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BIOTECHNOLOGY - An Old Solution To New Problems

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INTRODUCTION

MAN'S ESSENTIAL MATERIAL needs are commonly said to be "food, clothing, and shelter." In the parlance of an industrial civilization a better statement might be (1) food, (2) energy resources, and (3) material resources. Food and energy resources can be considered to be consumed immediately if we ignore processing, transportation, and storage lags; material resources, are those which are converted into durable or semidurable goods.

The needs of pre-industrial man were satisfied in large measure by renewable resources. Food supplies were completely renewable, although somewhat uncertain. Although coal was known to the Romans, its use was limited before the 18th century; useful energy was obtained mainly from water, wind, and wood. Non-renewable resources were exploited substantially only in the fabrication of utensils, weapons, and structures, and even here recycling was significant. Many a European farm house and villa incorporates carefully chiseled stones from Roman walls and roads.

One consequence of the industrial revolution was a rapid increase in dependence on non-renewable resources. Iron, and then steel, replaced wood in structures, machinery, vehicles, and ships; fossil fuels, coal, then oil and gas, became the primary sources of energy. The rapidity of this change is evident from the familiar data of Figure 1 (1), indicating the energy sources employed in the United States since 1800.

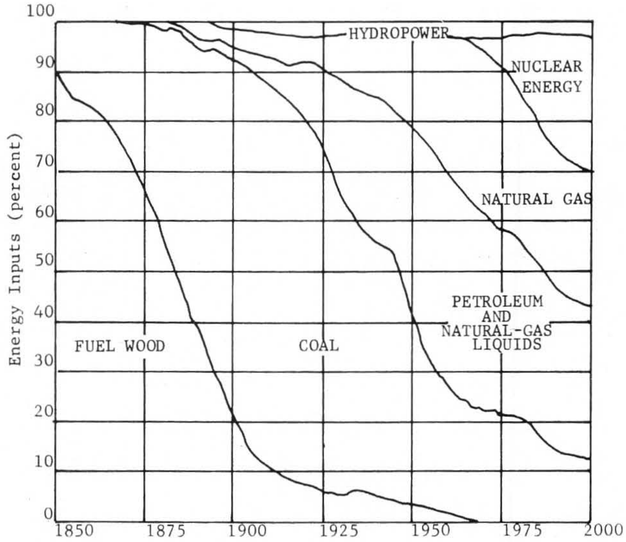

FIGURE 1

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Technological man has dramatically increased this dependence on non-renewable resources. Over the last thirty years the seeming abundance of low-cost petroleum and natural gas give birth to and sustained a burgeoning petrochemical industry. Through it a significant component of our material as well as energy needs became dependent on hydrocarbons. Synthetic polymers have replaced cellulosic substances, wood, paper, and cotton, in a host of applications while many industrial chemicals, once prepared from renewable raw materials, are now synthesized from petrochemical intermediates. Ethanol is the classic example. In 1939 about 85% of the industrial (non-beverage) alcohol produced in this country was manufactured by the fermentation, most of it from molasses and cereal grains. By 1960 ethylene had replaced these raw materials almost completely.

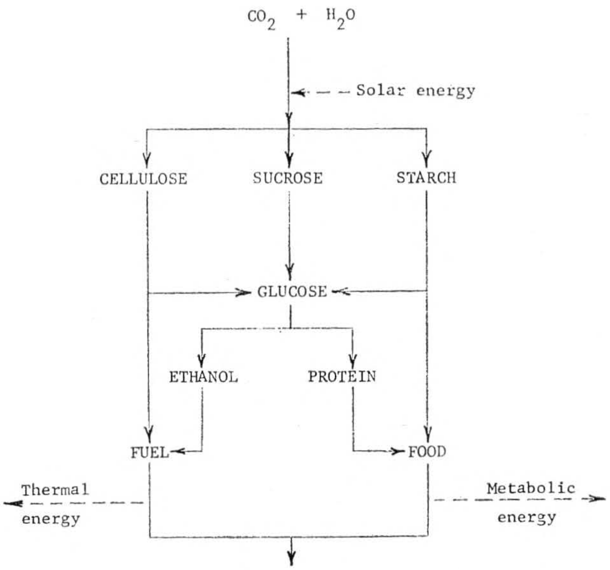
Parallel with, and in part related to this shift

At a point like this, one expects a clarion call for the development of new technology but I believe that much can be accomplished with technology already at hand . . . also that biotechnology—deliberate exploitation of the potential for chemical change inherent in living cells—can contribute signficantly to this effort.

in our resource base we have witnessed a significant and accelerating deterioration of the physical environment. The factors contributing to this decay have been discussed many times but one is directly related to the shift from wood to fossil fuels. This is a massive, environmental carbon imbalance. Carbon, fixed by photosynthesis and subsequently converted to coal, oil, and gas over millions of years, is being rapidly returned to the atmosphere through the combustion of fossil fuels. We do not know whether the consequences of this imbalance will be as serious—even dangerous— as some suggest but I would certainly rest easier if carbon dioxide production were better balanced by current photosynthetic activity (Figure 2).

We are now confronted with several vital and interconnected problems arising from our great dependence on non-renewable resources:

- **Petroleum and natural gas are in short supply and expensive. Availability may be increased for a time but the real cost will not decline. Furthermore, the environmental cost of substantially increased supplies may be catastrophic, e.g. shale oil.**
- **Our agriculture has become intensive and productive but at great cost, especially in terms of energy from fossil fuels.**
- **The accumulation of wastes from this technological structure has reached staggering proportions, especially in and around urban centers. Traditional methods of disposal either consume large amounts of energy or are environmentally unacceptable.**



THE ECOLOGICAL CARBON BALANCE

FIGURE 2

Most important, we now recognize that technological man has reached the point where his needs for food, energy, and durable goods are complex and interactive. The choices which can be made in satisfying them are highly constrained and often competitive. This is illustrated, albeit in grossly simplified terms, by the schemes presented in Figures 3 and 4. They summarize the various relationships, existant or potential, between the production of food proteins, energy for transportation and power generation, and petrochemicals. In fact Figures 2 and 3 should be one but such a presentation, even in the simple terms employed here, would be excessively complicated. I have therefore divided the total problem into those elements which are pertinent to food protein production (Figure 3) and those which provide energy for power and transportation and feedstocks for petrochemical manufacture (Figure 4).

The significant points to be noted with respect to Figure 3 are:

- **Cereal grains comprise the primary protein source for most of the world's population. Increased productivity can be achieved but only at the cost of relatively greater expenditures of fossil fuels, Heichel [2] has pointed out that modern agriculture derives practically all of its "cultural" (other than solar) energy from fossil fuels or other sources which replace labor. Increases of 10- to 50-fold in the cultural energy employed have only doubled or tripled the yield of digestible food energy.**
- **Major sources of protein for animal feeding are cereal grains, soy bean and fish meal. In addition, molasses, supplemented with nitrogen and phosphorus, has become a popular component of livestock feeds during the**

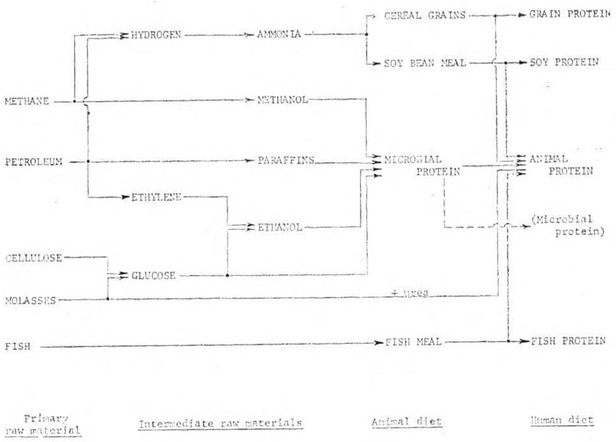


FIGURE 3. Food Relationships

past two decades. In 1946 less than one-third of the molasses consumed in the United States was used for livestock feeding. U. S. molasses consumption today is more than double that in 1946 and over 80% of it is used for liquid animal feeds. This escalation in demand, coupled with shortages of soybean and fish meal, has resulted in a three-fold increase in molasses prices over the last two years.

- **Microbial protein is another potential contributor to both animal and human diets. Virtually all of the microbial protein produced so far has been derived from molasses, primarily cane and beet. It is also technically possible to produce microbial protein from methane (very low yields) or methanol, from paraffins, and from ethanol. Commercial production from both alcohols has in fact, been announced [3, 4].**
- **Molasses was the dominant raw material for ethanol production prior to 1940. As we have seen, fermentation alcohol has subsequently been replaced almost completely by the ethylene-based product.**
- **Waste or virgin cellulose offers another potential raw material for the production of either microbial protein or ethanol.**

With respect to Figure 4 it should be noted that:

- **Electric power generation in the United States is currently dependent upon coal, natural gas, petroleum, and hydropower almost exclusively. Methanol is a potential fuel, either directly or following reconversion to methane.**
- **Methane may also be produced by the anaerobic digestion of cellulose and other solid wastes. Prolysis of such materials can also give oil and gas fractions said to be suitable as burner fuels.**
- **Transportation is almost totally dependent upon petroleum. Here we face a growing conflict between petrochemical needs and increased demands for aromatic components in gasoline to compensate for the reduction in performance occasioned by the elimination of lead.**
- **Ethanol is another potential fuel for internal combustion engines. As we have seen, it can be produced from a wide variety of saccharides including the glucose generated by cellulose hydrolysis,**

No matter what time scale one accepts for the continued availability of our fossil fuel resources, it is apparent that we must redress the imbalance of recent decades and move toward a greater dependence on renewable resources. This must be done in a manner which maximizes benefits by coupling material and energy generated in one sector as closely and efficiently as possible with material and energy needs elsewhere. Szego and Kemp [5] and Klass [6] have recently presented provacative analyses of the technical and economic aspects of renewable fuel resources. These proposals are based on direct combustion of wood (Szego and Kemp) and anaerobic digestion to methane (Klass).

There is no question that such a trend will have immense social impact. It will therefore be necessary to achieve a finer degree of integrated technical, economic, and social projection and planning than we have ever achieved before.

At a point like this one expects a clarion call for the development of new technology but I believe that much can be accomplished with technology already at hand. I also believe that biotechnology—deliberate exploitation of the potential for chemical change inherent in living cells—can contribute significantly to this effort. I propose to support these contentions by examining a specific proposal—the production of ethanol for use as an internal combustion engine fuel. I am not going to argue for this proposal—although it would be false for me not to confess an attraction for the prospect. Rather I want to use it to illustrate the opportunities which have been created by the sudden and, I believe permanent, rise in the real, relative cost of petroleum.

Before we look at this specific case, however,

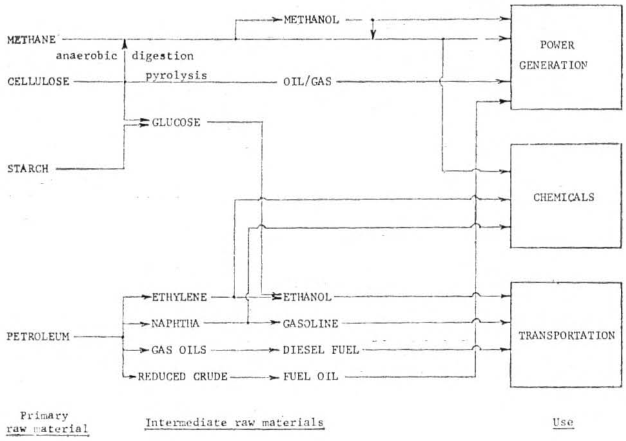


FIGURE 4. Energy Relationships

a few points about biotechnology and its potential role in the utilization of renewable resources are in order.

BIOTECHNOLOGY

I HAVE ALREADY ALLUDED to the special rôle which I expect biotechnology to play in increasing our dependence on renewable resources. Now I want to briefly outline the basis for that belief. Biotechnology can best be defined as the exploitation, under reasonably controlled conditions, of the potential for chemical change inherent in biological systems. Important applications include (1) isolation, purification, and modification of biologically active materials, (2) the use of individual enzymes and complete enzyme systems to effect chemical transformations, and (3) the use of populations of whole cells for the same purpose (fermentation, biological waste treatment, etc.).

As tools for generating chemical change, biological systems are powerful but often circumscribed [7]. They can catalyze a wide variety of chemical reactions, organic and inorganic, including oxidation, reduction, hydrolysis, substitutions, group transfers, etc. [8]. Products can be obtained through both endergonic ($\triangle G = +$) and exergonic ($\triangle G = -$) reactions, thanks to the unique energy transfer and coupling mechanisms found in living cells.

A considerable spectrum of raw materials is available for biological processes. In the realm of organic reactions these are referred to as "carbon sources." The traditional—and still the most widely used—carbon sources in biotechnology are the carbohydrates, especially starch and sugars. Reactions involving the exergonic degradation of sugars to products, alcohol production from glucose for example, are common. In other cases the energy obtained from sugar oxidation is coupled to energy-demanding processes (endergonic) to permit biosynthesis of complex structures, cell protein for example.

Recently hydrocarbons have become the focus of considerable interest as potential carbon sources for biotechnology. They supply much more energy per unit mass and yields of cell protein are correspondingly higher. On the other hand they introduce many problems for which satisfactory solutions are available, but expensive. In addition, recent rises in the costs of hydrocarbon raw materials have cast a pall over this whole matter.

Cellulose is another carbon source of potential value. Biological degradation of cellulose is an obvious and dominant feature of the natural world. But it is also a painfully slow process in nature. Generations of biologists have sought organisms and conditions which will achieve more rapid degradation of cellulose but success has not come easily. The great advantage of the carbohydrates—starch, cellulose, and the lower saccharides derived from them—is, of course, their potential renewability. Cultivation of carbohydrate producing plants represents the conversion—admittedly at low efficiency—of solar energy to available chemical energy.

. . . biotechnology . . . is relatively simple. Inherent in the use of biological systems is the employment of only moderate temperatures and pressures. Equipment is therefore relatively inexpensive and process plants are not so capital–intensive.

Another aspect of biotechnology which has been overlooked is that it is relatively simple. Inherent in the use of biological systems is the employment of only moderate temperatures and pressures. Equipment is therefore relatively inexpensive and process plants are not so capital-intensive as are those employed in the petrochemical area. Another point which follows from these observations is that plants employing biological processes are less sensitive to scale-factors. It is therefore possible to build several smaller units at a cost not much greater than one large unit.

CHEMURGY AND BIOTECHNOLOGY

THE CONTINUED AGRICULTURAL surpluses of the 1920's and 30's led to the development of the "chemurgic" movement [9]. Chemurgy included a number of specific proposals whose general objectives were to channel farm surpluses into the chemical industry for conversion to non-food products. Specific aims of the movement were:

- **to discover new uses for established farm crops**
- **to develop new crops for acreage producing surpluses of established crops**
- **to make use of agricultural residues and wastes from industries consuming agricultural materials**

Biotechnology was a key element in the overall chemurgic concept because biological processes offered some of the most promising avenues for utilizing agricultural materials. One of these was the proposal to hydrolyze starch from cereal grains to glucose and then ferment the glucose to ethanol for use as a motor fuel. We will look at this more closely in the next section.

The great hopes of the chemurgic movement came to naught because:

- **increased needs for food crops during and after World War II largely eliminated low-cost surpluses and led to a steady rise in the prices of commodity grains.**
- **rapid development of the petrochemical industry, based on low-cost hydrocarbon feedstocks, offered direct competition in many of the areas which seemed most attractive for chemurgic development. The example of ethyl alcohol, cited earlier, is typical.**

Recently the chemurgic concept has been trotted out, dusted off, and presented anew [10]. Its pitch has been changed, however. The raw materials of interests are no longer the cereal grains but rather the wastes and by-products generated by an industrialized agriculture and the society which it feeds.

FUELS FROM CELLULOSE

CELLULOSE, AS WOOD, is man's oldest fuel. It was not replaced by coal until the 19th century (Figure 1) and it is still the primary fuel for large segments of the world's population. The various natural woods exhibit somewhat higher heats of combustion that pure cellulose because of the oils and other materials which they contain but the differences are not significant. Wood is, of course, unsatisfactory for metallurgical operations because combustion temperatures are too low. It was therefore necessary, before coal became available, to convert wood to charcoal.

The great advantage offered by cellulose as a fuel is its renewability. This is the key to the proposal by Szego and Kemp [5] for "energy plantations." Substantial use of cellulose as a fuel would permit a more favorable environmental carbon balance, as we have seen (Figure 2). Carbon dioxide returned to the atmosphere would be equivalent to that removed. On the other hand cellulose cannot be used as a fuel for one of technological man's most prized possessions, the internal combustion engine. If renewable fuel resources are to be seriously considered, effective means must be found to convert them to useful liquid or gaseous forms.

The various proposals which have been made for the employment of cellulose as a fuel fall into four main categories (Table 1). These are:

- **direct combustion**
- **pyrolysis to combustible oil and gas fractions**

TABLE 1

Comparison Of Cellulose-Based Fuels

	Heat of combustion	Energy efficiency (a)	Limitations	Pollution (b)
Direct combustion of cellulose	3.5 kcal/gm	100%	External combustion only: conventional burners.	Particulate
Pyrolysis to oil and gas fractions		35% (11)	External combustion only: conventional burners.	?
Anerobic digestion to methane	12.4 kcal/gm	65% (11)	External combustion—conventional/Internal combustion—high-pressure storage.	None
Conversion to ethanol	7.1 kcal/gm	50%	Internal combustion: conventional design.	None
(Gasoline)	11.2 - 11.3 kcal/gm			Hydrocarbons, SO_x

Notes

(a) Energy efficiency refers to the fraction of the energy available in the original cellulose which is available in the final fuel.

(b) Other than CO and CO_2

> I am convinced that most current assessments of the future potential for various fuels is unrealistic because they are based upon established ratios between energy and other costs . . . Ethanol is the only reasonable candidate fuel for internal combustion engines which can be derived from renewable resources.

- anaerobic digestion to methane
- conversion to ethanol

Direct combustion of cellulose, usually in mixtures with other wastes, is already widespread. The use of wood wastes and shredded garbage in steam generating units are the most common examples. Pyrolysis schemes are still largely in the development stage but methane from the digestion of sludge and similar organic wastes has long been used as a fuel in waste treatment plants and sometimes in the surrounding community.

The fourth possibility, hydrolysis of cellulose to ethanol, is the only one which offers a liquid compatible with contemporary internal combustion engines. Alcohols, methanol and ethanol almost exclusively, enjoy a long history of use as internal combustion engine fuels. They were used experimentally in the early development of these engines when petroleum-based fuels were less readily available and have been widely employed when petroleum was in critical supply (Germany during the first World War; Eastern Europe after it).

ETHANOL AS A MOTOR FUEL

THERE IS ABUNDANT experience with ethanol as a motor fuel. It offers several advantages over, and suffers from some disadvantages in comparison with, gasoline. The most obvious disadvantage is its lower energy content (heating value) per unit weight (Table 1). This means that a larger volume and weight of fuel must be carried for the same vehicle range. Fuel lines, pump, etc., will also have to be larger to deliver the same fuel energy to the engine. Ethanol also exhibits a higher heat of vaporization which means that more heat must be supplied to the intake manifold of a carburetted engine. This is usually waste heat from the engine, however, and therefore represents no thermal penalty to the engine.

On the other hand, ethanol has a high octane rating (RON = 106). It should therefore be possible to design an Otto cycle engine for alcohol with a higher compression ratio, and hence higher thermal efficiency, than can be realized with gasoline. With the removal of lead, it has already become necessary to increase the aromatic content of gasoline in order to maintain current octane ratings. This has placed an additional demand on already precarious supplies of petrochemical feedstocks. Indeed, the question is widely asked whether we can afford to burn such precious commodities. Alcohol also offers substantial advantages over gasoline with respect to air pollution control. It contains no sulfur, leads to no unburned hydrocarbon, and the lower engine temperatures involved reduce NO_x formation.

So far, alcohol has been used almost exclusively in engines which were designed for gasoline. The development of smaller, higher compression engines for light-duty personal vehicles, commuter buses, smaller carriers, etc., is an especially attractive concept. Such an engine could exploit the unique advantages of ethanol as a fuel and could find immediate application in captive market services—urban transit, delivery fleets, etc.

POWER ALCOHOL

"POWER ALCOHOL" HAS had a checkered record in ordinary times [12, 13]. During the 20's and 30's many European countries either made the supplementation of gasoline with alcohol (10-15% was typical) mandatory or provided tax incentives to encourage it. These programs reflected both the general agricultural depression affecting much of the world during this period and the availability of surplus alcohols—from excess wine production, for example—in some countries.

Although these alcohol-supplemented fuels were satisfactory in a technical sense, the overall programs were less so. It has been claimed [14] that the essential difficulty was the instability of alcohol supplies. Since surpluses were the basis, the supply of alcohol for incorporation in fuel varied greatly and government regulations were changed frequently. This necessitated equally frequent engine adjustments followed by increasingly negative consumer reaction.

Willkie and Kolachov [14], in a provocative argument for an extensive, carefully planned alcohol program, urged the use of pure (190-proof or 90%) alcohol, rather than blends. They argued that "captive" markets existed, farm tractors for example, which could support such a program and that the use of pure alcohol rather than blends would eliminate the greatest short-coming of the earlier program. Willkie and Kolachov's proposal was published on the very eve of America's entry into the second World War. It represented the culmination of one of the strongest arguments in the "chemurgy" program of the 1930's, conversion of grain surpluses to power alcohol. The exigencies of a war economy, however, overwhelmed it. Grain surpluses disappeared as we were called upon to feed our allies during the war and much of western Europe after it. There was considerable production of alcohol from grain during the war but this was needed to supply increased industrial requirements and to replace the imported molasses previously used.

We must recognize the vital importance of developing renewable resource bases for our energy needs.

Since 1945 the United States has helped to supply the food needs of nations which had previously been cereal grain exporters but whose population growth had outstripped their own productive resources. The grain surpluses of earlier decades steadily dwindled away until, in the 1970's, we encountered shortages, for export at least, and rapidly increasing prices. Even in this unfavorable climate, the possibility of producing alcohol from starch for motor fuel use has been resurrected [15, 16]. In 1971 the Nebraska Legislature took the first positive step with passage of a law [17] providing for an allowance of 3-cents per gallon on the state motor fuel tax when fermentation ethanol is added to lead-free motor fuels. As the specter of fuel shortages became more real, pressure for the use of "gasohol," a 90% gasoline—10% alcohol blend increased. One Nebraska legislator suggested last year [17] that should gasoline prices rise to 65-70 cents per gallon, alcohol would become competitive.

At the same time that these predictions were being offered, however, the violent shifts in the world's grain markets experienced over the last year were just coming into play. These dim the prospects for grain-based ethanol for motor fuel just as petroleum price increases favor it. Once again we see at work the increasingly close interactions between food and energy production previously outlined in Figures 3 and 4.

ALCOHOL FROM CELLULOSE

THE HYDROLYSIS OF cellulose to glucose by various agents has held the interest of generations of applied scientists. Acid saccharification processes were described early in the 19th century and were successfully employed in Europe, especially Germany [18]. Much of the glucose produced was then fermented to ethanol. Alcohol has also been produced commercially from the sugars in waste sulfite liquors and other similar materials [18]. Acid hydrolysis of cellulose is an expensive, relatively low-yield process, however, and the advantages of enzymatic processes were recognized early. Unfortunately, satisfactory cellulase preparations were not available. More recently, however, the technology of cellulase preparation and its application has developed rapidly [19, 20]. Yields of glucose from waste cellulose of 50% and greater have been reported [21]. Cost estimates for the enzymatic production of glucose from cellulose vary widely, however, because of still unresolved questions about the amount of pretreatment necessary. Using a range of glucose costs covering most of the predictions made so far, plus past experience with ethanol fermentation costs, it is possible to estimate costs for ethanol production from cellulose (Table 2). These estimates include a rough credit for the protein-rich "distillers solubles" which are produced as a by-product but they do not include any credit for the elimination of solid wastes, mixed municipal refuse (MMR) for example, which may be applicable.

One should properly ask, "How much alcohol could be produced in this way and what impact, if any, would this have on the nation's fuel needs?" At this point the only answer to this question must be a crude estimate. We are said to produce about 200-million tons of MMR per year in the United States and these solid wastes are about half cellulose. Assuming demonstrated yields for glucose from waste cellulose and ethanol from glucose, these wastes could yield 25-million tons of ethanol, or about 8-billion gallons (190-proof), per year. This is equivalent to 0.58 x 15^{15} BTU/year. Current U.S. gasoline consumption is about 100-billion gallons or 11.5 x 10^{15} BTU per year. Conversion of all our MMR to ethanol would therefore provide only 5% of the energy now consumed in gasoline engines. Even so, this fraction

TABLE 2 Cost of Ethanol From Cellulose

Glucose cost	Raw material	Conversion	Total
$0.10/lb	$1.38	$0.15 - 0.30 (1) (0.10 - 0.15) (2)	$1.53 - 1.68 (1.48 - 1.53)
0.05/lb	0.69	0.15 - 0.30 (0.10 - 0.15)	0.84 - 0.99 (0.79 - 0.84)
0.01/lb	0.14	0.15 - 0.30 (0.10 - 0.15)	0.29 - 0.44 (0.24 - 0.29)

(1) Higher estimate based on past experience in production of ethanol from waste sulfite liquor; lower estimate by author.

(2) Figures in parantheses reflect higher credits for conversion by-products utilized in animal feeds.

is not significant, especially if the use of fuel alcohol were concentrated in captive services for urban areas. These services—street level transportation, delivery vans, refuse trucks, etc.—are major contributors to urban air pollution and the employment of ethanol as a fuel would be particularly advantageous in reducing emissions.

SUMMARY AND CONCLUSIONS

A NUMBER OF ARGUMENTS have been put forward in this discussion and I will conclude by summarizing what I believe to be the most important of these:

- **We must recognize the vital importance of developing renewable resource bases for our energy needs.**
- **Ethanol is the only reasonable candidate fuel for internal combustion engines which may be derived from renewable resources. While it is unlikely that ethanol can supply a substantial portion of the total national requirement for such fuels, it could contribute significantly to captive market needs in urban areas.**
- **Finally, I am convinced that most current assessments of the future potential for various fuels are unrealistic because they are based on established ratios between energy and other costs. The problem is not simply a matter of providing inflationary allowances in cost projections. It is a question of the essential relationship between the future cost of energy from conventional sources and the other costs involved in fuel production. Energy intensive technologies, e.g. shale oil, coal conversion, etc., will suffer increasing penalties as the relative cost of energy rises and projections based on past energy cost experience are bound to be in error.** ☐

REFERENCES

1. Cook, E., "The flow of energy in an industrialized society," Scientific American, September 1971.
2. Heichel, G. H., Comparative Efficiency of Energy Use in Crop Production, Bull. 739, Connecticut State Agricultural Experiment Station, New Haven (November, 1973).
3. Rozenzweig, M., and Ushio, S., "Protein from methanol," Chem. Engr., January 7, 1974, p. 62.
4. ———, Chem. Engr. News., April 22, 1974, p. 29.
5. Szego, G. C., and Kemp, C. C., "Energy forests and fuel plantations," Chemtech, 275 (May, 1973).
6. Klass, D. L., "A perpetual methane economy—is it possible?," Chemtech, 161 (March, 1974).
7. Rainbow, C., and Rose, A. H., *Biochemistry of Industrial Microorganisms,* Academic Press, London (1963).
8. Stodola, F. H., *Chemical Transformations by Microorganisms,* Wiley, N. Y. (1958).
9. Herrick, H. T., "New and better uses for our crops," in *Crops in Peace and War; the Yearbook of Agriculture,* 1950-1951, p. 6-9, U. S. Government Printing Office, Washington (1951).
10. Davis, J. C., "Chemurgy's second coming," Chem. Engr., p. 90, April 29, 1974.
11. Klass, D. L., and Ghosh, S., "Fuel gas from organic wastes," Chemtech, 689 (November, 1973).
12. Jacobs, P. B., and Newton, H. P., Motor Fuels from Farm Products, USDA Misc. Pub. No. 327, Washington, D. C. (December, 1938).
13. Hilbert, G. E., Alcohol from Agricultural Sources as a Potential Motor Fuel, USDA Publication AIC-233 (Rev.), Washington, D. C. (February, 1950).
14. Willkie, H. F., and Kolachov, P. J., *Food for Thought,* Indiana Farm Bureau, Indianapolis, Ind. (1942).
15. Miller, D. L., "Industrial alcohol from wheat, Sixth National Wheat Utilization Conference, Oakland, California, November 5-7, 1969.
16. Miller, D. L., "Fuel alcohol from wheat," Seventh National Wheat Utilization Conference, Manhattan, Kansas, November 3-5, 1971.
17. ———, Chemical Week, p. 24, April 4, 1973.
18. Prescott, S. C., and Dunn, C. G., *Industrial Microbiology,* 3rd Ed., McGraw-Hill, N. Y. (1959).
19. Hajny, G. J., and Reese, E. T., *Cellulases and their Applications,* Advances in Chemistry Series, No. 95, American Chemical Society, Washington, D. C. (1969).
20. Ghose, T. K., and Kostick, J. A., Biotech. Bioengr., *12,* 921 (1970).
21. Brandt, D., Hontz, L., and Mandels, M., AIChE Symposium Series No. 69, 127 (1973).