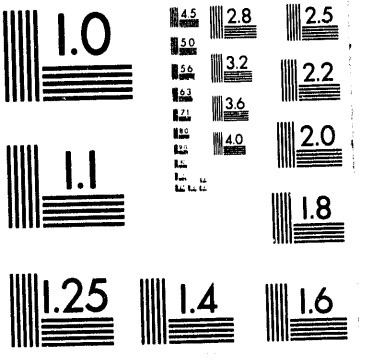
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IMPLICATIONS OF ETHANOL-BASED FUELS FOR GREENHOUSE GAS EMISSIONS

A Summary Prepared for the Governors' Ethanol Coalition
Governor E. Benjamin Nelson, chair

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by

Gregg Marland
Environmental Sciences Division
Oak Ridge National Laboratory *
Oak Ridge, TN 37831-6335

Mark A. DeLuchi
Institute of Transportation Studies
University of California
Davis, CA 95616

Charles Wyman
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393

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The U.S. Environmental Protection Agency has proposed a rule which would mandate that 30 percent of the oxygen content of reformulated gasoline be provided by renewable oxygenates. The rule would essentially require that biomass-based ethanol, or ETBE derived from ethanol, be used to supply 30% of the oxygen in reformulated gasoline. This short statement addresses the very narrow question, "Would this rule result in a net decrease in greenhouse gas emissions?"

In earlier papers, each of us has written separately about the implications of biomass-based transportation fuels for greenhouse gas emissions, but none of us has addressed the very specific question raised here. Without undertaking any new analyses, we try to summarize some of our earlier work and to show how it bears on the question posed. The question is not an easy one to provide with a precise, quantitative answer. It is not straightforward to compare our earlier work - we have had different objectives, have examined different systems, have chosen different boundary conditions. The available data are limited and sometimes in apparent conflict. We have not examined the exact alternatives to be contrasted. There are many important uncertainties in our understanding of what the system will look like and how all of the details should be treated. We will not provide a quantitative answer here. We believe, however, that our earlier work provides much insight into the greenhouse-gas implications of biomass-based ethanol and that this insight is useful in evaluating the proposed rule. This is a technical statement prepared by 3 scientists and we offer no apologies if it fails to provide a sharp quantitative distinction for those who must choose among the alternatives. The interested reader should consult our earlier papers for the details of our analyses.

At first glance, the question of greenhouse gas emissions from biomass-based fuels seems straightforward. Combustion of petroleum-based fuels releases to the atmosphere the greenhouse gas CO_2. Carbon is taken from long-term storage in the earth and released to the atmosphere as CO_2 as a necessary product of extracting useful energy from petroleum. The energy system is mature and we know the relationship between petroleum use and CO_2 emissions. On the other hand, ethanol is produced from, for example, corn. The growing corn plant removes CO_2 from the atmosphere and the CO_2 is simply recycled back to the atmosphere when the corn-derived products are burned. There is no net CO_2 released from the ethanol fuel itself. However, in order to produce corn and then ethanol, there are a variety of processes for which energy is required and during which CO_2 is thus released. In the

petroleum "fuel cycle" we need to consider how much energy is used for fuel production, refining, distribution, etc. In the ethanol "fuel cycle" we need to consider how much energy is used, and CO_2 released, for running tractors in the field, producing fertilizer, grinding and fermenting corn, etc. We need to carefully define systems which deliver equivalent services. And, we really should consider not just CO_2 but the full suite of greenhouse gases.

The challenge then is to determine how much greenhouse gas is emitted during the ethanol fuel cycle, a fuel cycle that is much less mature and less well documented than the petroleum fuel cycle. In the petroleum fuel cycle, most of the greenhouse gas emissions come from fuel combustion. In the ethanol fuel cycle most of the greenhouse gas emissions come from the fuel production processes. Details of corn productivity, fertilizer use, process efficiency, fuel source, etc. become very important. It is also important that the ethanol fuel cycle produces additional products and the greenhouse gas emissions have somehow to be allocated among the respective products. We need to acknowledge that, with so many variables in the ethanol fuel cycle, our concern is actually with ethanol-based additives which will be produced in response to the proposed rule, and not necessarily with the average of ethanol which is being produced now.

Table I shows emissions of greenhouse gases for four fuel cycles of interest here. The data are from DeLuchi (1991) and show emissions of all greenhouse gases summarized as CO_2 equivalents (based on IPCC indices of Global Warming Potential published in 1990) in units of grams CO_2 per mile of travel in a standard light duty vehicle. A first important observation is that the difference between standard gasoline and reformulated gasoline is very small so that when differences are drawn against alternative fuels, it makes little difference whether the contrast is against standard or reformulated gasoline. No where in our work have we considered the energy required to make ETBE from ethanol so our discussion below is based on using ethanol as the renewable oxygenate. A second observation is that for this base case comparison, emissions of CO_2 alone are roughly 13% less for the ethanol fuel cycle than for the reformulated gasoline cycle.

This last number provides us a point for preliminary comparison with the analysis published by Marland and Turhollow (M&T)- with all of the caveats about the details of the systems selected, the system boundaries, and the uncertainties in the analyses. M&T confined their analysis to CO_2 while DeLuchi tried to include all greenhouse gases, M&T tried to examine "the best

of current practice" while DeLuchi examined average current practice, DeLuchi expanded the system boundaries to include the vehicle while M&T made their comparison at the point of the energy content of the fuel. M&T reported that CO_2 emissions from the ethanol fuel cycle were 20 to 40% (depending on how by-products were treated) less than from the gasoline fuel cycle but added that "with the variability observed and the approximations necessary to complete these calculations, the results should be taken as approximate only." We strain the veracity of both analyses to suggest that they concur that, when compared with standard gasoline, the ethanol fuel cycle results in a small decrease in net CO_2 emissions when we examine average current practice and a decrease that may approach 30% when we examine the best of current practice. M&T did not examine the processes now under development which would allow production of ethanol from cellulosic feedstocks, but the DeLuchi analysis is clear that production of ethanol from wood by these processes would yield a substantial decrease in greenhouse gas emissions.

The DeLuchi analyses were published in 1991 and used, as did most analyses around that time, indices of Global Warming Potential (GWP) published by the IPCC in 1990. The 1992 Supplement to the IPCC report raised significant questions about the GWPs published in 1990, most importantly here with respect to NOX. In a supplement to his main text, DeLuchi has examined the implications of the IPCC 1992 values for GWP and at the bottom of Table 1 we show a revised total of greenhouse gas emissions when the GWP of NOX is taken to be 0, as now recommended. The effective total of all greenhouse gas emissions is now shown to be 11% higher for the ethanol fuel cycle than for the gasoline fuel cycle (10% in DeLuchi's supplement when all of the GWPs are changed to the 1992 values).

Another of the greenhouse gases merits some additional discussion here, N_2O. DeLuchi's text recognizes a contribution of N_2O from nitrogen fertilizers and from combustion but acknowledges the great variability and uncertainty in the emissions coefficients. An inventory of U.S. greenhouse gas emissions, published by the DOE in 1993 provides high and low estimates of U.S. N_2O emissions from nitrogen fertilizers which differ by a multiple of 14. We show in Table 1 the contribution of N_2O to the sum of greenhouse gas emissions and it is obvious that it is this contribution that now tips the balance and makes ethanol from corn a "loser" with respect to net greenhouse gas emissions. That is, if the estimated contribution of N_2O is significantly less than represented in this base case, the full fuel cycle for ethanol, with average current practice, could contribute to a net decrease in greenhouse gas emissions. DeLuchi's

analysis recognizes this problem and includes, as part of the sensitivity analysis, scenarios with reduced N_2O emissions - and net decreases in greenhouse gas emissions for the ethanol fuel cycle with respect to the standard gasoline fuel cycle.

To summarize the data presented in table 1, when we use best current understanding of the greenhouse contribution of NOX emissions, DeLuchi's base case analysis suggests that with the average of current practice, substitution of ethanol for reformulated gasoline would result in a small net increase in greenhouse gas emissions. The importance of N_2O in this calculation is such that this final value could be positive or negative, depending on the still poorly understood details of nitrous oxide production rates. Comparison of the data here with the estimates of M&T suggests that consideration of best current practice in the ethanol industry would result in net greenhouse gas reductions for the ethanol fuel cycle even with DeLuchi's base case estimate for N_2O emissions. DeLuchi's sensitivity analysis shows that a variety of assumptions about the treatment of by-product credits, process efficiency, and fuel type are important enough to swing the analysis from positive to negative for the average of current practice.

Will the proposed EPA rule result in a decrease in net greenhouse gas emissions? Based on the analyses available here, it will depend on the details of how ethanol is produced to meet the extra demand and on how effectively fertilizer nitrogen is, in fact, converted into N_2O. If new capacity more nearly resembles the best of current practice than it does the average of current practice, then it is likely that the rule will result in a decrease in greenhouse gas emissions. If the rule stimulates refinement and implementation of processes now under development for production of ethanol from cellulosic materials, then very large reductions in net greenhouse gas emissions are possible.

Greenhouse Gas Emissions From The Use Of Transportation Fuels‡
(grams CO_2 equivalent per mile)

	standard gasoline	reformulated gasoline	ethanol from corn	ethanol from wood
FUEL CYCLE STAGE				
gas leaks/flares	5.4	5.1		
feedstock recovery*	12.4	11.8	184.6	60.7
feedstock transport	11.1	10.6	16.5	13.9
fuel production	51.2	68.2	260.8	-63.1†
fuel distribution	5.9	5.9	19.3	14.1
vehicle end use	344.5	333.7	51.0	51.0
vehicle manufacture	55.9	55.9	55.9	55.9
Total	486.4	491.2	588.1	132.5
Total CO_2		404.1	352.5	32.0
Total Non-CO_2		87.0	235.5	100.4
Total N_2O		20.4	114.6	
Revised total (no contribution from NO_x)		459.4	511.7	

‡base case, total fuel cycle, using IPCC 1990, 100-year GWPs to calculate CO_2 equivalents

† becomes negative because of by-product credits, i.e., sale of excess electricity

* includes fertilizer manufacture and losses of N_2O from agriculture fields

references cited

DeLuchi, M. A., 1991, Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, ANL/ESD/TM-22, Vol.1, Center for Transportation Research, Argonne National Laboratory.

Isaksen, I. S. A., V. Ramaswamy, H. Rodhe, and T. M. L. Wigley, 1992, Radiative Forcing of Climate, pp. 47-67 *in* J. T. Houghton, B. A. Callander, and S. K. Varney (eds.) Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment, Cambridge University Press.

Marland, G., and A. F. Turhollow, 1991, CO_2 Emissions from the Production and Consumption of Fuel Ethanol from Corn, *Energy 16:1307-1316.*

Shine, K. P., R. G. Derwent, D. J. Wuebbles, and J-J. Morcrette, 1990, Radiative Forcing of Climate, pp. 41-68 *in* J. T. Houghton, G. J. Jenkins, and J. J. Ephraums (eds.) Climate Change: The IPCC Scientific Assessment, Cambridge University Press.

U. S. Department of Energy, Energy Information Administration, 1993, Emissions of Greenhouse Gases in the United States 1985-1990, DOE/EIA-0573, September, 1993.

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