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

Biomass - Agricultural Residues and Food Scraps

December 16, 2008
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1. *Definitions of Agricultural Residues and Food Scraps*

Agricultural residues include crop residues remaining in fields after harvest (primary residues) and processing residues generated from the harvested portions of crops during food, feed, and fiber production (secondary residues).

Food scraps are generated at all stages of the food system including farming, storage, processing, wholesaling, retail, and consumption (Scott Kantor *et al*. 1997). Food scraps, broadly defined, include both the portion of harvested crops and livestock that does not enter the retail market and the portion of food discarded by retailers and consumers. In this paper, food scraps generated by retailers and consumers are not considered because they enter the waste stream as municipal solid waste (MSW) (EPA 2006, Simmons *et al.* 2006). Food scraps generated in the manufacture and distribution of food are produced through spoilage, removal of unusable portions, discard of substandard products, and packaging failure.

2. *Annual Quantities of Agricultural Residues and Food Scraps Generated and Used*

(1) **Sectors that Generate Agricultural Residues and Food Scraps:**
- NAICS 111: Crop Production
- NAICS 11511: Support Activities for Crop Production
- NAICS 311: Food Manufacturing
- NAICS 312 Beverage and Tobacco Product Manufacturing

(2) **Quantities and Prices of Agricultural Residues and Food Scraps Generated:**
- Current annual production of agricultural residues from major crops is around 500 million dry tons (Milbrandt 2005, Haq and Easterly 2006). These crops include barley, canola, corn, cotton, dry beans, flax, oats, peanuts, peas, potatoes, rice, rye, safflower, sorghum, soybeans, sugarcane, sunflowers, and wheat, among others. The fraction of this amount that can be removed from fields in a sustainable manner (*i.e.*, while maintaining cropland fertility and quality) varies widely from 113 million tons by Perlack *et al*. (2005) to 173 million tons by Milbrandt (2005)). Newer analyses soon to be published tend to be even lower.
- Sugarcane production from 2005 through 2007 averaged 13.5 million tons of cane (ERS 2008). This yielded approximately 3.8 million tons of bagasse assuming 0.28 lbs. of bagasse produced per pound of cane (Macedo *et al.* 2004).

- Domestic production of peanut hulls was approximately 0.27 million tons in 1999 (Özyurt and Realff 2002).
- Total quantities of secondary agricultural residues and industrial food scraps produced on an annual basis are not readily accessible from the available literature.
- Further analysis could be used to derive an estimate of industrial food scrap production by applying known conversion factors for weight reductions that occur as crops and livestock are processed into retailed food products. These conversion factors range from 5 percent for fresh fruit to 30 percent for meat, poultry, and processed vegetables (Scott Kantor *et al.* 1997, Jones Putman and Allshouse 1999).
- Around 75 million tons, or two-thirds, of the 113 million tons of sustainably harvestable primary agricultural residue estimated by Perlack *et al.* (2005) is corn stover, which is composed of corn stalks, husks, and shelled cobs. Processing facilities experience marginal feedstock costs from $54 to $84 per dry ton depending on the fraction of stover collected from the field and transportation distance (Petrolia 2008).
- Haq and Easterly (2006) provide a detailed list of supply curves for primary and secondary agricultural residues. These could be updated for current collection and transportation costs given recent increases in energy prices.

(3) **Trends in Generation of Agricultural Residues and Food Scraps:**

- Total primary agricultural residue production fluctuates with 1) the amount of US land in crop production and 2) the relative proportion of crops, each with its own residue production rate. Current trends suggest that higher food prices will drive additional land into crop production (Secchi and Babcock 2007), thereby potentially increasing residue production.
- Domestic sugarcane production has decreased over the past decade (ERS 2008), thus reducing the total amount of secondary agricultural residue (bagasse) combusted in sugar mills. Conversely, new methods for utilizing sugarcane "trash," or field residue, may increase total biomass use from this crop (Macedo *et al.* 2008).
- Trends in other secondary agricultural residue and food scraps are not readily available.

3. *Uses of Agricultural Residues and Food Scraps*

(1) **Combustion Uses of Agricultural Residues and Food Scraps:**

- In 2007, approximately 6.0 million tons of agricultural residues were burned as fuel, 92 percent of which (Btu basis) provided useful thermal output (EIA 2008). The remaining 8 percent was used to produce electricity. Around 71 percent of total agricultural residues combusted (Btu basis) were secondary residues used in the food processing industry, mostly sugarcane bagasse at sugar mills (EIA 2007). The remaining 29 percent was used in the Agriculture, Forestry, and Mining, and the Paper and Allied Products industries (EIA 2008).

- An emerging market for corn stover and other primary and secondary agricultural residues is for use as a heat and power source for the production of corn and cellulosic ethanol (Morey *et al.* 2006, Farrell and Gopal 2008).

(2) **Non-Combustion Uses of Agricultural Residues and Food Scraps:**

- Primary agricultural residues play an important role in maintaining cropland production. Removing them can increase erosion, reduce crop productivity, and deplete soil carbon and nutrients (Graham *et al.* 2007). Recent work has shown that cropland is particularly susceptible to loss of soil carbon with increased residue removal (Wilhelm *et al.* 2007).
- Primary agricultural residues are often harvested to provide animal bedding.
- Certain secondary agricultural residues can be spread upon cropland as soil treatments. Such is the case with peanut hulls, where a majority in Georgia (40 percent of US production) are used in granular carriers for lawn and garden insecticide and fertilizer products, with the remainder sold for livestock feed and bedding (Özyurt and Realff 2002).
- Non-combustion uses for food scraps can include composting.

(3) **Quantities of Agricultural Residues and Food Scraps Landfilled:**

- Primary agricultural residues are not landfilled to an appreciable extent.
- Data on the quantity of food scraps landfilled are not readily accessible in the available literature. Further inquiry may reveal these amounts. For example, Annex 3 to the "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006" report describes a methodology (Pages A-179 and A-180) that was followed to estimate methane generation at industrial landfills (EPA 2008). This included gathering information on food processing wastes diverted to landfills.

(4) **Quantities of Agricultural Residues and Food Scraps Stockpiled/Stored:**

- Primary agricultural residues tend to degrade rapidly after harvest and are largely decomposed by the following planting season.
- Quantities of secondary agricultural residues and food scraps stockpiled or stored are unknown.

Exhibit 1: Overview of Generation and Use of Agricultural Residues and Food Scraps

Commodity	**Annual Quantity Generated**	**Annual Quantity Used as Fuel**		**Annual Quantity Landfilled**	**Annual Quantity in Other Uses**	**Total Quantity Stockpiled**
		Cement Kilns	**Other**			
	---------- Million Tons -----------					
Primary Ag. Residues	500[a]	N/I	6.0 Combined	0	327–387[b]	0
Secondary Ag. Residues	N/I	N/I		N/I	N/I	N/I
Food Scraps	N/I	N/I	N/I	N/I	N/I	N/I

Notes: [a]Total primary agricultural residue from major crops. [b]Minimum amount needed to remain on land to maintain soil fertility and moisture, and prevent erosion and carbon loss.

N/I = not identified

4. Management and Combustion Processes for Agricultural Residues and Food Scraps

(1) **Types of Units Using Agricultural Residues and Food Scraps:**

- The discussion for this section centers on the use of bagasse in sugar mills. Bagasse is burned in fuel cells, horseshoe boilers, and spreader stoker boilers (EPA 1996). Other emerging technologies of combusting agricultural residues and food scraps are described in Farrell and Gopal (2008).

(2) **Sourcing of Agricultural Residues and Food Scraps:**

- Agricultural residues and food scraps are generated from harvesting crops and processing crops and livestock into food products for retail sale.
- Bagasse is produced when chopped and crushed cane is milled through a series of grooved rolls, thereby releasing cane juices.

(3) **Processing of Agricultural Residues and Food Scraps:**

- Bagasse does not require special processing before being combusted.

(4) **State Status of Agricultural Residues and Food Scraps:**

- As of September 2006, approximately 50 percent of states had renewable fuels portfolio standards requiring that varying percentages of power generated within the individual states come from alternative fuels (including biomass) by a designated future date; several more states have enacted such regulations since then (DOE 2006).[1]

[1] The summary table in the reference does not always specify which types of biomass are included, however, it is likely that agricultural residues are included. For example, Nevada includes “agricultural wastes.”

5. *Agricultural Residues and Food Scraps Composition and Impacts*

(1) **Composition of Agricultural Residues and Food Scraps:**

- Most agricultural residues have a high heating value of between 12.9 and 14.6 million btu/ton (6,450 to 7,300 btu/lb) (Wright *et al.* 2006). Air-dried biomass is typically around 15 to 20 percent moisture.
- Bagasse has an approximate high heating value of 12.1 million btu/ton (6,065 btu/lb), (Wright *et al.* 2006). As burned in sugar mills (45 to 55 percent moisture by weight), its heating value is between 6.0 and 8.0 million btu/ton (3,000 and 4,000 btu/lb) (EPA 1996).
- The high heat value of peanut hulls is 16.0 million btu/ton (8,031 btu/lb) (Bain *et al.* 2003).
- The heating value of food scraps is likely to be close to the biogenic portion of MSW, which has an average heat content (moisture content unknown) of 9,696 btu/ton (4,848 btu/lb).

(2) **Impacts of Agricultural Residues and Food Scraps:**

- Use of biomass as a substitute for coal in an existing power plant reduces SO2, NOx, and other emissions (Hong 2007 p.13).
- Combustion of corn stover can yield NOx emissions of 0.22 pounds per MMBtu and SOx emissions of 0.10 pounds per MMBtu (De Kam 2007 p.12).
- Data on emissions from combustion of food scraps are not readily available.
- EPA's AP-42 includes estimated emission factors for bagasse combustion in boilers at sugar mills using a variety of control technologies. For example, for particulate matter (PM) of unspecified size, bagasse combustion emits between 0.2 and 2.2 pounds per MMBtu, depending on the type of control technology utilized. Estimated emissions of PM-10 are 0.19 lbs./MMBtu when using wet scrubber controls. Uncontrolled NO_x emissions are 0.17 lbs./MMBtu. Note that EPA rates the data quality of emission factors for controlled PM as high (i.e., based on repeated tests at multiple sites), while the remaining factors are less reliable estimates (EPA 1996, p. 1.8-4).

(3) **Lifecycle Emissions Impacts:**

Use of agricultural residues or food scraps as a replacement for traditional primary fuels eliminates the environmental impacts associated with extraction and processing of traditional fuels. In addition to the emissions impacts of combustion described above, Exhibit 2 lists the quantities of the total cradle-to-gate emissions for these fuels based on typical processes in the United States in the late 1990s.

Exhibit 2: Emissions from Extraction and Processing of Traditional Fuels (Lb./MMBtu)

Pollutant	Coal	Distillate Fuel Oil	Residual Fuel Oil	Wood	Natural Gas
Criteria Pollutants					
PM2.5	-	-	-	-	-
PM10	-	-	-	-	-
PM, unspecified	0.246	0.012	0.012	$6.67x10^{-4}$	0.004
NOx	0.022	0.061	0.062	0.08	0.117
VOCs	0.008	0.361	0.365	-	0.515
SOx	0.022	0.186	0.187	0.003	1.913
CO	0.017	0.046	0.046	0.022	0.223
Pb	$2.60x10^{-7}$	$1.01x10^{-6}$	$1.00x10^{-6}$	-	$2.72x10^{-7}$
Hg	$8.17x10^{-8}$	$1.87x10^{-7}$	$1.87x10^{-7}$	-	$7.18x10^{-8}$

Source:
Franklin Associates 1998.
Note:
"-" signifies data not available; may equal zero.

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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