Economic Cost of Biodiesel and Corn Ethanol per Net BTU of Energy Produced

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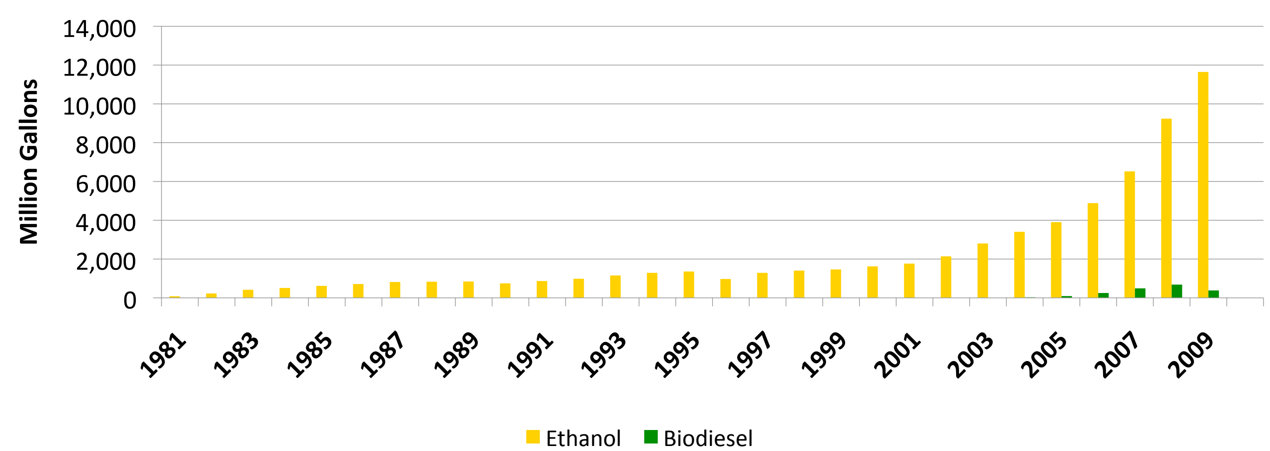
Biofuel production from first-generation technology, primarily ethanol from corn and biodiesel from transesterfication of soybean oil, has increased dramatically in recent years, now accounting for about 12 billion gallons annually. It takes energy—fossil fuel in particular—to grow, harvest, transport and convert plant biomass to liquid biofuel. Various scientific studies have examined the net energy contribution of first generation biofuels. This briefing paper extends the scientific studies to examine the aggregate economic cost per *net* Btu's generated from corn ethanol and from soy based biodiesel.

The fossil energy ratio (FER), defined as the ratio of the energy output of the final biofuel product to the fossil energy necessary to produce biofuel, is often used to measure the biofuel energy balance. Estimates of the net energy balance for corn ethanol vary widely. Pimentel estimated that corn ethanol requires more energy to produce than is contained in ethanol, and an FER of corn ethanol at 0.71.[i] An analysis of corn ethanol by USDA found an FER of 1.34,[ii] rising to 1.67 after accounting for co-product energy credits.[iii] However, the FER of 1.67 assumes that ethanol is able to replace gasoline on a gallon per gallon basis, which does not appear feasible with existing engines.[iv]

Studies of the FER for biodiesel derived by transesterfication of vegetable oils, particularly soybean oil, have shown much higher energy efficiencies. An often cited USDA study by Sheehan, et. al, showed an FER of 3.2.[v] A 2009 update by USDA established an FER of 4.40 for soy based biodiesel, increasing to 4.69 as projected soybean yield reaches 45 bushels per acre in 2015.[vi] A comparison of the trend in ethanol and biodiesel production is shown in Figure 1.

Figure 1. U.S. Production of Fuel Ethanol and Biodiesel



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Assumed energy inputs and ouptuts for corn ethanol and soy based biodiesel are shown in Table 1.[vii]

Table 1. Energy Input and Output Assumptions		
	Fossil Energy Use (Btu/gallon of Biofuel)	
Energy Inventory	**Biodiesel from Soybean Oil**	**Ethanol from Corn**
Agriculture	4,544	14,923
Transport	728	4,727
Crushing (soybeans)	3,930	
Conversion to Biofuel	15,467	39,171
Biofuel Transport	1,027	1,588
Total Energy Inputs Adjusted for Coproducts	25,696	60,409
Biofuel Total Energy Output	117,093	76,000
Net Energy Value	**91,397**	**15,991**
Fossil Energy Ratio	**4.56**	**1.26**

This briefing paper presents aggregate ***net*** Btu costs for corn ethanol or soy based biodiesel. U.S. total net Btu's considered are 100, 200, and 300 trillion Btu's. Table 2 shows the corn and biodiesel production levels expressed in million gallons of biofuel, gross and net. For example, 100 trillion Btu's come from 6,414 million gallons of ethanol, but considering fossil fuels for production of feedstock and conversion of the ethanol leaves only a net increase in energy of 1,350 million gallons. Effects of various combinations of corn ethanol and biodiesel can be interpolated from the scenarios in Table 2. About 12 billion gallons of ethanol and about 500 million gallons of biodiesel are currently produced in the U.S.

Table 2. Biofuel Production, Net and Gross						
	100 Trillion BTU Net		200 Trillion BTU Net		300 Trillion BTU Net	
	Corn Ethanol Only	Soybean Biodiesel Only	Corn Ethanol Only	Soybean Biodiesel Only	Corn Ethanol Only	Soybean Biodiesel Only
Gross Production (million gallons)	6,414	1,094	12,818	2,188	19,242	3,282
Net Production (million gallons)	**1,350**	**854**	**2,697**	**1,708**	**4,049**	**2,562**

AGSIM, a large-scale econometric-simulation model of the agricultural economy, was used to estimate the aggregate economic impacts on crop prices, farm income, taxpayer expenses, and food consumer well-being.[viii] Estimated impacts assume continuation of the $1.00/gallon tax credit for biodiesel from virgin vegetable oil and $0.45/gallon tax credit for corn ethanol. Results also assume a biofuel production cost, excluding feedstock cost, and includes co-product credits of $0.45/gallon for corn ethanol and $0.30/gallon for biodiesel. All costs and benefits are relative to a baseline of no biofuel production.

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Table 3 presents estimates of the aggregate economic effects from the various biofuel scenarios. The net economic surplus effect results in a positive farm income effect, negative food consumer effect, and negative taxpayer effect from biofuel tax credits, not accounting for the fuel market. The net economic surplus effects of producing a given level of net Btu's is substantially lower (less negative) with biodiesel than with corn ethanol, largely due to the substantially lower FER of ethanol compared to biodiesel (Table 1).

Table 3. Change in Key Economic Indicators for Producing Different Levels of Net BTU from Corn Ethanol and Soybean Biodiesel

CHANGE in Economic Surplus (million dollars) relative to ZERO Biofuel	100 Trillion BTU Net		200 Trillion BTU Net		300 Trillion BTU Net	
	Corn Ethanol Alone	Soybean Biodiesel Alone	Corn Ethanol Alone	Soybean Biodiesel Alone	Corn Ethanol Alone	Soybean Biodiesel Alone
Food Consumers' Well Being	-$6,159	-$3,580	-$14,265	-$11,714	-$23,848	-$26,356
Net Farm Income	$4,965	$4,568	$11,234	$12,240	$18,543	$24,608
Cost of Tax Credits	$3,271	$1,094	$6,542	$2,188	$9,813	$3,282
Net Surplus Change	**-$4,465**	**-$106**	**-$9,573**	**-$1,662**	**-$15,119**	**-$5,030**

Cost per gallon of biofuel, including production cost, feedstock cost, and net economic surplus effects, are shown in Table 4. These estimates are in terms of the biofuel output without accounting for energy inputs. Total cost per gallon of biodiesel is roughtly twice the cost of ethanol.

Table 4. Cost per Gallon of Producing Different Levels of Corn Ethanol and Soy Biodiesel

Cost per Gallon	100 Trillion BTU Net		200 Trillion BTU Net		300 Trillion BTU Net	
	Corn Ethanol Alone	Soybean Biodiesel Alone	Corn Ethanol Alone	Soybean Biodiesel Alone	Corn Ethanol Alone	Soybean Biodiesel Alone
Production Cost Allowing for Co-Product Credits	$0.45	$0.30	$0.45	$0.30	$0.45	$0.30
Feedstock Cost	$1.18	$2.93	$1.32	$3.43	$1.47	$4.15
Economic Surplus Cost	$0.70	$0.10	$0.75	$0.76	$0.79	$1.53
Total Costs	**$2.33**	**$3.33**	**$2.52**	**$4.49**	**$2.71**	**$5.98**

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Table 5 compares the total cost of biofuel on a gross and net energy basis, expressed per gallon of fuel.

Table 5. Biofuel Cost Comparison, Net and Gross

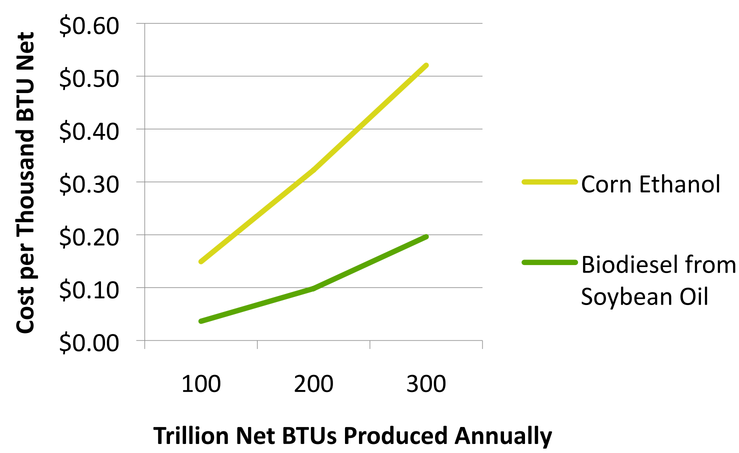
Cost ($/gallon)	100 Trillion BTU Net		200 Trillion BTU Net		300 Trillion BTU Net	
	Corn Ethanol Only	Soybean Biodiesel Only	Corn Ethanol Only	Soybean Biodiesel Only	Corn Ethanol Only	Soybean Biodiesel Only
per Gross Gallon Produced	$2.33	$3.33	$2.52	$4.49	$2.71	$5.98
per Net Gallon Produced	**$11.05**	**$4.27**	**$11.96**	**$5.76**	**$12.86**	**$7.66**

Since ethanol and biodiesel do not have the same Btu content per gallon (Table 1), a more appropriate cost comparison is per net Btu produced, as shown in Table 6 and Figure 2.

Table 6. Average Cost of Biofuel per Thousand Net BTU Produced

	100 Trillion BTU Net		**200 Trillion BTU Net**		**300 Trillion BTU Net**	
	Corn Ethanol Alone	Soybean Biodiesel Alone	Corn Ethanol Alone	Soybean Biodiesel Alone	Corn Ethanol Alone	Soybean Biodiesel Alone
Cost ($/1000 BTU)	**$0.1492**	**$0.0364**	**$0.3225**	**$0.0983**	**$0.5207**	**$0.1963**

Figure 2. Aggregate Economic Cost of Net BTU's From Corn Ethanol and Soybean Biodiesel



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Gross production of biofuel (ethanol) from an acre of corn is about 10 times higher than with biodiesel from soybean oil, and the per gallon tax credit for corn ethanol is less than one-half that of biodiesel. Nevertheless, due to a substantially lower FER, the net cost of a fossil fuel substitute is 2-3 times higher with corn ethanol than with soy-based biodiesel under current technology.

In the search for alternative renewable fuels in the US, a detailed review of implications (such as this briefing paper) on actual increases in the net amount of fuel as well as economic impacts on consumers, agriculture and taxpayers helps policy makers evaluate the consequences of alternative fuels.

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[i] Pimentel, David. 2003. "Ethanol Fuels: Energy Balance, Economics, and Environmental Impacts are Negative." *Natural Resources Research*, 12(2): 127-34. See also, Pimentel, David, and Tad W. Patzek. 2005. "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower." *Natural Resources Research*, 14(1): 65-76.

[ii] Shapouri, Hossein, James A. Diffield, and Michael Wang. 2002. "The Energy Balance of Corn Ethanol: An Update." Office of Energy Policy and New Uses, United States Department of Agriculture, Washington, D.C.

[iii] Hosein Shapouri and Andrew McAloon. "The 2001 Net Energy Balance of Corn-Ethanol, USDA/Agricultural Research Service (ARS). See also, Wang and Dan Santini, "Corn-Based Ethanol Does Indeed Achieve Energy Benefits," Center for Transportation Research, Argonne National Laboratory, February 15, 2000.

[iv] Shapouri and McAloon state, "A gallon of ethanol containing 76,330 Btu's is able to replace a gallon of gasoline containing about 115,000 Btu's because ethanol's higher octane rating (113-115, compared with 87) allows high-compression engines to perform as well with fewer Btu's." Actual fuel consumption studies, however, show lower mileage for ethanol and ethanol blends approaching the ratio of relative Btu's.

[v] Sheehan, J., V. Camobreco, J.A. Duffield, M. Graboski, and H. Shapouri, Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus, A Joint Study Sponsored by the U.S. Department of Agriculture and U.S. Department of Energy, NREL/SR-580-24089, National Renewable Energy Laboratory, U.S. Department of Energy, 1998.

[vi] Pradhan, A., D.S. Shrestha, A. McAloon, W. Yee, M. Haas, J.A. Duffield, and H. Shapouri, Energy Life-Cycle Assessment of Soybean Biodiesel, U.S. Department of Agriculture, Office of the Chief Economist, Office of Energy Policy and New Uses, Agricultural Economic Report 845, Sept. 2009.

[vii] Energy input and output assumptions in Table 1 differ from those used for the briefing paper by Emily K. Seawright, Ron D. Lacewell, Naveen Adusumilli, C. Robert Taylor, M. Edward Rister, **"**Net Energy Balance for Ethanol from Irrigated Corn in the High Plains of Texas," because that study applied only to irrigated corn and the study reported here applies to all corn produced in the U.S.

[viii] A brief description of AGSIM is available at:
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