800-328-9680 http://www.landolakesinc.com/ or http://www.landolakes.com/	**Contact for locations of dairy farms
~Lucerne Foods 5918 Stoneridge Mall Rd. Pleasanton, CA 94588 (925) 944-4444 http://www.lucernefoods.com/	**Contact for dairy farm locations (Western and Midwestern U.S.)
~Niman Ranch 1025 E. 12th St. Oakland, CA 94606 (866) 808-0340	Feedlots in: Ca, ID, IL, IA, KS, MI, MN, MO, NE, NC, OR, UT

See the "Farmers and Ranchers" section of http://www.nimanranch.com/ for locations and contacts.

~Omaha Steaks ** Contact for locations of feedlots (Midwest)
10909 John Galt Blvd.
P.O. Box 3300
Omaha, NE 68103
1-800-329-6500
http://www.omahasteaks.com/

~Organic Valley Family of Farms **801 farms, contact for locations
CROPP Cooperative
1 Organic Way
LaFarge, WI 54639
(888) 444-6455
http://organicvalley.coop/

~Stonyfield Farm **No longer *owns* cows – contact for supplier locations
Ten Burton Drive
Londonderry, NH 03053
(603) 437-4040
http://www.stonyfield.com/

~Wells Dairy, Inc
http://www.wellsdairy.com/

Pigs

~For a list of several pork producers in alphabetical (by state) order:
http://www.nichepork.org/findAProducer.asp?type=find

~Farmland Foods **Contact for dairy farmer locations
Consumer Relations
P.O. Box 20121
Kansas City, MO 64195-0121
http://www.farmlandfoods.com/contact.asp
1-888-327-6526

~Premium Standard Farms Located in: -Mercer, Putnam, Sullivan, Daviess and Gentry counties, MO
805 Pennsylvania Ave. Suite 200 -Dallam and Hartley counties, TX
Kansas City, MO 64105 -Duplin, Greene, Pitt and Sampson counties, NC
(816) 472-7675
http://www.psfarms.com/index.html

~Niman Ranch
See above under "Cows"

Appendix 3: Coal-Fired Power Plant Locations

~American Coal Ash Association Membership Directory:
http://www.acaa-usa.org/PDF/ASH_at_Work_Content(Jun05).pdf
*Note: Not all companies listed are generators or CCPs

~Basin Electric Power Cooperative
1717 East Interstate Ave.
Bismark, ND 58503-0564
(701) 223-0441
http://www.basinelectric.com/

Coal-fired plants in: Beulah, ND
Wheatland, WY
Stanton, ND

~Sierra Pacific & Nevada Power
http://www.sierrapacific.com/contact/

Coal-fired plants in Valmy and southern NV

Appendix 4: Pulp and Paper Mill Locations
(may also provide wood ash)

~Appleton
825 E Wisconsin Ave.
P.O. Box 359
Appleton, WI 54912-0359
(920) 734-9841
http://www.appletonideas.com//

Located in: MA, OH, PA, WI

~Atlas Paper Mills
3725 East 10th Ct
Hialeah, FL 33013
(305) 835-8046
http://www.atlaspapermills.com/

~Domtar Industries Inc.
Find contact info by mill location:
http://www.domtar.com/en/contacts/index.asp

Locations: Ashdown, AR
Port Edwards, WI
Port Huron, MI
Baileyville, ME

~FiberMark
161 Wellington Rd.
P.O. Box 498
Brattleboro, VT 05302
(802) 257 0365
http://www.fibermark.com

Locations: Brattleboro, VT
Brownville, NY
Lowville, NY
Quakertown, PA
Reading, PA
Warren Glen, NJ

~Georgia-Pacific
http://www.gp.com/
*For contact info for specific locations, see the "About US" section under "Facilities

Locations in:

Augusta, GA
Monticello, MS
Toledo, OR
Camas, WA
Palatka, FL
Cedar Springs, GA
New Augusta, MS
Big Island, VA
Green Bay, WI

~International Paper
Global Headquarters
6400 Poplar Ave.
Memphis, TN 38197
(901) 419-9000
http://www.internationalpaper.com/
For US locations: http://ipaper.know-where.com/ipaper_public/WorldForest.html

Located in: AL, AR, FL, GA, IN, LA, ME, MI, MN, MO, MS, NC, NH, NY, SC, TN, TX, VA, WI

~Louisiana-Pacific Corp.
LP Marketing Center
P.O. Box 7429
Endicott, NY 13761-7429
1-888-820-0325
http://www.lpcorp.com/

Locations in:

Carthage, TX
Hayward, WI
Holly Springs, MS
Jasper, TX
Newberry, MI
N. Wilmington, NC
Roaring River, NC
Sagola, MI
Selma, AL
Athens, GA
Hanceville, AL
Hines, OR
Houlton, ME
Meridian, ID
N. Two Harbors, MN
Red Bluff, CA
Roxboro, NC
Schaumburg, IL
Silsbee, TX

~Kimberly-Clark Corporation
Dept. INT
P.O. Box 2020
Neenah, WI 54957-2020
1-888-525-8388
http://www.kimberly-clark.com/

Locations in:

Tuscon, AZ
Maumelle, AR
New Milford, CT
Pocatello, ID
Corinth, MS
Lexington, NC
Chester, PA
Loudon, TN
Fort Worth, TX
San Antonio, TX
Ogden, UT
Marinette, WI
Mobile, AL
Conway, AR
Fullerton, CA
LaGrange, GA
Owensboro, KY
Hendersonville, NC
Jenks, OK
Beech Island, SC
Del Rio, TX
Paris, TX
Draper, UT
Everett, WA
Neenah, WI

~MeadWestvaco Corp.
World Headquarters
1 High Ridge Park
Stamford, CT 06905
(203) 461-7400
http://www.mead.com

Locations in: AL, CA, CO, CT, FL, GA, IL, IN, KY, LA, MA, NC, NJ, NY, OH, PA, SC, TX, VA, WI, WV
For specific locations go to: http://www.mwvlocations.com/

~Nashua Corp.
General Offices
11 Trafalgar Square, 2nd Fl.
Nashua, NH 03063
(603) 880-2323
http://www.nashua.com/

Locations in: Merrimack, NH; Jefferson City, TN; Los Angeles, CA; Omaha, NE; St. Louis, MO

~Sharma Group
Unicell Paper Mills Inc
3401 St. Johns Pkwy
Sanford, FL 32771
(407) 330-9696
http://www.thesharmagroup.com/

~Weyerhaeuser Corporation
P.O. Box 9777
Federal Way, WA 98063-9777
1-800-525-5440 or (253) 924-2345
http://www.weyerhaeuser.com

Located in all states EXCEPT: AK, CT, DE, ME, ND, NH, NM, RI, SD, VT, WY
For specific locations see:
http://www.weyerhaeuser.com/maps/displayt1.asp

~For a more complete list of pulp and paper companies, see http://www.paperage.com/pulp_paper.html or http://dir.yahoo.com/Business_and_Economy/Business_to_Business/Industrial_Supplies/Pulp_and_Paper/Manufacturing/

Appendix 5: Red Mud Locations

~Alcoa Inc. — Point Comfort, TX
http://www.alcoa.com/alumina/en/home.asp

~Sherwin Aluminum Co. — Corpus Christi, TX
(a division of BPU Reynolds, Inc.)
Bought by China Minmetals Nonferrous Metals Co. Ltd. in 2004
http://www.sherwinalumina.com/index.html

~Kaiser Aluminum Corp. — Gramercy, LA
Purchased by Century Aluminum Co. and Noranda Inc. in 2004
http://www.falconbridge.com/
http://centuryca.com/products/gramercy.html

~Ormet Corp. — Burnside, LA
http://www.ormet.com/

Appendix 6: Sugar Beet Lime Locations

~Amalgamated (Snake River) Sugar Company L.L.C. - Headquarters Location 3184 Elder St. Boise ID 83705 (208) 383-6500 http://www.amalgamatedsugar.com/	Factories in:	Paul, ID Twin Falls, ID Nampa, ID Nyssa, OR
~American Crystal Sugar Company Corporate Office 101 North 3rd Street Moorhead, MN 56560 (218) 236-4400 http://www.crystalsugar.com/	Factories in:	Crookston, MN Drayton, ND East Grand Forks, MN Hillsboro, ND Moorhead, MN
~Michigan Sugar Company 2600 South Euclid Avenue Bay City, MI 48706 (989) 686-0161 http://www.michigansugar.com/ **http://www.michigansugar.com/products/lime.php ← for lime pick-up information	Factories in:	Bay City, MI Caro, MI Croswell, MI Sebewaing, MI
~Minn-Dak Farmers Cooperative 7525 Red River Road Wahpeton, ND 58075 http://www.mdf.coop/	Factory in:	Wahpeton, ND
~Sidney Sugars Incorporated Owned by American Crystal Sugar Company	Factory in:	Sidney, MT
~Southern Minnesota Beet Sugar Coop. Headquarters Location 83550 County Rd. 21, Renville MN 56284 (320) 329-8305, (320) 329-3252 fax, http://www.smbsc.com ** http://www.smbsc.com/pcc/ ← to schedule pick up of lime	Lime pickup:	Renville, MN
~The Western Sugar Cooperative 7555 East Hampden Ave, Suite 600 Denver, CO 80231 (303) 830-3939 http://www.westernsugar.com/ **By-Products Sales: 308-632-4155	Factories in:	Fort Morgan, CO Greeley, CO Scottsbluff, NE Torrington, WY Lovell, WY Billings, MT