Chapter 11

ENERGY BALANCES FOR ALCOHOL FUELS

Chapter 11.-ENERGY BALANCES FOR ALCOHOL FUELS

TABLES

Chapter 11

ENERGY BALANCES FOR ALCOHOL FUELS

The energy objective of using alcohol fuels from biomass is the displacement of foreign oil and gas with domestic synthetic fuels. The effectiveness of a fuel alcohol program depends on the energy consumed in growing and harvesting the feedstock and converting it into alcohol, the type of fuel used in the conversion process, and the use of the alcohol.

The major sources of biomass alcohol fuels are grains, sugar crops, wood, grasses, and crop residues. Ethanol from grains and sugar crops is considered first, including a comparison of various feedstocks and end uses. Methanol and ethanol from the other feedstocks are then considered, and the use of these feedstocks directly as fuels is compared with the production of alcohols from them. Finally, some general considerations about the energy balance of these fuels are given.

Ethanol From Grains and Sugar Crops

Corn is currently a principal feedstock for ethanol production, but other grains and sugar crops could also be used. The energy balance for gasohol from corn is discussed in detail below, followed by a summary of the energy balance for various possible feedstocks and for use of the ethanol either as an octane booster or as a standalone fuel.

For each gallon of ethanol derived from corn, farming and grain drying consume, on the average, the energy equivalent of 0.29 gal of gasoline' in the form of oil (for fuel and petrochemicals) and natural gas (for nitrogen fertilizers). (See ch. 3 in pt. l.) The exact amount will vary with farming practices (e. g., irrigation) and yields. In general, however, the farming energy input per gallon of ethanol produced will increase when the farmland is of poorer quality (e. g., setaside acreage) and/or in dryer or colder climates (i.e., most of the western half of the country, excluding Hawaii).

The type of fuel used in the distillation process is perhaps the most important factor in determining the displacement potential of ethanol. Even under the most favorable circumstances, distillery energy consumption is significant. The distillery producing most of the fuel ethanol used today reportedly consumes 0.25 gal of gasoline equivalent (0.24 in the form of natural gas) per gallon of ethanol produced.[1] This number, however, involves some arbitrary decisions about what energy inputs should be attributed to the facility's food-processing operations. Total processing energy inputs in this plant amount to about 0.55 gal of gasoline equivalent per gallon of ethanol (see ch. 7).

Energy-efficient standalone fuel ethanol distilleries would consume the equivalent of about 0.45 gal of gasoline per gallon of ethanol produced (see ch. 7). Because the energy consumption of distilleries is not likely to be insignificant in relation to the alcohol produced in the foreseeable future, it is essential that distilleries use abundant or renewable domestic energy sources such as coal, biomass, and/or solar heat or obtain their heat from sources that would otherwise be wasted. Reliance on these fuels would reduce the total use of oil and gas at the distillery to insignificant levels.

● Some authors have Included the energy used to manufacture farming equipment and the materials from which they are made as part of the farm energy inputs However, for consistency one should also Include, as a credit, the energy used in manufacturing the goods that would have been exported to pay for importing the 011 displaced by the ethanol Because of the uncertainty in these factors, and the fact that they are relatively small, they are not included in the energy balance calculations

'Archer Daniels Midland Co , Decatur, Ill , "Update of Domestic Crude Oil Entitlements, Application for Petroleum Substitutes, " ERA-O 3, submitted to the Department of Energy, May 17, 1979

The amount of petroleum displaced by ethanol fuel also depends on the manner in which it is **used.** As a standalone fuel, each gallon of ethanol displaces about 0.65 gal of gasoline equivalent. As an additive in gasohol, each gallon of ethanol displaces about **0.8 (± 0.2) gal of gasoline. * (See ch. 10.) If the oil refinery pro**duces a lower grade of gasoline to take advantage of the octane-boosting properties of ethanol, up to **0.4 gal of gasoline** energy equivalent can be saved in refinery processing energy (see ch. 10) for each gallon of ethanol used.

Additional energy savings are achieved by using the byproduct distillers' grain as an animal feed. To the extent that crop production is displaced by this animal feed substitute, the energy required to grow the **feed** crop is displaced.

Table 65 summarizes the oil and natural gas used and displaced for the entire gasohol fuel cycle. The **energy is expressed as gallons of gasoline energy equivalent for** each gallon of ethanol produced and used in gasohol (i. e., 1.0 in the table represents 117,000 **Btu/gal of ethanol, 0.5 represents 58,500 Btu/gal of ethanol, etc.)** The three cases presented correspond to: 1) two ways to calculate the present situation, 2) future production of ethanol from the less productive land that can be brought into crop production and using coal as a distillery **fuel,** and **3)** the same as **(2)** except that the octane of the gasoline is lowered to exactly compensate for ethanol's octane-boosting properties. They result in net displacements of: 1) from zero to one-third gal, 2) about one-half gal, and 3) slightly less than 1 gal of gasoline and natural gas equivalent per gallon of ethanol used.

***The greater displacement results from the alcohol's leaning effect**

In all, the total displacement of premium fuels (oil and natural gas) achieved per gallon of ethanol can be nearly 1 gal of gasoline equivalent **per gallon of ethanol if petroleum and natural gas are not used to fuel ethanol distilleries and 2)** lower octane gasoline is used in gasohol blends. Failure to take these steps, however, can result in the fuel cycle consum**ing slightly** more oil and natural gas than it displaces leading to a net increase in oil and gas consumption with ethanol production and use. This is the situation that is alluded to in most debates over gasohol's energy balance, but it is a situation that can be avoided with appropriate legislation.

Nevertheless in the most favorable case (case 3) and with an energy-efficient distillery, the ratio of total energy displaced to total energy consumed is 1.5 (± 0.4), i.e., the energy balance is positive (a ratio greater than 1). And if the feedstocks are derived from more productive farmland, or local conditions allow energy savings at the distillery, e.g., not having to dry the distillers' grain, then the balance is even more favorable. Alternatively, an energy

Table 65.–Energy Balance of Gasohol From Corn: Oil and Natural Gas Used(+) and Displaced (-)
(in gallons of gasoline equivalent per gallon of ethanol produced and used[a])

	Present		Set-aside and potential cropland		
	Entire plant	Ethanol only	Coal-fired distillery	Coal-fired distillery and lowering of gasoline octane	Uncertainty
Farming	0.3[b]	0.3[b]	**0.4**[c]	0.4[c]	**?0.15**
Distillery	0.55	0.24	0[e]	0[e]	—
Distillery byproduct	-0.09[d]	0	-0.09[d]	–0.09[d]	±0.03
Automobile	-0.8	-0.8	-0.8	-0.8	±0.2
Oil refinery	—	—	—	-0.4	± 0.2
Total	-0.0	-0.3	-0.5	-0.9	*0.3

[a]Lower heat content Of gasoline and ethanol taken to be 117,000 Btu/gal and 76,000 Btu/gal, respectively
[b]0 16 as nitrogen fertilizer (from natural gas) and 0.13 mostly as petroleum products
[c]Estimated uncertainty of ± 0 15, assumes 75% of the yield achievable on average cropland
[d]Based on soybean cultivation and crushing energy The byproduct of 1 gal of ethanol from corn displaces 12 lb of crushed soybeans, which requires 0.09 gal Of gasoline equivalent to produce private communication with R Thomas, Van Arsdall, National Council of Farmer Cooperates
[e]55,000 Btu of coal per gallon of ethanol

SOURCE Office of Technology Assessment

credit could be taken for the crop residues, which would also improve the calculated balance. This general approach to the energy balance, however, does not consider the different values of liquid versus solid fuels.

The uncertainty factor in table 65 of ± 0.3 gal of gasoline per gallon of ethanol is due primarily to inherent differences in farming practices and yields, errors in fuel efficiency measurements, uncertainties in oil refinery savings, and the magnifying effect on these errors of the low (10 percent) ethanol content of gasohol. These factors make more precise estimates unlikely in the near term.

Not only does the farming energy used for grain or sugar crop production vary considerably from State to State, but also the average energy usage displays some differences between the various feedstocks. **A more significant difference arises, however, between use of the ethanol as an octane-boosting additive to gasoline and as a standalone fuel, e.g., in diesel tractors or** for grain drying. **As an oc**tane-boosting additive, each gallon of ethanol displaces up to 1.2 **gal** of gasoline energy equivalent in the automobile and at the refinery (see table **65). * As a standalone fuel,** however, the displacement at the end use is only 0.65 to 0.8 gal of gasoline energy equivalent per gallon of ethanol.**

Table 66 summarizes the net displacement of premium fuels (oil and natural gas) for various feedstocks and the two end uses. **In each case it was assumed that the feedstocks would be grown on marginal cropland with yields that are 75 percent of those obtained on average U.S. cropland.**

The striking feature displayed in table 66 is that use of ethanol as a standalone fuel is considerably less efficient in displacing premium fuels than use of it as an octane-boosting additive. In some cases, e.g., with grain sorghum and in areas with poor yields of the other grains, ethanol produced from grains and used as a standalone fuel (e. g., onfarm as a diesel fuel substitute) may actually lead to an increased use of premium fuels, even **if nonpremium fuels are** used in the distillery. Consequently, caution should be exercised if onfarm ethanol production and use are encouraged as a means of reducing the **U.S.** dependence on imported fuels.

Furthermore, the agricultural system is so complex and interconnected that it is virtually impossible to ensure that large levels of grain production for standalone ethanol fuel would not lead to a net increase in premium fuel consumption. Two examples illustrate this point. If grain sorghum from Nebraska is used as an ethanol feedstock (to produce a standalone fuel), the net displacement of premium fuels per gallon of ethanol is similar to the national average for corn. A secondary effect of this, however, could be an increase in grain sorghum production on marginal cropland in Texas, and the increased energy required to grow this grain sorghum could more than negate the fuel displaced by the Nebraska sorghum. Similarly, ethanol production from corn **could raise corn prices and lead to some shift from corn to grain sorghum as an animal feed. Depending on where the shifts occurred,** U.S. **premium fuel consumption could either increase or decrease as a result.**

Table 66.–Net Displacement of Premium Fuels (oil and natural gas) From Various Feedstocks and Two End Uses (energy expressed as gallons of gasoline equivalent per gallon of ethanol produced and used[a])

Feedstock	Ethanol used as an octane-boosting additive to gasoline[b]	Ethanol used as a standalone fuel[c]
Corn	**0.9**	**0.4**
Grain sorghum . . .	0.7	0.1
Spring wheat	1.0	0.5
Oats. .,	1.0	0.5
Barley ... ., ., ., .	1,0	0.4
Sugarcane	0.9	0.3

[a]Assuming lower heat content of gasoline and ethanol to be 117000 Btu/gal and 76000 Btu/gal respectively; crops grown on marginal cropland with yields of 75 percent of average cropland yields, distillers' gram energy credits as in table 65 for all grams and no credit for sugars, distillers fueled with nonpremium fuels, national average energy inputs S Barber et al The Potential of Producing Energy From Agriculture. contractor report to OTA
[b]Uncertainty ± O 3
[c]Uncertainty ± O 2

SOURCE Off Ice of Technology Assessment

*0 4 gal of gasoline equivalent is due to the octam-boosting properties of ethanol and 0 15 gal 15 due to the leaning effect of the alcohol

•* Used as a standalone fuel in spark-ignition engines, alcohol-fueled engines **can have a** 20 **percent** higher **thermal** efficiency **than their** gasoline-fueled **counterparts** (see **ch 10)**

The crucial point is that the energy usage in agriculture is an important consideration in determining the effectiveness of a fuel ethanol program. Because of this, there can be situations where energy from agriculture does not result in a net displacement of premium fuels. In order to avoid this situation, care should be taken to ensure that ethanol derived from grains and sugar crops **be used** in the most energy-efficient manner possible, i.e., as an octane-boosting additive.

Methanol and Ethanol From Wood, Grasses, and Crop Residues

Methanol, like ethanol, can be used as an octane-boosting additive and the oil refinery energy saved per gallon of methanol is roughly equivalent to that of ethanol. The lower energy content (per gal lon) of methanol, however, leads to a smaller displacement of gasoline in the automobile per gallon of alcohol (0.6 gal of gasoline equivalent per gallon of methanol versus 0.8 for ethanol; see ch. 10). On the other hand, the energy used to grow, collect, and transport wood and plant herbage for methanol production is less than for ethanol **feed**stocks such as grain and sugars. There are, **however, considerable local variations and where,** for example, crop residues are collected on lands with poor yields, the energy consumed in collection could be comparable to that needed to produce some grains and sugar crops.

Table 67 presents a summary of the net displacement per gallon of alcohol for the various lignocellulosic feedstocks and two end uses. The net displacement **per gal lon of methanol is comparable to that obtained** for ethanol from grains and sugar **crops, because the** lower energy content of methanol (as compared to ethanol) is largely compensated for by the lower energy required to obtain methanol **feedstocks.**

Another aspect of the energy balance for the lignocellulosic feedstocks is the net displacement of premium fuels per ton of feedstock. In table 68, direct combustion, airblown gasification, and alcohol fuels production are compared with wood as the feedstock. Similar results can also be derived for crop residues and grasses.

Table 67.–Net Displacement of Premium Fuels (oil and natural gas) With Alcohol Production From Various Feedstocks and Two End Uses (energy expressed as gallons of gasoline equivalent per gallon of alcohol produced and used[a])

Feedstock	Fuel	Used as an octane-boosting additive to gasoline	Used as a standalone fuel
Wood	Methanol	0.9[b]	0.4[c]
Grasses or crop residues. .	Methanol	0.8[b]	0.3[c]
Wood.	Ethanol	1.1[d]	0.6[d]
Grasses or crop residues.	Ethanol	1.0[d]	0.5[d]

[a] Assumes I) lower heating values of 57,000, 76,000, and 117,000 Btu/gal for methanol, ethanol, and gasoline, respectively; 2) cultivation (grasses) collection and transport (all feedstocks) energy of O 75 million Btu/dry Ion for wood and 2 million Btu/dry ton for grasses and crop residues (including fertilizers for grasses and fertilizer replacements needed when crop residues are collected), 3) methanol yields of 120 gal/ton for wood and 100 gal/ton for grasses and crop residues (50% energy conversion efficiency); 4) ethanol yields are 100 gal/ton of feedstock fermented, but additional feedstock amounting to 25,000 Btu/gal of ethanol is required for distillery energy over and above that obtained from burning the byproduct lignin (based on G H Emert and R Katzen, "Chemicals From Biomass by Improved Enzyme Technology, " presented at the *Symposium* orr *Biomass as a Non-Foss// Fuel Source,* ACS/CST Joint Chemical Congress, Honolulu, Hawaii, Apr 1-6, 1979); resulting m net yields of 86 and 84 gal/ton of feedstock for wood and grasses/crop residues, respectively; 5) methanol and ethanol displace 1 0 and 1 2 gal, respectively, of gasoline energy equivalent (per gallon of alcohol) at the refinery and in the automobile when used as octane-boosting additives 10 gasoline; 6) they replace O 48 and O 65 gal of gasoline equivalent (per gallon of alcohol) al the end use when used as standalone fuels
[b] Uncertainty ± 0 3
[c] Uncertainty ± 0 1
[d] Uncertainty large, since future processes for producing ethanol from these feedstocks are not fully defined (see footnote a)

SOURCE Office of Technology Assessment

Table 68.-Net Displacement of Premium Fuel (oil and natural gas) per Dry Ton of Wood for Various Uses

Use	Net displacement of premium fuel (10⁶Btu/dry ton of feedstock)	(% of feedstock energy content)
Direct combustion (68% efficiency).	1 2[ab]	75
Air gasification and combustion of fuel gas (85% overall efficiency)	1 5[ab]	95
Methanol (used as octane-boosting additive).	13[c]	80
Ethanol (used as octane-boosting additive).	11[c]	70
Methanol (standalone fuel).	6[c]	40
Ethanol (standalone fuel)	6[c]	40

[a] Assuming 16 million Btu/dry ton; 0.75 million Btu/ton required for collection and transport
[b] Assuming it replaces 011 burned with 85% efficiency
[c] Based on table 67

SOURCE Off Ice of Technology Assessment

Care should be exercised when interpreting table 68. The ethanol yields (per ton of wood) and the energy that will be required by wood-to-ethanol distilleries are still highly uncertain. Nevertheless, this table does display the general feature that alcohol fuels used as octane-boosting additives can be nearly as efficient in displacing premium fuels as the direct combustion or airblown gasification of wood. On the other hand, if the alcohols are used as standalone fuels, the premium fuels displacement is considerably smaller.

General Considerations

The results presented in tables 65 through 68 are based on OTA's estimates of average values for the energy consumed and displaced by the various feedstocks. These figures, however, cannot be taken too literally since local variations and changing circumstances can influence the results. Two of the more important factors which influence the results–the energy required to obtain the feedstock and the end use of the fuel — are discussed below.

The energy needed to grow, harvest, and transport the feedstocks varies considerably, depending on a number of site-specific factors such as quantity of available biomass per acre, terrain, soil productivity, plant type, harvesting techniques, etc. Generally, however, factors that increase the energy requirements also increase the costs. For example, where the quantity of collectable crop residues per acre is small both the energy used and the cost (per ton **of** residue) will be higher than the average. The economics will therefore usually dictate that— locally, at least—the more energy-efficient source of a given feedstock be used.

As the use of bioenergy increases, however, the tendency will be to move to less energy-efficient sources of feedstocks, and large Government incentives could lead to the use of bioenergy that actually increases domestic consumption of premium fuels. The danger of this is minimal with wood, but somewhat greater for grasses and crop residues due to the larger amount of energy needed to grow and/or collect them. The danger is even greater when grain or sugar feedstocks are used for the production of standalone fuel ethanol.

Another important factor in the energy bal**ance is the end** use of the alcohol fuel. As has been emphasized above, there is a significant increase in the displacement of premium fuels when the alcohol is used as an octane-boosting additive. In the 1980's, **however, there could be an increased use of automobile engines that do not require high-octane** fuels and that have automatic carburetor adjustment to maintain the proper air to fuel ratio (see ch. 10). With these engines, the octane-boosting properties of the alcohols are essentially irrelevant. Consequently, if the automobile fleet is gradually converted in this way, there will be a gradual reduction in the fuel displacement per gallon of alcohol, until the energy balances derived **for standalone** fuels pertain. The same conclusion would hold if oil refineries convert to more energy-efficient processes for producing high-octane gasoline.

Another consequence of these possible changes would be to increase the importance of the energy required to obtain the feedstock. For example, if ethanol only displaces as much premium fuel as indicated when used as a standalone fuel, then, as mentioned above, cultivating and harvesting the grains or sugar crops used as feedstocks may require more premium fuel than is displaced by the ethanol. The danger of this is considerably less for grasses and crop residues and virtually nonexistent for forest wood used as feedstock for alcohol production.