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Dairy Biomass as a Renewable Fuel Source

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As the need for cleaner, cheaper, more environmentally friendly fuels grows, engineers, scientists and researchers at Texas AgriLife Extension, Texas AgriLife Research and Texas Engineering Experiment Station are investigating ways of generating those fuels. One possibility is dairy biomass.

Texas has a large concentration of dairy operations that, like other such operations, produce more than milk—they also generate, animal manure, carcasses and other biological material often called dairy biomass (DB). In the past, these products were considered waste, and disposing of it was a cost of doing business or, at best, revenue neutral for many facilities. But as researchers look for alternate fuel sources to replace fossil fuels, many are focusing on these dairy byproducts, specifically manure, as a renewable energy source.

Dairy biomass has been used as fertilizer, but because many of Texas' ever-growing operations are located close to each other and producing increasing amounts of this biomass, it is no longer possible to apply all of it to the land adjacent to these operations. In some areas of the state, such as the North Bosque watershed, the excessive application of dairy biomass to crop land has caused excess nutrients in the rainfall runoff.

Damage to the North Bosque watershed led to the development of a total maximum daily load (TMDL) program for phosphorus, which calls for removing 50 percent of the animal manure from the watershed. Transporting a low-value product such as manure over long distances is expensive; using the dairy byproduct as a fuel source instead of a fertilizer could save not only money but also the environment.

Dairies have a variety of methods for disposing of manure. To assist in evaluating these different methods, manure samples from 12 dairies in the three major dairy regions of the state—six in Central Texas, four in the Panhandle and two in Northeast Texas—have been characterized. Herd sizes of these dairies ranged from fewer than 300 cattle to more than 4,000.

Manure Management in Texas

Management methods vary in each region. In the Northeast, cattle are generally reared on pastures and the manure is not concentrated in one area so removal is not a large problem. Central Texas and Panhandle dairies employ two primary management styles—open lot dairies and hybrid facilities. Open lot dairies house the cattle in earthen corrals with minimal shade structures and paved feed lanes. In these facilities manure is removed through periodic scraping and piling. This method allows the manure to dry in the corral before transport; however, a large amount of soil is collected with the manure, so the material has a higher ash (dirt) content. A hybrid facility houses some of the cattle in open lot corrals and the rest in free-stall structures, or large, open-air barns with concrete floors and loafing beds. Free-stall dairies use several manure management techniques, including flushing the feed lanes with large volumes of water or vacuuming the manure into "slurry wagons." In the flushing method, water washes the manure to a liquid-solid separator. The liquid manure is returned to a water storage and treatment structure to be used for irrigation and as flush water. The vacuum process uses a slurry wagon equipped with a heavy-duty vacuum system to collect the manure several times each day. This system scrapes the manure to the center of the machine where it is vacuumed into a storage tank. Once collected, the manure is either taken to fields to be used as fertilizer or spread to dry in the sun. The vacuum method removes nearly all the manure in the corrals along with any bedding material that may have been moved from the free stalls. Table 1 shows the size and location of the facilities sampled and type of manure management system used.

The dairy biomass streams included open lot scrapings, feed, as-excreted manure, vacuumed manure, mechanically and gravitationally separated solids, open-lot scrapings and aged solids. Samples were collected in the winter and summer to determine how the biomass varies seasonally.

Region	Dairy	Head Count	Facility Type	Feedlane Manure Removal
Central Texas	C1	2500	Free Stall Vacuum	Vacuum
	C2	2200	Hybrid	Scrape
	C3	2100	Open Lot	Flush
	C4	1500	Hybrid	Flush
	C5	1500	Hybrid Vacuum	Vacuum
	C6	1500	Open Lot	Scrape
Northeast	E1	299	Pasture	N/A
	E2	299	Pasture	N/A
Panhandle	P1	4000	Hybrid	Scrape
	P2	3000	Open Lot Flush	Flush
	P3	3500	Hybrid	Flush
	P4	4000	Open Lot	Scrape

Table 1
Summary of facilities sampled for dairy biomass analysis.

Biomass Characterization

Biomass collected at the dairies was analyzed for nutrient content and thermo-chemical properties. The nutrient content is critical to this research because of the common practice of using dairy biomass as fertilizer. When excessive dairy biomass is used in this way, runoff can pollute surface water, as happened in the Bosque Watershed. Nutrient analysis allows the value of dairy biomass as a fertilizer to be assessed and compared to its value as an energy source.

Thermo-chemical analysis of the material evaluates how well dairy biomass can be used in generating power. Two types of analyses are required:

• Ultimate analysis is the percentage of carbon, hydrogen, nitrogen, oxygen and sulfur in the fuel. These elements, the primary constituents of the fuel, can be used to calculate its energy content. All of these elements are reported on an as-received basis to reflect their nutrient content.

• Proximate analysis determines the moisture content, high heating value (HHV), ash content and volatile matter content of the fuel. The moisture content is the amount of moisture in the fuel when sampled. The high heating value of the fuel measures the total energy contained in the material in British Thermal Units per pound (BTU/lb) of biomass. A BTU is the amount of energy required to heat 1 pound of water 1 degree Fahrenheit. The ash content is the percentage of material remaining after complete combustion; this is the material that must be disposed of after the dairy biomass is used for energy conversion. Ash does not contribute to the heating value of the fuel and varies by source. Volatile matter is the non-moisture part of biomass that is liberated at high temperature in the absence of oxygen. This material is biodegradable.

Sampled Biomass Streams

For the research, several biomass streams were sampled at each facility. The samples were classified into these categories:

• **Feed.** Feed was collected as a composite sample from all feeding areas at each dairy in order to measure the raw source of the dairy manure.

• **As-excreted.** Freshly excreted manure was collected from several housing areas at each facility to determine the purest form of manure available. Moisture and soil may lower its thermo-chemical quality.

• **Vacuumed solids.** Vacuumed solids were collected from two facilities with different bedding types, sand and composted manure. This type of biomass has the least amount of soil or water mixed with the biomass during collection. An example of a vacuum collection apparatus is shown in Figure 1.

• **Separated solids.** Separated solids were collected from several facilities that use both mechanical and gravitational separation. Mechanical solids separation systems produce a pile of solids that is periodically removed. Gravitational separation systems slow the flow of water, allowing the solids to settle. These systems use parallel settling basins that are alternately shut off to allow for drying. Once a settling basin has dried out, the solids are removed for use. A picture of a mechanical solid separation system is shown in Figure 2 and the gravitational solids separation basin is illustrated in Figure 3.

• **Scraped solids.** This material is collected periodically from earthen pens by scraping the pen surface with a tractor and piling up the resulting material. This material, which is stored on site and then used as a fertilizer, constitutes a large portion of the total dairy biomass produced. Figure 4 shows the scraped solids piled for removal.

• **Aged solids.** This material is aggregated from several biomass streams at each facility. Some facilities have active compost operations, while others stockpile it for later use. A large quantity of this material is available as a fuel or fertilizer.

Material Properties

Table 2 shows the nutrient and trace metal analysis of the sampled dairy biomass streams on an as-received basis. The nutrient values can be used to determine the value of the biomass as a fertilizer. Commercial fertilizer is sold at different ratios of N, P and K, where P is in the form of phosphate (P_2O_5) and K is potash (K_2O). To convert the P and K values in Table 2 to equivalent fertilizer values, multiply them by 2.29 and 1.2 respectively. These values also can be used to calculate the quantity of nutrients exported from a region for specific sources of dairy biomass. The most nutrient-dense form of biomass, besides feed, is aged solids. This material is nutrient-rich because of its lower moisture content and the accumulation of non-volatile nutrients over time. For facilities that do not use vacuum equipment, it is the primary source of biomass for fertilizer and, because of its low moisture content, for fuel. Facilities that use vacuum

Figure 1. Vacuum collection apparatus in use. The equipment is used while the cattle are away from their pens being milked. On the left are the stalls with sand bedding; at right is animal feed.

Figure 2. Mechanical solids separation system. Water flows across a sloped screen that collects the solids. The solids then fall to the bottom and are collected by an auger and stacked using the flighted-conveyor separator.

Figure 3. Gravitational solids separation basin during clean out. The water enters the basin in the foreground and slows to allow solids to separate from the water, which continues to flow through the basin and to the lagoon.

Figure 4. Scraped solids piled for removal. The solids are scraped into piles before being moved to a storage area or loaded onto trucks for removal.

Table 2

Nutrient characteristics of various dairy biomass streams on an as-received basis.

Nutrient (lb/ton)	Feed n = 69	As Excreted n = 26	Vacuumed w/ Sand Bedding n = 9	Vacuumed w/ Compost Bedding n = 6	Mechanically Separated Solids n = 9	Gravitationally Separated Solids n = 24	Scraped Solids n = 81	Aged Solids n = 18
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Total N	33.8 ± 7.8	7.8 ± 1.3	5.6 ± 1.2	6.9 ± 1.2	5.3 ± 2.1	7.9 ± 7.6	21.9 ± 10.7	30.6 ± 13.3
P	4.6 ± 0.0	2.1 ± 0.0	1.5 ± 0.0	2.3 ± 0.0	1.1 ± 0.0	1.6 ± 0.0	6.4 ± 0.0	9.5 ± 0.0
K	17.8 ± 1.8	1.2 ± 0.5	4.8 ± 0.2	4.2 ± 0.7	1.9 ± 0.2	5.3 ± 2.0	22.9 ± 2.6	31.5 ± 5.1
Ca	14.1 ± 5.5	9.0 ± 0.5	8.1 ± 1.1	10.2 ± 1.5	9.0 ± 0.6	12.9 ± 8.4	38.9 ± 13.8	100.8 ± 15.5
Mg	4.9 ± 3.4	3.1 ± 1.5	2.6 ± 1.6	2.2 ± 2.1	1.7 ± 1.7	2.7 ± 15.0	8.9 ± 22.4	16.8 ± 74.7
Na	7.1 ± 1.1	1.2 ± 0.9	3.5 ± 0.3	2.2 ± 0.3	1.4 ± 0.4	3.0 ± 3.5	7.9 ± 3.9	10.3 ± 8.7
Zn	0.1 ± 4.6	0.1 ± 0.3	0.1 ± 0.5	0.1 ± 0.6	0.1 ± 0.3	0.2 ± 3.1	0.2 ± 3.9	1.6 ± 2.7
Fe	0.2 ± 0.0	0.8 ± 0.0	3.3 ± 0.0	0.9 ± 0.0	0.8 ± 0.0	2.5 ± 0.4	5.4 ± 0.1	16.1 ± 1.9
Cu	0.0 ± 0.3	0.0 ± 0.5	0.0 ± 0.5	0.0 ± 0.2	0.0 ± 0.2	0.1 ± 2.7	0.1 ± 3.8	0.1 ± 4.8
Mn	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.3 ± 0.1	0.6 ± 0.0

Table 3

Proximate and ultimate analysis properties of various dairy biomass streams on an as-received basis.

Property		Feed	As Excreted	Vacuumed w/ Sand Bedding	Vacuumed w/ Compost Bedding	Mechanically Separated Solids	Gravitationally Separated Solids	Scraped Solids	Aged Solids
		n = 69	n = 26	n = 9	n = 6	n = 9	n = 24	n = 81	n = 69
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Moisture	%	41.4 ± 10.1	84.1 ± 1.8	52.0 ± 10.0	83.6 ± 2.4	83.2 ± 2.9	69.9 ± 20.1	40.8 ± 22.3	36.2 ± 18.0
Carbon	%	26.3 ± 3.6	6.8 ± 0.9	5.9 ± 0.7	6.8 ± 1.0	8.0 ± 1.5	12.0 ± 9.5	18.8 ± 6.9	11.1 ± 4.2
Hydrogen	%	3.2 ± 0.4	0.8 ± 0.1	0.7 ± 0.1	0.8 ± 0.1	0.9 ± 0.2	1.4 ± 1.1	2.2 ± 0.8	1.2 ± 0.4
Nitrogen	%	1.5 ± 0.2	0.4 ± 0.1	0.3 ± 0.0	0.4 ± 0.0	0.3 ± 0.0	0.5 ± 0.3	1.3 ± 0.6	1.0 ± 0.6
Oxygen	%	21.7 ± 3.3	4.7 ± 0.6	2.4 ± 1.0	4.7 ± 0.6	6.2 ± 1.3	8.2 ± 7.5	13.8 ± 5.5	8.6 ± 4.4
Sulfur	%	0.2 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.1	0.3 ± 0.1	0.3 ± 0.1
Ash	%	5.2 ± 4.7	3.2 ± 1.2	38.6 ± 12.0	3.6 ± 0.7	1.3 ± 0.2	12.4 ± 12.0	21.1 ± 12.1	41.7 ± 13.0
Volatile Matter	%	42.2 ± 4.9	10.4 ± 2.8	2.7 ± 4.1	7.2 ± 5.8	5.0 ± 7.0	9.2 ± 6.0	32.7 ± 9.8	21.4 ± 13.3
HHV_{dry}	BTU/lb	6790 ± 595	3162 ± 154	2087 ± 401	6369 ± 116	6656 ± 224	4924 ± 2099	4885 ± 962	1943 ± 1183
HHV DAF	BTU/lb	7156 ± 686	7218 ± 1616	10297 ± 2001	8225 ± 194	7218 ± 226	7849 ± 1606	7596 ± 713	5609 ± 3274
HHV AR	BTU/lb	3938 ± 523	499 ± 64	971 ± 188	1178 ± 86	1098 ± 215	1624 ± 1435	2766 ± 1073	1208 ± 812

manure removal methods apply the removed biomass more continually.

Table 3 shows the proximate and ultimate analyses of the dairy biomass streams on an as-received basis. The data show large variations in moisture content for the materials (41 percent to 84 percent moisture). Note the variability in moisture content even within each biomass stream. The variation in moisture content illustrates one of the challenges in using biological materials as energy sources. Energy conversion facilities such as coal-fired power plants are designed for homogenous materials. Significant energy is available from dairy biomass as shown in the three high heating value numbers for each biomass source. The high heating value on a dry basis is the maximum amount of energy that can be extracted from the biomass, although it is not always possible to obtain this amount of energy because of difficulties in completely removing moisture. The dry, ash free (DAF) high heating value is the energy in the dry biomass assuming the ash is removed. This number is relatively constant since ash does not contribute to the high heating value of any material. The third value is the as-received (AR) high heating value, or the energy value of the biomass, with no changes to moisture content or ash, when collected from the facility. Compare these values with Powder River Basin coal that has a high heating value of 12,100 BTUs per pound (BTU/lb) on a dry basis, a dry ash-free high heating value of 13,000 BTU/lb, and an as-received high heating value of 8,800 BTU/lb.

Summary

Dairy biomass could be an excellent feedstock for alternative energy systems to generate heat, power or fuel. Its high heating value of 8,500 BTU/lb on a dry ash-free basis is comparable to as-received low grade coal. In addition, the use of dairy manure for alternative fuel could be an excellent mitigation measure to reduce excessive nutrient loading of land, groundwater and waterways. However, large variation in composition of different types of dairy biomass presents a unique challenge to use it for power generation. The successful use of animal manure for fuel depends upon its meeting the required physical and chemical characteristics that are ideal for thermal conversion systems. These include (a) low moisture, (b) low ash, (c) homogeneous in physical form and (d) low delivered cost. Producers who wish to use biomass resources such as animal manure as a feedstock for alternative energy production will need to implement best management practices to make such material more suitable as a renewable fuel source.

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