BIOMASS ENERGY POTENTIAL FROM LIVESTOCK AND POULTRY WASTES IN THE NORTHEAST

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Abstract

This study estimates the potential energy available from livestock and poultry wastes in the northeastern United States for 1982, with projections for 1990. Anaerobic digestion of dairy cow, hog, and laying hen manures could have produced 16.9 billion cubic feet of methane gas in 1982, with little change for 1990. Direct burning of litter from broilers, turkeys, and pullets could have resulted in 8.9 trillion Btu's in 1982 and 10.3 trillion Btu's in 1990. The total potential farm value of biomass energy ranged from $166 to $255 million in 1982 and $289 million to $458 million in 1990.

Key words: biomass energy, animal wastes, anaerobic digestion, energy potential, direct combustion, energy values.

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Introduction

The energy crisis of the 1970's created renewed interest in alternative energy sources. Biomass energy from agricultural sources is one major alternative that has not been fully explored. This study focuses on the economic potential for biomass energy from livestock and poultry wastes in the northeastern United States. The objectives were to: (1) determine the quantity and location of manure and litter available for conversion to energy, (2) assess the feasibility of various conversion processes, and (3) estimate the quantity and value of potential energy available from these sources.

There were two major regions included in this study: New England and the Middle Atlantic States (Figure 1). Estimates of livestock and poultry manure and biomass energy potential were derived for various livestock and poultry species in these regions by states for the base year 1982, and projected for 1990. Biomass energy potentials will vary greatly by states and regions due to differences in types and sizes of livestock and poultry enterprises and manure handling practices.

Procedure

The procedure was: (1) livestock and poultry numbers confined on farms in the Northeast were compiled by states for 1982 and projected for 1990 based on the outlook for the various species; (2) the quantity, location, and availability of manure was estimated by applying manure output rates to animal numbers; (3) manure volumes were converted to gross energy potentials assuming

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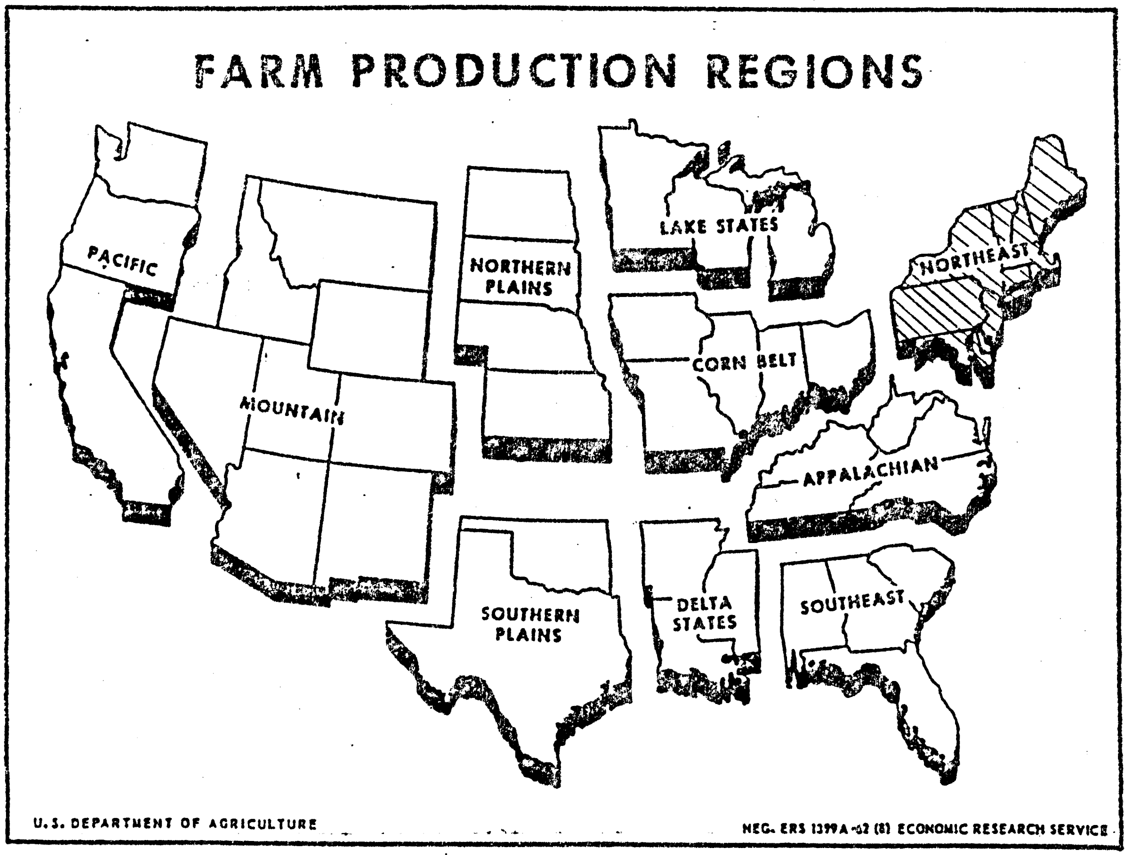

Figure 1. Outline of Farm Production Regions in the United States Including Major Subregions Included in this Study

anaerobic digestion of wastes or direct combustion of litter; (4) previous studies were evaluated to determine minimum size enterprises feasible for utilizing on-site energy conversion processes; (5) animal numbers and manure volumes were adjusted to include only output from farms of minimum size or larger; (6) allowance was made for on-farm handling losses and conversion efficiencies in the anaerobic digestion and direct burning processes (including electrical power generation from methane gas); (7) values of the various forms of biomass energy were then determined based on prices for conventional fuels that the biomass energy could replace on the farm.

Energy Conversion Processes

The conversion of organic matter to energy can be accomplished by a number of technical processes depending on the raw material and the type of energy desired. However, according to the U.S. Dept. of Energy (DOE), 1980, and Office of Technology Assessment (OTA), the anaerobic digestion process is probably the most feasible system for converting livestock and laying hen manures into energy. These manures are suitable for the digestive process, and most livestock and poultry enterprises with confined housing have integrated manure handling systems. The process is well-established from a technical standpoint, and commercial-scale systems are available. Poultry enterprises with large quantities of litter-based manure are not as adaptable to anaerobic digestion due to the lignin-cellulose content of the litter which affects the digestive process. Direct combustion is therefore the most feasible process for converting litter-based manure into energy.

Anaerobic Digestion

Anaerobic digestion is a relatively efficient process producing a biogas mixture with an average methane content of 60% (OTA). Most systems are site-specific and enterprises must have a certain minimum amount of manure to supply a given system. The methane could be used as a heating fuel for boilers or to replace natural gas, fuel oil, or LP gas, and the residual sludge can be used as a soil fertilizer or livestock feed ingredient. In large-scale operations, the gas could be scrubbed to remove impurities, compressed, and sold as synthetic natural gas to pipeline companies. The gas could also be fired in engine-generators to produce electricity for on-farm use or sale to electric utilities in some areas.

The capital investment required for anaerobic digester systems is relatively low compared to other forms of biomass energy conversion (DOE, 1980), but these costs can be relatively high for individual farm operations depending upon the size of the system and current manure handling practices. Large-scale commercially built digesters, such as those used by cattle feeding operations of 10,000 head or more, could cost $1- to $2 million or more (DOE, 1980; Hashimoto et al.). Smaller farm digester systems could be built for less than $100,000 (Timmons). Some very small systems have been built for less than $50,000, and they may be suitable for small dairy, swine, or poultry farms in some areas of the country (Fischer et al.; Hayes et al.). Capital costs are highly variable, however, depending upon design factors and availability of farm labor for construction.

Direct Combustion

Direct combustion of litter-based poultry manure is more advantageous than anaerobic digestion due to lower capital investment costs and the irregular supplies of litter from poultry houses that are cleaned only once or twice a year. Also, the steady flow of energy from anaerobic digesters does not fit the specific energy needs of poultry growers where the brooding process requires extensive heat during the first two weeks of the growing stage. Direct combustion is also more flexible in terms of feedstock storage and for meeting seasonal or cyclical energy needs for functions other than brooding.

Direct combustion of poultry litter is similar to burning other wood residues. With moisture content ranging from 25 to 35%, litter could be burned directly or pelletized for easier storage and handling, and more efficient burning (OTA; Smith et al.). Energy values from burning litter are relatively high, and capital investment costs for furnace or boiler facilities are relatively low for small-scale operations. Small, wood-fired warm-air heating systems for broiler houses can be constructed for less than $18,000 and possibly as low as $8,800 depending on the types of systems needed (Nolter et al.), but large-scale steam boilers using wood fuels could cost $500,000 or more (U.S. General Accounting Office). Wood-burning systems, however, have lower capital investment costs per unit of energy than anaerobic digestion systems even though operating costs may be somewhat higher.

Economically Recoverable Biomass Energy

The energy potentially available from livestock and poultry wastes was based on manure output from operations of certain minimum sizes or larger where on-site anaerobic digestion or direct combustion processes were considered feasible. Actual manure residues and costs for individual farms will vary greatly. Recoverable energy will also be affected by manure handling losses, storage losses, variations in biogas yields, and conversion losses in the anaerobic digestion, direct burning, and electrical generation processes.

Methane Gas Production

The potential quantity and value of recoverable energy from livestock and poultry wastes in the Northeast are given in Table 1. Anaerobic digestion was the conversion process used for dairy, swine, and laying hen enterprises. Manure volumes available from these enterprises were based on 1.95 tons of dry weight manure per cow from dairy farms with herds of 30 cows or more minus 20% pasture and handling losses; .07 tons of manure per pig from hog farms with sales of 500 head per year or more minus 10% handling losses; and 12.6 tons per 1,000 layers from poultry farms with flocks of 20,000 hens or more minus 3% handling losses (Christensen et al.; Fischer et al.; Van Dyne and Gilbertson; Strong and Segars). These enterprises produced an estimated 3.5 million tons of manure in 1982 with a biogas potential of 28.1 billion cubic feet. This is the equivalent of 16.9 billion cubic feet of methane gas with a thermal energy potential of 16.9 trillion Btu's. Dairy cows accounted for 81% of this energy, laying hens 16%, and hogs 3%. The major producing states were New York and Pennsylvania, accounting for 71% of the biogas potential in the Northeast (Table 2). The primary sources of biogas in these two states were dairy cows (85%) and layers (13%). Other states with a biogas production potential of more than 1 billion cubic feet were Maine, Vermont, Connecticut, and Maryland. Dairy cows accounted for most of the biogas potential in

Table 1. Potential Quantity and Value of Economically Recoverable Biomass Energy from Livestock and Poultry Manure and Litter, by Species, Northeast Region, 1982, with Projections for 1990

Item			Dairy	Hogs & Pigs	Layers	Broilers	Turkeys	Pullets	Total
Number of Animals or Birds[a]									
	1982	(millions)	2.0	1.0	30.0	578.9	5.4	17.4	634.7
	1990		2.0	1.0	29.0	677.3	5.6	18.8	733.7
Manure Volume Produced[b]									
	1982	(000 tons)	3,087.4	60.6	367.3	701.9	54.2	50.7	4,322.1
	1990		3,092.2	66.0	354.4	821.2	56.2	54.8	4,444.8
Biogas Potential[c]									
	1982	(bil. ft^3)	22.8	0.7	4.6	--	--	--	28.1
	1990		22.9	0.8	4.5	--	--	--	28.2
Thermal Energy Potential[d]									
	1982	(bil. Btu's)	13,708.0	423.8	2,776.8	7,721.3	650.1	557.7	25,837.9
	1990		13,729.0	461.5	2,679.2	9,033.5	674.8	602.8	27,180.6
Electrical Energy Potential[e]									
	1982	(Gwhrs)	1,204.1	37.2	255.0	--	--	--	1,496.3
	1990		1,206.0	40.5	235.3	--	--	--	1,481.8
Value Electrical Energy[f]									
	1982	(mil. $)	77.8	2.5	17.4	--	--	--	97.7
	1990		115.9	4.0	23.7	--	--	--	143.6
Value Thermal Energy[g]									
NG	1982	(mil. $)	86.4	2.5	18.6	50.9	3.5	3.8	165.7
	1990		147.2	4.6	30.6	93.5	6.2	6.9	289.0
FO	1982	(mil. $)	116.2	3.5	23.5	64.1	5.4	4.7	217.4
	1990		174.2	5.8	33.9	112.4	8.4	7.6	342.3
LP	1982	(mil. $)	141.2	4.1	28.6	69.3	6.5	5.7	255.4
	1990		242.0	7.6	47.1	138.9	11.5	10.5	457.6

[a] Based on minimum herd or flock sizes feasible for anaerobic digestion or direct burning processes.

[b] Economically recoverable manure and litter on dry weight basis after various handling losses.

[c] Based on 3.7 to 6.3 ft^3 of biogas per pound of manure with digester efficiencies ranging from 35 to 65%.

[d] Based on 600 Btu's per ft^3 of biogas at 60% methane content, and 11 to 12 million Btu's per ton of litter.

[e] Based on 30% electrical conversion efficiency and 3.4153 billion Btu's per Gwhr. One Gwhr = 1 million Kwhrs.

[f] Based on electricity prices paid by farmers by states for 1982 and projected prices for 1990.

[g] Based on NG, fuel oil, and LP gas prices paid by farmers by states for 1982 and projected prices for 1990.

Table 2. Potential Quantity and Value of Economically Recoverable Biomass Enegry from Livestock and Poultry Manure and Litter, by States, Northeast Region, 1982, with Projections for 1990

Item			ME	NH	VT	MA	CT	RI	NY	NJ	PA	DE	MD	Total
Number of Animals or Birds[a]														
	1982	(millions)	34.5	0.6	0.3	1.4	5.3	0.3	11.2	0.8	134.5	177.3	268.5	634.7
	1990	(millions)	34.0	0.5	0.3	1.3	5.5	0.2	11.2	0.7	169.4	199.3	311.3	733.7
Manure Volume Produced[b]														
	1982	(000 tons)	180.6	46.1	279.4	78.7	123.0	6.3	1,410	68.0	1,352	237.6	540.4	4,322.1
	1990	(000 tons)	173.1	43.6	274.3	75.9	120.7	6.4	1,406	64.2	1,425	263.0	592.6	4,444.8
Biogas Potential[c]														
	1982	(bil. ft^3)	1.34	0.36	2.08	0.64	1.13	0.06	10.73	0.54	9.36	0.19	1.75	28.18
	1990	(bil. ft^3)	1.25	0.34	2.04	0.61	1.12	0.06	10.69	0.51	9.55	0.18	1.77	28.12
Thermal Energy Potential[d]														
	1982	(tril. Btu's)	1.27	0.22	1.25	0.40	0.72	0.04	6.58	0.33	7.89	2.50	4.64	25.84
	1990	(tril. Btu's)	1.21	0.21	1.22	0.38	0.72	0.04	6.57	0.31	8.52	2.78	5.22	27.18
Electrical Energy[e]														
	1982	(Gwhr's)	70.5	19.0	109.5	33.6	59.3	3.3	565.6	28.5	493.5	10.1	103.5	1,496.4
	1990	(Gwhr's)	65.8	17.7	107.4	32.0	58.9	3.3	563.5	26.8	503.6	9.5	93.3	1,481.8
Value of Electricity[f]														
	1982	(mil. $)	4.8	1.5	7.0	2.8	5.0	0.3	35.6	2.6	29.1	0.7	8.3	97.7
	1990	(mil. $)	6.7	2.0	10.2	3.9	7.5	0.4	52.9	3.6	44.3	1.0	11.0	143.5
Value Thermal Energy[g]														
NG	1982	(mil. $)	11.5	1.4	9.4	3.5	5.8	0.3	41.6	2.3	44.4	15.2	30.1	165.5
NG	1990	(mil. $)	16.5	2.3	15.7	5.7	9.9	0.5	71.0	3.7	77.0	28.9	57.8	289.0
FO	1982	(mil. $)	10.8	1.9	10.7	3.4	6.2	0.3	56.8	2.8	65.4	20.7	38.4	217.4
FO	1990	(mil. $)	15.6	2.7	15.7	4.9	9.2	0.5	84.5	4.0	105.8	34.6	64.9	342.4
LP	1982	(mil. $)	13.6	2.4	13.4	4.3	7.7	0.4	70.0	3.2	78.8	21.5	39.9	255.2
LP	1990	(mil. $)	22.4	3.9	22.5	7.0	13.2	0.7	119.6	5.1	145.2	41.0	77.0	457.6

[a]Includes dairy cows, hogs and pigs, layers, broilers, turkeys, and pullets confined on farms with at least minimum herd or flock sizes to make anaerobic digestion or direct burning feasible.

[b]Economically recoverable manure and litter on dry weight basis after various handling losses.

[c]Based on 3.7 to 6.3 ft^3 of biogas per pound of manure with digester efficiencies ranging from 35 to 65%.

[d]Based on 600 Btu's per ft^3 of biogas at 60% methane content, and 11 to 12 million Btu's per ton of litter.

[e]Based on 30% electrical conversion efficiency and 3.4153 billion Btu's per Gwhr. One Gwhr = 1 million Kwhr's.

[f]Based on electricity prices paid by farmers by states for 1982 and projected prices for 1990.

[g]Based on NG, fuel oil, and LP gas prices paid by farmers by states for 1982 and projected prices for 1990.

Vermont (99%) and Maryland (76%), but layers and dairy cows were about equally important in Maine and Connecticut. Biogas potential from dairy cows was also important in Massachusetts, New Hampshire, and New Jersey. However, the only states with a significant biogas potential from hogs were Pennsylvania and Maryland. Projected biogas and methane production for the Northeast for 1990 shows little change from 1982 except for a slight decrease in energy potential from laying hens which are expected to decline somewhat in numbers by 1990.

The methane production potential for the region was based on the following production coefficients: an output of 3.7 cubic feet of biogas per pound of manure at 35% digester efficiency for dairy cows; 5.83 cubic feet at 55% digester efficiency for hogs; 6.3 cubic feet at 65% efficiency for laying hens; and biogas at 60% methane content (Hayes et al.; Bartlett et al.; Fischer et al.; Slane et al.; Timmons). Improved technology or higher operating efficiencies for digesters could result in substantially higher levels of energy output.

If the methane from the anaerobic digestion process was burned directly as a substitute for conventional fuels, the value of the gas produced in the region in 1982 would be $107.5 million if substituted for natural gas, $143.2 million if substituted for fuel oil, or $173.9 million if substituted for liquefied petroleum (LP) gas (Table 1). The potential value depends on the prices of conventional fuels in the various states. The average natural gas price in the Northeast for 1982 was $7.16 per million Btu's (American Gas Association, 1982), $1.19 per gallon for fuel oil (DOE, 1984), and 97¢ per gallon for LP gas (U.S. Dept. of Agriculture). Natural gas has traditionally been priced much lower than LP gas on a Btu basis, but government deregulation of natural gas has narrowed the gap in recent years. Fuel oil prices are currently competitive with natural gas in some states, but prices probably average slightly higher than natural gas in the Northeast. However, natural gas is not available in many rural areas of the Northeast, except for the Mid-Atlantic states, so the higher priced fuel oil or LP gas would be the most common conventional fuels displaced by methane gas. The potential value of methane gas is projected to be much higher by 1990, rising to $182.4 million if substituted for natural gas, $213.9 million if substituted for fuel oil, and $296.7 million if substituted for LP gas. These higher values are based on projected energy prices in the various states. The average projected prices for the Northeast region for 1990 were $12.21 per million Btu's for natural gas, $1.78 per gallon for fuel oil, and $1.66 per gallon for LP gas (American Gas Association, 1983; and DOE, 1983).

If the methane gas from anaerobic digestion was converted to electricity, the production potential for the region would be 1,496 gigawatt-hours (Gwhr) (or 1.496 billion kilowatt-hours) in 1982 and 1,482 Gwhr's in 1990 (Table 1). This electrical power potential was based on 30% conversion efficiency from engine generators fueled by methane gas (Fischer et al.; Bartlett et al.). The potential value of this electricity depends on electrical power rates in the various states. In 1982, prices paid by farmers reported by USDA varied from 5.9¢ per kilowatt-hour (kwhr) in Pennsylvania to 9.1¢ per kwhr in New Jersey. For the Northeast as a whole, electrical power rates were 7.5¢ per kwhr in 1982. Using prices by states resulted in a value of $97.7 million for the electricity potential from methane gas for the region in 1982. This electricity value was only slightly lower than that of methane used as a substitute for natural gas, but substantially lower than methane substituted for fuel oil or LP gas. The states with the highest potential electricity values from biomass energy were New York and Pennsylvania (Table 2). With the average price for electricity in the Northeast in 1990 projected at 11.1¢ per kwhr, the potential value of electricity generated from methane gas based on projected prices in the various states will increase to $143.6 million in

1990. However, the electricity value in 1990 will still be considerably lower than methane gas used as a substitute for other fuels.

Direct Burning of Litter

The potential quantity and value of recoverable energy from direct burning of litter and manure from broiler, turkey, and pullet growing enterprises in the Northeast are given in Table 1. The volume of manure and litter available from these enterprises is based on 1.25 tons dry weight per 1,000 birds from broiler farms with sales of 60,000 birds per year or more minus 3% handling losses; 12.6 tons per 1,000 birds from turkey farms with sales of 30,000 birds per year or more minus 20% range and handling losses; and 3.0 tons per 1,000 birds from pullet growing farms with sales of 30,000 birds or more per year minus 3% handling losses (Van Dyne and Gilbertson; Strong and Segars). These enterprises produced an estimated 807 thousand tons of manure and litter in 1982 with a thermal energy potential of 8.9 trillion Btu's (Rokeby and Mayo). Broilers accounted for 87% of this energy, turkeys 7%, and pullets 6%. The major producing states were Maryland, Delaware, and Pennsylvania, accounting for 95% of the energy potential from direct burning of manure and litter (Table 2). Broilers were the primary litter-based energy source for these states, but turkeys were also important in Pennsylvania and to a much lesser extent in New York, Delaware, and Massachusetts. Pullet production was also a significant enterprise in Pennsylvania, Maine, Maryland, Connecticut, and Massachusetts. Projected energy production from litter-based manure shows significant increases in the 1980's, reaching 10.3 trillion Btu's in 1990 (Table 1) due primarily to the continued expansion of broiler production in the three major producing states of Maryland, Delaware, and Pennsylvania.

The potential value of this energy depends on whether it is used to replace natural gas, fuel oil, or LP gas. LP gas is the most common fuel used on poultry farms in the Northeast, but fuel oil is also used on many farms in certain areas, particularly New England and New York. Natural gas is used very little except in certain sections of the Mid-Atlantic states. If poultry litter was used as a substitute for natural gas, the value of the thermal energy produced in the Northeast in 1982 would be $58.2 million, as compared to $74.2 million if replacing fuel oil or $81.5 million if it replaced LP gas (Table 1). These values are expected to increase substantially by 1990, however, with the potential value of energy from poultry litter rising to $106.6 million if substituted for natural gas, $128.4 million if substituted for fuel oil, and $160.9 million if used to replace LP gas.

Total Energy Production

The total recoverable thermal energy potential from livestock and poultry manure in the Northeast was 25.8 trillion Btu's in 1982 with 53.1% of this energy derived from dairy cow enterprises, 29.9% from broiler farms, 10.7% from laying hens, 2.5% from turkeys, 2.2% from pullets, and 1.6% from hogs (Table 1). Methane gas from dairy, hog, and laying hen enterprises accounted for 65% of this energy potential, and direct burning of litter from broilers, turkeys, and pullets accounted for 35%. It was estimated that this energy production potential for the Northeast was 10% of the total potential energy output from these enterprises in the United States in 1982. The major energy producing states were Pennsylvania, New York, Maryland, and Delaware, accounting for 84% of the thermal energy in the region (Table 2). Other states with important energy potential were Maine and Vermont. Most of the other states had relatively few livestock and poultry enterprises of sufficient size to utilize current biomass conversion technologies.

The economically recoverable energy potential from these enterprises in the Northeast was projected at 27.2 trillion Btu's in 1990 (Table 1). Most of the increase is due to expected increases in production of broilers in Maryland, Delaware, and Pennsylvania (Figure 2). Slight increases in the

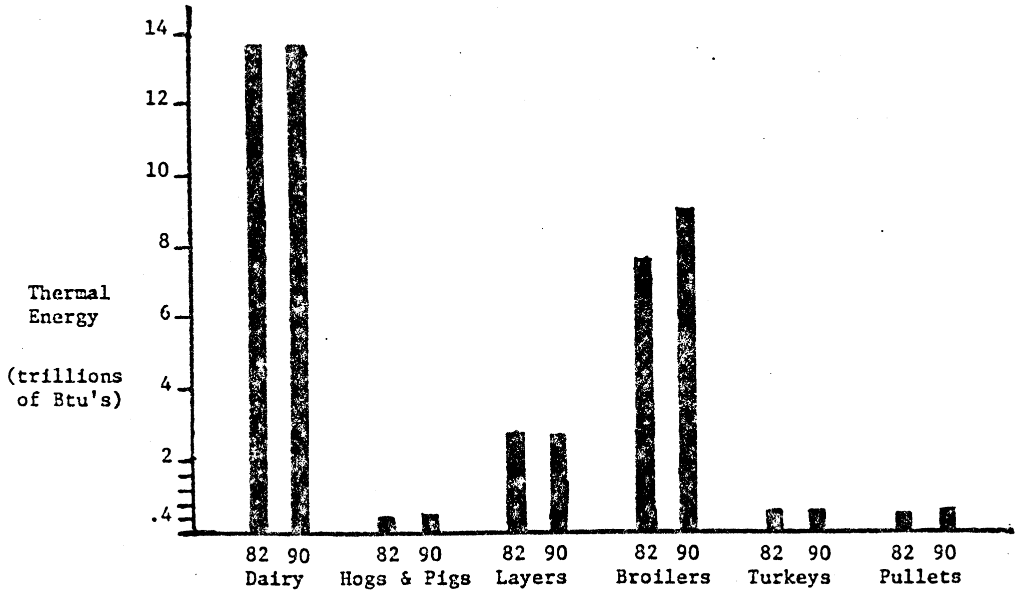

Figure 2. Comparison of Economically Recoverable Thermal Energy from Livestock and Poultry Manure and Litter, by Species, Northeastern United States, 1982, with Projections for 1990

number of hogs, turkeys, pullets, and dairy cows is also expected in the 1980's which will increase their potential energy output to some extent, but laying hen numbers are projected to decline somewhat.

The potential value of recoverable energy from these enterprises at the farm level varies widely depending upon the form of energy produced and the type of conventional energy displaced. The lowest values in 1982 for enterprises utilizing anaerobic digestion occurred when methane gas was substituted for electricity. The next highest values were from methane replacing natural gas, then fuel oil, and the highest values occurred when methane was used as a substitute for LP gas (Table 1). In 1990, these relationships would be about the same. The lowest values for enterprises utilizing direct burning of litter in both 1982 and 1990 occurred when this energy was substituted for natural gas, the next highest values occurred when litter energy displaced fuel oil, and the highest values occurred when litter energy replaced LP gas. These values vary among states depending upon electricity rates, prices of natural and LP gas, the price of fuel oil, and other factors.

The lowest total on-site energy value for all six enterprises in 1982 would be $165.7 million if energy from burning litter and methane gas were substituted for natural gas. In 1990 this value would be $289 million. Total values would be slightly lower, $155.9 million in 1982 and $250.2 million in 1990, if litter combustion replaced natural gas and methane gas was used for electricity. If the energy from all enterprises was used to replace fuel oil, it would be worth $217.4 million in 1982 and $342.3 million in 1990 (Table 1). The highest values for all enterprises would be $255.4 million in 1982 and $457.6 million in 1990 based on LP gas as the conventional fuel displaced. Market values for energy sold to potential outlets off-farm would be even more variable, although probably lower than on-site use values.

Since the anaerobic digestion process leaves a residual sludge that can also be used as a fertilizer or animal feed ingredient, the total value of these energy conversion processes will be increased if residues can be utilized effectively. Fertilizer and feed values for manure vary widely, depending upon the composition of the manure, plant nutrient values, the protein content of manure, and feed ingredient prices. However, fertilizer values were estimated to be $21.10 per ton dry weight for dairy cows, $16.25 per ton for hogs, and $31.30 per ton for laying hens in the early 1980's (Strong and Segars; Charles; Lance; Bezpa). Based on these values, plus projections, the additional fertilizer values in the Northeast for enterprises using anaerobic digestion could range up to $77.9 million in 1982 and $108.8 million in 1990. Animal feed values for manure were estimated at $46.80 per ton dry weight for dairy cows, $53.90 per ton for hogs, and $55.90 for laying hens in the early 1980's (Cullison; Lance; Smith and Wheeler). The additional animal feed values for these enterprises in the Northeast would therefore range up to $168.9 million in 1982 and $235.8 million when projected to 1990. It should be noted, however, that not all manure is suitable for animal feeding due to regulatory and other considerations. The most common practices currently used involve feeding broiler litter mixtures to beef cattle. Other uses are possible but are not in widespread use at present. Nevertheless, usage of residues from the anaerobic digestion process for fertilizer or feed would greatly enhance the economic value of biomass energy from livestock and poultry enterprises.

For enterprises that burn litter-based manure, there would be no salvageable residue. Therefore the choice is between using these wastes for energy, or for fertilizer or animal feeding. Fertilizer values were estimated to be $32.50 per ton dry weight for broiler and pullet litter, and $38.40 per ton for turkey litter in the early 1980's (Strong and Segars; Charles; Lance). Animal feed values for the same period were estimated at $65.00 per ton dry weight for broiler and pullet litter, and $68.00 per ton for turkey litter (Cullison; Lance; Smith and Wheeler). Based on these values, plus projections, the estimated fertilizer values for litter-based manure enterprises in the Northeast would be $26.5 million in 1982 and $42.9 million in 1990. These values were substantially below the potential values from direct burning of litter, which ranged from $58.2 to $81.5 million in 1982 and $106.6 to $160.9 million in 1990. However, animal feed values from the litter-based enterprises for the region would be $52.6 million in 1982, and $85.1 million in 1990, which were substantially higher than the fertilizer values and only slightly below the lower range of values from direct burning of litter. In all cases for litter-based enterprises then, utilizing wastes for energy would have the highest use value.

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