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

Biomass - Animal Manure and Gaseous Fuels

December 16, 2008

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1. Definitions of Animal Manure and Gaseous Fuels

In this context, we are defining animal manure as the excrement of livestock reared in agricultural operations as well as straw, sawdust, and other residues used as animal bedding.

Gaseous fuels may be derived from municipal and industrial landfills (landfill gas) or from animal manure and solid biomass such as crop silage or the organic fraction of MSW (biogas). Both landfill gas and biogas are generated via anaerobic digestion, a multi-stage process whereby bacteria convert carbohydrates, fats, and proteins to methane (Evans 2001). EPA does not consider these materials to be wastes in themselves, when used as fuel, but rather materials derived from wastes.

2. Annual Quantities of Animal Manure and Gaseous Fuels Generated and Used

(1) **Sectors that Generate Animal Manure and Gaseous Fuels:**

- NAICS 1121: Cattle Ranching and Farming
- NAICS 1122: Hog and Pig Farming
- NAICS 1123: Poultry and Egg Production
- NAICS 1124: Sheep and Goat Farming
- NAICS 112920: Horses and Other Equine Production
- NAICS 562212: Solid Waste Landfill
- NAICS 221320: Sewage Treatment Facilities

(2) **Quantities and Prices of Animal Manure and Gaseous Fuels Generated:**

- Domestic livestock production generates over a billion tons of manure annually. If all of this were used to produce biogas, it would yield approximately 19.4 million tons of methane (Cuéllar and Webber 2008).[1]
- Anaerobic digestion of current manure production managed in ponds, anaerobic lagoons, and holding tanks would yield 2.4 million tons of methane. Current production is 0.07 million tons from 111 operating digesters (EPA 2008a).
- Around 35 million dry tons of current manure production could be used for bioenergy purposes once sustainability concerns are met (*e.g.*, this manure is

[1] Biomass production estimates are presented on an annual basis.

available after primary use of manure on soils to maintain fertility) (Perlack *et al*. 2005).
- In 2006, 11.4 million tons of landfill gas (3.0 million tons of methane) provided the equivalent of 150 trillion Btus for heat and electicity generation (EIA 2008).
- Current landfill gas production from 455 operational projects is 3.6 million tons of methane (EPA 2008b).
- A 2007 survey of anaerobic digestion systems at livestock facilities found an average biogas production cost of $6.60 per million btu (NRCS 2007).
- Poultry litter sold for electricity generation at the Fibrominn LLC plant in Benson, MN, is purchased by contract with farmers at $3 to $5 per ton. The power helps meet a Minnesota legislative mandate for power generation from biomass, although it is not competitive with fossil fuels (Karnowski 2007).

(3) **Trends in Generation of Animal Manure and Gaseous Fuels:**
- Livestock production has become increasingly concentrated in recent years (Kellogg *et al*. 2000). This facilitates the collection of secondary materials for bioenergy purposes.
- Opportunities for utilizing animal byproducts for bioenergy production may increase in coming years with higher fossil fuel prices and improved conversion technologies including both biochemical and thermochemical platforms (Cantrell *et al.* 2008).

3. Uses of Animal Manure and Gaseous Fuels

(1) **Combustion Uses of Animal Manure and Gaseous Fuels:**
- Biogas produced on farms is typically used to heat water for purposes of cleaning and sanitizing milking pipelines and equipment in dairy operations (NRCS 2007). Note that this biogas is derived from animal products, and is not an animal product itself.
- An emerging market for animal manure is direct production of heat and power (*e.g.*, the 55 megawatt Fibrominn LLC plant).
- In 2006, landfill gas was used by the following sectors (energy basis): commercial (2.7 percent), industrial (49.3 percent), electric utilities (5.3 percent), and independent power producers (42.7 percent) (EIA 2008).

(2) **Non-Combustion Uses of Animal Manure and Gaseous Fuels:**
- Animal manure is spread on cropland and pastureland as a fertilizer to replenish nutrients and as a soil treatment to improve soil quality by enhancing soil structure and increasing the soil's ability to hold water and resist compaction (Kellogg *et al.* 2000). Other uses are uncommon in the US (*e.g.*, home heating, cooking, and paper production).

(3) **Quantities of Animal Manure and Gaseous Fuels Landfilled:**
- The amount of animal manure landfilled has not been identified.
- An additional 535 candidate landfills have been identified with the potential to provide 2.4 million tons of methane (EPA 2008b). Milbrandt (2005) estimated

total domestic production from landfills and domestic wastewater treatment sites at 13.6 and 0.5 million tons of methane, respectively.

(4) **Quantities of Animal Manure and Gaseous Fuels Stockpiled/Stored:**

- Information about quantities of animal manure stockpiled are unknown. While the quantity of animal manure undergoing short-term storage is significant, decay rates and issues associated with storage (leaks and odor), along with technical limitations associated with storage of gases likely place some limits on stockpiling activity, particularly because the value of these materials is not likely to appreciate as the result of long-term stockpiling.

Exhibit 1: Overview of Generation and Use of Animal Manure and Gaseous Fuels

Commodity	Annual Quantity Generated	Annual Quantity Used as Fuel		Additional Annual Quantity	Annual Quantity in Other Uses	Total Quantity Stockpiled as of 2008
		Cement Kilns	Other			
	---------- million tons of methane per year ----------					
Biogas from Agricultural Anaerobic Digesters	0.07	N/I	0.07	N/I	N/I	N/I
Landfill Gas	3.60	N/I	3.60	2.4 – 10.0	N/I	N/I
N/I = not identified						

4. *Management and Combustion Processes for Animal Manure and Gaseous Fuels*

(1) **Types of Units Using Animal Manure and Gaseous Fuels:**

- Biogas generated on farms is typically combusted directly in boilers and to a lesser extent is burned for space heating (NRCS 2007).
- Landfill gas is used to generate electricity in internal combustion engines, gas turbines, and microturbines. It also has direct use applications in boilers, combined heat and power systems, dryers, kilns, and greenhouses (EPA 2008d).

(2) **Sourcing of Animal Manure and Gaseous Fuels:**

- Manure is generated in all livestock operations. Anaerobic digesters for biogas production accommodate manure handled as a liquid, slurry, or semi-solid (*i.e.*, total solids up to approximately 12 percent) (EPA 2002).
- Landfill gas forms as a by-product of manure decomposition.

(3) **Processing of Animal Manure and Gaseous Fuels:**

- Biogas generated on farms is typically combusted on-site with little upgrading other than hydrogen sulfide and moisture removal. Carbon dioxide may also be removed for applications where high thermal values are needed (NRCS 2007).

- Landfill gas also needs to undergo minimal upgrading when used in most applications (EPA 2000). Substantial upgrading is needed, however, should landfill gas be introduced into natural gas distribution networks. Here a series of membrane separation processes, molecular sieves, and absorption processes are employed (CCTP 2005).

(4) **State Status of Animal Manure and Gaseous Fuels:**

- At this stage, we have not identified any states that have specifically granted a beneficial use designation for the use of animal manure as fuel, but we have not performed an exhaustive investigation of state activities and regulations. For example, it is possible that equivalent designations are made by states as part of agricultural regulation.

- 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).[2] For instance, in August 2007, North Carolina enacted a law to "promote the development or renewable energy…through implementation of a renewable energy and energy efficiency portfolio standard (REPS)" (Session Law 2007-397. This law specifically calls for the following:

> Sec. 62-133.7 (e). Compliance with REPS requirement through use of swine waste resources. -- For calendar year 2018 and for each calendar year thereafter, at least two-tenths of one percent (0.2%) of the total electric power in kilowatt hours sold to retail electric customers in the State shall be supplied, or contracted for supply in each year, by swine waste. [Interim percentages are mandated for 2012 and 2015.]
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> Sec 62.133.7(f). Compliance with REPS requirement through use of poultry waste resources. -- For calendar year 2014 and for each calendar year thereafter, at least 900,000 megawatt hours of the total electric power sold to retail electric customers in the State shall be supplied, or contracted for supply in each year, by poultry waste combined with wood shavings, rice hulls, or other bedding material. [Interim megawatt hour values are mandated for 2012 and 2013.]

[2] The summary table in the reference does not always specify which types of biomass are included, however, some examples specific to animal manure and gaseous fuels include: Maryland specifies "poultry litter incineration"; Nevada specifies "biomass (includes…animal waste...)"; and New Mexico specifies "animal waste" in the definition of "biomass resources". Other states use the term "sustainable biomass" which could include animal manure/gaseous fuels, while others may include animal manure/gaseous fuels in the generic term "biomass".

5. Animal Manure and Gaseous Fuels Composition and Impacts

(1) **Composition of Animal Manure and Gaseous Fuels:**

- Biogas from on-farm anaerobic digesters typically contains 60 to 70 percent methane and 30 to 40 percent carbon dioxide by volume (NRCS 2007). Landfill gas tends to contain between 45 to 55 percent methane and 45 to 55 percent carbon dioxide (Messics 2001). Average low heat values of gaseous fuels are approximately 19,840 btu/lb for methane, 11,820 for biogas, and 6,500 for landfill gas (EIA 2008).
- Poultry litter has a high heat value of 6,187 btu/lb (Wright *et al.* 2006).

(2) **Impacts of Animal Manure and Gaseous Fuels Use:**

- Benefits include 1) energy use of methane, otherwise released to the atmosphere (EPA 2008e), 2) displacement of fossil fuel, primarily natural gas, and, 3) potential reduction of pollutants harmful to human health (NRC 2003).
- Landfill gas emissions vary considerably depending on the composition of the waste in the landfill, the efficiency with which gas is captured, and the pollution control technologies used in combustion. Combustion of landfill gas for energy leads to reductions in VOCs, and organic mercury compounds relative to uncontrolled emissions from landfills (EPA 2008f). In addition, combustion of landfill gas avoids the impacts associated with extraction, processing, and transportation of typical primary fuels like natural gas. The emissions and upstream impacts associated with natural gas combustion are identified in Exhibit 2.
- Fermentation of pig manure to create biogas has been shown to reduce nitrous oxide by 14 grams per ton of manure compared to typical storage and fertilizer applications (Nielsen 2002).
- Combustion of biogas as a replacement for natural gas avoids the emissions associated with the extraction and processing of natural gas. Exhibit 2 lists the emissions from combustion of biogas from a typical pig farm and combustion and pre-combustion processing of natural gas at a typical industrial boiler in the U.S. in the late 1990s. Note that the emissions of many of the criteria pollutants are similar to natural gas combustion, but significant reductions are achieved by avoiding the impacts associated with extraction and processing of natural gas.

Exhibit 2: Comparative Emissions of Biogas and Natural Gas Combustion

Pollutant	Biogas	Natural Gas	
	Combustion	Combustion	Combustion plus Upstream
	----- *Lb./MMBtu* -----		
Criteria Pollutants			
PM2.5	0.003	-	-
PM10	0.003	0.009	0.009
PM, unspecified	-	-	0.004
NOx	0.072	0.301	0.417
VOCs	0.009	0.009	0.524
SOx	0.026	0.073	1.985
CO	0.084	0.058	0.282
Pb	-	-	2.72×10^{-7}
Hg	-	-	7.18×10^{-8}

Sources:
Franklin Associates 1998; Nielson 2002.
Notes:
"-" signifies data not available; may equal zero. Emissions of biogas reflect combustion process only and do not include upstream, downstream, or avoided impacts.

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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