Materials Characterization Paper
In Support of the
Advanced Notice of Proposed Rulemaking –
Identification of Nonhazardous Materials That Are Solid Waste

Wastewater Treatment Sludge

December 16, 2008

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1. Definition of Wastewater Treatment Sludge

The suspended and dissolved solids generated in the wastewater treatment process are called sludges or sewage sludge. This sludge is also commonly known as biosolids. Wastewater treatment operations require careful management of sludge, not only after removal from the treatment process, but also during the treatment process: sludge is a critical biologically active mix of water, organic matter (derived from human wastes, food wastes, etc.), inorganic solids (including trace elements), dead and alive micro-organisms (including pathogens), and trace contaminants (e.g., chemicals). Some sludge is routinely recycled within the treatment facility process to optimize operations. However, as sludge builds up, batches of it are regularly removed from effluent treatment operations. This "raw" sludge is typically two to three percent solids and 97 to 98 percent water and must be further treated to be utilized in a beneficial manner. Most sludge comes from primary settling tanks ("clarifiers") and/or secondary settling tanks and, in most cases, is a slightly thick, gray-bottom liquid. In this analysis, wastewater treatment sludge includes materials generated after both primary and secondary treatment stages.

Sludges generated from the pulp and paper industry are discussed in the Materials Characterization Paper entitled, "Forest-Derived Biomass and Pulp and Paper Residues."

2. Annual Quantities of Wastewater Treatment Sludge Generated and Used:

(1) **Sectors that generate Wastewater Treatment Sludge:**
The NAICS code for sewage treatment facilities is 221320.

(2) **Quantities and Prices of Wastewater Treatment Sludge Generated:**

- Data sources for the 2002-2003 period differ in their assessment of the generation of wastewater treatment sludge in the U.S. Based on the range of values reported by these sources, an estimated 5 to 7 million tons were generated annually in the U.S. during this period. (City of Toronto 2003; WEF 2002; NBP 2005, p. 19-1).
- Nationwide data on the market value of wastewater treatment sludge are not readily available. On a local scale, a 1996 article by *BioCycle* magazine estimated that biosolids produced by the Hampton Roads Sanitation District in Virginia was worth approximately $20 per dry ton of biosolids (or $95 per acre for land application) (NBP 2005). More recent estimates of the economic value of biosolids were not readily available.

(3) **Trends in Generation of Wastewater Treatment Sludge:**

- The readily available data do not show a clear trend in the generation of wastewater treatment sludge.

3. *Uses of Wastewater Treatment Sludge*

(1) **Fuel uses:**

- Wastewater treatment sludge may be used as a fuel in cement kilns (NAICS 327310 cement industry). The available data do not indicate how widespread this practice is.
- Various sources indicate that between 15 and 22 percent of wastewater treatment sludge is incinerated (WEF 2002; City of Toronto 2003; UNEP). Approximately 150 municipalities in the U.S. - representing approximately 250 installations - engage in this practice (City of Toronto 2003). However, when wastewater treatment sludge is burned in dedicated wastewater treatment sludge incinerators, it is most likely not used as a substitute for conventional fossil fuels that incinerators may burn to maintain efficient combustion.
- There are two fundamental options for recovery of energy from dried biosolids: 1) utilize an existing offsite “host” process in which the biosolids replace a portion of the prime fuel; and 2) construct a dedicated plant onsite to produce energy for either onsite use or export (ENERGOs, 2007).
- Atlanta-based EnerTech Environmental recently developed the “Slurry-Carb™” process that converts biosolids into a renewable fuel called E-Fuel. The E-Fuel product derived from the Slurry-Carb™ process is suitable for gasification, co-firing, use in cement kilns or utilization in industrial and utility boilers (PWM 2007; EnerTech 2008). The cost of the Slurry-Carb process is approximately $72 per ton (PWM 2007). The first Slurry-Carb facility is scheduled to open in the Los Angeles area in 2008 and will convert 675 wet tons of sludge per day into approximately 145 tons per day of E-fuel, which will be sold to a local cement kiln as a substitute for coal (PWM 2007).
- Incineration of wastewater treatment sludge is regulated under 40 CFR 503 Subpart E. These regulations cover pollutant limits; general management practices; and monitoring, reporting, and recordkeeping requirements (EPA 2004).

(2) **Non-Fuel Uses of Wastewater Treatment Sludge**

- According to EPA data summarized by the Water Environment Federation, more than 60 percent of wastewater treatment sludge produced in the United States is beneficially used on land following treatment, frequently by alkaline addition (WEF 2002). Similarly, another data source indicates that 63 percent of biosolids in the U.S. were land applied in 1998, with this figure expected to reach 66 percent in 2005 and 70 percent in 2010 (Oleszkiewicz and Mavinic 2002).
- Nearly 42 percent of all U.S. wastewater treatment solids are land applied as fertilizer (Clackamas County 2006). Based on the figures presented in the

previous bullet, this represents approximately two-thirds of the total percentage land applied.

- Data published by the United Nations Environment Program (UNEP) suggest that approximately 36 percent of wastewater treatment sludge generated in the mid-1990s was beneficially used for agricultural applications (land applied) and 10 percent was managed through other methods (UNEP). Examples of land application uses include:
    - Agricultural cropland application, through liquid injection, or surface spreading followed by incorporation into the soil;
    - Commercial sale as a fertilizer or soil conditioning material, particularly for horticultural and landscaping applications;
    - Rangeland and pasture application to improve available grazing;
    - Remediation of contaminated areas such as mine sites;
    - Soil amendment and recovery of marginal land; and
    - Land application in reforested areas (UNEP).
- A potential future use of wastewater treatment sludge is as an anaerobic agent to optimize the natural degradation of waste in municipal solid waste landfills. (NBP 2005, p 19-1).
- Land application of wastewater treatment sludge is regulated under 40 CFR 503. These regulations cover pollutant limits; general management practices; and monitoring, reporting, and recordkeeping requirements (EPA 2004). The pollutant limits are listed below in Exhibit 4.

(3) **Quantities of Wastewater Treatment Sludge Landfilled**

- Based on EPA estimates from the 2000-2002 period, approximately 14 to 17 percent of wastewater treatment sludge is landfilled, and, of this, approximately 3 percent is used as daily or final cover in landfills (EPA as cited in WEF 2002 and NBP 2005, p. 19-1).
- Data published by UNEP suggest that 38 percent of wastewater treatment sludge was disposed in landfills in the mid-1990s (Chang, Pang and Asano 1996).

(4) **Quantities Wastewater Treatment Sludge Stockpiled/Stored**

- The available information sources do not suggest that wastewater treatment sludge is stockpiled or stored.

Exhibit 1: Overview of Generation and Use - Wastewater Treatment Sludge

Commodity	**Annual Quantity Generated**	**Beneficial Use**		**Annual Quantity Landfilled**	**Annual Quantity Incinerated**	**Annual Quantity in Other Uses (landfill cover)**
		Fuel (cement kiln)	**Land Applied**			
	Short Tons					
Biosolids (Wastewater Treatment Sludge)	5 to 7 million dry tons	Quantity data unavailable	60%+	14 to 17%	15 to 22%	Quantity data unavailable

Sources:
City of Toronto 2003, NBP 2005, Oleszkiewicz and Mavinic 2002, UNEP, and WEF 2002

4. Management and Combustion processes

(1) **Types of Units**

- Fluidized Bed Incineration (FBI)
- Multiple Hearth Furnace (MHF)
- Cement Kilns

(2) **Sourcing information**

- Municipal and food wastewater treatment plants.

(3) **Processing Information:**

- Most often, wastewater treatment sludge is treated in either an aerobic or anaerobic digester to stabilize the material and reduce pathogen concentrations (disease-causing organisms). A variety of other treatment options may be used to ensure that sludge meets federal and state requirements for beneficial use. Upon satisfying these requirements, the sludge is considered a "biosolid" (NEBRA 2005).
- The Slurry-Carb™ technology converts biosolids to fuel using the following processes:
  - Biosolids are subjected to pressure and heat;
  - Upon reaching the desired reaction temperature, the biosolids break down into carbon and light gases;
  - The result is a slurry with molecules that are much smaller than the original biosolids and very high in energy;
  - The slurry is dewatered to 50 percent total solids through centrifugation rather than evaporation, allowing it to dry using approximately two-thirds less energy than conventional drying methods;
  - The end product, a renewable fuel called E-Fuel, is an alternative to fossil fuels (EnerTech 2008).
- Energy recovery technologies can be classified into sludge-to-biogas processes, sludge-to-syngas processes, sludge-to-oil processes, and sludge-to-liquid processes. The technologies available for resource recovery include those to recover phosphorus, building materials, nitrogen, volatile acids, etc (WERF, 2008a).

(4) **Changes in Technology to improve use as a fuel:**

- Information is not readily available on specific technological developments to improve the use of wastewater treatment sludge in combustion applications. The Lehigh Cement Company, however, began performing tests in 2004 on the use of dried sewage pellets from two Baltimore treatment plants to replace some of the coal burned by Lehigh's kiln near Union Bridge. Lehigh's parent corporation, Heidelberger Zement, and other cement makers have been using sludge pellets for about 20 years in Europe. Approximately 55 dry tons of pellets are produced each day at the Back River and the Patapsco wastewater treatment plants in Baltimore (Hand-Smith 2007, p5).

(5) **State status of Combustion as beneficial use:**

- At this stage, we have not identified any states that have approved use of wastewater treatment sludge as fuel, but we have not performed an exhaustive investigation of state activities and regulations.

5. Wastewater Treatment Sludge Composition and Impacts

(1) **Composition of Commodity**

- The Slurry-Carb™ process recently developed by EnerTech Environmental, produces a final product called "E-Fuel" from biosolids that can be sold as a renewable fuel with approximately 7,000 BTU per pound (EnerTech 2008).
- According to the Water Environment Foundation, the energy value of biosolids is approximately 5,500 kcal/kg (10,000 Btu per pound) of dry volatile solids or 2,500 to 3,000 kcal/kg (4,500 to 5,500 Btu per pound) of total dry matter (WEF 2000). Exhibit 2 presents separate Btu values for different types of wastewater treatment sludge.

Exhibit 2: Btu Value of Different Types of Wastewater Treatment Sludge

Wastewater Treatment Sludge Material	**Heating Value (Btu per pound of dry solids)**
Fine Screenings	9,000
Grit	4,000
Grease and Scum	16,700
Dewatered Raw Biosolids	10,300
Chemical Precipitated Biosolids	7,500
Dewatered Digested Biosolids	5,300

<u>Source:</u>
NBP 2005, p 15-10

- Exhibit 3 compares the results of two surveys of the chemical composition of biosolids, and, for comparison, also includes the composition of coal. The 40-City Study, which was conducted in 1979 and 1980, examined the solids generated at 40 publicly-owned wastewater treatment facilities, while the National Sewage Sludge Survey conducted in 1989 summarizes the results of testing conducted at over 200 wastewater treatment facilities (NBP 2005, pp. 3-1 to 3-2). While dated, the results of the two surveys indicate that, in almost every case, the observed concentrations in the National Sewage Sludge Survey are less than those in the 40-city study, suggesting that concentrations fell during the 1980s. Copper and mercury concentrations, however, appear to have increased during this period. The increase in copper concentrations most likely reflects increased use of copper plumbing in new homes. There is no clear explanation for the increase in the average mercury concentration (NBP 2005, p.3-2).

Exhibit 3: Composition of Municipal Wastewater Treatment Sludges

Element	**Wastewater Treatment Sludge**		**Coal (mg/kg)**
	40-City Study (1980) mg/kg dry weight	**National Sewage Sludge Study (1989) mg/kg dry weight**	
Arsenic	9.9	6.7	10
Cadmium	69	6.9	0.5
Chromium	429	119	20
Copper	602	741	Not available
Lead	369	134.4	40
Mercury	2.8	5.2	0.1
Molybdenum	17.7	9.2	Not available
Nickel	135.1	42.7	20
Selenium	7.3	5.2	1
Zinc	1,594	1,202	Not available

Sources:
NBP 2005, pp. 3-1 to 3-2 and EPA 1998, p. 1-5

In accordance with Part 503, all biosolids applied to the land must be within the limits listed in Exhibit 4.

Exhibit 4: Pollutant Limits for Biosolids Applied to the Land

Pollutant	**Ceiling Concentration Limits for All Biosolids Applied to Land (milligrams per kilogram)[a]**
Arsenic	75
Cadmium	85
Chromium	3000
Copper	4300
Lead	840
Mercury	57
Molybdenum[b]	75
Nickel	420
Selenium	100
Zinc	7500
Applies to:	All biosolids that are land applied
From Part 503	Table 1, Section 503.13

Source:
EPA 2004
Notes:
[a] Dry-weight basis
[b] As a result of the February 25, 1994, Amendment to the rule, the limits for molybdenum were deleted from the Part 503 rule pending EPA reconsideration.

(2) **Impact Information**

- ***Cost Impacts:*** The net cost impacts associated with the beneficial use of wastewater treatment sludge as a fuel in cement kilns depends on the value of the fuel that this material replaces and the cost of processing the material prior to its use as a fuel. Information on these processing costs is not readily available, but we estimate that the fuel savings associated with using wastewater treatment sludge as a substitute for conventional fuels would be $2.23 per MMBtu, assuming that the wastewater treatment sludge would replace coal (EIA 2007, Table ES1).[1]
- ***Emissions Impacts of Using Wastewater Treatment Sludge as a Fuel in Cement Kilns:*** As indicated above, an unknown quantity of wastewater treatment sludge may be beneficially used as a fuel in cement kilns. Information is not available on the emissions associated with this activity, but we were able to identify information on the emissions associated with the *incineration* of wastewater treatment sludge, as summarized in Exhibit 5. The exhibit also summarizes the combustion-related emissions for coal, distillate oil, residual oil, and natural gas.
- ***Upstream Emissions Impacts:*** Use of wastewater treatment sludge as a replacement for traditional primary fuels in cement kilns eliminates the environmental impacts associated with extraction and processing of the traditional fuels. Exhibit 5 lists the quantities of cradle-to-gate (i.e., combustion plus upstream) emissions for coal, the fuel typically used by cement kilns, and other fossil fuels based on typical processes in the United States in the late 1990s.

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[1] To express this value as dollars per MMBtu, we assumed 22,473,000 Btu per short ton of coal (EIA 2005, Table A5).

Exhibit 5: Comparative Impacts of Sludge Incineration versus Alternative Primary Fuels

Pollutant	Sludge Incineration	Coal		Distillate Fuel Oil		Residual Fuel Oil		Natural Gas	
	Combustion (Incineration)	Combustion	Combustion plus Upstream	Combustion	Combustion plus Upstream	Combustion	Combustion plus Upstream	Combustion	Combustion plus Upstream
	------ *lb./MMBtu* ------								
Criteria Pollutants									
PM2.5	0.025	-	-	-	-	-	-	-	-
PM10	0.043	0.054	0.054	0.011	0.011	0.093	0.093	0.009	0.009
PM, unspecified	0.010	-	0.246	-	0.012	-	0.012	-	0.004
NOx	0.201	0.482	0.504	0.173	0.234	0.367	0.428	0.301	0.417
VOCs	0.008	0.006	0.014	0.001	0.363	0.002	0.367	0.009	0.524
SOx	0.28	1.446	1.469	0.209	0.394	1.593	1.781	0.073	1.985
CO	0.8	0.068	0.085	0.036	0.082	0.033	0.079	0.058	0.282
Pb	$3.1\text{x}10^{-3}$	$8.93\text{x}10^{-6}$	$9.19\text{x}10^{-6}$	$4.60\text{x}10^{-6}$	$5.61\text{x}10^{-6}$	$5.80\text{x}10^{-5}$	$5.90\text{x}10^{-5}$	-	$2.72\text{x}10^{-7}$
Hg	-	$2.05\text{x}10^{-6}$	$2.14\text{x}10^{-6}$	$1.58\text{x}10^{-6}$	$1.77\text{x}10^{-6}$	$8.67\text{x}10^{-6}$	$8.85\text{x}10^{-6}$	-	$7.18\text{x}10^{-8}$

Source:
Franklin Associates 1998.

Notes:
"-" signifies data not available; may equal zero.
The sludge incineration numbers are based on a combination of averages, including the average controlled emissions rates from 12 sources and three different incineration technologies (multiple hearth, fluidized bed, and electric). Additionally, a midpoint value of 10,350 BTUs/lb heating value for wastewater treatment sludge was used (heating values ranged from 4,000 btu/lb to 16,700 btu/lb).

The emission information presented in this table is derived from Life Cycle Inventory (LCI) data, as compiled by Franklin Associates. LCI data identifies and quantifies resource inputs, energy requirements, and releases to the air, water, and land for each step in the manufacture of a product or process, from the extraction of the raw materials to ultimate disposal. The LCI can be used to identify those system components or life cycle steps that are the main contributors to environmental burdens such as energy use, solid waste, and atmospheric and waterborne emissions. Uncertainty in an LCI is due to the cumulative effects of input uncertainties and data variability.

There are several life cycle inventory databases available in the U.S. and Europe. For this paper, we applied the most readily available LCI database that was most consistent with the materials and uses examined. These LCI data rely on system boundaries as defined by Franklin Associates, as described in the documentation for this database, available at: http://www.pre.nl/download/manuals/DatabaseManualFranklinUS98.pdf.

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