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FOR PETROLEUM SUPPLY STUDIES

M. KING HUBBERT CENTER
Petroleum Engineering Department
COLORADO SCHOOL OF MINES
GOLDEN CO 80401-1887

ENERGY AND DOLLAR COSTS OF ETHANOL PRODUCTION WITH CORN

by
David Pimentel

Introduction

Ethanol does not provide energy security for the future. It is not a renewable energy source, is costly in terms of production and subsidies, and its production causes serious environmental degradation (ERAB, 1980, 1981; Dorving, 1988; GAO, 1990; Pimentel, 1991; Sparks Commodities, 1990; Giampietro et al., 1997).

Clearly, conclusions drawn about the benefits and costs of ethanol production will be incomplete or misleading if only a part of the total system is assessed (Giampietro et al., 1997). The objective of this analysis is to update and assess all the recognized factors that operate in the entire ethanol production system. These include direct and indirect costs in terms of fossil energy and dollars expended in producing the corn feedstock as well as in the fermentation and distillation processes.

Energy Balance

The conversion of corn and some other food/feed crops into ethanol by fermentation is a well known and established technology. In a large and efficient plant with economies of scale, the yield from a bushel of corn is about 2.5 gallons of ethanol.

The production of corn in the United States requires significant energy and dollar inputs. Indeed, growing corn is a major energy and dollar cost of producing ethanol (Pimentel, 1991; Giampietro et al., 1997). For example, to produce an average of 120 bushels of corn per acre using conventional production technology requires more than 140 gallons of gasoline equivalents and costs about $280 (Pimentel, 1992). The major energy inputs in U.S. corn production are oil, natural gas, and/or other high grade fuels. Fertilizer production and fuels for mechanization account for about two-thirds of these energy inputs for corn production (Pimentel, 1991).

Once corn is harvested, three additional energy expenditures contribute to the total costs in the conversion process. These include energy to transport the corn material to the ethanol plant, energy expended relating to capital equipment requirements for the plant, and energy expended in the plant operations for the fermentation and distillation processes.

The average costs in terms of energy and dollars for a large modern ethanol plant (60-70 million gallon/yr) are listed in Table 1. The largest energy inputs are for corn production and fuel energy expended in the fermentation/distillation process. The total energy input to produce one gallon of ethanol is 129,600 BTU. However, one gallon of ethanol has an energy value of only 76,000 BTU. Thus, a net energy loss of 53,600 BTU occurs for each gallon of ethanol produced. Put another way, about 71% more energy is required to produce a gallon of ethanol than the energy that is contained in a gallon of ethanol (Table 1).

About 63% of the cost of producing ethanol ($2.52 per gallon) in a large plant is for the corn feedstock itself (Table 1). This cost is offset, in part, by the by-product (dried-distillers grain) which is produced and can be fed to livestock. However, most of the cost contributions from by-products are negated by the costs of environmental pollution that result from the production processes. These are estimated to be $0.36 per gallon of ethanol produced (Pimentel, 1991; Giampietro et al., 1997). This shows that the environmental system in which corn is being produced is rapidly being degraded. Furthermore, it substantiates the finding that the U.S. corn production system is not sustainable unless major changes are made in the cultivation of this important food/feed crop. Hence, corn cannot be considered a renewable resource.

Energy Inputs in Ethanol Production

About 1 billion gallons of ethanol are currently produced in the United States each year (Peterson et al., 1995). This quantity of ethanol provides less than 1% of the fuel utilized by U.S. automobiles (USBC, 1996).

The amount of cropland that is required to grow sufficient corn to fuel each automobile is a vital factor when considering the advisability of producing ethanol for automobiles. To clarify this problem, the amount of cropland needed to fuel one automobile with ethanol was calculated. An average U.S. car travels about 10,000 miles per year and uses about 520 gallons of gasoline. Although 120 bushels per acre of corn yield 300 gallons of ethanol, its energy equivalent to gasoline is only 190 gallons because ethanol has a much lower BTU content than gasoline (76,000 BTU versus 120,000 BTU for gasoline per gallon). As shown above, there is a significant net energy loss in producing ethanol. However, even assuming zero or no energy charge for the fermentation and distillation processes and charging only for the energy required to produce corn (Table 1), the net ethanol energy yield from one acre of corn is only 50 gallons (190 gallons minus 140 gallons). Therefore, to provide the equivalent of 520 gallons of gasoline per car, about 10.4 acres of corn must be grown to fuel one car with ethanol for one year.

Land Used in Ethanol Production

To fuel one car with ethanol for one year means that nearly 7-times more cropland would be required to fuel one car than is needed to feed one American (USDA, 1996).

Assuming a net production of 50 gallons of fuel per acre of corn, and assuming that all cars in the United States were fueled with ethanol, a total of approximately 2 billion acres of cropland would be required to provide the corn feedstock. This amount of acreage is more than 5-times all the cropland that is actually and potentially available for all crops in the future in the United States.

A major problem associated with corn production is soil erosion. In U.S. corn production, soil erodes about 20-times faster than soil can be reformed (Pimentel et al., 1995). As soil quality diminishes, production moves to marginal land which increases the susceptibility of the corn crop to climate fluctuations, particularly droughts. For example, during 1988 a drought reduced the corn crop by about 30% (USDA, 1989). These severe fluctuations in corn production occur periodically every 4 to 5 years. Additionally, in irrigated corn acreage, groundwater is being mined 25% faster than the recharge rate (USWRC, 1979).

These land and water problems already demonstrate that the U.S. corn production system uses large quantities of basic resources. Unless major changes can be made in the cultivation of this major food/feed crop it cannot be considered a renewable resource that can be relied on to provide energy security for the United States.

Environmental Impacts

Ethanol production, in both the growing of the corn and in the fermentation / distillation process, adversely affects the quality of the environment in diverse ways. All these environmental problems cost the consumer and the nation, and most importantly, diminish the long term sustainability of U.S. agriculture and environmental integrity.

As mentioned, corn is one of the major row crops now responsible for serious soil erosion in the United States. Estimates are that about 9 tons of soil per acre are eroded per year by rain and wind in corn production areas (Lal and Pierce, 1991). Note, this rate of soil loss is about 20-times faster than soil reformation in agriculture (Lal and Stewart, 1990; Pimentel et al., 1995). To replace soil nutrients that are lost as soil erodes, an estimated $20 billion per year is required (Troeh et al., 1991).

In addition to being the largest user of fertilizers among all U.S. crops, corn production also is the largest user of insecticides and herbicides (Pimentel, 1997). Unfortunately, substantial amounts of these chemicals are washed and/or drift from the target areas to contaminate adjoining terrestrial and aquatic ecosystems. Monitoring for fertilizer and pesticide pollution in U.S. well water and groundwater is estimated to cost the nation $2 billion per year-- if an adequate job of monitoring were done-- of which $1.2 billion would be expended just for pesticides (Nielsen and Lee, 1987). Other environmental damages caused by pesticides are estimated to cost the nation more than $8 billion per year (Pimentel, 1997). Although these may be necessary expenditures for food production, their impact must be considered when evaluating the environmental effects of producing ethanol fuels.

Furthermore, major pollution problems also are associated with the production of ethanol in the conversion plant. For each gallon of corn ethanol produced, about 160 gallons of waste water are produced. This waste water has a biological oxygen demand (BOD) of 18,000-37,000 mg/liter depending on the type of plant. If the cost of processing this sewage is included in the pollution cost of $0.36 per gallon, it would add another $0.06 per gallon and the total pollution costs per gallon would be $0.42.

Ethanol produces less carbon monoxide than gasoline, but it produces just as much nitrous oxides as gasoline. In addition, ethanol adds aldehydes and alcohol to the atmosphere, all of which are carcinogenic. When all air pollutants associated with the entire ethanol system are measured, ethanol production is found to contribute to major air pollution problems. The 129,600 BTU of fossil fuel including coal, oil, and natural gas, which are expended in corn production and subsequently burned in the ethanol plant release significant amounts of pollutants into the atmosphere. Also, the carbon dioxide emissions released from burning these fossil fuels contribute to the global warming problem (Parry, 1990). This becomes an extremely serious concern when coal is used as the fuel for the fermentation/distillation processes. Thus, overall environmental pollution and its costs associated with ethanol production will increase if ethanol production is expanded.

Food Versus Fuel Issues

Burning a human-food resource (corn) for fuel, as happens when ethanol is produced, raises important ethical and moral issues. Today the number of malnourished people in the world stands at more than 2 billion, about one-third of the world's population (WHO, 1995). This is the largest number of malnourished people in human history, and the number is growing. Coupled with this existing problem is the escalating rate of growth in the human population. More than a quarter of a million people are added each day to the world population, and each of these human beings requires adequate food. World data confirm that per capita food supplies have been declining for the past 12 years (FAO, 1996; Pimentel et al., 1997).

Present food shortages throughout the world call attention to the importance of continuing U.S. exports of corn and other grains for human food to reduce malnutrition and starvation. Increased corn exports increase the market for corn, improve the U.S. balance of payments, and most importantly help feed people who need additional food for their survival. Present U.S. grain exports total about $40 billion per year (USBC, 1996). Clearly using corn for food is beneficial for many reasons.

Agricultural land supplies more than 99% of all world food while the oceans supply less than 1% (FAO, 1991). Expanding ethanol production could entail diverting essential cropland from producing corn needed to sustain human life to producing corn for ethanol factories. This will create serious practical as well as ethical problems. Already worldwide (including the United States) per capita supplies of cropland and fresh water are declining, while soil erosion, deforestation, and food losses to pests are increasing. All these factors are contributing to food shortages throughout the world. Therefore, the practical aspects as well as the moral and ethical issues must be seriously considered before steps are taken to produce and convert more corn into ethanol. Clearly the ethical issue of burning corn will become more intense as human food supplies must be augmented to meet the basic needs of the rapidly growing world population.

Subsidies

A recent report by the U.S. General Accounting Office which analyzed tax costs and federal farm program expenditures associated with projected increased ethanol production has added to our understanding of the complexities of ethanol production. The 1990 report concluded that: (1) increasing ethanol production would greatly increase tax-subsidy expenditures; (2) no projections could be made concerning any net federal budget savings from increasing ethanol production; and (3) an estimate of any overall federal budget impact was precluded because of the uncertainties about production economics for both ethanol and gasoline (GAO, 1990). In addition the report indicated that it was impossible to calculate how much higher the subsidies might have to be increased to encourage a measured expansion of ethanol production, if the expansion were needed at all.

Conclusion

Ethanol production is wasteful of fossil energy resources and does not increase energy security. This is because considerably more energy, much of it high-grade fossil fuels, is required to produce ethanol than is available in the ethanol output. Specifically, about 71% more energy is used to produce a gallon of ethanol than the energy contained in a gallon of ethanol.

Furthermore, ethanol production from corn cannot be considered renewable energy. Its production uses more nonrenewable fossil energy resources both in the production of the corn and in the fermentation/distillation processes than is produced as ethanol energy.

Unfortunately ethanol produced from corn and other food crops is an unreliable source of energy because of uncontrollable climatic fluctuations, particularly droughts which frequently reduce crop yields. The expected priority for corn and other food crops would be for food and feed.

Increasing ethanol production will increase degradation of vital agricultural land and water resources and will seriously contribute to the pollution of the environment. In U.S. corn production, soil erodes some 20-times faster than soil is reformed.

If there were no tax payer money paid to subsidize the ethanol production industry, there would be no ethanol produced as a fuel for automobiles.

Increasing the diversion of human food resources to support the costly and inefficient production of ethanol fuel raises major ethical questions. This is especially true when there are more than two billion humans who are malnourished in the world.

TABLE 1
Energy and dollar inputs for a gallon of ethanol
(Pimentel, 1991, 1992; USBC, 1996; USDA, 1996; Giampietro et al., 1997).

Inputs	BTU	Dollars
Corn Production	55,300	$1.60
Fermentation/Distillation	74,300	$0.92
TOTAL	129,600	$2.52

References

1. Dorving, F. 1988. Farming for Fuel. New York: Praeger.
2. ERAB. 1980. Gasohol. Washington, DC: Energy Research Advisory Board, U.S. Department of Energy.
3. ERAB. 1981. Biomass Energy. Washington, DC: Energy Research Advisory Board, U.S. Department of Energy.
4. FAO. 1991. Food Balance Sheets. Rome: Food and Agriculture Organization of the United Nations.
5. FAO. 1996. Quarterly Bulletin of Statistics. FAO Quarterly Bulletin of Statistics 9: 1-121.
6. GAO. 1990. Alcohol Fuels. Washington, DC: U.S. General Accounting Office, GAO/RCED-90-156.
7. Giampietro, M., S. Ulgiati, and D. Pimentel. 1997. Feasibility of large-scale biofuel production. BioScience 47 (9): 587-600.
8. Lal, R. and B.A. Stewart. 1990. Soil Degradation. New York: Springer-Verlag.
9. Lal, R. and F.J. Pierce. 1991. Soil Management for Sustainability. Ankeny, Iowa: Soil and Water Conservation Soc. in Coop. with World Assoc. of Soil and Water Conservation and Soil Sci. Soc. of Amer.
10. Nielson, E.G. and L.K. Lee. 1987. The Magnitude and Costs of Groundwater Contamination from Agricultural Chemicals. U.S. Dept. of Agr., Econ. Res. Ser., Nat., Res. Econ. Div., Staff. Re., AGES 870318.
11. Parry, M. 1990. Climate Change and World Agriculture. London: Earthscan Publications, Ltd.
12. Peterson, C.L., M.E. Casada, L.M. Safley, and J.D. Broder. 1995. Potential production of agriculturally produced fuels. Applied Engineering in Agriculture 11(6): 767-772.
13. Pimentel, D. 1991. Ethanol fuels: Energy security, economics, and the environment. J. Agr. Environ. Ethics 4: 1-13.
14. Pimentel, D. 1992. Energy inputs in production agriculture. In Energy in World Agriculture, ed. R.C. Fluck. pp. 13-29. Amsterdam: Elsevier.
15. Pimentel, D. 1997. Techniques for Reducing Pesticides: Environmental and Economic Benefits. Chichester, UK: John Wiley & Sons.
16. Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Sphpritz, L. Fitton, R. Saffouri, and R. Blair. 1995. Environmental and economic costs of soil erosion and conservation benefits. Science 267: 1117-1123.
17. Pimentel, D., X. Huang, A. Cardova, and M. Pimentel. 1997. Impact of population growth on food supplies and environment. Population and Environment 19(1): 9-14.
18. Sparks Commodities. 1990. Impacts of the Richardson Amendment to H.R. 3030 on U.S. Agricultural Sector. McLean, VA: Sparks Commodities, Inc., Washington Division.
19. Troeh, F.R, J.A Hobbs, and R.L. Donahue. 1991. Soil and Water Conservation. 2nd ed., Englewood Cliffs, NJ: Prentice Hall.
20. USBC. 1996. Statistical Abstract of the United States. 201st ed. Washington, DC: U.S. Bureau of the Census, U.S. Government Printing Office.
21. USDA. 1989. Agricultural Statistics. Washington, DC: USDA.

HC#98/2-1-6

22. USDA. 1996. Agricultural Statistics. Washington, DC: USDA.

23. USWRC. 1979. The Nation's Water Resources. 1975-2000. Vol. 1-4. Second National Water Assessment, Washington, DC: U.S. Water Resources Council.
24. WHO. 1995. Bridging the Gaps. Geneva: World Health Organization.

The Author: David Pimentel

David Pimentel is a professor of ecology and agricultural science at Cornell University, Ithaca, NY 14853-0901. His Ph.D. is from Cornell University. His research spans the fields of energy, land and water conservation, and natural resource management. Pimentel has published more than 475 scientific papers and 20 books and has served on many national and government committees including the National Academy of Sciences; President's Science Advisory Council; U.S. Department of Agriculture; U.S. Department of Energy; U.S. Department of Health, Education and Welfare; Office of Technology Assessment of the U.S. Congress; and the U.S. State Department.

David Pimentel
College of Agriculture and Life Sciences
Cornell University
5126 Comstock Hall
Ithaca, New York 14853-0901
607-255-2212
607-255-0939 (fax)
dp18@cornell.edu

April 1998

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Colorado School of Mines
Golden, Colorado

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For further information contact:

Hubbert Center Chairman
Prof. Craig W. Van Kirk
Head of Petroleum Engineering Dept.
Colorado School of Mines
Golden CO 80401-1887
Phone 1-800-446-9488
Fax 1-303-273-3189
Internet Address: *http://hubbert.mines.edu*

Hubbert Center Coordinator
L. F. Ivanhoe
1217 Gregory St.
Ojai CA 93023-3038

Phone 1-805-646-8620
Fax 1-805-646-5506

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