High-Grade Fuels from Biomass Farming: Potentials and Constraints

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The use of biomass as a source of fuel is a topic of growing interest and debate. Here we present an analysis of the key technical and economic potentials and constraints of systems designed to use agricultural crops to displace nonrenewable hydrocarbon fuels, namely petroleum and natural gas.

We first examine the controlling parameters and general behavior of such systems. We then examine the quantitative aspects of existing grain alcohol technology. This technology we use as a reference case for examining the potential for other biomass crops. It is our intent to provide a rigorous treatment and descriptive framework to aid in future research and development.

Fuel Productivity and Energy Balance

Any biomass-to-fuel system (Fig. 1) consists of a combination of an agricultural effort to produce a biomass crop (Y_0) and a conversion effort in which a fraction ϵ of that biomass, $Y = \epsilon Y_0$, is used to produce the gross fuel product G; $G = \eta Y$, where η is the conversion efficiency from biomass utilized, Y, to fuel G; and $G = \epsilon\eta Y_0$.

We will use A and B to represent the required inputs of high-grade fuels to the agricultural enterprise (including its industrial support activities) and to the fuel conversion technology, respectively. It will be convenient to express the agricultural fuel energy input A as a fraction f of the (heat of combustion of the) total biomass crop Y_0 it creates.

The net productivity of N of high-grade fuel from the total system is:

$$N = G - A - B = Y_0(\epsilon\eta - f) - B \quad (1)$$

If $B > Y_0(\epsilon\eta - f)$, the system is a consumer of high-grade fuel.

To obtain the highest possible net yield of high-grade fuel, one must minimize or eliminate the high-grade fuel consumption B by the conversion process. One may use raw biomass itself, such as crop residue, or coal. In any case, we can examine the ideal limit of the conversion technology by proceeding to the assumption that no high-grade fuel is used for the processing of the agricultural crop; that is, that $B = 0$. The net productivity of fuel is then:

$$N = Y_0(\epsilon\eta - f) \quad (2)$$

The quantities Y_0 and N can be the biomass yield and net fuel productivity, respectively, in energy units per acre per year, or other mutually consistent units.

Summary. The key parameters controlling the productivity and the cost of net high-grade fuel from a system for biomass agriculture and conversion are analyzed. Performance depends sensitively on a "symbiotic" interaction between agronomy and technology. The conditions for obtaining net productivity and costs are explored for U.S. grain alcohol as a reference point. Currently practiced technology consumes more high-grade fuel than it generates. Some potentials and constraints for future systems, including use of other plant species and conversion systems, are explored.

The system will be a net positive fuel producer as long as the agricultural fuel energy subsidy fraction, f, is smaller than the overall energy conversion efficiency $\epsilon\eta$ of the conversion process. When there is positive productivity, the true net productivity N differs from the visible gross production G according to:

$$N/G = (\epsilon\eta - f)/\epsilon\eta \quad (3)$$

One can visualize (Fig. 2) agriculture as "amplifying" the fuel energy input into the agricultural effort by a factor $(1/f)$ by action of solar energy. Subsequently, conversion technology "attenuates" the biomass crop energy downward by the factor $(\epsilon\eta)$. Thus arises a sensitive dependence of the net benefit to society on the difference in magnitude of the two measures of performance, as expressed in Eqs. 2 and 3.

Apparent and Actual Economics

The unit cost (K_G) of the gross fuel G "visible" at the conversion plant gives no indication of the true cost of net fuel acquisition (K_N). If the system does produce net high-grade fuel, creation of one unit of net fuel by the system will require the actual outlay by the consumer of G/N times the cost calculated for the unit of visible fuel at the plant:

$$K_N = K_G(G/N) \quad (4)$$

Figure 3 illustrates an operation (agriculture plus conversion) assumed to produce 3 gallons of the desired fuel at a total cost of \$6.60. It uses up conventional fuel equivalent to 2 gallons. The system is a net producer, but \$6.60 must be paid by the consumer to acquire one new gallon of fuel. The total cost of \$6.60 contains—but does not show explicitly—the cost of two units of conventional, high-grade fuel acquired somewhere in the system. These were introduced at the much lower cost of perhaps \$0.30 per gallon. Thus, in effect, two units costing a total of \$0.60 were "passed through" the operation, and the one new and third unit was acquired for \$6.00 per gallon.

Reliance on conventional economics of the gross plant-produced fuel is misleading in this case, because it is based on the use of two different prices for the same market-equivalent commodity, the high-grade fuel. In fact, if the system in Fig. 3 were a net consumer, requiring 4 gallons of fuel instead of 2 gallons to produce the 3 gallons of (gross) fuel product, a gallon of it would now cost \$2.40 instead of \$2.20 (the cost of the 3 gallons increased by \$0.60, the cost of two more gallons of support fuel).

This exemplifies a key problem encountered in current discussions of biomass-to-fuels systems. Reliance on local market forces does not test the successful performance of the total system as a net fuel producer for the nation.

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Magnitude of Realistic Cost Target

The quantitative aspects of this analysis are concerned with the U.S. economic environment, where the most plentiful alternative resource is coal.

Current estimates for the cost (*1*) of high-grade fuels derivable from coal are about $0.80 to $1.00 per gallon for gasoline or distillate fuels (*2–4*). In the United States, this cost is currently not viable for manufacture under the free market system; also, government subsidies are not considered justified for this source of high-grade fuel. The cost level of $0.80 to $1.00 will therefore represent a convenient reference point for cost acceptability.

The Grain Alcohol System

Current technology. In Fig. 4 we summarize the fuel energy inputs and outputs for the existing technologies of grain agriculture and alcohol production. We include the usual operation of obtaining distillers' grains from the still residue, which is usually sold as animal feed. The use of distillers' grains is considered economically desirable since the revenue from its sale supports the net ethanol cost to the extent of reducing it from about $1.60 to about $1.25 per gallon of ethanol.

The data for Fig. 4 are from Scheller and Mohr (*5*). The agricultural fuel energy input is based on the original study by Pimentel *et al.* (*6*). For convenience, all energy magnitudes in this article have been converted (*7*) into energy-equivalent "gallons of fuel," for which we use the abbreviation GAL.

It is apparent that the system in Fig. 4 is a net consumer of high-grade fuel: 2.9 GAL of hydrocarbon fuel are consumed for every GAL of fuel output from the distillery. Ethanol contains 0.67 times the fuel energy of an equal volume of gasoline. Even if alcohol, when used as an automotive fuel, were equivalent to gasoline on an equal volume basis (which would, in effect, increase the gross fuel G produced in Fig. 4 to 2.6 GAL), the system would remain a net fuel consumer.

No amount of expenditure would create net fuel, or displace hydrocarbon fuel in the economy.

Proposed improvements. Cray (*8*) has indicated that some distilleries operate with better fuel economy than others; Scheller and Mohr (*5*) have suggested the use of crop residues to fuel the distillery; and new technologies continue to be suggested. These include more economical process designs [for example, see (*9*)], or the use of coal or solar stills, for example. We have found it useful to examine the limiting, most optimistic case, however it may be achieved: no high-grade fuel consumption at all by the processing system (see Fig. 5). For this system, all the high-grade fuel inputs are assumed to be zero [the distillery obtains fuel from crop residue, in the manner suggested by Scheller and Mohr (*5*)]. We are left with only the agricultural fuel input of 2 GAL. About 3.1 GAL of fuel are produced at the distillery.

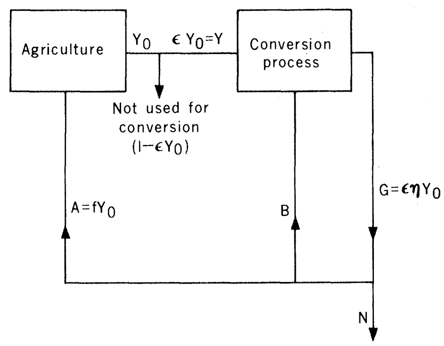


Fig. 1. Basic network of biomass-to-fuel systems. For the idealized system to be examined, $B = 0$.

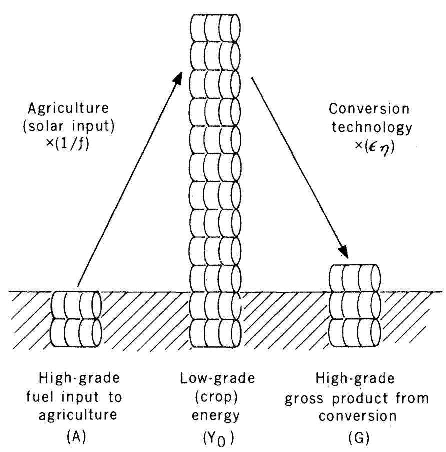


Fig. 2. Graphical representation of fuel energy sequence in biomass-to-fuel systems.

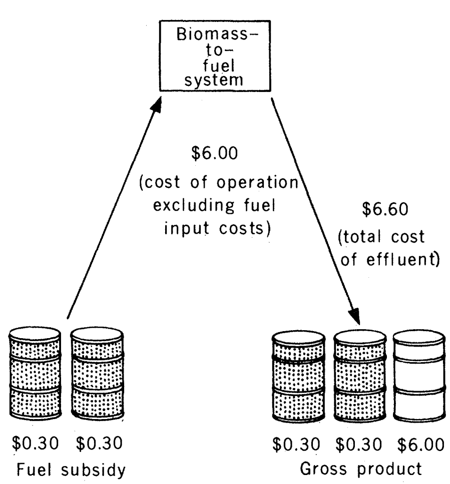


Fig. 3. A hypothetical system in which 3 gallons of fuel are produced at a total cost of $6.60. The net product is unshaded.

Such a system is a net producer of fuel. Very approximately, 1 gallon of net fuel is generated for 3 GAL of gross product G. We thus have approximately the situation discussed for the hypothetical case of Fig. 3. In mathematical terms, for Fig. 5, $f = 0.164$, $\epsilon = 0.86$, $\eta = 0.3$. Also, $\epsilon\eta = 0.26$, and $N/Y_0 = \epsilon\eta - f \approx 0.1$, and $N/G \approx 0.36$.

With grain alcohol (ethanol at about $1.60 per gallon, which is about K_G = $2.40 per GAL), it will require a consumer outlay of about three times that value, or some $6.60, to generate 1 GAL of net fuel, again corresponding to Fig. 3.

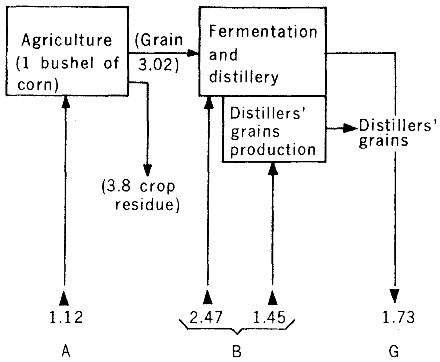
In Fig. 6 we summarize the best cost data that we have been able to obtain by including the following assumptions and credits for this future system: (i) no high-grade fuel consumption by any part of the processing complex; (ii) assigning ethanol a combustion efficiency (mileage performance) advantage of $R = 1.10$ over the British thermal unit equivalent volume of gasoline fuel (*10*); (iii) alcohol price reduced to $1.25 per gallon by price support from distillers' grains sales (without adding high-grade fuel use in the distillers' grains production); and (iv) a credit for agricultural fuel energy input not required to the extent that distillers' grains feed byproduct displaces feed grain production (on an equal calorie basis) (*11*).

The cost of net high-grade fuel product remains two-and-a-half to five times that producible from coal.

The factor R [in item (ii)] modifies the effective gross fuel product G to RG, that is, from 3.1 to 3.4 GAL.

The credit for agricultural fuel input [item (iv)], called "feed acreage credit" in Fig. 6, is formally introduced by reducing the agricultural fuel input A (see Fig. 1, Fig. 4, and Eq. 1) to $A(1 - \alpha)$, or the quantity f (Eqs. 1 to 3) to $f(1 - \alpha)$, where α = (energy units of feed byproduct)/(energy units of crop previously used as feed). In the case above (*5*), α = (117 kBtu's of distillers' grain)/(342 kBtu's of corn grain), or about 1/3.

Such energy credits for simultaneous alcohol and feed production can have an appreciable impact. However, it also assumes controlled substitution of one feed for another, and acceptability of changes in nutritional constituents (fiber and protein for carbohydrates in the above



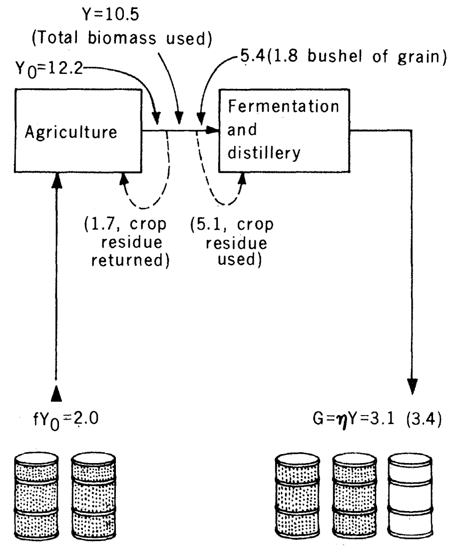


Fig. 4 (left). Current grain alcohol technology. High-grade fuel inputs and outputs for processing 1 bushel of corn. Fig. 5 (right). The idealized system of grain alcohol production with no high-grade fuel inputs to the conversion process. G becomes 3.4 if R = 1.1.

case), without new energetic or economic consequences.

The assumption of R = 1.1 for the relative efficiency of grain alcohol to gasoline in an engine needs further substantiation; it depends sensitively on the nature of the car population and on evolving emissions controls technology.

The contribution of octane number of ethanol to a mixture with gasoline could be formally incorporated in the factor R, since, in principle, there can be a differential gain in gasoline volume as a result of less severe operation of the "reforming" process. However, such a correction is not included because this analysis addresses itself to the net productivity of *total* high-grade fuel. The net effect of lower reforming severity is complex: it is also accompanied by a decrease in the production of liquified petroleum gas, isobutane, and often of hydrogen, which places a variety of new demands on other parts of the refining system and its energetics.

The case of surplus grain. When a true surplus of grain is utilized, the farm energy input need not be debited. This can substantially improve the ratio to the theoretical limit of N/G = 1. We find that net fuel cost could approach $1.70 per GAL, if the conversion technology uses no high-grade fuel, and if feed credits are allowable. For the cost to approach about $1.10 per GAL, the "distress" price of grain would have to dip below 50 percent of its regular value. It is useful to observe that, if the gross alcohol cost could be reduced to less than $1.70 per GAL (which here corresponds to less than $1.25 per gallon of ethanol), the industrial alcohol market would present and would have presented a competitive opportunity without the need for fuels considerations.

There are stringent constraints on what grain qualifies as true surplus: (i) it must be produced within the necessary strategy to ensure the normal supply of the nonfuel market (as insurance against unforeseen fluctuations); and (ii) it must be surplus that cannot be stored for later use in that nonfuel market. Only then is the farm energy input a necessary energy expenditure of the nonfuel farming operation. In any other case, the regular fuel energy subsidy must be debited against the fuel farming scheme. This restricts the use of surpluses to very special situations.

This constraint also raises an interesting policy question: can financial incentives (tax forgiveness or subsidies, for example) toward fuels objectives be devised without inducing the production of nonqualifying surpluses?

We also note (see Fig. 5) that 1.8 bushels of corn grown for fuel production by the ideal system release 1.4 GAL of fuel (3.4 − 2.0 GAL) to the nation; but the same amount of corn not grown as a result of more stringent management of true surplus in the conventional nonfuel market would release 2.0 GAL of fuel previously consumed.

Land requirements. A yield of 90 bushels of corn per acre produces a net of 55 GAL of fuel per acre per year. If the entire acreage of U.S. corn agriculture (about 75 million acres) were dedicated to grain alcohol fuel production, the net fuel generated (based on the hypothetical process requiring no high-grade fuel inputs) would correspond to 3.7 percent of (1977) U.S. gasoline, or less than 1 percent of U.S. petroleum consumption.

In the case of surplus grain, we would gain a factor of $G/N \approx 2.8$, but the fraction of true surplus to total grain harvest would surely be less than 1/2.8. The total potential contribution would therefore be less.

Grain alcohol system as a gas-to-liquids converter. If we make the outside assumption that all process operations and half of the agricultural fuel inputs are natural gas, we would obtain a net yield of liquid fuel, as seen in Fig. 7.

In essence, the system converts (nonrenewable) gas to liquid fuel. With the cost of gross alcohol produced at $1.25 per gallon, the amount and cost of net liquid fuel produced are 3.1 − 1.0 = 2.1 GAL at $2.80 per GAL. If we assume the thermal efficiency advantage of R = 1.1, they are 3.4 − 1.0 = 2.4 GAL at $2.40 per GAL; if we allow acreage credit for distillers' grain, we get 3.4 − 0.66 = 2.74 GAL at $2.12 per GAL.

The use of less natural gas by more efficient designs would not alter the net liq-

Distillation (no high-grade fuel)	•	•	•
Distillers' grains feed production (no high-grade fuel)		•	•
Feed acreage credit			•
Fuel cost at distillery — $/gallon alcohol	1.60	1.25	1.25
Fuel cost at distillery — $/GAL fuel	2.18	1.70	1.70
Gross to net fuel ratio, G/N	2.43	2.43	1.65
Net fuel cost $/GAL	5.30	4.13	2.81

Fig. 6. The most optimistic net fuel costs for hypothetical grain alcohol systems.

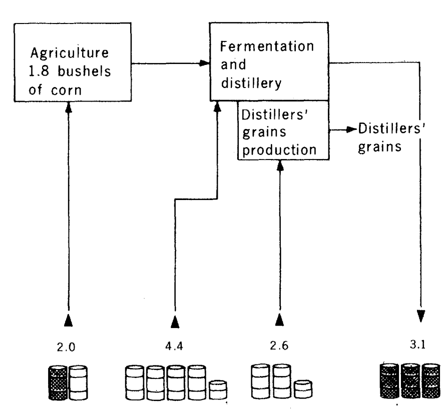


Fig. 7. Conventional system of grain alcohol production viewed as a gas-to-liquids conversion process. Empty gallon containers represent gas, shaded containers represent liquid fuel.

uids made, nor greatly effect gross liquids cost and, therefore, net liquids cost.

For comparison, natural gas conversion to alcohol (methanol) is an existing technology; the 1977 market price of methanol (*1*) of \$0.40 per gallon corresponds to \$0.80 per GAL of fuel value, or \$0.72 per GAL if we are to ascribe the 10 percent thermal efficiency advantage.

Since both petroleum and gas resources are declining in the United States, and both are currently being imported, the conversion of gas to liquid fuel is not the usual and proper objective considered for biomass.

Exploration of Future Potentials

Key factors in cost reduction. The cost of gross product K_G includes two components: the cost k_{Y_0} per unit energy of Y_0 of the total agricultural biomass product, and the cost k_p, the subsequent processing cost per energy unit of the charge stock for conversion:

$$K_G = k_{Y_0}/\epsilon\eta + k_p/\eta \quad (5)$$

With Eqs. 3 and 4, the cost of net fuel product K_N becomes

$$K_N = (k_{Y_0} + \epsilon k_p)(\epsilon\eta - f)^{-1} \quad (6)$$

For comparison, the cost elements of the base case (Fig. 5) of U.S. grain alcohol production, corresponding to Eq. 6, are (*14*)

$$K_N = (0.33 + 0.86 \times 0.34)10.6 = 6.60 \quad (7)$$

The contributions from the costs of the biomass crop and from the subsequent conversion operation are about equal. The net energy balance problem adds the large multiplier $(\epsilon\eta - f)^{-1}$.

Increasing the crop yield per land unit could reduce that part of k_{Y_0} which contains the land cost and perhaps the labor cost to work the smaller area. Equation 7 shows that even if all the k_{Y_0} were to respond inversely to yield—a most unlikely limiting case—approach to infinite yield ($k_{Y_0} \rightarrow 0$) would result in a cost of \$3.10 per GAL. This assumes constancy of the fraction of agricultural energy f required to achieve such successes in higher yield.

Increasing the overall conversion efficiency or, more precisely, the product $\epsilon\eta$ of the biomass utilized, ϵ, and the efficiency of its conversion, η, would be far more effective. Figure 8 shows the response of net cost to improvements to $\epsilon\eta$, relative to the grain alcohol reference case ($\eta = 0.3$), except that we have also

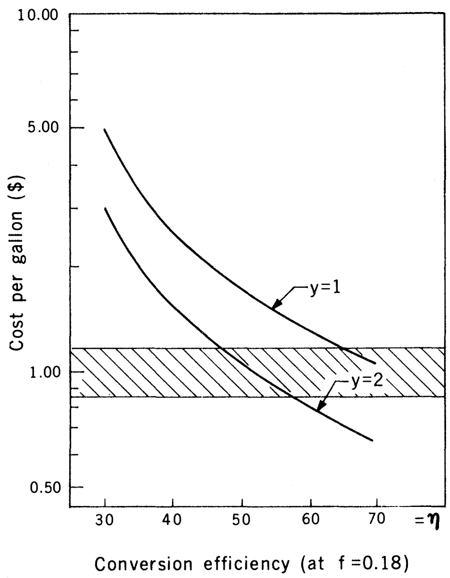


Fig. 8. Net fuel cost from biomass-to-fuel systems. Response to the overall efficiency of conversion process at two crop yields (y = 1 applies to the biomass yield of corn agriculture; y = 2 assumes that the yield is doubled).

assumed that it has already been possible to reduce unit processing cost k_p to one-half its value.

An approach of the cost of net fuel toward that of synthetic fuel from coal could result from: (i) use of no high-grade energy in the conversion technology; (ii) a very substantial gain in the product of conversion technology (or in the fraction of biomass converted); and (iii) a substantial increase in yield. The fraction f of high-grade fuel support to agriculture would have to be maintained.

Decreasing the agricultural fuel input fraction would have a substantial effect since f, too, appears in the difference term $(\epsilon\eta - f)$. If f were reduced to zero, the factor $(\epsilon\eta - f)$, which, in corn agriculture is about $0.3 - 0.2 \approx 0.1$, would increase to 0.3, thereby increasing net fuel yield and causing a threefold decrease in net fuel cost.

The interactive search. In any effort to improve one parameter we must allow for the constant interaction that occurs with other parameters. Measures that yield an improvement in Y_0 are most likely to alter the agricultural fuel input f, and vice versa. Choice of a different biomass species will not only entail characteristic new values of Y_0 and f, but will make different demands on the conversion process and its conversion efficiency η, and is likely to alter the fraction of biomass utilizable, ϵ.

The agronomy parameters. The search for plant species that provide unusual biomass yields per land unit has been a logical early response to the new fuels challenge. Good quantitative data for valid comparisons for sustained, steady-state experience are fairly scarce, and are confined to the few well-known crops. When we eliminate some confusion over dry as opposed to "as is" weights of crops, and differentiate climatic (mainly growing season) from species effects, we find a surprising similarity in the average rates of biomass production among species as different as cereals, trees, and grasses (see Table 1).

Water availability is particularly important because arid land use, for example, if supplemented by irrigation, will produce more biomass yield, but will also add dramatically to f.

What is also important is that, for any proposed or new situation, we must establish the quantitative values for yield Y_0, fuel input f, and the useful fraction for conversion ϵ for steady-state operation; that is, repetitive operation on the same land area.

Comparative data on steady-state requirements for agricultural fuel inputs are scarce. This was not considered an

Table 1. Typical yields (expressed as tons of dry weight per acre per year) of various crops in sustained agricultural experience in the United States.

Crop	Reference	Yield	Biomass yield (dry weight): Per ton of crop	Biomass yield (dry weight): Total
Corn	(*6*)	2.3	~2.3	~5.3
Sugar beets	(*24*)	2.5 to 5.7	~1.7	4.2 to 9.7
Wheat	(*25*)	0.8	~2.5	~2.0
Rice	(*25*)	2.4	~2.5	~6.0
Trees	(*20*)	5.0	~1.0	~5.0
Sugar cane*	(*21*)	7.5	~1.0	~7.5
Alfalfa	(*22, 23*)	5.0 to 6.1	~1.0	5.0 to 6.1
Slash pine†	(*22, 23*)	5.0 to 7.0	~1.3	6.5 to 9.0
Sugar cane‡	(*21*)	20.0	~1.0	20.0
Napier grass§	(*22*)	19.0	~1.0	19.0

*Data for Mississippi. †Data for wood and bark in the southeastern United States (*22*) and New Mexico (*23*). ‡Data for Hawaii. §Data for Puerto Rico.

Table 2. Similarity of fraction f of agricultural energy input, A, to total biomass Y_0.

Crop	Agricultural energy input* (kcal/pound of crop)	Ratio of crop to total biomass (by weight)	Agricultural energy input (kcal/pound of total biomass)	Ratio of A to G†
Alfalfa	425	~0.9	382	0.21
Sorghum (dryland)	443	~0.9	399	0.22
Sorghum (irrigated)	506	~0.9	455	0.25
Wheat (dryland)	393	~0.5	200	0.11
Wheat (irrigated)	790	~0.5	395	0.22
Corn	622	~0.5‡	331	0.18
Sugar beets (24)§	320 to 700	~0.6	195 to 420	0.10 to 0.23

*From (*23*). †Biomass energy content assumed to be 1800 kcal/pound. ‡Value from (*5*). §Variation over eight states (U.S.).

important subject for research in the past; with cheap fuel it had no great significance. Only relatively recently has it been pointed out (*6*) that the achievements in yield multiplication by the Green Revolution required a similar multiplication of f; that is, of high-grade fuel energy inputs. With growing fuel prices, and most certainly for the objective of harvesting fuels themselves, this becomes a most important new focus for agronomy research.

A survey of the relatively few available data (see Table 2) suggests a close similarity in agricultural input energy requirements across species. The question of whether plant species can be found that provide appreciable factors of improvement in sustained annual biomass yields, or which have the capability of production with fewer cultural fuel energy inputs, remains an open question.

The conversion factors. The choice and performance of conversion methods depends on the chemical nature of the biomass material utilized. The utilization $\epsilon\eta$ by fermentation and distillation is about 0.3. Gasification or liquefaction could make use of nearly all of a biomass crop (≈ 1) with $\epsilon\eta \approx 0.5$. However, process costs would be higher than those discussed in connection with coal because of the relatively much smaller magnitude of the operation. Compared to coal, the cost of raw material is much greater. Compared to about \$0.40 to \$1.00 per 10^6 Btu of coal (Western and bituminous, respectively), the total biomass from corn (assuming no cost for the biomass other than the grain) would be about \$3.00 per 10^6 Btu.

Oil- and hydrocarbon-producing crops, such as suggested by Calvin and coworkers (*15, 16*) and surveyed by Buchannan and Otey (*17*), are conceptually attractive because the conversion efficiency η of the hydrocarbon-like constituents to lower-molecular-weight, high-grade fuel could be high. We have demonstrated (*18*) the ability for existing catalysts to convert plant extracts almost completely into high octane number gasoline. The challenge in this case rests with agronomy to produce a sufficiently high fraction ϵ of such hydrocarbon-like constituents, since, when $\eta \rightarrow 1$, the condition for and magnitude of net high-grade fuels productivity will depend on $(\epsilon - f) > 1$. With $f \approx 0.15$, the fraction ϵ would obviously have to be much greater than 15 percent.

Socioeconomic factors. Technological and agronomic parameters can be dependent on socioeconomic factors. For example, the agricultural fuel input requirements, expressed by f, would be lowered by application of more human labor, which in turn would either require an upward change in cost of the crop commodity or imply acceptability of lower unit income. Similarly, we have seen how other modifications of the basic biomass-to-fuel system lead to alteration in cattle feed practices, the total practicability and consequences of which are untested.

Conclusion

The net productivity of high-grade fuel obtained per unit of land, as well as the actual price of net fuel, depend sensitively on interacting parameters of both agronomy and conversion technology. These include, in agronomy, high-grade fuel energy support of agriculture, f; and in technology, energy efficiency of conversion, η. The fraction of plant species useful for fuel production, ϵ, connects both skill areas.

With respect to grain alcohol production in the United States, the current practices in agriculture and technology lead to increased consumption of high-grade fuels (petroleum and gas); that is, every GAL of fuel generated in the form of grain alcohol will consume between 2 and 3 GAL of high-grade fuel equivalent (from natural gas and petroleum suppliers).

Positive net productivity can be attained. But it requires elimination of high-grade fuel input to the alcohol process facility and, in the context of U.S. agricultural practices, approximately 0.35 to 0.60 GAL of new high-grade fuel is then created per GAL of gross (visible) fuel. The greater values depend on realization of some of the additional assumptions. This corresponds to 0.25 to 0.44 GAL of new fuel per volumetric gallon of grain alcohol produced. Therefore, the actual cost of a net GAL of new fuel ranges from about \$5.00 down to about \$2.80, which is about three to six times that of liquid fuel from coal.

The search for new plant species or biomass systems must focus on minimizing the high-grade fuel energy input f to the agricultural sector (*19*). Any agronomy research toward the fuels-from-biomass objective must seek quantitative knowledge of f for steady-state operation. This quantity, f, will become more important as fuel energy costs escalate.

In addition, realistic figures must be obtained for the high-grade fuel consumption of all practical steps and operations in preparing and processing the crop.

This article can discuss (*19*) only briefly what are seen to be key parameters in a basic and conventional system, combining agriculture and process technology. It is confined to the context of current agricultural practices and socioeconomic expectations. It should be helpful in identifying key elements in innovative systems proposed to improve productivity and costs of net high-grade fuel.

References and Notes

1. All cost figures in this article are based on 1977 dollars and estimates. It should be noted that relevant results and conclusions depend on relative comparisons of alternatives, and the accuracy of absolute data in the exact time frame is secondary.
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