ECONOMIC POTENTIAL FOR BIOMASS ENERGY FROM LIVESTOCK AND POULTRY WASTES IN THE SOUTH

Harold B. Jones, Jr., and E. A. Ogden

ERS, USDA, Dept. of Agricultural Economics
University of Georgia, Athens, Georgia 30602

Abstract

Livestock and poultry wastes could produce significant amounts of biomass energy if conventional energy prices continue to rise. This study estimates the recoverable energy potentially available from livestock and poultry wastes in the southern United States in 1980 with projections for 1990. The potential energy from anaerobic digestion of dairy cow, hog, fed beef, and laying hen manures was 20.6 billion cubic feet of methane gas in 1980 with 20.6 trillion Btu's of energy; only slight increases are projected for 1990. Direct burning of litter from broilers, turkeys, and pullets could have produced 43.7 trillion Btu's of energy in 1980 with 58.6 trillion Btu's projected for 1990. The total potential farm value of biomass energy from these enterprises ranged from $141 to $446 million in 1980 and $340 million to $1.08 billion in 1990 depending upon the types of conventional energy displaced. Biomass energy values were highest when substituted for LP gas.

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

Paper presented at the American Agricultural Economics Association Annual Meeting, Cornell University, Ithaca, New York, August 5-8, 1984

ECONOMIC POTENTIAL FOR BIOMASS ENERGY FROM
LIVESTOCK AND POULTRY WASTES IN THE SOUTH

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 southern 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 three farm production regions included in this study: the Southeast, the Delta States, and the Appalachian region (Figure 1). Estimates of livestock and poultry manure and biomass energy potential were derived for livestock and poultry species by states for the base year 1980, 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 South were compiled for the period 1960 to 1981 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 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

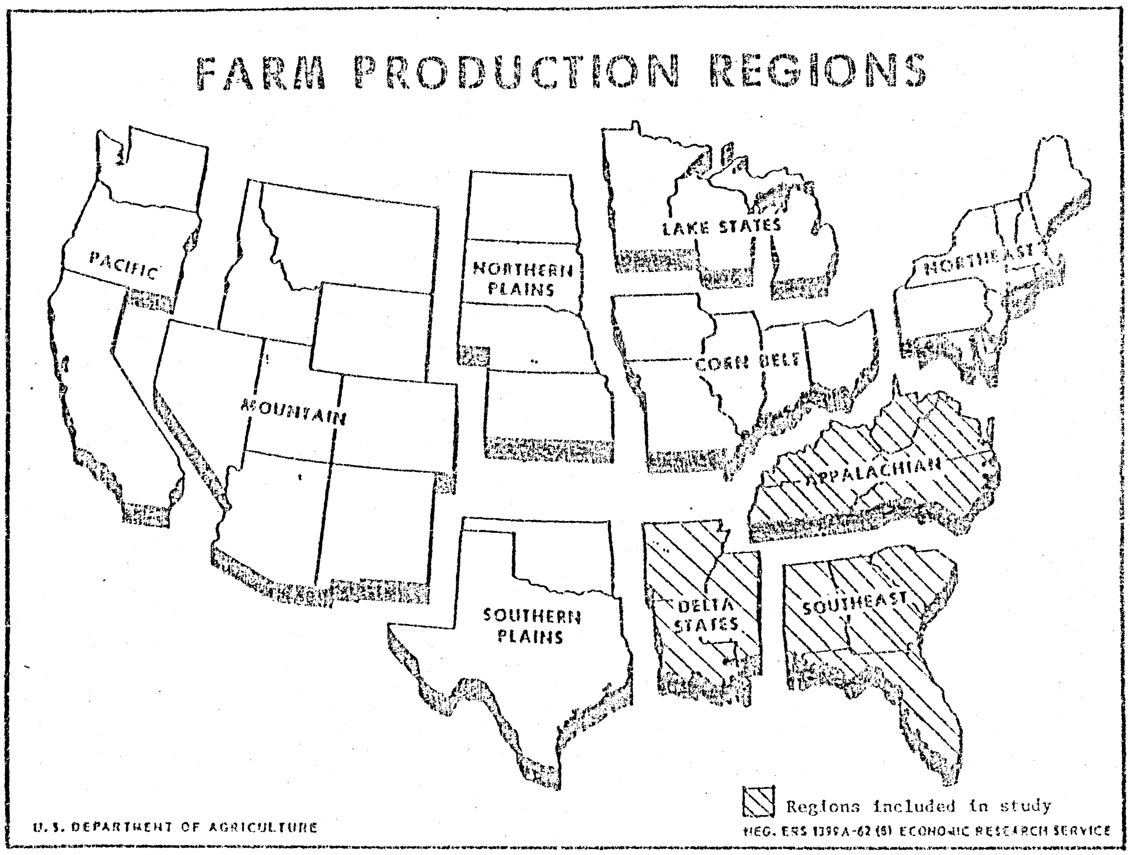

Figure 1. Outline of Farm Production Regions in the United States Including Major Regions Included in this Study

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. 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 the 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 South are given in Table 1. Anaerobic digestion was the conversion process used for dairy, swine, fed beef, 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; .62 tons per head from fed cattle on farms with sales of 1,000 head or more per year minus 5% 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 3.6 million tons of manure in 1980 with a biogas potential of 34.4 billion cubic feet. This is the equivalent of 20.6 billion cubic feet of methane gas with a thermal energy potential of 20.6 trillion Btu's. Dairy cows accounted for 43% of this energy, laying hens 32%, hogs 21%, and fed beef 4%. The major producing states were Georgia, North Carolina, and Florida, accounting for 43% of the biogas potential in the South (Table 2). Production potential was generally widespread throughout the region except in West Virginia which had relatively few livestock and poultry farms. Projected methane production for 1990 shows little change from 1980 except for a slight increase in energy potential from hogs which are expected to expand 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

Table 1. Potential Quantity and Value of Economically Recoverable Biomass Energy from Livestock and Poultry Manure and Litter, by Species, Southern Region, 1980, with Projections for 1990

Item	Dairy	Beef	Hogs	Layers	Broilers	Turkeys	Pullets	Total
Number of Animals or Birds[a]								
1980 (millions)	1.3	0.2	9.8	71.3	2,674.3	50.1	60.8	2,867.8
1990	1.2	0.2	11.0	73.4	3,574.3	74.4	60.4	3,794.9
Manure Volume Produced[b]								
1980 (mil. tons)	2.0	0.1	0.6	0.9	3.2	0.5	0.2	7.5
1990	1.9	0.1	0.7	0.9	4.3	0.8	0.2	8.9
Biogas Potential[c]								
1980 (bil. ft^3)	14.8	1.4	7.2	11.0	--	--	--	34.4
1990	14.2	1.4	8.1	11.1	--	--	--	34.8
Thermal Energy Potential[d]								
1980 (bil. Btu's)	8,880	810	4,317	6,606	35,669	6,068	1,945	64,295
1990	8,520	868	4,864	6,666	47,675	9,003	1,933	79,529
Electrical Energy Potential[e]								
1980 (Gwhr's)	780.0	71.1	379.2	580.3	--	--	--	1,810.6
1990	748.4	76.2	427.2	585.4	--	--	--	1,837.2
Value Electrical Energy[f]								
1980 (mil. $)	36.7	3.3	17.8	27.3	--	--	--	85.3
1990	70.3	7.2	40.2	55.0	--	--	--	173.0
Value Thermal Energy[g]								
NG 1980 (mil. $)	33.0	3.0	16.1	24.6	132.7	22.6	7.2	239.2
NG 1990	83.1	8.5	47.4	65.0	464.8	87.8	18.8	775.4
LP 1980 (mil. $)	62.6	5.7	30.4	46.6	246.2	41.1	13.8	446.4
LP 1990	117.4	12.0	67.0	91.9	643.4	119.6	26.5	1,077.8

[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 Kwhr's.

[f] Based on electricity prices paid by farmers by states for 1980 and projected prices for 1990.

[g] Based on NG and LP gas prices paid by farmers by states for 1980 and projected prices for 1990.

Table 2. Potential Quantity and Value of Economically Recoverable Biomass Energy from Livestock and Poultry Manure and Litter, by States, Southern Region, 1980, with Projections for 1990

Item			AL	FL	GA	SC	AR	LA	MS	KY	NC	TN	VA	WV	Total
Number of Animals or Birds[a]															
	1980	(millions)	482	105	571	54	640	100	277	5	412	65	136	23	2,870
	1990	(millions)	632	142	709	68	896	146	364	5	533	78	191	31	3,795
Manure Volume Produced[b]															
	1980	(mil. tons)	0.8	0.6	1.2	0.3	1.2	0.3	0.5	0.3	1.2	0.4	0.5	0.1	7.4
	1990	(mil. tons)	1.0	0.7	1.4	0.3	1.6	0.3	0.6	0.3	1.4	0.4	0.7	0.1	8.8
Biogas Potential[c]															
	1980	(bil. ft^3)	2.6	4.7	5.3	1.8	3.0	1.5	1.9	2.9	4.8	3.0	2.7	0.3	34.5
	1990	(bil. ft^3)	2.7	4.8	5.2	1.9	3.3	1.4	1.7	2.8	5.0	3.0	2.8	0.3	34.9
Thermal Energy Potential[d]															
	1980	(tril. Btu's)	8.0	4.2	11.0	2.1	11.8	2.2	4.9	1.8	10.8	2.6	4.3	0.7	64.4
	1990	(tril. Btu's)	10.1	4.7	12.8	2.5	16.1	2.8	5.9	1.7	13.7	2.8	5.5	0.9	79.5
Electrical Energy Potential[e]															
	1980	(Gwhr's)	135	246	279	93	159	77	100	154	252	157	142	18	1,812
	1990	(Gwhr's)	144	252	275	100	175	71	90	145	265	155	147	18	1,837
Value Electrical Energy[f]															
	1980	(mil. $)	6.9	14.5	13.1	4.3	7.6	3.3	4.7	6.1	11.3	5.9	7.2	0.8	85.7
	1990	(mil. $)	14.7	29.7	25.8	9.2	16.8	6.1	8.5	11.6	23.8	10.9	14.4	1.5	173.0
Value Thermal Energy[g]															
NG	1980	(mil. $)	33	19	45	9	27	7	16	6	43	8	18	3	234
NG	1990	(mil. $)	109	56	137	27	97	22	52	14	144	22	61	9	750
LP	1980	(mil. $)	53	35	77	15	79	16	35	12	72	20	30	5	449
LP	1990	(mil. $)	130	77	176	35	211	40	82	22	179	40	75	13	1,080

[a]Includes confined livestock and poultry on farms with at least the minimum number of animals 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 1980 and projected prices for 1990.

[g]Based on NG and LP gas prices paid by farmers by states for 1980 and projected prices for 1990.

manure at 35% digester efficiency for dairy cows; 5.83 cubic feet at 55% digester efficiency for hogs; 5.3 cubic feet at 50% efficiency for fed beef; 6.3 cubic feet at 65% efficiency for laying hens (Hayes et al.; Bartlett et al., Fischer et al., Hashimoto et al., Slane et al.); and biogas at 60% methane content. Improved technology and 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 1980 would be $76.7 million if substituted for natural gas, or $145.3 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 South was $3.72 per million Btu, (American Gas Association, 1982) and LP gas prices were 67¢/gallon in 1980 (U.S. Dept. of Agriculture). Natural gas has traditionally been priced much lower than LP gas on a Btu basis. However, since natural gas is not generally available in most rural areas of the South, the higher-priced LP gas is the most common conventional fuel that would be displaced by methane. The potential value of the methane gas is projected to be much higher by 1990, rising to $203.8 million if substituted for natural gas and $290.8 million if substituted for LP gas. These higher values are based on projected natural gas prices of $9.75 per million Btu and LP gas prices of $1.31/gallon for 1990, due to government deregulation of the natural gas industry (American Gas Association, 1983; DOE, 1983).

If methane gas from anaerobic digestion was converted to electricity, the production potential for the region would be 1,810 gigawatt-hours (Gwhr) (or 1.81 billion kilowatt-hours) in 1980 and 1,837 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 the electrical power rates in the various states. In 1980, prices paid by farmers reported by USDA varied from 3.5¢/kilowatt-hour (kwhr) in Tennessee to 5.9¢/kwhr in Florida. For the South as a whole, electrical power rates were 4.7¢/kwhr in 1980 which resulted in a value of $85.3 million for the electricity potential from methane gas. This electricity value was slightly higher than methane used as a substitute for natural gas, but substantially lower than methane substituted for LP gas. The states with the highest potential electricity values were Florida, Georgia, and North Carolina (Table 2). With the average price for electricity in the South in 1990 projected at 9.4¢/kwhr, the potential value of electricity generated from methane gas in the South will increase to $173 million in 1990. However, the electricity value in 1990 will still be considerably lower than methane gas used as a substitute for natural or LP gases.

<u>Direct Burning of Litter</u>

The potential quantity and value of recoverable energy from direct burning of litter and manure from broiler, turkey, and pullet growing enterprises in the South are given in Table 1. The volume of manure and litter available from these enterprises is based on 1.25 tons 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 3.9 million tons of manure and litter in 1980 with a thermal energy potential of 43.7 trillion Btu's (Rokeby and Mayo). Broilers accounted for 82% of this energy, turkeys 14%, and pullets 4%. The major producing states were Arkansas, North Carolina, Georgia, and Alabama, accounting for 74% of the energy potential from direct burning of manure and litter (Table 2). Projected energy production shows significant increases in the 1980's, reaching 58.6 trillion Btu's in 1990 due primarily to the continued expansion of broiler and turkey production in the South (Table 1).

The potential value of this energy depends on whether it is used to replace natural gas or LP gas. LP gas is the most common fuel used on poultry farms in the South, but natural gas is used to some extent in certain areas. If poultry litter was used as a substitute for natural gas, the value of the thermal energy produced in 1980 would be $162.5 million, as compared to $301.1 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 $571.4 million if substituted for natural gas, and $789.5 million if used to replace LP gas.

Total Energy Production

The total recoverable thermal energy potential from livestock and poultry manure in the South was 64.3 trillion Btu's in 1980 with 55.4% of this energy derived from broiler enterprises, 13.8% from dairy cows, 10.4% from laying hens, 9.4% from turkeys, 6.7% from hogs, 3.0% from pullets, and 1.3% from fed beef (Table 1). Methane gas from dairy, fed beef, hog, and laying hen enterprises accounted for 32% of this energy potential, and direct burning of litter from broilers, turkeys, and pullets accounted for 68%. It was estimated that this energy production potential for the South was 26% of the total potential energy output from these enterprises in the United States in 1980. The major energy producing states were Arkansas, Georgia, North Carolina, and Alabama, accounting for 64% of the thermal energy in the region (Table 2). The other states also had significant energy potential except for West Virginia which 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 South was projected at 79.5 trillion Btu's in 1990 (Table 1). Most of the increase is due to expected increases in production of broilers and turkeys which have been expanding rapidly in the South in recent years (Figure 2). A slight increase in number of hogs is also expected in the 1980's which will increase their potential energy output, but dairy cow numbers are projected to decline somewhat. Fed cattle numbers may increase slightly also, but little change is expected in laying hen and pullet numbers.

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 1980 for enterprises utilizing anaerobic digestion occurred when methane was substituted for natural gas. The next highest values were from electrical power generation, and the highest values occurred when methane was used as a substitute for LP gas (Table 1). In 1990, however, electrical power generation is projected to have the lowest value, followed by methane substituted for natural gas, but methane used as a substitute for LP gas will continue to have the highest value. The lowest values for enterprises utilizing direct burning in both 1980 and 1990 occurred when litter was substituted for natural gas, and the highest values occurred when litter displaced LP gas. These values vary among states depending upon electricity rates, prices of natural and LP gas, and other factors.

The lowest total on-site energy farm value for all seven enterprises in 1980 would be $239.2 million if energy from burning litter and methane gas were substituted for natural gas. In 1990 this value would be $744.1 million with litter combustion replacing natural gas and methane gas used for electricity. If the energy from all enterprises was used to replace natural gas, it would be worth $775.4 million in 1990 (Table 1). The highest values

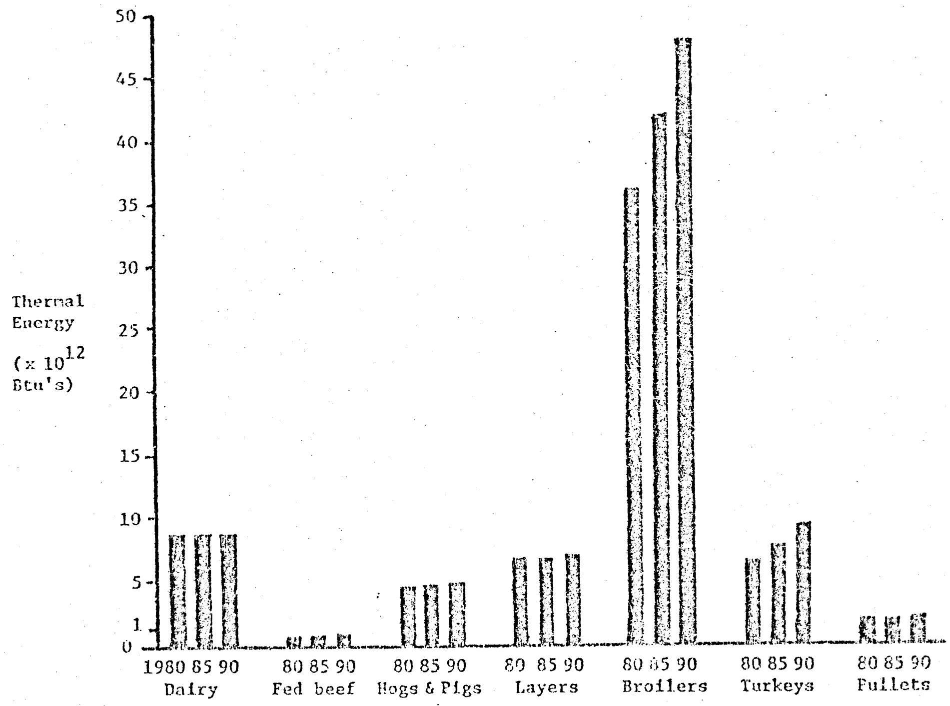

Figure 2. Comparison of Economically Recoverable Thermal Energy from Livestock and Poultry Manure and Litter, by Species, Southern United States, 1980, with Projections for 1985 and 1990

for all enterprises would be $446.4 million in 1980 and $1.08 billion 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. The potential fertilizer values for enterprises using anaerobic digestion ranged up to $82.2 million in 1980 and $114.5 million in 1990 (Strong and Segars). Potential animal feed values for the same enterprises ranged up to $181.0 million in 1980 and $254.3 million in 1990 (Cullison). Usage of these residues would therefore greatly enhance the economic potential of biomass energy from livestock and poultry wastes.

REFERENCES

American Gas Association. Gas Facts. 1981 Data, Arlington, Va., 1982.

American Gas Association. TERA Analysis Forecast, Arlington, Va., 1983.

Bartlett, H. D., S. P. Persson, and R. W. Regan. "Energy Production Potential for a 100m^3 Biogas Generator." Agricultural Energy, Vol. 2, Biomass Energy Crop Production, Paper from 1980 National Energy Symp., Am. Soc. Ag. Eng., St. Joseph, Mich., 1981.

Christensen, L. A., J. R. Trierweiler, T. J. Ulrich, and M. W. Erickson. Managing Animal Wastes: Guidelines for Decisionmaking. ERS-671, Econ. Research Serv., USDA, Wash., D.C., Nov. 1981.

Cullison, A. E. "Feeding Poultry Manure to Cattle." Broiler Industry, May 1979.

Fischer, J. R., D. D. Osburn, N. F. Meador, and C. D. Fulhage. "Economics of a Swine Anaerobic Digester." Paper 79-4580, Am. Soc. Ag. Eng. Winter Meeting, New Orleans, La., Dec. 11-14, 1979.

Hashimoto, A. G., Y. R. Chen, and V. H. Varel. Anaerobic Fermentation of Beef Cattle Manure. SERI/TR/98372-1, Solar Energy Research Institute, Golden, Col., Jan. 1981.

Hayes, T.D., W. J. Jewell, J. A. Chandler, S. Dell'Orto, K. J. Fanfoni, A.P. Leuschner, and D. F. Sherman. "Methane Generation from Small Scale Farms." Cornell Univ., Ithaca, N.Y. in Biogas and Alcohol Fuels Production. Proc. Seminar on Biomass Energy for City, Farm and Industry. J. G. Press, Emmaus, Penn., Jan. 1980, pp. 88-117.

Nolter, W. H., M. S. Smith, and C. C. Ross. "A Wood Fired Warm Air Broiler Brooding System." Paper SER 81-001, Am. Soc. Ag. Eng. Southeast Meeting, Atlanta, Ga., Feb. 1-4, 1981.

Office of Technology Assessment. Energy from Biological Processes, Vol. 1., U.S. Congress, Wash., D.C., May 1980, pp. 124-128.

Rokeby, T. R. C., and R. D. Mayo. "The Potential of Broiler Litter as Fuel." Arkansas Farm Research, March-April 1978, p. 14.

Slane, T. C., R. L. Christensen, C. E. Willis, and R. G. Light. An Econmic Analaysis of Methane Generation: Internal Costs and External Benefits. Bul. 618, Mass. Agric. Expt. Sta., Univ. of Mass., Amherst, Mass., Jan. 1975.

Smith, Norman, J. G. Riley, C. W. Kittridge, and N. E. Putnam. "Use of Litter for Broiler House Heating." Paper 78-4552, Am. Soc. Ag. Eng., Winter Meeting, Chicago, Ill., Dec. 18-20, 1978.

Strong, C. F., Jr., and W. I. Segars. Poultry Waste. Leaflet 206, Coop. Ext. Serv., Univ. of Georgia, Athens, Ga., Oct. 1981.

U.S. Dept. of Agriculture . Agricultural Prices. Crop Reporting Board, Econ. Research Serv., Wash., D.C., 1983.

U.S. Dept. of Energy. Technical and Economic Evaluations of Biomass Utilization Processes. Tech. Rep. No. 1, DOE/ET/20605-T4, Contract with SRI International, Biomass Energy System Branch, Wash., D.C., Sept. 1980, pp. 2-1 to 2-16, 7-1 to 7-12.

U.S. Dept. of Energy. 1982 Annual Energy Outlook with Projections to 1990. Energy Inf. Admin., Wash., D.C., April 1983.

U.S. General Accounting Office. The Nation's Unused Wood Offers Vast Potential Energy and Product Benefits. EMD-81-6, Report to the Congress of the U.S., Wash., D.C., Mar. 3, 1981, pp. 37-39.

Van Dyne, D. L., and C. B. Gilbertson. Estimating U.S. Livestock and Poultry Manure and Nutrient Production. ESCS-12, Econ., Statistics, and Coop. Serv., USDA, Wash., D.C., Mar. 1978.