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ABSTRACT

As available energy reserves decline, renewable sources must be utilized. Organic matter, grown agriculturally, represents a renewable energy source, which is readily available. This paper reviews the methods by which organic matter can be converted to energy sources by biochemical processes. The economics of conversion of agricultural crops and by-products to alcohols by fermentation and conversion of these agricultural materials to methane by anaerobic digestion are examined. Projections of the potential of this energy source are quite promising.

INTRODUCTION

During the past few years, we have seen demand for energy and petrochemicals grow at a pace so rapid that we now realize that reserves of fossil fuels, which were once considered inexhaustible, are being quickly depleted. The world's reserves of petroleum and other carbonaceous material was built up over a period of millions of years from the only source of carbon which is continuously available, CO_2 in the atmosphere. Plant life uses the carbon in CO_2 along with H_2 and O_2 from water to build cellulose, sugars and protein. Because we can no longer afford to wait for nature to convert plant life into coal, oil or gas, which are readily usable as energy and raw materials, more direct ways must be found to use this source of energy.

There are large quantities of agricultural by-products from food producing operations that today represent a waste disposal problem. In addition, unused cropland can be put into production. Both these sources represent a significant renewable source of organic matter available for conversion into energy.

Processes For Energy Conversion

A number of processes are available for converting agricultural products or by-products into energy forms and chemical feedstocks.

Plant material may be burned directly in a boiler to generate electricity. Drying would probably be required to reduce the moisture content so that efficient combustion temperatures could be achieved. Although the exhaust gases would be essentially sulfur free, there are many other disadvantages associated with direct combustion of plant material. These disadvantages include transportation and dry storage during the non-growing season and the possible redesign of boilers to accomodate low BTU content fuel.

Methods have been developed for converting organic material into other energy forms. These energy forms are more suited to transportation and storage and also offer the added potential of serving as petrochemical feedstocks.

Organic material may be converted to a low-sulfur fuel oil in a high temperature, high pressure liquifaction process developed by the Bureau of Mines. In this process, the organic material is treated with carbon monoxide at temperatures from 25-400°C and 2000-5000 psi pressure. One disadvantage of this process is the high temperature and pressure involved. Of the available energy from direct combustion of the organic matter, only 35 percent is available in the processed fuel oil[1].

A similar process for converting organic wastes to a usable form of energy involves gasification to methane. A temperature near 750°F and a pressure around 1000 psi are required[1,2]. About 1.7 scf of hydrogen are consumed per scf of methane produced. This process also suffers from a significant reduction in energy availability.

Biological processes can be used to convert wastes to methane, ethyl alcohol, acetic acid, furfural and a variety of other chemicals. Of these methods, fermentations of hydrolyzed cellulosic materials to alcohol, furfural and acetic acid, and anaerobic digestion of various substrates to methane have been demonstrated commercially. These processes result in recovery of 70-90 percent of the energy available in the raw material[3,4].

The purpose of this study is to demonstrate the potential of biological processes for the conversion of agricultural by-products to energy forms and chemical feedstocks. Economic analyses of the alcoholic fermentation and anaerobic digestion processes are presented. The basis of this study is published data available for these processes and data from the research laboratories in the Chemical Engineering Department at the University of Missouri-Rolla.

Alcohol Fermentation Process

The alcoholic fermentation process involves converting such carbohydrates as cellulose, starch, and sugar to alcohol. Materials such as wood, corncobs, oathulls, straw and other roughage contain primarily cellulose, hemicellulose and lignin. The hydrolysis of cellulose and hemicellulose is catalyzed by sulfuric acid which does not affect the lignin.

The description of a fermentation process using corncobs is presented in Figure 1[3]. In this process, the cobs are crushed and carried countercurrent to a solution of hot 5 percent sulfuric acid by a screw conveyor in the pentosan hydrolyzer. About 95 percent of the pentosans are converted to xylose in a 15 percent solution which may be further processed to furfural and acetic acid.

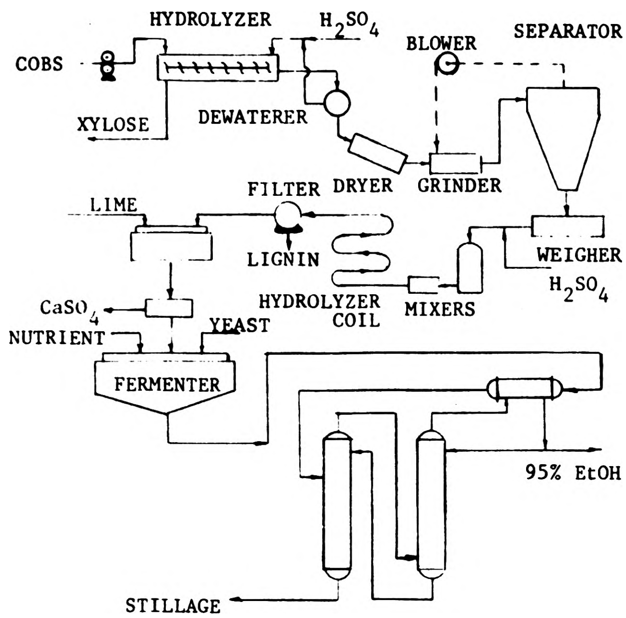

FIGURE 1. ALCOHOLIC FERMENTATION PROCESS

The remaining solids are dewatered, dried and ground. The fine powder is sprayed with about one-third its weight of 85 percent sulfuric acid in a water-cooled mixer. This mixture is then plasticized in a screw press impregnator, mixed with 10 parts cold water and pumped into steam heated coils where the hydrolysis of the cellulose is completed. The slurry is filtered to remove the lignin, neutralized and filtered to remove calcium sulfate before the clear glucose solution is fed to the fermenters. Yeast and nutrients are added to initiate alcoholic fermentation. The material from the fermenters is purified to 95 percent ethyl alcohol in a two-step distillation.

The xylose solution may then be converted to furfural and acetic acid in a process described in Figure 2[5]. The dilute feed solution of xylose and acetic acid is preheated and brought to reactor temperature by the injection of high pressure steam. Following

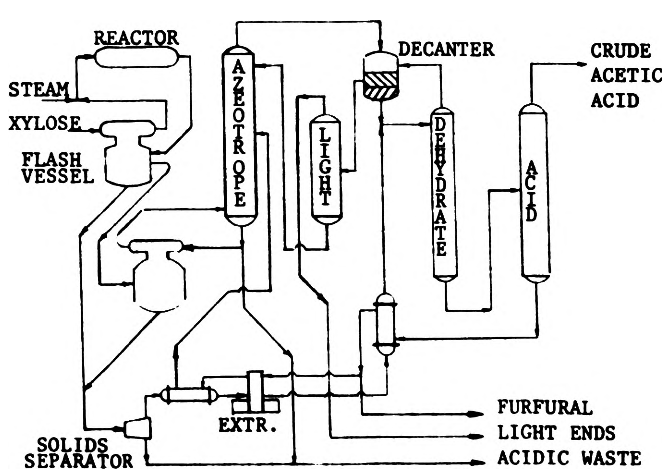

FIGURE 2. FURFURAL AND ACETIC ACID PROCESS

reaction, the solution is flashed to supply heat to the azeotrope column and incoming feed. The solids are removed and the solution is cooled before entering the extractor. In the extractor, the dilute solution of furfural and acetic acid is contacted with cooled anhydrous furfural.

A raffinate solution consisting of about 8 percent furfural and a small amount of acetic acid is charged to the azeotrope tower for recovery of furfural. The azeotrope from the column is broken by allowing the condensate to separate into two phases, 18 and 87 percent furfural. The dilute phase is returned to the azeotrope tower as reflux.

The extract, 87 percent furfural, is mixed with the rich phase from the azeotrope column and the water is removed in the dehydrating column. The acetic acid-furfural mixture from the dehydrating column is separated in the acid column. The furfural stream is split so that a portion leaves the system as product and the rest recycles as a solvent.

An economic evaluation of the manufacture of 3,500,000 gallons per year of ethyl alcohol, 21,700,000 pounds per year of furfural, and 9,770,000 pounds per year of acetic acid from corncobs is presented in Table 1. This evaluation is based on the data presented by Arnold[3] and Harris[5]. Adjustment has been made for increasing investment and operating costs to present day levels. Today's market value was used for raw materials and products. An investment of $6.50 million is required for this plant. Operating costs of $4.88 million are estimated including about $480,000 for 79,500 tons of corncobs. A surprising return on investment of 19.5 percent is estimated with a payout of about 5 years. It should be emphasized that this analysis is based upon present prices for products. Projected future increases in prices for energy and petrochemicals provide added economic incentive for producing energy by fermentation.

Table I. Economic Evaluation of Alcoholic Fermentation Process

PLANT INVESTMENT	$6,500,000
REVENUE	$6,502,000
Direct Costs	
1. Raw Material Cost	
Corncobs	477,000
Sulfuric Acid	156,000
2. Utilities	
Steam	956,000
Water	94,000
Electricity	106,000
3. Operating Labor	696,000
4. Supervision	209,000
5. Payroll Burden	272,000
6. Maintenance and Supplies	868,000
Fixed Costs	
1. Taxes and Insurance	145,000
2. Depreciation	592,000
TOTAL PRODUCTION COST	$4,601,000
Sales Expense	274,000
TOTAL OPERATING COST	$4,875,000
GROSS PROFIT	$1,627,000
NET PROFIT	$ 813,000
RETURN ON INVESTMENT (Percent)	19.5
PAYOUT (Years)	5.2

An estimated 640 million tons of agricultural organic wastes are available from processing crops in this country[6]. If 10 percent of this amount were readily available and could be used for alcohol fermentation, 1.5 million gallons of alcohol could be produced.

On a BTU basis, this is the equivalent of roughly 150 million barrels of crude oil, or about 5.4 percent of the petroleum consumed for transportation in this country in 1970. Alcohol may be added to gasoline in amounts up to 10 percent without greatly affecting engine efficiency while requiring only minor engine adjustments[7]. Ethanol, furfural and acetic acid also may be used as starting materials to synthesize a wide variety of chemicals such as synthetic rubber, plastics, solvents and drugs.

Methane Production By Anaerobic Digestion

The formation of methane in the decomposition of organic compounds is brought about by the action of methane producing bacteria. Investigations into the nature of the reactions has lead researchers to believe that anaerobic digestion of a complex substrate proceeds in three steps. First, enzymes convert the solid organic material to soluble organic compounds. These soluble carbohydrates, proteins, alcohols and fats are then fermented to organic acids which are further metabolized by methane bacteria to CO_2 and methane.

Most investigations of anaerobic digestion have been concerned with disposal of sewerage and feedlot wastes and considerable data is available on these substrates[4,8]. Data is somewhat more limited on the production of methane from other agricultural wastes, although it has been shown that anaerobic digestion of such materials as cannery wastes, molasses[8] and algae[9] is feasible.

A recent study at the University of Missouri-Rolla has demonstrated quantitatively the feasibility of producing methane from hay. These investigations, covering a period of about 6 months, started by digesting manure and gradually replacing the manure fed to the reactors with hay, until the reactors were operating on 100 percent hay. About 30 days operation on pure hay were attained. A similar reactor was operated simultaneously on pure manure. Both reactors were maintained at 95°F and were operated with a 10 day retention time. The results of this study are presented in Table II. It is significant to note that 12.5 scf of gas (or about 8 scf of methane) is obtained per pound of volatile solids destroyed.

Table II. Results of Anaerobic Digestion of Hay

	Reactor 2 Hay	Reactor 3 Manure
Reactor Volume, liter	6	6
Reactor Temperature, °F	95	95
Feed Rate, ml/day	600	600
gm VS*/day	25	25
Feed Composition, mg VS /liter	83,267	83,267
mg/liter BOD_5	7,087	7,087
Effluent Rate, ml/day	600	600
gm VS /day	13.4	13.98
Effluent Composition, mg VS /liter	22,333	23,300
mg/liter BOD_5	1,171	1,351
Total Gas Production**scf/day	0.320	0.250
Gas Production, scf/lb VS destroyed	12.5	10.3

*VS - Volitile Solids
**65% CH_4, 35% CO_2

A process to produce 8 million scf/day of methane anaerobically from hay is shown in Figure 3. This

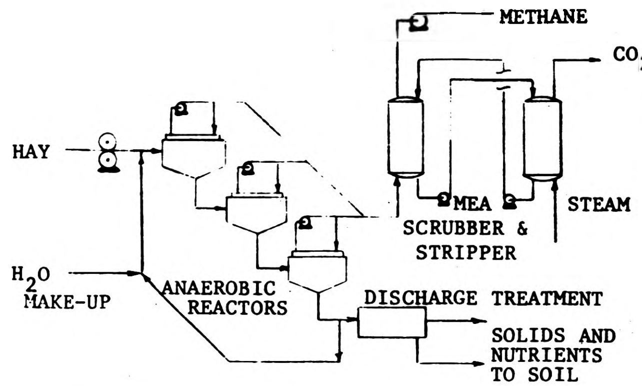

FIGURE 3. ANAEROBIC METHANE PROCESS

process includes a grinder or shredder to prepare the waste material, reactors or holding tanks where the conversion to methane takes place, a monethanolamine scrubber system to remove the CO_2 from the gas produced and compressors to bring the methane to pipeline pressure. Provision must be made to treat the reactor effluent to meet water quality standards for disposal or to dewater the solids, recycle the liquid and return the solids to the soil as fertilizer. An activated sludge process is included for this purpose.

Table III presents an economic analysis of the process shown in Figure 3. An investment of about $2 million is estimated to be required to produce about 3 billion scf/year of CH_4 from 4,250 tons of hay. This plant was designed using the data from Table II. Reactors were designed using kinetic data for digestion of manure[4] since more data were available for this substrate and the digestion characteristics are noted to be quite similar.

Table III. Economic Analysis of Methane Production from Hay

PLANT INVESTMENT	$1,940,000
REVENUE	$3,650,000
Operating Costs	
Raw Material	2,130,000
Anaerobic Digestion	154,000
Waste Treatment	30,000
Compressors	995,000
MEA Scrubber and Stripper	85,000
Maintenance, Supplies, Taxes and Insurance	272,000
Depreciation	159,000
TOTAL PRODUCTION COSTS	$3,205,000
GROSS PROFIT	$ 445,000
NET PROFIT	$ 223,000
RETURN ON INVESTMENT (Percent)	19.7
PAYOUT (Years)	5.1

Operating costs for this process are estimated to be $3.2 million including $2.13 million for hay. About 20,000 bales of hay or straw are consumed per day in producing 8 million scf of CH_4 from this process. A cost of hay of $.25/bale is based upon use of wheat straw available in large quantities in the Midwest. This cost is also not unreasonable for mass production of hay from idle grasslands. The cost of cutting, storage and transportation are included.

Revenue from the process is based upon a methane price of $1.25/million BTU, which is being used as a future price of energy from LNG[10,11]. Based upon these estimates, a return on investment of about 20 percent is available.

It should be pointed out that anaerobic digestion has not been studied from the standpoint of production of methane, rather this process has been studied primarily as a waste treatment method. Therefore, considerable improvement in gas yields and reaction rates might be expected. These are matters under study in our laboratories.

The economics of methane produced by anaerobic digestion are highly dependent upon the price of raw materials. Studies are planned to determine the best type of agricultural raw material to be used in this process. Of course, by-products, such as those proposed for alcohol fermentation, can be utilized with a significant improvement in the economics.

In this nation, the natural gas deficit is forecast to be about 5 trillion scf/year by 1977, or about one third of our consumption[12]. If use could be made of all available crop waste (640 million tons per year), we could produce more than enough CH_4 to make up the deficit. In addition there are vast quantities of materials such as wheat straw or corn stalks that can be utilized as sources of methane. There is also the potential of placing new land into cultivation of agricultural products for conversion to methane.

SUMMARY AND CONCLUSIONS

The economic potential of biological production of energy from agricultural products or by-products is seen to be surprisingly good. Improvement in anaerobic processes is expected to provide added economic incentive for this process. As naturally occurring fuels and petrochemical feedstocks are depleted, use can be made of agricultural raw materials which can be converted into a variety of energy forms.

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