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ENERGY FROM AGRICULTURE

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During the past few years, the demand for energy and petrochemicals has grown at a pace so rapid that our reserves of fossil fuels, once considered inexhaustible, are now being quickly depleted. To help lessen this impending problem, alternative sources of energy must be rapidly developed.

Of the many new sources of energy being studied, solar energy, undisputedly, is the most inexhaustible. Energy from the sun, incident upon the earth's surface, exceeds by nearly three orders of magnitude the total energy consumption today. Furthermore, it is not subject to nationalistic boundaries and its use would be compatible with our environmental goals.

Several methods of using solar energy are under investigation. Photovoltaic and photo-thermal methods both require large land areas and large capital investments. In addition, energy storage must be provided to assure an uninterrupted supply. Significant progress is being made in resolving these problems, but it appears that it will be a number of years before these methods are economically attractive enough to receive widespread use.

A third means of collecting the sun's energy is by photosynthesis. Most of the fossil fuels we now burn originated from plants produced by photosynthesis. Plant matter can, of course, be used as a source of energy today. This means of capturing the sun's energy has several advantages:

1) energy storage in the plant, available for use upon harvest
2) readily developed with existing technology and manpower
3) ecologically inoffensive
4) economically beneficial to put idle land into productivity

The efficiency of converting sunlight into fuel by photosynthesis is rather poor Table 1 shows that conversion efficiencies for common crops range from about .2 percent for a pine forest to 1 percent for a corn or sugar cane field. However, if cropping systems were developed specifically for the production of fuel, much higher efficiencies would result. Based upon a collection efficiency of .8 percent and a heating value of 6500 BTU per pound, a land area of about 100 sq. mi. would be required to supply the fuel for a 250 mw generating station, operating with a 55 percent load factor.

Food represents only a small part of the energy available from much of our agricultural crops. Large quantities of corn stalks, wheat straw, soybean foliage etc.

represent an unused source of energy. Estimates of available crop wastes vary, but are around 400 million tons annually. If half of this could be collected, it would represent 2.6 x 10^{15} BTU annually, or about 3 percent of our total energy requirement.

Clearly, crop wastes are an important source of energy, but will not be adequate to make us energy sufficient. Fortunately, there are vast acreages of marginal or unused land that could be placed into production of uncultivated energy crops.

Crop matter is an inconvenient form of energy. It can be burned directly, but the high moisture content produces inefficient combustion. Also, storage and transportation of crop matter is inconvenient and expensive. These difficulties can be overcome by converting crop matter to gas. Pyrolysis and hydrogasification are two methods for making gas from organic matter. These processes operate at elevated temperatures and pressures, and, although not fully perfected, suffer from low conversion efficiencies.

1. BIOCONVERSION OF PLANT MATTER

Plant matter can be converted to methane by anaerobic digestion. This process is carried out at ordinary temperature and pressure with a conversion efficiency of 94 percent. Conversion of organic matter to methane by anaerobic digestion is a biological or bioconversion process. Micro-organisms convert solid organics first to soluble carbohydrates, fats and proteins; then to organic acids, aldehydes and alcohols; and, finally, methane and carbon dioxide are produced by metabolism of anaerobic bacteria.

Most investigations of anaerobic digestion have been concerned with disposal of sewage and feedlot waste and considerable data is available on these substrates. Data are somewhat more limited on the production of methane from agricultural products; although it has been shown that anaerobic digestion of such material as cannery wastes, molasses, algae and municiple refuse is feasible.

Recent studies at the University of Missouri-Rolla have demonstrated quantitatively the feasibility of producing methane from hay, oak leaves and comfrey. These investigations, covering a period of about two years, indicate that 19.5 cubic feet of methane can be obtained per pound of carbon digested. The carbon content of most plants is 35-40 percent. Carbon destructions of 80 percent are achieved, so that 5-6 cubic feet of methane would be available from each pound of dry crop matter.

2. ECONOMIC POTENTIAL OF BIOCONVERSION

Bioconversion could be applied on a small scale to the production of energy for a single farm. The method could also be used to produce large quantities of methane for distribution in existing natural gas pipelines. The equipment for a large process is shown in Figure 1. The crop matter is put through a shredder to reduce the size, then mixed with water and fed to reactors, where a culture of bacteria is maintained to produce methane. Carbon dioxide and hydrogen sulfide are removed by scrubbing with monoethanol amine and the remaining methane is compressed to the desired pressure. Effluent from the reactors is expected to be a good fertilizer, since it would contain all the minerals and nitrogen from the plant.

Table 2 presents the availability of crop wastes in Missouri. There are ten million tons of residue available from the production of corn, soybeans and small grains. Over half of this tonnage is available in NW Missouri, around Chillicothe. A bioconversion plant, as shown in Figure 1, could be built in Chillicothe to use waste in that area. A plant to produce 50 million cubic feet per day would require 1.5 million tons of crop residue annually, or about 30 percent of the available quantity. This amount of gas would generate 250 mw of electricity continuously, or the residential requirement of the city of Kansas City.

The economics of this plant are presented in Table 3. An investment of $35 million is required for the reactors, compressors, scrubbers, grinders and miscellaneous equipment. Reactors are based on series operation and a first order kinetic rate coefficient of .2 hr^{-1}, as measured in the UMR laboratories. Reactors are 5 million gallon floating head steel insulated tanks. Heating and agitation are by gas recirculation. As noted, a contingency of 30 percent has been included in the estimate.

The energy balance on the process shows that 10 percent of the methane is consumed for power, compression and steam. Revenue from the sale of gas at $2 per mscf is $33.5 million annually. Operating costs are $12.5 million, including collection of the crop residue, utilities, maintenance, labor and depreciation. Collection and transport of the crop waste were estimated at $5 per ton.

A respectable 35 percent return on investment is available from this project. If the gas price was $1.50 per mscf, the return would reduce to only 23 percent. With a raw material cost of $10 per ton the return is 25 percent. Clearly, the production of methane from crop wastes is an economically attractive energy alternative.

Table 4 presents the economics for the same size plant using hay as a feedstock. A value of hay of $15 per ton is used. This is based upon a collection cost of $5 per ton in large one ton bales. Wheat straw or hay from idle grasslands would be used. A return of 14 percent is available from this operation.

It should be pointed out that anaerobic digestion has not been studied extensively 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 are expected. These matters are 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 most efficient photosynthetic collectors and the digestion characteristics of various materials. Also, the economics may be further improved if the reactor effluent can be used as fertilizer and investigations of the fertilizer value are planned.

3. SUMMARY

Bioconversion of crops or crop residues to methane can provide the energy source to fill the gap. Technology is available, and being rapidly advanced, to make use of this energy source now. The process is economically attractive at todays fossil fuel energy prices, a potential that few other alternative energy schemes can match.

TABLE 1. Solar Efficiencies of Various Crops

Plant Type	Location	Fuel Value BTU/lb	Dry Yield Tons/Acre·Year	Total Radiation Falling Upon Location[A] BTU/ft^2	Estimated Solar Energy Conversion Percent
Oak - Pine Forest	New York	7000[C]	5.4[E]	4.24×10^5	0.41
Southern Pine	South U.S.	7000[C]	2 - 5[B]	5.34×10^5	0.13 - 0.33
Hybrid Poplar	Pennsylvania	5625[B]	4 - 8[B]	4.35×10^5	0.24 - 0.47
Sycamore	Georgia	5800[C]	1.6 - 11.2[C]	5.34×10^5	0.09 - 0.61
Reed Canary Grass	U.S. Midwest	6500[C]	6.32[C]	4.65×10^5	0.29
Bermuda Grass	Alabama	5625[B]	8 - 11[B]	5.34×10^5	0.42 - 0.58
Alfalfa	U.S. Average	6500[C]	2.85[C]	4.65×10^5	0.18
Corn	U.S. Average	6500[C]	11.2 - 17.9[E]	4.65×10^5	0.72 - 1.15
Sugar Cane	La. & Fla.	6500[C]	20[C]	5.34×10^5	1.11
Cattail Swamp	Minnesota	6500[D]	11.2[E]	3.76×10^5	0.88
Marine Algae	Nova Scotia	6500[D]	9.0 - 11.7[E]	4.24×10^5	0.63 - 0.74
Sewage Pond	California	6500[D]	25.1[E]	5.56×10^5	1.34

[A] Estimated from W. Gorczynski, Comparison of Climate of the U.S. and Europe, 1945, New York.

[B] Clinton C. Kemp and George C. Szego, The Energy Plantation, A.I.Ch.E. Symposium on Solar Energy Utilization, March 20, 1975.

[C] George C. Szego and Clinton C. Kemp, Energy Forests and Fuel Plantations, Chem. Tech., May, 1973.

[D] Estimated

[E] A New Look at Energy Sources, ASA Special Publication No. 22.

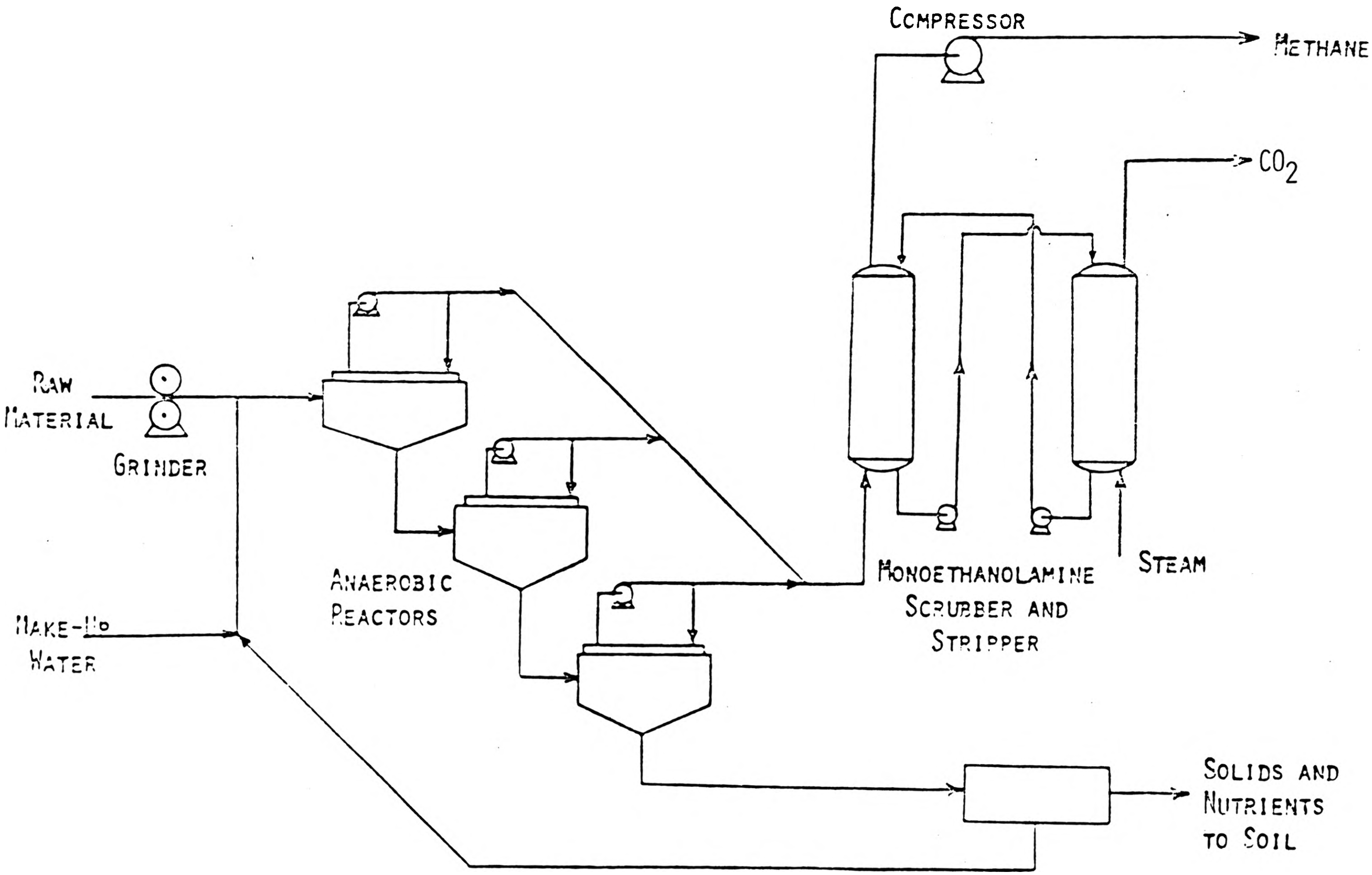

FIGURE 1. Process for Producing Methane by Anaerobic Digestion

TABLE 2.

AVAILABLE WASTE MATERIAL IN MISSOURI AND THE CHILLICOTHE AREA*

	10^6 TONS/YEAR	
	MISSOURI	CHILLICOTHE AREA
SOYBEANS	2.4	1.2
CORN	5.4	3.0
SMALL GRAINS	1.4	0.9
SORGHUM	0.6	0.3
COTTON	0.2	---
TOTAL	10.0	5.4

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* DR. J. W. NELSON, AGRONOMIST, UNIVERSITY OF MISSOURI-COLUMBIA.

TABLE 3.

ECONOMIC ANALYSIS OF METHANE PRODUCTION FROM CROP WASTE IN NORTHWEST MISSOURI

		M̄$
CAPITAL INVESTMENT		
DIGESTORS		22.0
COMPRESSORS		1.3
MEA SCRUBBERS AND STRIPPERS		0.3
GRINDING AND STORAGE		1.8
PUMPING AND PIPING		2.0
CONTINGENCY (30%)		7.6
	TOTAL	35.0
		M̄ $/ YR
REVENUE ($2/MSCF)		33.5
OPERATING COSTS		
RAW MATERIAL		7.3
POWER		0.6
LABOR		0.3
MAINTENANCE		1.8
TAXES AND INSURANCE		0.7
DEPRECIATION		1.8
	TOTAL	12.5
GROSS PROFIT		21.0
NET PROFIT		10.5
RETURN ON INVESTMENT		35.1%

TABLE 4.

ECONOMIC ANALYSIS OF METHANE PRODUCTION FROM HAY

CAPITAL INVESTMENT		M̄$
DIGESTORS		22.0
COMPRESSORS		1.3
MEA SCRUBBERS AND STRIPPERS		0.3
GRINDING AND STORAGE		1.8
PUMPING AND PIPING		2.0
CONTINGENCY (30%)		7.6
	TOTAL	35.0
		M̄$/YR.
REVENUE ($2/MSCF)		33.5
OPERATING COSTS		
RAW MATERIAL		21.9
POWER		0.6
LABOR		0.3
MAINTENANCE		1.8
TAXES AND INSURANCE		0.7
DEPRECIATION		1.8
	TOTAL	27.1
GROSS PROFIT		6.4
NET PROFIT		3.2
RETURN ON INVESTMENT		14.3%