PARTICIPATION IN A CENTRAL ANEROBIC DIGESTER AND COGENERATION FACILITY: ECONOMIC AND ENVIRONMENTAL ANALYSIS FOR FARM DECISION MAKING

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ABSTRACT

Farmer participation in a proposed 5,600 cow central digester facility is a function of herd size, present manure handling system, income tax effects and expectations about future changes in contract terms. The present value of net benefits from participation ranges from $6,000 to $6,400 for large herds and $3,200 for medium herds with manure storage. No net benefits accrue to medium sized herds not currently storing manure. Environmental impacts of the proposal will likely be positive for air and water quality but could reduce soil quality unless organic matter is returned to cropland.

INTRODUCTION

The energy crunch of the 1970s forced a reexamination of uses and sources of energy, in agriculture no less than other sectors of the economy. Experiments with animal manures led to workable processes for extracting methane gas (Jesell, et al. 1976; Persson and Bartlett, 1979). Passage of the Public Utility Regulatory Policies Act of 1978 and accompanying regulations (18CFR 292.304) created a marketing channel for electricity generated by burning the methane produced from manure. However, the large capital investment needed to build a methane digester and the low income tax liability of most farmers preclude such developments on the majority of dairy farms. A group of investors in Vermont propose to step into this gap by constructing a 5,600-cow central anerobic digester and cogeneration facility.

The company plans to put "cow power" to work by trucking manure from cooperators' farms to the central digester on a daily basis and returning 94 percent of the digested liquid manure to the farm periodically. No charge will be made for hauling manure. Each cooperator will be paid an initial bonus of $10 per cow to sign a ten-year contract and an annual payment of $25 per cow. Dried solids from the manure can be repurchased for use as bedding or refeed for $5 per cubic yard ($12.50 per ton). The company will derive revenue from sale of generated electricity to the local power company and sale of dried solids to cooperators and others.

Aside from the general question of the viability of such a proposal, a number of specific economic questions surround the farmer's decision to participate in the venture. What are the benefits and costs? Do they vary by size of farm? Does the present manure handling system make any difference? At what levels of key parameters would the decision to participate change? A number of noneconomic questins can also be asked. What are the effects on the soil if the farm's manure goes to the digester? What are the environmental consequences?

This paper examines these questions for typical Vermont dairy farms based on data developed for an earlier study, details of which are not reported here. Physical transformations of the manure through the digestion process are taken as presented in the company's literature.

ECONOMIC ANALYSIS

As discussed in Heimlich (1982), economics of manure systems depend on the herd size, the types of crops grown, the characteristics of soils to which manure is applied and the way in which manure is handled. This analysis considers two typical dairy farms, as summarized in Table 1. The farms assumed here are based on 1974 Census of Agriculture statistics for Vermont dairy farms, Standard Industrial Classification 024. The average herd size in Addison County in 1978 was 64 cows, and 17 percent of the herds were over 100 cows. Thus, these hypothetical farms are typical of medium to large farms in the area. The soil type is Vergennes, a heavy, lake-laid clay soil which comprises about 90 percent of cropland soils in Addison County. Values for manure production, nutrient content and losses are taken from published literature. The anerobic digestion and separation process envisioned has the physical characteristics shown in Figure 1, according to the company.

The initial bonus and annual payments that accrue to a farmer who decides to participate in this project are complemented or offset by changes in three kinds of costs: manure handling, manure nutrient values and bedding. Participation requires a manure storage for the liquid manure that is returned to the farm. Based on the analysis in Heimlich (1982), annual operating costs for components of an earthen pit system with 180 days of storage, a comparable system for a free stall barn with daily spreading and a stanchion barn system with daily spreading are shown for 60- and 115-cow herds in Table 2.

As shown in Figure 1, digestion reduces the amount of manure to be spread 22.6 percent since solids are separated out. This reduces spreading costs with the liquid system proportionally. Costs with the free stall daily spread system rise due to construction of the earthen pit and purchase of a liquid spreader. A piston pump may not be required as manure is scraped directly to the truck and returned in liquid form to the pit, but it is included here. Costs with the stanchion barn also increase to cover the earthen pit and liquid spreader. A tractor scraper and piston pump may not be required as manure is loaded from the gutter cleaner and returned as a liquid

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Table 1 — Characteristics of Hypothetical Farms

	Medium Herd	Large Herd
Farm Characteristics		
Cows	60	115
Corn	39	75
Hay	97	186
Total cropland[1]	136 acres	261 acres
Soil Characteristics		
Soil type	Vergennes	Vergennes
Productivity[2]	Medium	Medium
Hydrologic soil group	D	D
Field Nitrogen Losses[3]		
Surface applied	33%	33%
Soil incorporated	67%	67%
Nitrogen requirements[4]	7,505 lbs./yr.	14,415 lbs./yr.

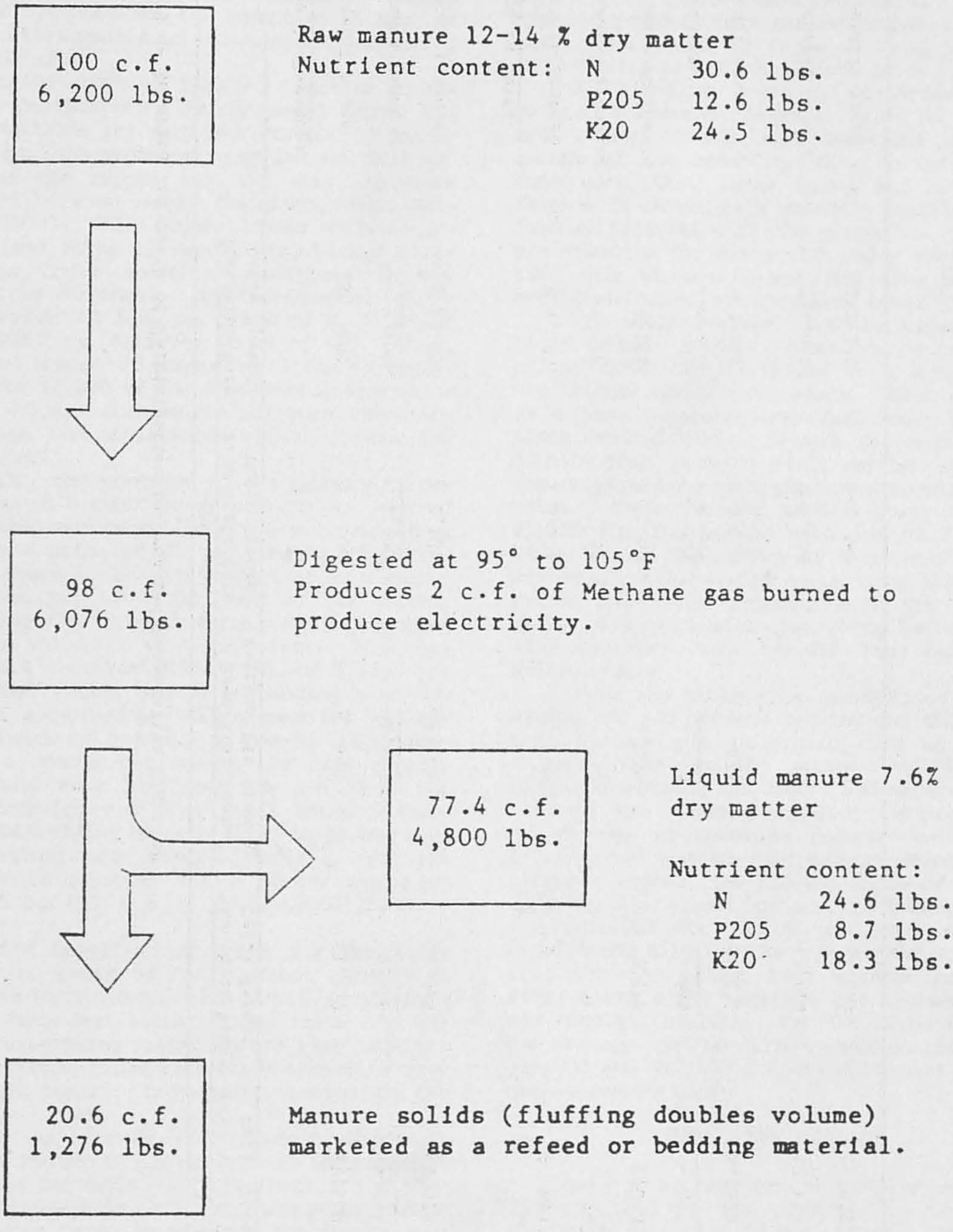
[1] Based on average cropland acres per cow for commercial dairy farms (Class I to V farms in SIC 024) in Vermont of 2.27 acres (1974 Census of Agriculture).
[2] Sixteen to nineteen tons per acre of corn silage.
[3] Volitilization and denitrification losses (Gilbertson, et. al., 1979).
[4] Based on nitrogen needs of the crops as follows:
17.5 tons/acre corn silage x 6.2 lbs. N/ton = 108.5 lbs./acre.
3.0 tons/acre hay x 11.25 lbs. N/ton = 33.75 lbs./acre.
Legume hay is assumed to take 80 percent of its nitrogen needs from the atmosphere (Midwest Plan Service, 1975).

Table 2 — Costs of Manure Systems, 60 and 115 Cows, 1979

	Annual Operating Costs			
	Storage and handling[1]		Spreading[2]	
System	60 Cows	115 Cows	60 Cows	115 Cows
Stanchion barn-gutter cleaner-solid spread daily	$2,763	$7,163	$209	$263
Free stall barn-tractor scraper-solid spread	$2,763	$7,163	$209	$263
Free stall barn-tractor scraper-piston pump-earthen pit (180 days)-liquid spreader	$5,836	$7,651	$249	$377

[1] Fixed and variable costs of storage and unloading storage and fixed costs of the spreader.
[2] Variable costs of spreading, including fuel, labor and repairs.
Source: Heimlich (1982).

Figure 1 — Physical Characteristics of Anerobic Digestion[1]



1 Raw manure nutrient values of 9.88/4.05/7.91 pounds per ton N/P205/K20 substituted for the company's values of 10.4/2.8/8.8 pounds per ton N/P/K for consistency with other analysis. Retention rates of 80/70/75 percent are the company's.

Table 3 -- Benefits and Costs of Participation in Proposed Cooperative Digester

	60 Cows			115 Cows		
	Stanchion Barn Daily Spread	Free Stall Barn Daily Spread	Free Stall Barn Earthen Pit Storage	Stanchion Barn Daily Spread	Free Stall Barn Daily Spread	Free Stall Barn Earthen Pit Storage
Change in Revenue:						
Initial bonus	$ 600	$ 600	$ 600	$1,150	$1,150	$1,150
Annual payment	1,500	1,500	1,500	2,875	2,875	2,875
Total revenue	$ 2,100	$ 2,100	$2,100	$4,025	$4,025	$4,025
Change in Costs:						
Manure storage	$ 3,073	$ 3,073	$ 0	$ 488	$ 488	$ 0
Manure spreading	- 16	- 16	- 56	29	29	- 85
Manure nutrients	1,184	1,040	1,060	2,278	2,003	2,038
Bedding	- 493	- 329	- 329	- 944	- 630	- 630
Total costs	$ 3,748	$ 3,768	$ 675	$1,851	$1,890	$1,323
Net benefit year 1	$-1,648	$-1,668	$1,425	$2,174	$2,135	$2,702
Net benefit years 2-10	$-2,248	$-2,268	$ 825	$1,024	$ 985	$1,552

to the earthen pit, but they are included here. The net change in manure handling costs, shown in Table 3, includes the increased costs of storage and liquid spreader and the reduction in cost of spreading attributable to the decreased amount of manure handled.

Referring again to Figure 1, another consequence of participation is decreased manure nutrients available for crop production. If participants empty the storages in spring and fall and incorporate the manure into the soil, nitrogen losses will be even larger (Heimlich, 1982; Gilbertson, 1979). The higher losses with incorporation (see Table 1) result from higher denitrification under anerobic conditions in wet soils such as Vergennes. Manure elemental nutrients are valued at $.32 per pound of N, $.30 per pound of P205 and $.15 per pound of K20. Thus, the reduced amount of manure available to spread accounts for $1,060 of the decreased manure value in Table 3, and changes in nitrogen retention with storage and application method account for the remainder.

Finally, the contract allows members to repurchase up to 5 cubic yards per cow per year of the processed manure solids for use as refeed or bedding at a price of $5 per cubic yard. From Figure 1, there is 20.6 cubic feet of this material produced per 100 cubic feet of raw manure, but fluffing the dried material as it is dried doubles its volume to 41.2 cubic feet. This converts to 0.4 tons per cubic yard, or $12.50 per ton of dried solids usable as bedding. At $20 per ton of alternative bedding material and assuming 6 pounds of bedding per cow-day in stanchions and 4 pounds per cow-day in free stalls, members could save $8.21 per cow and $5.48 per cow in stanchion and free stall barns respectively. Multiplying by herd size yields the savings in bedding costs shown in Table 3. For example, the calculation for a 60-cow stanchion barn would be [60 x 6 x (20.00-12.50)]/2000 = $492.75.

Totaling benefits and costs for the first and remaining years of the contract shows that participants with pre-existing liquid manure pits benefit at both farm sizes. Large farms with any kind of pre-existing liquid manure pits benefit, but medium sized farms with daily spreading systems do not benefit from participation in the proposal.

Income tax effects attributable to increased investments needed to participate in the proposal are analyzed in Table 4. Investment tax credit on liquid manure pits and liquid manure spreaders reduces income taxes in the year the investments are made. Accelerated cost recovery allows depreciation of these investments over five years, reducing taxable income. Tax benefits which would have accrued to investments in replacement equipment associated with the pre-existing manure handling system must be accounted for in the years in which they would normally occur. In this analysis, the farms are assumed to have sufficient income to utilize the tax shelter provided and are in the 25 percent tax bracket. Income averaging or carry forward/carry back is not considered, nor are possible salvage values or capital gains from disposal of manure handling equipment. Income taxes associated with the increased revenue from participating in the proposal, not shown in Table 4, must be deducted from the bonus and annual fees paid.

All benefits, costs and tax effects are discounted to present value in Table 5. While tax and present value considerations change the amount of net benefits, they do not alter the conclusion that large farms and medium sized farms with manure pits can reap positive benefits from participation in the proposal. Tax effects are positive for farms with daily spreading systems only at the 60-cow herd size but are not sufficient to offset increased costs.

Two modifications to these assumptions may be in order. First, farmers may be reluctant to accept dried manure solids as a substitute for traditional bedding materials. Eliminating this as a cost reduction does not alter the conclusions reached above. Second, the company has indicated that it may install earthen storage pits for cooperators who might not otherwise participate. This reduces annual costs of storage $1,368 for the medium herd and $2,339 for the large herd. The effect of these two changes on net benefits for medium herds is to make participation marginally attractive in the first year only. The conclusion that large herds and herds with storages would benefit from participation still obtains.

Under the alternative assumptions that dried solids are not used as bedding and that the earthen storage pit is provided at no cost, two changes occur in the present value analysis. First, investment tax credit and accelerated cost recovery are reduced, so that the present value of changes in taxes is reduced to $1,197 and $-5,437 for the 60- and 115-cow herds, respectively. Second, the present value of the change in costs is reduced, on net, to between $-16,752 and $-16,052 for the 60-cow herd and between $-1,576 and $114 for the 115-cow herd. Net benefits for the medium herd without pre-existing storage are still negative and between five and six thousand dollars. For the large farms without storage, net benefits remain positive and are $11,803 and $13,493 for stanchion and free stall barns, respectively.

BREAK-EVEN ANALYSIS

One way to look at the break-even point for participating in the proposal is to ask what change in the terms of the contract would be required to make participation attractive, assuming no inflation in costs or revenues and no change in other aspects of the contract. The last two items in Table 5 show the minimum annual fee or minimum initial bonus needed to justify participation, all other terms held constant. That is, what change in the net present value of the stream of revenues is needed just to equal the net present benefits? For the bonus, this is just net present benefits divided by herd size, plus the existing $10 bonus. For the annual fee,

Table 4 — Tax Effects of Participation in Proposed Cooperative Digester

Herd Size and Item	Year 1	2	3	4	5	6	7	8	9	10
60 Cow Daily Spread										
Investment tax credit[1]	2,729						559	406		
Investment tax credit foregone[2]	-352			-352			-352			-352
Accelerated cost recovery[3]	1,364	1,364	1,364	1,364	1,364		280	482	482	482
Accelerated cost recovery foregone[4]	-293	-293	-293	-293	-293	-293	-293	-293	-293	-293
Tax effect	3,448	1,071	1,071	719	1,071	-293	194	595	189	-163
115 Cow Daily Spread										
Investment tax credit[5]	3,630						813	406		
Investment tax credit foregone[6]	-1,068			-1,068			-1,068			-1,068
Accelerated cost recovery[7]	1,815	1,815	1,815	1,815	1,815		406	609	609	609
Accelerated cost recovery foregone[8]	-890	-890	-890	-890	-890	-890	-890	-890	-890	-890
Tax effect	3,487	925	925	-143	925	-890	-739	125	-281	-1,349

[1] Ten percent of investment: Year 1:

Year 1:	Piston pump	$ 8,516
	Earthen pit & ramp	9,123
	Liquid manure pump	4,058
	Liquid manure spreader	5,590
	Total	$27,287
Year 7:	Replace liquid manure spreader	$ 5,590
Year 8:	Replace liquid manure pump	$ 4,058

[2] Ten percent of investment: Years 1, 4, 7, 10 avoid replacing solid manure spreader $3,516.

[3] Year 1: Initial investment depreciated over 5 years: $27,287 ÷ 5 = $5,457 at 25 percent tax rate = $1,364.

Years 7-10: Replacement of liquid manure spreader depreciated over 5 years: $5,590 ÷ 5 = $1,118 at 25 percent tax rate = $280.

Years 8-10: Replacement of liquid manure pump depreciated over 5 years: $4,058 ÷ 5 = $812 at 25 percent tax rate = $202.

[4] Years 1-10: Replacement of solid manure spreader avoided depreciated over 3 years: $3,516 ÷ 3 = $1,172 at 25 percent tax rate = $293.

[5] Ten percent of investment: Year 1:

Year 1:	Piston pump	$ 8,516
	Earthen pit & ramp	15,598
	Liquid manure pump	4,058
	Liquid manure spreader	8,125
	Total	$36,297
Year 7:	Replace liquid manure spreader	$ 8,125
Year 8:	Replace liquid manure pump	$ 4,058

[6] Ten percent of investment: Years 1, 4, 7, 10 avoid replacing solid manure spreader $10,678.

[7] Year 1: Initial investment depreciated over 5 years: $36,297 ÷ 5 = $7,259 at 25 percent tax rate = $1,815.

Years 7-10: Replacement of liquid manure spreader depreciated over 5 years: $8,125 ÷ 5 = $1,625 at 25 percent tax rate = $406.

Years 8-10: Replacement of liquid manure pump depreciated over 5 years: $4,058 ÷ 5 = $812 at 25 percent tax rate = $203.

[8] Years 1-10: Replacement of solid manure spreader avoided preciated over 3 years: $10,678 ÷ 3 = $3,559 at 25 percent tax rate = $890.

Table 5 — Present Value of Benefits, Costs and Tax Effects of Participation in Proposed Cooperative Digester

	Herd Size and Present Manure Handling Method					
	60 Cows			115 Cows		
	Stanchion Barn Daily Spread	Free Stall Barn Daily Spread	Free Stall Barn Earthen Pit Storage	Stanchion Barn Daily Spread	Free Stall Barn Daily Spread	Free Stall Barn Earthen Pit Storage
Change in Revenue:						
Present value[1]	$ 9,817	$ 9,817	$ 9,817	$ 18,816	$ 18,816	$18,816
Change in Costs:						
Present value[1]	$-22,846	$-23,153	$-4,148	$-11,374	$-11,613	$-8,129
Change in Taxes:						
Present value[2]	$ 3,768	$ 3,768	$-2,441	$ -1,035	$ -1,035	$-4,678
Net Benefits:						
Present value[3]	$ -9,261	$ -9,568	$ 3,228	$ 6,407	$ 6,168	$ 6,009
Break-Even Analysis:						
Annual fee[4]	$ 50.12	$ 50.95	$ 16.24	$ 15.93	$ 16.27	$ 16.50
Initial bonus[5]	$164.35	$169.47	$-43.80	$-45.71	$-43.63	$-42.25

[1] From Table 3 discounted at 10 percent annual rate.
[2] Includes effect from Table 4 less taxes on increased revenue at 25 percent rate. Discounted at 10 percent annual rate.
[3] Sum of present value streams from change in revenue, change in costs and change in taxes.
[4] Annual fee needed to break even assuming no inflation and ignoring changes in tax effects. Includes $10 per cow initial bonus.
[5] Initial bonus needed to break even with $25 annual fee per cow assuming no inflation and ignoring changes in tax effects.

this is the annuity whose present value equals net present benefits divided by herd size, plus the existing $25 annual fee. The 60-cow herds with daily spreading systems would require twice as large an annual fee as is being offered. Both the medium and large herds with pre-existing earthen pits could break even with an annual fee only two-thirds as large as that being offered. The large herds with daily manure handling systems need about two-thirds the existing per-cow fee to break even.

The medium herds with daily spreading would need an initial bonus fee of at least $165 per cow to make the proposal attractive. This assumes that the same $25 per cow annual fee is paid, there is no inflation in costs or revenues and ignores changes in tax effects. Herds with pre-existing earthen pits should be willing to pay up to aout $43 per cow to participate, while large herds with daily spreading systems could pay up to about $44 per cow to participate.

Participation in the proposed central digester requires signing a ten-year contract to supply manure. Any decision with consequences over a ten-year period should be made with explicit consideration given to the effect of possible future inflation on the outcome of the decision. The contract for this proposal stipulates that the annual per-cow fee will be increased by the same percentage as the project's per-kilowatt-hour charge to the local utility. Other company literature indicates that an annual increase of at least 3 percent is expected, although rates could increase more rapidly.

Annual average inflation in prices paid by farmers for inputs relevant to this analysis ran at double-digit rates during the decade 1970 to 1980. By contrast, all of the rates in 1981 were in single digits, and some rates in 1982 were even negative. There is scope in these trends for the brightest optimism and the most severe pessimism regarding future rates of inflation, but little certainty. Assuming a 3 percent growth in revenues and still discounting at 10 percent, the conclusions reached in the preceding section remain valid for rates of inflation in costs between 0 and 7.5 percent for daily spreading at both herd sizes. For operations with pre-existing storage, benefits of participation remain positive for cost inflation rates up to about 10 percent.

The conclusions reached in the preceding section have proven relatively insensitive to changes in the terms of the contract or to changes in costs over the life of the contract. As in any analysis of this sort, different assumptions about growth in revenues, discount rates or contract terms could alter the results. Results of simultaneous changes in more than one parameter are especially unpredictable and would have to be analyzed specifically.

ENVIRONMENTAL ANALYSIS

The cooperative digester will potentially impact air, soil and water quality in direct and indirect ways. These impacts are discussed here in a preliminary way, but a complete evaluation obviously requires a detailed physical analysis.

Utilizing cow manure to generate electricity will reduce demand for some amount of alternative conventional generating capacity, presumably burning coal or oil. Whether air quality is improved by this substitution depends on the relative emission characteristics of the engine used to burn the methane versus the coal or oil-fired plants, the location at which the conventionally supplied electricity would have been generated and the existing air quality at the two locations. It is likely that the methane-powered generator burns cleaner than competing fossil-fueled generators, that the generating capacity substituted for is located outside Addison County and that existing air quality in Addison County is better than at the alternative generating site. Preliminary analysis by air quality planners of the Vermont Agency of Environmental Conservation indicates that combustion contaminants from burning the methane would be similar to natural gas, a relatively clean-burning fuel. Lower heat of combustion and higher water content of the bio-gas would act to reduce nitrous oxide emissions to levels below those for natural gas (Wishinski, 1982).

Another direct effect is the increased emissions generated by the trucks hauling manure to and from the digester. This is probably more than offset by the decreased emissions from tractors hauling manure on a daily basis, especially considering the number of cold starts involved.

An indirect and localized air quality effect of the proposal is to change manure spreading practices. If most participants switch from daily spreading systems to liquid systems spread once or twice a year, the intensity of odor problems may increase while the duration of odor problems decreases. If most participants already have liquid storage systems, odor problems will be reduced since digestion reduces the odor of the liquid manure. Overall, the direct and indirect air quality effects of the proposal are probably positive and small.

The primary impact on soil quality was treated as an economic effect above. Decreased plant nutrients available from manure do not harm soil quality since they are replaced by commercial fertilizers of equal nutrient content.

Another potentially serious problem with the proposal is that it could reduce the amount of manure organic matter returned to the soil. Organic matter, or humus, is important for maintaining the tilth, drainage and moisture-holding capacity of the soil, especially on the heavy clay soils typical of Addison County (McCalla, 1942). Klausner (1980, 1981) found that corn yields with manure were higher than without manure at the same level of fertilization. Manure organic matter can be as important as manure nutrients in maintaining the productivity of the soil.

At a minimum, one-third of the manure dry matter will be lost to the farm under the proposal. If that portion of manure solids available to the cooperator as bedding is not purchased, loss of manure dry matter increases to 58 percent.[1] This potentially damaging reduction in organic matter to the farm's soil can be avoided if manure solids used as bedding are returned to the soil after use or if cover crops or other "green manure" crops are plowed into the soil to maintain humus content. Without such measures, impact of the proposal on soil quality is probably negative.

One of the most important environmental problems in Vermont is increasing eutrophication of Lake Champlain associated with phosphorus loadings from nonpoint sources, including agriculture (NERBC, 1979; USDA, 1982). As discussed in Heimlich (1982), changing from daily manure spreading to 180 days of storage with spreading in fall and spring and soil incorporation of manure could reduce average annual phosphorus loads from manured fields up to 90 percent. To the extent that participants with daily spreading systems participate in the venture, a greater percentage of the manure will be stored and spread, reducing phosphorus loadings. The proposal will thus lend assistance to state and federal programs subsidizing manure storages for water quality protection purposes. It is important that the earthen pits or other manure storages meet proper design standards, such as those developed by the Soil Conservation Service, in order to avoid more localized sanitary and environmental problems.

CONCLUSIONS

The cooperative digester is proposing a unique approach to transform a neglected resource into an asset for rural Vermont. For farms with the characteristics presented in Table 1 and 2, the decision to participate is related to herd size, present manure handling system, income tax effects and expectations about future price changes.

The present value of net benefits from participating in the proposal ranges from \$6,000 to \$6,400 for large herds. Large herd owners will find it attractive to participate regardless of existing manure handling system. For medium herds, only farms that already have earthen pit manure storages (or other liquid manure storage) are likely to find participation attractive. These conclusions are relatively unaffected whether dried solids are reused for bedding or not, whether the farmer must bear the cost of constructing the earthen storage or not, and under wide variations in initial bonus or annual fee stated in the contract.

Overall, the environmental effects of the proposal are probably positive. Impacts on air quality are both positive and negative but are probably insignificant, except for local reductions in waste odors. Water quality effects are all positive as long as stored manure is spread at appropriate times and incorporated into the soil. Reduction in phosphorus loadings to Lake Champlain could be significant. The impact of reduced manure organic matter returned to the soil is negative and could be significant. This impact could be reduced if reused manure bedding material or cover crops are plowed into the soil to maintain soil humus.

The company should be credited with a positive step toward increasing our energy resources, decreasing an environmental problem and more completely utilizing an undervalued resource. Their venture will be closely watched and rapidly imitated if it is successful.

[1] Calculates as: 6,200 pounds x 14 percent dry matter = 868 pounds manure dry matter in original manure; 4,800 pounds x 7.6 percent dry matter = 365 pounds dry matter in returned liquids; (868 - 365)/2 = 252 pounds dry matter in purchased manure solids; (868 - 365)/868 = 58 percent loss; (868 - 365 - 252)/868 = 29 percent loss.

REFERENCES

Gilbertson, C.B., F.A. Norstadt, A.C. Mathers, R.F. Holt, A.P. Barnett, T.M. McCalla, C.A. Onstad and R.W. Young. "Animal Waste Utilization on Cropland and Pastureland: A Manual for Evaluating Agronomic and Environmental Effects." USDA Science and Education Administration/U.S.E.P.A., Office of Research and Development, USDA URR No. 6, October 1979.

Heimlich, R.E. "Economics and Environmental Effects of Manure Handling Systems for Northeastern Dairy Farms." Journal of the Northeastern Agricultural Economics Council, 11(1): 45-56, Spring 1982.

Jewell, W.J. and others. "Bioconversion of Agricultural Wastes for Pollution Control and Energy Conservation." TID-27164, U.S. Energy Research and Development Administration, September 1976.

Klausner, S.D. "Manure Management -- Facts and Figures." Unpublished material from the 1980 Production Agriculture Training School, Cornell University, Ithaca, New York, 1980.

Klausner, S.D. and R.W. Guest. "Influence of NH3 Conservation from Dairy Manure on the Yield of Corn." Agronomy Journal, 73:720-723, July-August 1981.

McCalla, T.M. "Influence of Biological Products on Soil Structure and Infiltration." Soil Sci. Soc. Amer. Proc., 7:209-214, 1942.

Midwest Plan Service. Livestock Waste Facilities Handbook. MWPS-18, Iowa State University, Ames, Iowa, July 1975.

New England River Basin Commission. Shaping the Future of Lake Champlain: The Final Report of the Lake Champlain Basin Study. NERBC, Burlington, Vermont, 1979.

Persson, S.P.E. and H.D. Bartlett. "Agricultural Anerobic Digesters: Design and Operation." Agr. Exp. Station Bull. 827, College of Agriculture, Pennsylvania State University, University Park, Pennsylvania, 1979.

U.S. Department of Agriculture. Agricultural Runoff in Selected Vermont Watersheds. Main report draft, Soil Conservation Service, Burlington, Vermont, November 1982.

Wishinski, P.R. Unpublished memorandum on visit to Foster Bros. digester, Middlebury, Vermont. Vermont Agency of Environmental Conservation, October, 1982.