NYSERDA New York State Energy Research and Development Authority

Environmental Impacts of Ethanol and Biodiesel

Review of Approach and Preliminary Results

Carl J. Mas
New York State Energy Research and Development Authority

September 14, 2007

HANDOUTS

Preliminary Ethanol Environmental Impact Matrix

Feedstock [a]	Total Fuel Cycle Net-Energy-Ratio [b]	Total Fuel Cycle Greenhouse Gas Emissions (g CO2eq/MJ) [c]
Corn (Coal)	**0.78 - 1.3** [d] [1,2,3,6,13]	**43 - 96** [e] [1,2,5,8,9,11]
Corn (Natural Gas)		
Corn (Biomass)		
Cellulosic - Mixed Grasses	**0.68 - 10** [d] [1,2,13]	**8.6 - 14** [1,2,5,8,9,11]
Cellulosic - Wood Crops		
Cellulosic - Wood Wastes		
Cellulosic - Stover		

NOTES

a - A significant amount of process energy is required to produce ethanol derived from corn. The source of a majority of the required energy is given in parentheses. Most plants at present use natural gas.

b - "Net-energy-ratio" is the energy content of a fuel divided by the nonrenewable energy required to produce and deliver the fuel. This is sometimes also called "energy return-on-investment". Note that the net-energy-ratio is not equivalent to petroleum savings, which can differ greatly from net-energy-ratio. Net energy ratio of conventional gasoline is 0.81 [1].

c - This refers to an assessment of greenhouse gas (GHG) emissions during the fuel cycle (from field-to-wheel). This metric is presented as net greenhouse gas emissions (g CO2-equivalent) per MJ of fuel. The g/MJ metric was chosen since this was the metric reported by the study authors. It can be interpreted as a full field to wheel result, with the caveat that a MJ of renewable fuel is assumed to be combusted at the same efficiency as a MJ of petroleum based fuel. The approximate GHG emissions of gasoline is 93 g CO2eq / MJ [2, 8, 9].

d - This wide range of net energy ratio values obscures the results in at least two ways: first, some older studies which reported values under 1.0 have generally been superseded by updated parameters, altered co-products handing, and other improvements; secondly, the largest single source of energy use for the corn-ethanol dry mill pathway is the process energy; and depending upon whether the process fuel assumption is for natural gas (the fuel of choice for the wide majority of existing and planned plants), coal, or biomass, the results vary considerably. For dry mill, natural gas fired plants, the range of net energy values would appear to be about 1.2 to 1.4. Upcoming intensive data analysis and study of existing work will deliver more detailed tabulations clarifying these two fundamental issues.

e - The wide range of greenhouse gas emissions reported occurs at least partially from the significant variation caused by the different process fuels. In very rough terms, to be clarified via further analysis, one would expect values of about 45, 75, and 95 g CO2eq/MJ for the process fuels biomass, natural gas, and coal, respectively [2].

SOURCES

[1] - Farrell, A.E., et al. "Ethanol Can Contribute to Energy and Environmental Goals", Science Volume 311: 506-508. 2006. http://rael.berkeley.edu/EBAMM/

[2] - Wang, M., et al. “Life-cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types”, Environmental Research Letters, Vol 2, 2007

[3] - Shapouri, H., et al., “The Energy Balance of Corn Ethanol: An Update”, USDA, Office of Energy Policy and New Uses, Agricultural Economic Report No 814. 2002. http://www.usda.gov/oce/reports/energy/aer-814.pdf

[4] - Hill, J., et al., “Environmental. Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels”, Proceedings of the National Academy of Sciences. Vol. 103: 11206-11210. 2006. www.pnas.org/cgi/doi/10.1073/pnas.0604600103

[5] - Turner, B.T., et al. "Creating Markets for Green Biofuels: Measuring and Improving Environmental Performance", Institute of Transportation Studies, U.C. Berkeley Transportation Sustainability Research Center. 2007. http://repositories.cdlib.org/its/

[6] - Hammerschlag, R. "Ethanol's Energy Return on Investment: A Survey of the Literature 1990 - Present". Environmental Science and Technology, Volume 40, No. 6. 2006.

[7] - Tilman, D., et al., “Carbon Negative Biofuels from Low-Input High Diversity Grassland Biomass”, Science, Vol. 314:1598-1600. 2006. http://www.sciencemag.org/cgi/content/abstract/314/5805/1598

[8] - U.S. EPA, “Regulatory Impact Analysis: Renewable Fuel Standard Program”, Ch. 6, 2007, http://nsdi.epa.gov/otaq/renewablefuels/420r07004.pdf

[9] - Wu, M., et al., “Fuel-Cycle Assessment of Selected Bioethanol Production Pathways in the United States”, Argonne National Labs. 2006. http://www.transportation.anl.gov/pdfs/TA/377.pdf

[10] - Delucchi, M.A., “Life-Cycle Analyses of Biofuels” (Draft Manuscript), Institute for Transportation Studies, U.C. Davis. 2006. hydrogen.its.ucdavis.edu/publications/pubpres/2006pub/delucchi06/attachment_download/file

[11] - Wu, M. et al., “Energy and Emission Benefits of Alternative Transportation Liquid Fuels Derived from Switchgrass: A Fuel Life Cycle Assessment”, Biotechnology Progress, Vol. 22:1012-1024. 2006. http://www.transportation.anl.gov/pdfs/TA/379.pdf

[12] - Sheehan, J. "Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus." U.S. Department of Energy's Office of Fuels Development. NREL/SR-580-24089. May 1998. http://www.nrel.gov/docs/legosti/fy98/24089.pdf

[13] – Pimentel, D., Patzek, T., “Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower,” Natural Resources Review, Vol 14, No. 1, March 2005.

Preliminary Biodiesel Environmental Impact Matrix

Feedstock [a]	Total Fuel Cycle Net-Energy-Ratio [b]	Total Fuel Cycle Greenhouse Gas Emissions (g CO2eq/MJ) [c]
Animal Fats / Used Cooking Grease		
Canola/Soy/Sunflower	**0.52 - 3.2** [d] [2, 4, 6]	**30 - 33** [2, 3] [e]
Palm Oil (Tropical)	**5.4 - 10** [5]	

NOTES

a - A significant amount of process energy is required to produce ethanol derived from corn. The source of a majority of the required energy is given in parentheses. Most plants at present use natural gas.

b - "Net-energy-ratio" is the energy content of a fuel divided by the nonrenewable energy required to produce and deliver the fuel. This is sometimes also called "energy return-on-investment". Note that the net-energy-ratio is not equivalent to petroleum savings, which can differ greatly from net-energy-ratio. Net energy ratio for low-sulfur diesel is 0.83 [4].

c - This refers to an assessment of greenhouse gas (GHG) emissions during the fuel cycle (from field-to-wheel) for B100. This metric is presented as net greenhouse gas emissions (g CO_2-equivalent) per MJ of fuel. The reported values for GHG emissions of petroleum diesel is 92 g CO2-equivalent) / MJ [3].

d - This wide range of net energy ratio values obscures the results as older studies which reported values under 1.0 have generally been superseded by updated parameters, altered co-products handing, and other improvements. Upcoming intensive data analysis and study of existing work will deliver more detailed tabulations clarifying this issue.

e - The reported values are for soy biodiesel (2) and a soy yellow grease mix (3).

SOURCES

[1] - Farrell, A.E., et al. "Ethanol Can Contribute to Energy and Environmental Goals", Science Volume 311: 506-508. 2006. http://rael.berkeley.edu/EBAMM/

[4] - Hill, J., et al., “Environmental. Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels”, Proceedings of the National Academy of Sciences. Vol. 103: 11206-11210. 2006. www.pnas.org/cgi/doi/10.1073/pnas.0604600103

[3] - U.S. EPA, “Regulatory Impact Analysis: Renewable Fuel Standard Program”, Ch. 6, 2007, http://nsdi.epa.gov/otaq/renewablefuels/420r07004.pdf

[4] - Sheehan, J. "Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus." U.S. Department of Energy’s Office of Fuels Development. NREL/SR-580-24089. May 1998. http://www.nrel.gov/docs/legosti/fy98/24089.pdf

[5] - THE ENERGY BALANCE IN THE PRODUCTION OF PALM OIL BIODIESEL - TWO CASE STUDIES: BRAZIL AND COLOMBIA. Rosélis Ester da Costa, Electo Eduardo Silva Lora. http://www.svebio.se/attachments/33/295.pdf August 2007

[6] – Pimentel, D., Patzek, T., “Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower,” Natural Resources Review, Vol 14, No. 1, March 2005.

Preliminary Ethanol Air Emissions

E85 ETHANOL[a] RELATIVE TO CONVENTIONAL GASOLINE

EMISSIONS	PERCENTAGE DIFFERENCE (RANGE)	SOURCES
PM	-20	1
CO	-40 to +31	1, 5, 9, 10, 12
HC	-30 to -15	10, 18
NOx	-20 to -10	1, 10
TOXICS:		
benzene (C6H6)	-87 to -50	6, 10, 18, 19
1,3-butadiene (C4H6)	-79 to -13	10, 18, 19
peroxyacetyl nitrate (PAN)	see b	
acetaldehyde	+1430 to +2149	6, 10,14, 19
formaldehyde (HCHO)	+240 to +254	10, 14, 19

E85 ETHANOL [a] RELATIVE TO REFORMULATED GASOLINE

EMISSIONS	PERCENTAGE DIFFERENCE (RANGE)	SOURCES
PM		
CO	-24 to +62	4, 7, 11, 15
HC	-15 to +18	7
NOx	-40 to -25	4, 7, 11, 15
TOXICS:		
benzene (C6H6)	-79 to -62	4, 7, 11
1,3-butadiene (C4H6)	-80 to -68	4, 7, 11
peroxyacetyl nitrate (PAN)	see b	
acetaldehyde (CH3CHO)	+1949 to +4340	4, 7, 11, 15
formaldehyde (HCHO)	+20 to +92	4, 7, 11, 15

E10 ETHANOL RELATIVE TO CONVENTIONAL GASOLINE

EMISSIONS	PERCENTAGE DIFFERENCE (RANGE)	SOURCES
PM	-36 to -30	17
CO	-32 to -9	2, 3, 8, 13, 16, 20, 17
HC	-19 to -5	3, 13, 16, 20, 17
NOx	-5 to +7	2, 3, 8, 13, 16, 20, 17
TOXICS:		3
benzene (C6H6)	-27	3
1,3-butadiene (C4H6)	-19	3
peroxyacetyl nitrate (PAN)	see b	
acetaldehyde (CH3CHO)	+89 to +180	2, 3, 8, 13, 16, 20, 17
formaldehyde (HCHO)	+6 to +28	2, 3, 8, 13, 16, 20, 17

NOTES

a. E85 is a blend of ethanol and gasoline ranging from 70% to 85% ethanol by volume. However, ethanol contains 5% gasoline as a denaturant; therefore, E85 does not contain more than 80% ethanol by volume.

b Although the connection between ethanol combustion and acetaldehyde emissions is well established, the relationship between ethanol combustion and PAN formation is harder to quantify. At this point, a range for PAN has not been presented in the matrix; however, a positive relationship with acetaldehyde emissions may be assumed.

SOURCES

1	AIR Ethanol Fact Sheet, Oklahoma Department of Environmental Quality, 2007
2	Anderson, L.G.; Wolfe, P.; Barrell, R.A.; Lanning, J.A. The effects of oxygenated fuels on the atmospheric concentrations of carbon monoxide and aldehydes in Colorado. In F.S. Sterrett (Ed.), Alternative Fuels and the Environment (pp. 75-102). Boca Raton, FL; Lewis Publishers, 1995.
3	Apace Research Ltd., Intensive Field Trial of Ethanol/Petrol Blend in Vehicles, ERDC Project No. 2511, 1998
4	Black, F.; Tejada, S.; Gurevich, M. alternative fuel motor vehicle tailpipe and evaporative emissions composition and ozone potential. *JAWMA* 1998, 48, 578-591.
5	Dept. of Energy (DOE). Ethanol. 2006; results summarized at www.afvi.org/ethanol.html.
6	Delucchi, M. Emissions of criteria pollutants, toxic air pollutants, and greenhouse gases from the use of alternative transportation modes and fuels; UCD-ITS-RR-96-12; U.C. Davis: Davis, CA; 1996; Table 13
7	Dept. Of Energy (DOE). Federal Test Procedure Results, E.E.R.E., 1999
8	EPA Fact Sheet EPA420-F-00-035, 2000.
9	General Motors Corporation. *2007 Model Year E85 and gasoline flex-fuel vehicle certification data summary; GM: Detroit, MI, 2007.*
10	Kiran L. Kadam, Environmental Life Cycle Implications of Using Bagasse-Derived Ethanol as a Gasoline Oxygenate in Mumbai (Bombay), Prepared for the National Energy Technology Laboratory Pittsburgh, Pennsylvania, USA and USAID, New Delhi, India, NREL/TP-580-28705, 2000.
11	Kenneth J. Kelly, Brent K. Bailey, Timothy C. Coburn, Wendy Clark, Peter Lissiuk, "Federal Test Procedure Emissions Test Results from Ethanol Variable-Fuel Vehicle Chevrolet Luminas," presented at Society for Automotive Engineers International Spring Fuels and Lubricants Meeting, Deerborn, MI May 6-8, 1996.
12	MacDonald, T. Alcohol fuel flexibility - progress and prospects, Presented at Fifteenth International Symposium on Alcohol Fuels, San Diego, CA, Sept. 26-28, 2005.
13	Mayotte, S.C.; Lindhjem, C.E.; Rao, V; Skiar, M.S. Reformulated Gasoline Effects on Exhaust Emissions: Phase 1: Initial Investigation of Oxygenate, Volatility, Distillation, and Sulfur Effects. SAE Technical Paper Series No. 941973, 1994.
14	Jacobson, M. "Effects of Ethanol (E85) Versus Gasoline Vehicles on Cancer and Mortality in the United States." Environmental Science and Technology, April 18, 2007.
15	NREL. Final results from Ohio ethanol-fueled light-duty fleet deployment project, 1998. Summarized in Karman, D. Ethanol Fueled Motor Vehicle Emissions: A Literature Review; 1998; www.cleanairnet.org/caiasia/1412/articles-69504_paper.pdf.
16	Reuter, R.M.; Benson, J.D.; Burns, V.R.; Gorse, R.A. Jr.; Hochhauser, A.M.; Koehl, W.J.; Painter, L.J.; Rippon, B.H.; Rutherford, J.A. Effects of Oxygenated Fuels and RVP on Automotive Emissions - Auto/Oil Air Quality Improvement Program. SAE Technical Paper Series No. 920326, pp. 391-412, 1992.
17	Ragazzi, R. and Nelson, K., The Impact of a 10% Ethanol Blended Fuel on the Exhaust Emissions of Tier 0 and Tier 1 Light Duty Gasoline Vehicles at 35 Degrees F, Colorado Department of Public Health and Environment, Mobile Sources Program, 1999.
18	Winebrake, J.; Dongquan, H; Wang, M. Fuel-Cycle Emissions for Conventional and Alternative Fuel Vehicles: An Assessment of Air Toxics. Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, US Dept. of Energy. 2000.
19	Winebrake, J.J.; Wang, M.Q.; He, D. Toxic emissions from mobile sources: A total fuel-cycle analysis for conventional and alternative fuel vehicles. *J. air Waste Management Association.* 2001, 51, 1073-1086.
20	Williams, Pamela R.D.; Cushing, Colleen A.; Sheehan, Patrick J. Data Available for Evaluating the Risks and Benefits of MTBE and Ethanol as Alternative Fuel Oxygenates, Risk Analysis, Vol. 23, No. 5, 2003.

Preliminary Biodiesel Air Emissions

B20 BIODIESEL RELATIVE TO NO. 2 DIESEL - TRANSPORTATION

EMISSIONS	PERCENTAGE DIFFERENCE (RANGE)	SOURCES
PM	-36 to 0	1, 3, 4, 5, 6, 7, 9, 10, 12, 13
CO	-38 to 0	3, 4, 5, 7, 9, 10, 12, 13
HC	-36 to 0	3, 4, 5, 7, 9, 10, 12, 13
NOx	-10 to +14	1, 3, 4, 5, 7, 9, 10, 12, 13
TOXICS:		
"Air Toxics"	-20 to -3	3, 11
Mutagenicity	-20	3, 11
benzene (C6H6)	-	
1,3-butadiene (C4H6)	-	
peroxyacetyl nitrate (PAN)	-	
acetaldehyde (CH3CHO)	-7.1	3
formaldehyde (HCHO)	-7.8	3
Acrolein	-1.5	3
Ethylbenzene	-44.9	3
n-Hexane	-48.7	3
Naphthalene	-13.8	3
Styrene	-3.7	3
Toluene		3
Xylene	-12.3	3

B20 BIODIESEL RELATIVE TO NO. 2 DIESEL - HEATING[a]

EMISSIONS	PERCENTAGE DIFFERENCE (RANGE)	SOURCES
PM	-13	8
CO	-10 to 0	2, 14
NOx	-20 to -10	2, 14

NOTES

a - Because stack emissions of CO and NOx are reported by the referenced sources as values relative to levels of stack oxygen (0_2), the metrics given here are estimated from charts.

SOURCES

1	Alam, M.; Song, J.; Acharya, R.; Boehman, A.; Miller, K. “Combustion and Emissions Performance of Low Sulfur, Ultra Low Sulfur and Biodiesel Blends in a DI Diesel Engine”, SAE Tech. Pap. No. 2004-01-3024 (2004).
2	Batey, John E., Energy Research Center Inc., Combustion Testing of a Bio-Diesel Fuel Oil Blend in Residential Oil Burning Equipment, 2003.
3	United States Environmental Protection Agency. “A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions”, Draft Technical Report, EPA420-P-02001, (2002).
4	Environment Canada. “Emissions Characterization of a Caterpillar 3126E Equipped with a Prototype SCRT System with Ultra Low Sulphur Diesel and a Biodiesel Blend”, ERMD Report # 2005-32 (2005).
5	Frank, B.et al., A Study of the Effects of Fuel Type and Emission Control Systems on Regulated Gaseous Emissions from Heavy-Duty Diesel Engines, SAE Tech. Pap. No. 2004-01-1085 (2004).
6	Frey, H.; Kim, K. “Operational Evaluation of Emissions and Fuel Use of B20 versus Diesel Fueled Dump Trucks”, Research Project No. 2004-18 FHWA/NC/2005-07, September 2005.
7	Holden, B.; Jack, j.; Miller, W.; Durbin, T. "Effect of Biodiesel on Diesel Engine Nitrogen Oxide and Other Regulated Emissions," Technical Report TR-2275-ENV, Naval Facilities Engineering Command, Port Hueneme, CA, 2006
8	Lee, S. W.; Herage, T.; Young, B. Emission reduction potential from the combustion of soy methyl ester fuel blended with petroleum distillate fuel. CANMET Energy Technology Centre, Natural Resources Canada, Published by Elsevier Ltd. 2004
9	McCormick, R.; Tennant, C.; Hayes, R.; Black, S.; Ireland, J.; McDaniel, T.; Williams, A.; Frailey, M.; Sharp, C. “Regulated Emissions from Biodiesel Tested in Heavy-Duty Engines Meeting 2004 Emission Standards”, SAE Tech. Pap. No. 200501-2200 (2005).
10	McCormick, R.L.; Williams, A.; Ireland, J.; Brimhall, M.; Hayes, R.R.; "Effects of Biodiesel Blends on Vehicle Emissions," National Renewable Energy Laboratory Milestone Report, NREL/MP-540-40554, 2006
11	NREL. "Biodiesel - Clean, Green Diesel Fuel," DOE/GO-102000-1449, 2002
12	Peterson, C.; Taberski, J.; Thompson, J.; Chase, C.L. “The Effect of Biodiesel Feedstock on Regulated Emissions in Chassis Dynamometer Tests of a Pickup Truck”, Transactions of the ASAE 43 (6) 1371-1381 (2000).
13	Souligny, M.; Graham, L.; Rideout, G.; Hosatte, P. “Heavy-Duty Diesel Engine Performance and Comparative Emission Measurements for Different Biodiesel Blends Used in the Montreal BIOBUS Project”, SAE Tech. Pap. No. 2004-01-1861 (2004).
14	Krishna, C.R. "Biodiesel Blends in Space Heating Equipment," NREL informal report prepared by Brookhaven national Laboratory, BNL-68852, 2001.

Preliminary Biofuels Land Use Impacts Matrix

Fuel	Feedstock	Yield (liters/ha)	Nitrogen Application (kg/ha/yr)	Nitrogen Runoff (kg/ha/yr)	Soil Erosion (tons/ha/yr)
Corn-ethanol	Corn (starch)	2,521 - 4,828 [1]	135 -153 [2, 5]	79 [2]	22 [2]
Cellulosic Ethanol	Switch grass	2,150 -2,336 [2]	50 [3]	9.5 [2]	0.2-2 [2]
	Wood crops	-	-	-	2-4 [2]
Biodiesel	Soy	353 - 544 [1, 6]	5.7-20 [6, 7]	16 [2]	-
	Canola (Rapeseed)	1,000-1,300 [3, 4]	-	-	-
	Sugar cane	5000 [3]	-	-	-
	Palm Oil	5800 [3]	-	-	-

Sources

[1] – Wright, L, Boundy, B, Perlack, B; Davis, S., Saulsbury, B., “BioEnergy Data Book,” Oak Ridge National Laboratory for US Department of Energy – Energy Efficiency and Renewable Energy. ORNL/TM-2006/571, 2006.

[2] – Greene, N. et al, “Growing Energy: How Biofuels Can Help End America's Oil Dependence,” Natural Resources Defense Council, December 2004.

[3] – Fulton, L., “Biodiesel: Technology Perspectives,” Slide presentation at at Geneve UNCTAD Conference, UNEP Division of Global Environmental Facility Coordination, 2006.

[4] – Energy Systems Research Unit, University of Stratheclythe, “Biodiesel Production,” http://www.esru.strath.ac.uk/EandE/Web_sites/02-03/biofuels/quant_biodiesel.htm#limitations, Accessed on 9/07/2007

[5] – Pimentel, D., Patzek, T., “Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower,” Natural Resources Review, Vol 14, No. 1, March 2005.

[6] - Hill, J., Nelson, E., Tilman, D., Polasky, S., Tiffany, D., “Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels - Table 2 Farm Energy Inputs into Soybean biodiesel production," Proceedings National Academy of Sciences, vol. 103 no. 30, July 25, 2006.

[7] – National Renewable Energy Laboratory, “Life Cycle Inventory of Biodiesel and Petroleum Diesel – Table 49,” NREL/SR/580-24089. May 1998.

Ethanol Byproduct Allocation

There are a number of by-products made during the production of ethanol. In lifecycle analyses, the energy consumed and emissions generated by an ethanol plant must be allocated not only to ethanol, but also to each of the by-products. There are a number of methods that can be used to estimate by-product allocations. These include methods based on the economic value of each by-product, or on energy usage, based on engineering analysis of the actual processes related to each product. The method preferred by EPA is called the displacement method. This method most accurately accounts for these by-products by calculating the lifecycle emissions of the products that will be displaced by them. In this method the lifecycle emissions of the displaced product are calculated and subtracted from the ethanol lifecycle. The ethanol receives a credit for the lifecycle emissions of whatever product is displaced, since a quantity of that product is no longer needed and is displaced by the ethanol by-products.

For example, the DDGS produced by an ethanol dry mill plant is a replacement for corn and soybean animal feed. We based the amount of DDGS produced by an ethanol dry mill plant on the USDA model used in the cost analysis work of this rulemaking. That model predicted 6.21 dry lb. of DDGS per gallon of ethanol produced. As per the agricultural sector modeling done for this rulemaking, we assumed that this DDGS displaces 50% corn and 50% soybean meal on a mass basis. So the lifecycle emissions of producing 3.1 lb. of corn and 3.1 lb. of soybean meal were calculated and subtracted from the lifecycle emissions associated with producing a gallon of ethanol.

By-products from the ethanol wet milling process include corn gluten meal and corn gluten feed that are assumed to displace corn production, as well as corn oil that is assumed to displace soybean oil. Ethanol produced from cellulosic feedstock through the fermentation route is assumed to produce excess electricity as a by-product, from onsite combustion of lignin. This excess electricity is assumed to displace electricity from the grid. The fermentation process used to produce ethanol in corn wet and dry milling and cellulosic ethanol production also produces CO_2 as a by-product. This CO_2 could be sold to an organization that specializes in cleaning and pressurizing it for use in the food industry for example to carbonate beverages, to manufacture dry ice, and to flash freeze meat. While CO_2 could potentially displace other sources of CO_2 production, this was not considered in our analysis and no value was associated with this CO2 co-product.

Taken from:

EPA420-R-07-004 April 2007
"Regulatory Impact Analysis: Renewable Fuel Standard Program"
Assessment and Standards Division Office of Transportation and Air Quality U.S.
U.S. Environmental Protection Agency