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IMPLICATIONS OF THE USDA 2002 UPDATE ON ETHANOL FROM CORN

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Without doubt, there are workers in the field who would challenge some of the data used in the USDA's report, *The Energy Balance of Corn Ethanol: An Update*.[1] However, it is admirably comprehensive. It includes data from nine previous reports, and it uses them to guide its own judgements; so the best course of action would seem to be to accept the figures emanating from this USDA update, and enquire only about the implications. These are summarized in the final section.

First, we should note that ethanol has two possible functions. One of them is as a gasoline *enhancer*, that is to make gasoline burn more efficiently, producing less noxious gases. For this purpose, since no definite value can be ascribed to living in a smog free and healthy environment, no clear boundary can be set at which the energy efficiency of ethanol production becomes unacceptable. However, we should note that it seems likely that *overall*, using ethanol increases *atmospheric* pollution, as is fairly obvious from Shapouri et al.'s calculation (2002, p. 10) of an energy ratio of 1.34. This means that for each 100 units of ethanol emissions coming out of the tail pipe, a further 75 units are burnt 'off-scene'. In fact the balance of the evidence at present appears to be that ethanol increases even tailpipe emissions, but as the use of ethanol as a gasoline *enhancer* is not germane to this analysis, further points on that aspect are relegated to endnote 2.[2]

The other mooted function of ethanol is as a gasoline *extender*, that is to reduce the amount of gasoline that has to be used. It is this second function which has a reasonably clear boundary, and is the subject of this paper.

In order to be able to see the underlying energy efficiency more clearly, we will consider ethanol being used by itself to power vehicles (rather than as a gasoline extender), even though using undiluted ethanol may be unlikely to happen on a large scale.

The report's Table 1 uses an average corn yield of 125 bushels/acre = 308.7 bu/ha. The corn to ethanol conversion rate is shown in the same table as 2.66 gals/bu. So ethanol yield is:

308.7 x 2.66 x 3.785 = **3108** liters/ha.

The net energy value (surplus *useful* energy), as shown in Table 7, bottom line, comprises a co-product credit of 14,372 Btu/gal, to make a total of 21,105 Btu/gal = **5.88** MJ/liter. So net energy-capture (amount of *useful* energy captured per hectare), including co-products, is

3108 x 5.88 x 10^6 = 18.3 GJ/ha/yr = 18.3 / 31.5 = **0.58** kW/ha.

0.58 kW/ha is an impractically low net energy-capture. This is best shown by the following hypothetical case. Supposing that it were possible to make 50 Mha of cropland (nearly a third of U.S. cropland) available for growing corn for ethanol production, this would produce

0.58 x 50 x 10^6 = 29 x 10^6 kW.

For a population of 280 million, this is 29 / 280 = **0.104** kW/cap. As the amount of net power available to the average American is about 9 kW, this is **1.2**% of net energy — a tiny reward for the expenditure of 50 million hectares of cropland. That it would be almost impossible to allocate as much as 50 Mha for this purpose is of no concern, since the argument is of the *reductio ad absurdum* type — the premise which is hereby shown to be absurd is this: a *useful* amount of energy can be captured during the process of making ethanol from corn.

Production of liquid fuel

Although it is clear that it makes no sense to try to capture energy by producing ethanol, there is another possible reason for producing it. Shapouri et al. make the point that it is legitimate to look upon the ethanol program as one which is aimed at producing *liquid* energy, since the energy needed to effect the transformation into ethanol can mainly be derived from *"abundant domestic feedstocks such as coal and natural gas."* One might query the assertion that domestic supplies of natural gas are abundant,[3] and also question if coal will continue to be abundant in the light of the fact that Gever et al., 1986, reported that the gross output to input energy ratio for U.S. coal fell from 80:1 in the 1940s to 30:1 in the 1970s, but, since we are taking Shapouri et al. at face value, let us start by considering this question: to what extent will U.S. liquid fuel requirements be diminished if 50 Mha of cropland are used for growing corn for ethanol?

On page 11, the report states that *"about 83 percent of the total energy requirements come from non-liquid fuels, such as coal, and natural gas. The liquid fuels, which include gasoline, diesel, and fuel oil, account for about 21,700 Btu per bushel."*

In conjunction with our previous parameter — an average yield of 308.7 bu/ha — we can see that there is a need for

> 21,700 x 308.7 = 6.70 x 10^6 Btu/ha = 7.07 GJ/ha = 7.07 x 10^9 / 21.3 x 10^6 = **332** liters of ethanol/ha as input.

So the *net* ethanol yield = 3108 - 332 = **2776** liters/ha.

Thus our 50 million hectares will provide

> 50 x 10^6 x 2776 x 21.3 x 10^6 / 32.5 x 10^6 = **91** billion liters of *gasoline* equivalent.

U.S. gasoline consumption (March 2000 data) was 480 billion liters per year. 91 billion liters is 19% of that. Gasoline represents about 56% of the oil used in U.S. transport, so the 50 million hectares of cropland would supply about 11% of the liquid fuel used by U.S. transport. To put it another way, it would suffice to meet 10 years of U.S. population growth (at the 1.06% per year rate of the three closing decades of the last century).

It is unlikely that an attempt will be made to find 50 Mha of cropland for producing corn for ethanol when the benefit, *as a gasoline extender*, amounts to satisfying the transport demands of only 10 years of population growth. So let us look at a more realistic figure. Shapouri suggested to me that nobody plans for a future use of even 10 Mha. 10 Mha would provide the transport needs of 2 years of population growth. To put it in yet another light, at least 5 Mha of cropland are needed to satisfy the transport needs of 1 year's growth of U.S. population. It is hard to say *categorically* that it cannot be justified to put 5 Mha of cropland to this use, because that judgement depends on how important it is deemed to be to allow the population to keep expanding, and/or to maintain per capita liquid fuel consumption. Nevertheless, the great majority of people would surely deem it a mistake to use 5 Mha (50,000 km^2) in order to provide transport energy for just one year of U.S. population growth; especially because growing corn has many detrimental effects, which we will now consider within the context of 5 million ha being devoted to growing corn — sufficient to provide transport energy for 1 year of U.S. population growth.

Soil erosion is one of the fundamental problems of growing corn. The weight of stover — the residue of harvesting — is about equal to the weight of the crop. With this removed, erosion rates as high as 54 t/ha/yr have been reported, but it is normally left on the ground, and with conventional agriculture the soil erosion rate associated with growing corn is 15 t/ha/yr (Pimentel et al., 1995). This can be reduced to 5 t/ha/yr by adoption of no-till agriculture (Troeh and Thompson, 1993). The downside of

Table 1. Chemicals used for growing U.S. corn, covering both conventional and no-till agriculture

Application	Used on	5 Mha over 70 years[a]
	kg/ha/yr	tonnes
Insecticides	0.15[b]	52,000
Herbicides	2.10[b]	735,000
Nitrogen	144.93[c]	51,000,000
Phosphate	53.95[c]	19,000,000
Potash	66.37[c]	23,000,000
Total N, P, K	267.50	93,000,000

a Useful ethanol production, from 5 Mha, would be 9.1 billion liters a year, 1.9% of U.S. gasoline consumption, or **1.06**% of transport consumption — by coincidence, exactly the amount which would be sufficient for providing transport fuel for 1 year of population growth (which was **1.06**% per year over the last three decades of the past century). By taking a period of 70 years, the average lifespan, a measure is given of the total impact of one year's increment of people, under this 'ethanol scenario'.

b Average for all U.S. corn, covering both conventional and no-till agriculture (Pimentel, 2002).

c "Nine-State weighted average, 1996." Taken from page 6 of Shapouri et al., 2002.

Table 1.

no-till corn production is that it uses more herbicides, insecticides, molluscicides and rodenticides. Leaving this stover on the ground has the effect of keeping the soil moist, and suitable for slugs, providing an excellent habitat for mice, and results in more insect pests and plant pathogens attacking the corn. Despite these problems, Pimentel (2002) favors no-till agriculture for corn because it reduces soil erosion by over 50%. Since about 50% of US corn production is no-till, the average rate of soil erosion when growing corn is 10 t/ha/yr, or 50 mm in 70 years. 5 cm in a lifetime may not seem much, but 5 cm may be critical for substantial areas which already have thin soils. The other fundamental problem is that pesticides have an unquantifiable penalty in terms of damage done to insect life, and hence to the animals that feed on them and to biodiversity. And nitrogen pollution is already a serious problem, which causes both air pollution and contaminates water supplies.[4] The cost of dealing with excess nitrates in water is another hidden cost of ethanol production.

Based on average U.S. corn production, the 5 million hectares under consideration, sufficient for the transport needs of 1 year's population growth, would require, over a lifespan of 70 years, 52,000 tonnes of insecticide, 735,000 tonnes of herbicide, 51 million tonnes of nitrogen, 19 millon tonnes of phosphate and 23 million tonnes of potash (**Table 1.**). Also 5 cm of soil would be lost.

The implications of USDA Report Number 814

Shapouri et al.'s comprehensive, and brilliantly presented study of the entire range of earlier work done on the energetics of ethanol production leads to unequivocal conclusions:

1. Overall, ethanol increases atmospheric pollution. But when ethanol is being produced as a gasoline *enhancer*, to reduce *tail pipe* emissions, no clear boundary can be set at which the energy efficiency of ethanol production becomes unacceptable.

2. The amount of energy produced — as *useful* energy in liquid form — is so small in relation to the area of land needed to produce it, that the production of ethanol as a gasoline *extender* cannot be justified, especially in view of the associated environmental damage.

Acknowledgment

My thanks are due to David Pimentel, of Cornell University, not only for having brought the Report to my attention, but also for giving a great deal of help in developing the paper, by researching the relevant data on the detrimental ecological effects of growing corn under current U.S. agricultural practices, and much other valuable advice.

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Endnotes

1. United States Department of Agriculture (USDA), Agricultural Economic Report Number 813, by Hosein Shapouri, James A. Duffield, and Michael Wang, dated July 2002.

2. Probably the most authoritative survey of the use of ethanol in cars is that of Cal Hodge in the *Oil & Gas Journal*, Sept. 9, 2002, pp. 20-28. Hodge raises serious concerns about emissions at production plants. Omitting that aspect, I will quote him, compressing his conclusions concerning tailpipe emissions (mainly about the number of occasions on which legal limits on air pollution were exceeded) into the smallest possible compass:

> Using ozone is more likely to increased ozone exceedances and cancer risk. . . . Its use in reformulated gasoline [between the two periods 1993-94 and 1995-96] caused ozone exceedances to double.
>
> America should wait to see if California's switch to ethanol confirms or denies that ethanol increases ozone . . . If we do not want to wait for the outcome of the California experiment, the use of ethanol in motor gasoline should be banned, not expanded.

Turning now to 'off-scene' pollution, in addition to ethanol plant emissions, since coal and gas are used for 83% of the input (page 11 of the report), the situation seems to be this. The coal and gas combustion will amount to 0.83 x 77,228 = 64,099 Btu/gallon, or 64,099 / 83,960 = **76**% of the high heating value of the ethanol; thus the total release of fossil carbon may not be reduced at all (coal has a high carbon content), moreover carbon dioxide is far from being the only pollutant from burning coal. For the remaining 17% of inputs, liquid fuels are required. These would amount to 0.17 x 77,228 = 13,129 Btu/gallon, or 13,129 / 83,960 = **16**% of the HHV of ethanol. Thus 100 units of ethanol energy emerging from the tail pipe will be associated with 76 + 16 = another 92 units burnt 'off-scene'. In the main text, I gave a figure of 75 instead of 92. This is because Shapouri et al. increase the energy ratio to 1.34 by allocating some inputs to co-products. But even an *additional* emission of 75% still suggests fairly strongly that overall atmospheric pollution is increased by ethanol combustion.

3. U.S. natural gas *production* has roughly flat-lined for the last twenty years, at around 19 trillion cubic feet a year (tcf/yr). In the year 2000, US natural gas *consumption* was about 22 tcf. Between 1985 and 2000, imports from Canada increased by about 2.5 tcf/yr, to make up the difference. The increasing imports from Canada *might* just be because Canadian gas was cheaper, so U.S. gas producers consequently saw little profit in making substantial investment to expand production. However, that does not appear to be the explanation; rather it is increased difficulty in obtaining the gas: Texas, which produces one-third of US gas, in 1999 had to drill 6,400 wells to keep up its production, whereas 4,000 were sufficient in 1998. Neither are Canadian resources unlimited: Canadians are having to drill nearly 7,500 wells a year to keep up Alberta's production.

   Other reasons for doubting that U.S. natural gas supplies can be regarded as "abundant" are, first, that the Energy Information Administration have suggested that by 2015 the US may need 50% more natural gas than today, i.e. another 11 tcf/yr. The Energy Administration did not say where this was to come from. Secondly, during 2001 natural gas prices in the U.S. increased by an amount ranging from 33% to 50%, depending on location (Pimentel, 2002).

4. Problems of the nitrogen cycle were summarised by Danielle Nierenberg, in the March/April, 2001 issue of *World Watch*, in an article titled *Toxic Fertility*. It had the caption, *"Over the past half century, the amount of biologically active nitrogen circulating through the world's living things has probably doubled. In unnatural excess, an essential nutrient is becoming a kind of ecological poison."*

   Extracts relevant to corn-based ethanol production, and the associated problems, are: *"Fertilizer is often very inefficiently applied; much of it never reaches the crop. It leaches out of the fields and into the streams, or it's converted into a nitrogenous gas like nitrous oxide and escapes into the atmosphere. . . . Three basic reforms appear to be necessary if we are to achieve major reductions of our fixed nitrogen emissions. We will need to convert the dominant mode of agricultural production from its current, 'high input' paradigm to one that emphasizes organic production. . . . "*