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BY-PRODUCTS UTILIZATION: AN INTEGRATED SOLUTION

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ABSTRACT

The farming community regards agricultural wastes as resources. In addition to utilizing nutrient as fertilizer, green energy production is a well-known by-product. Examples include: anaerobic digestion (AD) of livestock manure to produce biogas for use as fuel for stove, boiler, combined heat and power (CHP) generation or even as vehicle fuel; and gasification of relatively dry wastes such as poultry manure, wood chips, and saw dust for power generation.

Besides green energy, processing of agricultural waste can provide many additional benefits. Utilization of carbon dioxide from combustion exhaust in greenhouses is less commonly known, and the environmental benefits such as the reduction of pathogens, odour, greenhouse gas emission and water contamination are difficult to quantify. These benefits are discussed in greater detail in this paper, and quantification methods are proposed. The overall cost of agricultural waste management can be significantly reduced when "full-benefit" accounting is applied, and the cost of implementing advanced technologies can be justified. An integrated solution for agricultural, environmental, public health and energy concerns can be developed by fully utilizing the by-products. A recent case of locally initiated efforts in developing such an integrated solution for the rural community of Chatham-Kent in Ontario, Canada will be briefly described.

KEYWORDS. Agricultural waste, by-products, manure, biodigestion, biogas, compost, green energy, combined heat and power, cogeneration, integrated solution.

INTRODUCTION

With the recent advent in green energy technology and their favourable impact on global warming, agricultural waste material is increasingly being recognized as a valuable source of biomass renewable energy. The ethanol production from potato and corn wastes (Mann 2002, Kadam, 2002); combustion, gasification and co-firing of poultry manure, plant stems and straw for fuel gas

(Tschanum 2001, Morris 2002, Rizeq 2002, Smeenk 2002, Zygarlicke 2002); and manufacture of biodiesel from vegetable oil (Cruz 2002, Worgetter 2002) are some examples.

Livestock manure has always been regarded as a resource on farms. As wet sludge, it is simply land applied for its nutrient value. In remote areas of India, dried dung is being burned for energy even today. However, without the guidance of science and technology, such simplistic approaches are not sustainable. The adverse effects of nutrient saturation and pathogens on soil and water; and the deterioration of air quality owing to emissions of particulates and products of incomplete combustion such as carbon monoxide are causing major environmental and health concerns in both industrialized and developing countries (Overend 2002)

As well developed green technologies are becoming increasingly affordable, and by-product recovery techniques are becoming more fully developed, an integrated solution can often be assembled to utilize the full potential of agricultural wastes. One example of such a solution is the integrated process of anaerobic digestion and biogas cogeneration of electricity and heat, and the proper management of the digestate.

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This paper presents a detailed consideration of the various by-product recovery options, and the full potential value of the integrated solution.

GOAL: MANURE MANAGEMENT PRACTICE THAT EXCEEDS STANDARDS

It is the intent of this paper to establish a manure management practice that can exceed most of the current standards. The generally accepted standards usually require several months of safe storage to avoid seepage into ground water or overrun into surface water. The storage facility must meet some minimum distance requirements to avoid causing odourous nuisance to the neighbouring public. After storage, the manure can be land applied within the guidelines of soil nutrient levels and minimum distances from water courses and residences.

In principle, the enforced standard in most livestock farming communities is one of properly administered storage and land application. The solution analyzed in this paper is an alternative to this, and will involve technologies based on scientific knowledge and engineering practice that deal with the problem on a more fundamental level.

AN INTEGRATED SOLUTION:
ANAEROBIC DIGESTION WITH FULL BY-PRODUCTS RECOVERY

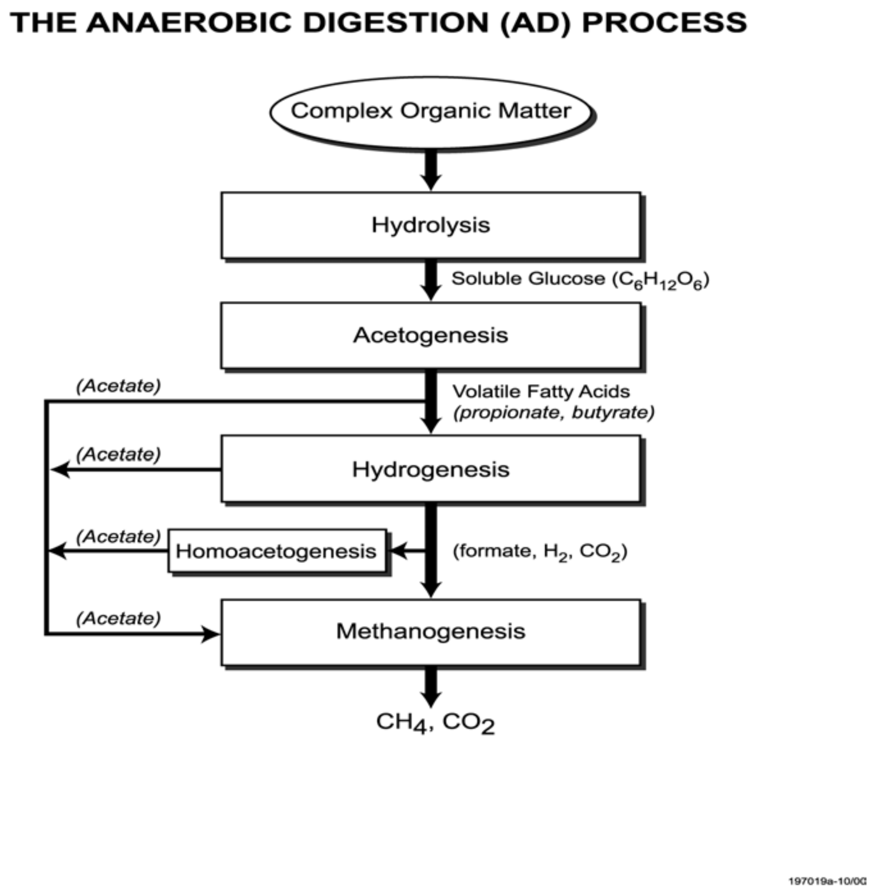

Figure 1. Biochemical Reactions of Anaerobic Digestion (AD) Process

Organic wastes can be processed by anaerobic digestion (AD) reactions, which can be simply defined as the decomposition of organic matter in the absence of oxygen, to produce methane. The basic reaction steps of the conversion are summarized in Figure 1.

Figure 2 illustrates the overall concept of applying the AD technology to develop an integrated solution for livestock manure management.

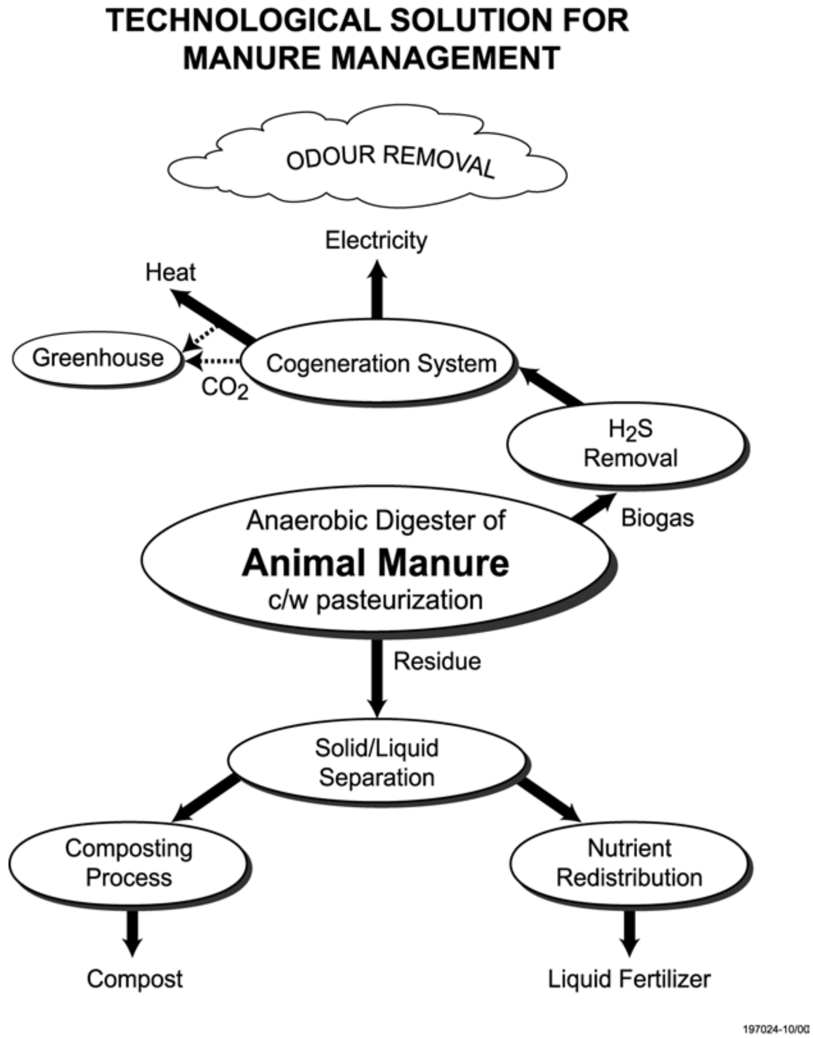

Figure 2. Anaerobic Digestion of Manure with Full By-products Recovery

Primary Product and By-products of the Integrated Solution

Primary Product (Goal): It must be recognized that the primary product, or the goal, of this solution should be considered to be the disposal of livestock manure in a sustainable manner, so that the livestock industry can continue to operate and the potential bottlenecks to the industry's expansion and growth can be avoided.

The most significant value of the primary product is obviously the continued operation and perhaps expansion of the livestock farming industry.

By-products: Referring to Figure 2, it is not difficult to recognize that, in addition to the Primary Product as defined above, the following by-products are derivable from this process:

<u>Tangible Benefits</u>

Energy

Biogas: The primary energy by-product is the methane (CH_4) reactant of the bacterial reactions. When diluted by the carbon dioxide (CO_2) produced simultaneously from the reaction, a mixture product containing about 55-70% CH_4 and 30-45% CO_2 with some other gaseous inerts and contaminants is formed which is commonly called biogas. It has between 55-70% the heating value of natural gas. It can be used as a medium value fuel gas, or be purified by a suitable separation method to become a natural gas substitute. Sweden is already using upgraded biogas for vehicle fuel and plans to permit purified biogas into their natural gas grid system (Jonsson 2000)

Electricity: The energy content of the biogas can be converted to electrical energy using one of several conversion technologies: gas engine generator, gas turbine or microturbine generator, and fuel cell. But practically, gas engine generator is a more feasible technology from reliability and economic points of consideration.

Heat: Heat can be generated from combustion of the biogas, or can be generated as by-product of the electricity generation. The engine block heat and the waste heat in the engine exhaust can both be recovered by a waste heat recovery system for desired application.

Nutrients

Nutrients in substrate: Livestock manure contains nutrients that are essential to plant and crop growth. Only the macro nutrients, nitrogen (N), phosphorus (P) and potassium (K) are considered here and the nutrient contents in the manure substrate and their values are based on documents from American Society of Agicultural Engineers, ASAE, and Ontario Ministry of Agriculture and Food, OMAF (ASAE 1998, OMAF 1999).

Nutrients in digestate: The process of anaerobic digestion only removes carbon for conversion to methane and carbon dioxide. Some nitrogen in the form of ammonia may be lost from the digestate during storage unless the storage facility is well covered. Other nonvolatile nutrients are maintained in the digestate.

Nutrients after solid/liquid separation: If the disgestate is separated into two component streams, solids and liquid, the nutrients will be distributed between these two phases. The liquid phase can be land applied as is on crop farms or be further processed. The nitrogen, phosphorus and potassium elements in the liquid stream can be processed by struvite crystallization to produce fertilizer solids. The much diluted liquid can be processed until it becomes reusable water (Li 2002).

Compost: The solid component after solid/liquid separation with the absorbed nutrients can be composted to provide soil amendment material for farmland conditioning or landscape use

Fertilizer crystal: The struvite granules produced by crystallization can be transported in concentrated form and marketed as a valuable fertilizer.

Gaseous Emissions:

Carbon dioxide: Carbon dioxide is a major component of the biogas, and can be a source of industrial gas if available in sufficiently large quantity. A proven application related to agriculture is for CO_2 enhancement in greenhouse operation. It is desirable to raise the CO_2 conecentration in greenhouse from about 300 ppm to about 800 ppm to enhance plant growth. The CO_2 gas from biogas and from combustion product are both passed through a selective catalytic reduction process to remove the NO_x and unburnt hydrocarbons that are harmful to greenhouse plants before they are used in the greenhouse. Rosa Flora Ltd. Of Ontario, Canada, has implemented successfully such a technology and found the application profitable (Bulk 2000).

Greenhouse gas emission reduction credits: Reductions of greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are awarded with credits, which can be traded for monetary values if the credits can be certified by the authorized certifying government agencies (e.g. the Clean Air Canada Inc.). The values are assigned on the basis of dollars per ton of CO_2 mitigated or off-set. For CH_4 the value is based on equivalent of tons of CO_2. Since the global warming potential of CH_4 is 21 times that of CO_2, the reduction of methane release could result in a significant value.

B. Intangible Benefits

In addition to the tangible benefits described above, the by-products also include several intangible benefits, which are listed here but will not be discussed in detail due to the limited scope of this paper. Quantification of such benefits such as pathogen destruction, odour reduction, ground and surface water protection, and rural hygiene improvement is being studied, and will be the subject of a separate paper in the future.

By-Product Values

The values of the various tangible by-products listed above will be assessed to provide data that can be used to conduct an overall evaluation of the integrated solution

The amount of biogas yield is based on 340 m^3 per ton of volatile solids for the quantity of hog manure produced in an average 2000-head hog farm. The hog manure production is estimated from ASAE Standards 1998 (ASAE 1998). Approximately 84 kg of manure and 39 kg urine are produced per 1000 kg of live weight of hog, based on an average 52 kg hog. Similar tables can be calculated for other types of livestock manure.

A. Values of the Tangible Benefits

Energy

The unit value of biogas is based on 65% methane content with a 20% discount in price for adulteration by CO2. Methane price is set at that of December, 2002 contract price of natural gas of $5 U.S. per MMBTU (exchange rate of $1.0 CDN at $0.64 U.S. per Revenue Canada 2002 average).

The price of electricity in Ontario, Canada is currently capped at 4.3¢/kWh which may be artificially low.

Heat value is based on production from natural gas with a boiler of about 80% efficiency.

	Unit Value	Availability (2000 Hog per Year)	Total Value (2000 Hog per Year)
Biogas	12 ¢ per m3	93,200 m3	$ 7,600
Purified biogas	22¢ per m3	60,600 m3	$14,700
Electricity	4.3 ¢ per kWh	275,200 kWh	$ 7,500
Heat	$8 per MMBTU	1,000 MMBTU	$ 8,200

Nutrients

Only the macro nutrients; nitrogen, phosphorus and potassium, are considered. The unit values assigned are the values suggested by OMAF (OMAF, 1999) to represent the purchase price of an equivalent amount of available nutrient as mineral fertilizer.

	Unit Value	Availability (2000 Hog per Year)	Total Value (2000 Hog per Year)
Nutrients (N, P2O5, K2O)			
Value in Manure*	$10.5/tonne	3,190 tonnes	$33,500*
Nutrients (N, P2O5, K2O)			
Value in Urine*	$17.2/ 1000 Imp. Gallon	329,000 Imp. Gallon	$5,660*
Nutrients (N, P2O5, K2O)			
Value in Digestate	Ave. $8.9/tonne	4,395 tonnes	$39,160
Nutrients after Solid/Liquid Separat.			
Value in Solids	Ave. $11.2/tonne	300 tonnes	$3,360
Value in Liquid	Ave. $8.7/tonne	4,095 tonnes	$35,800
Compost	$15/tonne	270 tonnes	$4,050
Fertilizer crystals	N/A	N/A	N/A

*Usually mixed, and thus values can be totaled.

The process of producing high value fertilizer by crystallization is being studied by Li et.al. (Li 2002), but the price information is not yet available.

Gaseous Emissions

The unit value of CO2 is the current market price provided by industrial gas supplier. An alternative method for providing CO2 to greenhouse is by natural gas burner. The cost of the alternative method has yet to be assessed. The value of emission reduction credit is based on $5 U.S. per tonne of CO2 (exchange rate based on $1 CDN = $0.64 U.S. per Revenue Canada 2002 average).

	Unit Value	Availability (2000 Hog per Year)	Total Value (2000 Hog per Year)
Carbon Dioxide for Greenhouse	$65 per Size 1-A Bottle of 27.22 kg	54,920 kg**	$131,150
GHG Emission Reduction Credit			
Electricity Off-Set	$7.8 /tonne CO2	175 tonnes	$1,370
Heat Off-Set	$7.8 /tonne CO2	580 tonnes	$4,520
Methane Mitigation	$7.8 /tonne CO2	1,330 tonnes	$10,400

** Sufficient for 20 acres of 20-ft high greenhouse with an air displacement of 0.3 per day.

<u>B. Values of Intangible Benefits</u>

As a by-product of applying the AD/Biogas Cogen technology, the pathogen count of the digestate can be significantly reduced. Thermophilic process with one hour pasteurization at elevated temperature of 70oC is claimed to achieve over 90% pathogen reduction.

The odour of the digestate is considerably less than that of the raw manure because the sulphurous compounds can be removed. The totally enclosed biodigester provides better protection against accidental spills and run-off, and offers better means to achieve water quality protection and rural hygiene. However, the quantification of these intangible benefits remains a challenge. Some evaluation methods are being developed by the author and will be the subject of a future paper.

CHATHAM-KENT, ONTARIO, CANADA EXAMPLE

The Economic Development Services of the Municipality of Chatham-Kent in Ontario, Canada has taken the initiative to seek a manure management practice for the local hog industry that will exceed the acceptable standard.

Chatham-Kent is a rural community of about 110,000 population with a hog industry consisting of about 190 producers. Small farms (i.e. < 500 hogs) accounted for 39%; medium sized operations (between 501 and 3000 hogs) accounted for 46%; and large farms (i.e. >3001) accounted for 15%.

A promising site and a 20 km radius was identified by the Council for consideration of an integrated processing facility. The total hog manure and septage, which has similar waste characteristics, within that area amounts to about 100,000 tonnes/year.

The following is a simplified assessment based on the concept described in this paper. A 500 kW cogeneration facility is sized for the volume of biogas potentially available; the preliminary assessment of the by-product values is summarized in Table 1. A feasibility study has been commissioned and the detailed results shall be available later in 2003 (Anderson 2003).

Table 1. By-product Potentials of a 100,000 tonnes/year hog manure Plant in Chatham-Kent

	Potential Quantity (Per Year)	Market Value (Per Year)	Intrinsic Value (Per Year)
Electricity	500 kW	$ 188,340	
Heat	22,470 MMBTU		$179,800
Compost	5,475 tonnes		$82,100
Liquid Fertilizer	90,520 tonnes		$787,500
Carbon Dioxide	611,910 m3		$2,870,200
Emission Reduction			
Electricity Off-set	3,830 tonnes CO2		$30,000
Heat Off-set	12,690 tonnes CO2		$99,000
Methane Mitigation	29,110 tonnes CO2		$227,600

It must be emphasized that these values only provide an understanding of the theoretical potential. In reality the operating costs, marketing costs and negotiated market values can be quite different. In Table 1, only electricity price is confirmed because currently the price is capped by the Ontario government at 4.3 cents per kWh. All other by-products that have not yet located a committed purchaser are indicated with an "Intrinsic Value" until purchasers can be located and negotiated market value and operating costs can be assigned.

CONCLUSIONS

Many by-products can be derived from an AD/Biogas Cogeneration process for manure management. It is seen that some by-products have very high intrinsic values. These provide opportunities to lower the cost of manure management, or even to generate profit. However, there will be operating costs and investments required for each revenue stream, an understanding of the potential of each by-product will assist the selection of an optimum combination of byproducts that will yield the best overall return.

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