Biofuel Energy Balance Review

Yuki Otoko, August 2008

Contents

1. What is energy balance?

Energy Balance	Energy OUT / Energy IN
EROEI – Energy Return on Energy Invested	
EPR – Energy Profit Ratio	

OR: The energy used to obtain a unit of energy. An EROEI or ERP of
1.0 means that the energy used to obtain a unit of energy was one unit. **1:1 conversion of energy**.
<1.0 means that the energy used to obtain a unit of energy was MORE than a unit of energy. I.e. there was a net energy **loss**
>1.0 means that the energy used to obtain a unit of energy was LESS than a unit of energy. I.e. there was a net energy **gain**.

For further information, please refer to:
http://en.wikipedia.org/wiki/Ethanol_fuel_energy_balance
http://en.wikipedia.org/wiki/Energy_balance

2. World production of liquid fuels

Here is a table showing world production of liquid fuels that is useful in getting biofuels into perspective. Biofuels provided just under 1% of world commercial liquid fuels in 2005, but this proportion is probably rising rapidly.

Table 1: World Production of liquid fuels (million tons, 2005)

Hydrocarbons		Biofuels	
Resource	**Fuels**	**Raw materials**	**Biofuels**
Petroleum (4252 MT, 184.9 EJ)	Gasoline (1237 MT, 53.8 EJ) *Diesel (1077 MT, 46.1 EJ) LPG (391 MT, 11.9 EJ) Kerosene (92 MT, 3.9 EJ)	Sugarcane (1292 MT) Maize (702 MT) Wheat (628 MT)	**Ethanol (36 MT, 0.96 EJ)**
		Soy (214 MT) Rapeseed (47 MT) Sunflower (31 MT) Palm (8 MT) Castor seed (1.4 MT)	**Biodiesel (3.2 MT, 0.12 EJ)**
	Total 115.7 EJ		**Total 1.1 EJ**

Source: The Global Dynamics of Biofuels, http://www.wilsoncenter.org/topics/pubs/Brazil_SR_e3.pdf
MT = million tonnes, EJ = Exajoules = 10^{18} J
Notes: 2003 for palm, gasoline, diesel, LPG and Kerosene. *Distillated Diesel. LPG: Liquified petroleum gases.

3. Energy balance in bioethanol production from corn (maize) in the USA

The main controversy surrounding the conventional production of bioethanol from corn (maize) through energy- intensive (fossil-energy-resource-intensive) agriculture on good cropland capable of producing food for the human population is the energy balance of the resulting bioethanol with respect to the fossil fuel inputs.

In this review I have tried to give an overall comparison of the various studies, through converting all units into the metric SI system (joules, kilograms, tonnes, and so on), give a certain amount of explanation and extra relevant information, and state the main conclusions. Even so, some may feel that there is still too much data shown. I have tried to be brief, but at the same time show why different researchers reached different conclusions. For full details of the data and the conversions to metric units, please see the Excel file "Bioethanol Conversion Units.xls" AND the original papers, all of which can be found on the Internet, URLs being given in the Excel file and in the reference section to this review.

The main points are:

1. Is the energy balance positive or negative?
2. What is counted as output? E.g. does a negative energy balance become positive when coproducts are included in the energy balance?
3. Are the data used old or up-to-date, national averages, regional averages, best practices, state-of-the-art, and so on? This may include corn yield, amounts of fertilizers, especially nitrogen fertilizers, and so on.
4. What is counted in the energy input side? Are fossil fuel inputs only counted, or is there some energy factor input for human labour, machinery, plant buildings and other infrastructure?

Firstly, Shapouri (2002) and Graboski (2002) both give brief reviews of the results from other studies along with their own results.

Table 2: Energy input assumptions of corn-ethanol studies (Shapouri, 2002)

Study/year	Corn Yield	Nitrogen Fertilizer Application Rate	Inputs for N Fertilizer	Ethanol Conversion Process	Total Energy Use	Coproduct Energy Credits	Energy Content of Ethanol	**EPR Excluding Coproducts**	**EPR Including Coproducts**
	kg/ha	kg/ha	J/kg	MJ/1000					
Pimentel (1991)	6406.3	152.32	87343.6	20.537	36.514	5.992	21.18	**0.58**	**0.694**
Pimentel (2001)	7396.4	144.48	78030.3	20.935	36.527	5.992	21.18	**0.58**	**0.694**
Keeney and DeLuca (1992)	6930.4	151.2	88290.3	13.509	25.416	2.251	20.81	**0.82**	**0.9**
Marland and Turhollow (1990)	6930.4	142.24	72420.0	13.964	20.605	2.265	23.40	**1.136**	**1.276**
Lorenz and Morris (1995)	6988.7	137.76	64209.2	15.038	22.600	7.686	23.44	**1.037**	**1.57**
Ho (1989)	5241.5	NR	NR	15.886	25.083	2.926	21.18	**0.844**	**0.956**
Wang et al. (1999)	7279.9	146.72	49060.0	11.385	19.077	4.167	21.18	**1.11**	**1.42**
Agri. and Agri-Food Canada (1999)	6755.7	140	NR	14.051	19.077	3.917	21.18	**1.11**	**1.4**
Shapouri et al. (1995)	7105.2	140	51541.8	14.848	23.083	4.196	23.40	**1.014**	**1.24**
This study (2002)	7279.9	144.48	42779.8	14.431	21.523	4.005	23.40	**1.09**	**1.34**
NR: Not reported									

Table 3: Net Energy and Energy Ratio of Recent Corn-Ethanol Studies (Graboski, 2002, p.13)

Study/Year	Corn Yield	Ethanol Yield	Ethanol Plant	Total Energy Use	Co-product Credits	Net Energy	**Energy Ratio (EPR)**
	kg/ha	l/kg	MJ/1000				
This Study, 2000 Baseline	8,153.5	0.424	15.34	21.60	4.13	3.72	**1.21**
This Study, 2002-2004 New Plants	8,153.5	0.437	13.36	19.66	3.59	5.11	**1.32**
This Study, 2002-2004 Industry	8,153.5	0.429	14.64	20.91	3.94	4.21	**1.25**
This Study, 2012 Industry	8,968.8	0.448	12.76	17.97	2.80	6.02	**1.40**
Wang (2001)	7,279.9	0.413	10.89	18.55	3.99	6.62	**1.46**
Agriculture & Agri -Food Canada (1999)	6,755.7	0.430	14.05	19.00	3.92	8.40	**1.56**

Note that sometimes different results are reported for the same study (Agriculture & Agri-Food Canada (1999)). It can be seen that results are in the range of about 0.6 to 1.57. Pimentel is well known for his conspicuously low results. This is usually attributed to old (low) data for corn yields, old (high) data for nitrogen fertilizer (N) production and application, and old (high) data for the production process of the bioethanol. This can be seen quite clearly in the above tables, where positive EPRs are generally associated with higher corn yields, lower N application, lower energy inputs for N production, and lower energy use for the bioethanol production process..

Table 4: Energy Inputs to US Corn Production (Pimentel, 2003, 2005)

Inputs	**MJ/ha (2003)**	**MJ/ha (2005)**
Labor	1.055	1.934
Machinery	5.967	4.262
Diesel	3.798	4.199
Gasoline	2.334	1.696
Nitrogen	11.555	10.249
Phosphorus	0.924	1.130
Potassium	0.785	1.051
Lime	0.928	1.319
Seeds	2.195	2.177
Irrigation	3.971	1.340
Herbicides	0.886	2.596
Insecticides	0.063	1.172
Electricity	0.143	0.142
Transportation	1.131	0.708
TOTAL	**35.737**	**33.976**
Yield: tonnes **Yield MJ**	**8.590** **130.507**	**8.655** **130.452**
EPR	**3.652**	**3.840**
MJ/tonne	**4.160**	**3.926**

Table 5: Inputs Per 1000 litres of 95% Ethanol Produced from Corn (Pimentel, 2003, 2005)

Inputs	MJ/1000 litres (2003)	MJ/1000 litres (2005)
Corn	11.21	10.56
Transport of corn	1.32	1.35
Water	0.38	0.38
Stainless steel	0.38	0.05
Steel	0.59	0.05
Cement	0.25	0.03
Coal (Steam)	10.89	10.66
Electricity (kWh)	2.61	4.23
95% ethanol to 99.5%	NR	0.04
Sewage effluent	NR	0.29
TOTAL	27.63	27.62
Output: 1 liter of ethanol	21.46	21.46
EPR=	**0.777**	**0.777**

The above two tables show how Pimentel includes quite high figures for human labour, machinery, N applications, and so on, and that even though some of the figures fall in the two years from 2003 to 2005, somehow Pimentel still manages to come out with the same negative energy balance for the production of bioethanol in the two studies, possibly partly due to the rise in proof of the ethanol produced from 95% to 99.5%. Detailed critiques of Pimentel's studies can be seen in Graboski (2002), Morris and Blume (pp.519-525). Graboski states that, "The total 'capital energy' is estimated to be in the order of 1% of the energy in the ethanol." In the above table, Pimentel's 2003 figures appear to represent about 4.45% whereas the 2005 figures appear to be about 0.5% of the total energy input.

Graboski shows two tables comparing his work with the of Pimentel (2001). These tables show quite clearly how Pimentel arrives at a negative energy balance for bioethanol.

Table 6: Comparison of Key Assumptions (Graboski, p.71)

	Pimentel	This Work, dry mill
Energy in machinery and human labor	Yes	No
Corn Yield, kg/ha	7396	8153
Energy in N fertilizer, LHV J/kg	77,884	51,188
Nitrogen use, kg/tonne corn produced	19.6	18.5
Energy in Irrigation, MJ/ha	12.88	1.10
Energy in Ethanol Manufacture, MJ/1000 l	19.3	13.3
Ethanol yield, litres/tonne of corn	0.400	0.424
Co product credit	No	Yes

Table 7: Comparison of Energy Balances, Pimentel Compared to This Study result for Total LHV MJ/1000 litres, 2000 and 2012 Industry Average Ethanol Production (Graboski, p.72)

	Pimentel (2001)	2000	2012
Energy in ethanol	21.181	21.181	21.181
Corn Production & Transport	15.551	6.051	4.924
Ethanol Production & Distribution	20.882	14.935	12.586
Co product Credit	0.000	-3.225	-2.784
Total Inputs	36.433	17.760	14.727
Net Energy Difference	-15.252	3.421	6.455
Energy Ratio (EPR)	**0.581**	**1.193**	**1.438**

Lorenz and Morris show a spread of energy inputs and positive energy balances for industry average, industry best, and state-of-the-art production of bioethanol from corn.

Table 8: Energy Used to Make Ethanol From Corn and Cellulose (Lorenz and Morris, 1995)
(MJ/1000 litres)

	Corn Ethanol (Industry Average)	**Corn Ethanol (Industry Best)**	**Corn Ethanol (State-of-the-Art)**	**Cellulosic Crop-Based Ethanol**
Fertilizer	3.62	2.10	1.08	0.99
Pesticide	0.30	0.18	0.11	0.12
Fuel	0.74	0.44	0.37	2.26
Irrigation	1.96	1.85	1.69	-
Other (Feedstock)	0.95	0.91	0.87	0.71
Total (feedstock)	7.56	5.47	4.12	4.09
Process Steam	10.24	7.86	7.30	13.68
Electricity	4.03	2.03	1.43	2.49
Bulk Transport	0.37	0.31	0.22	0.37
Other (process)	0.40	0.36	0.29	0.59
Total (processing)	15.04	10.56	9.25	17.12
TOTAL ENERGY INPUT	22.60	16.03	13.36	21.21
Energy in Ethanol	23.44	23.44	23.44	23.44
Co-product Credits	7.69	10.11	10.11	32.16
TOTAL ENERGY OUTPUT	31.12	33.54	33.54	55.60
Net Energy Gain	8.53	17.52	20.18	34.39
EPR	**1.38**	**2.09**	**2.51**	**2.62**

Table 9: Agricultural Energy Use for Corn Production in the United States (Lorenz and Morris, 1995)

	Average (National)		**Best Existing (State)**		**State of the Art (Farmer)**	
	kg/ha (corn)	MJ/ha (corn)	kg/ha (corn)	MJ/ha (corn)	kg/ha (corn)	MJ/ha (corn)
Nitrogen	137.76	8.862	81.76	5.260	42.56	2.738
Phosphorus	52.64	0.757	41.44	0.596	16.80	0.242
Potash	61.60	0.749	23.52	0.286	19.04	0.231
Pesticide	3.36	0.847	2.15	0.524	1.34	0.337
Fuel	54.68	2.118	32.90	1.274	28.32	1.097
Irrigation	-	5.628	-	5.290	-	4.829
Other	-	2.711	-	2.645	-	2.592
Total Energy	-	21.671	-	15.874	-	12.065

(red figures: litres/ha)

It should also be note that studies such as Shapouri's use averages of corn cultivation data from the nine largest corn-growing states, this being thought to be the method of reaching the most representative values for the USA. In contrast, Pimentel has attempted to average corn agriculture statistics over *all* states. This is also possibly one reason why his yield figures are lower than those cited by other researchers.

Finally, Shapouri shows how the manufacture of bioethanol by conventional agricultural practices 'replaces' one litre of gasoline with seven litres of bioethanol.

Table 10: Energy requirements by feedstock and petroleum replacement value of ethanol (Shapouri, 1995)

Item	Dry Mill	Wet Mill	Weighted Average
	J/kg		
Coal Total	5868	6306	6162
Natural gas & LP Total	1277	1277	1277
Liquid fuels Total	**1349**	**1338**	**1342**
Total energy input	8494	8921	8780
Total energy output	**9765**	**9389**	**9513**
Petroleum replacement factor	**7.236**	**7.017**	**7.090**

This table shows that one unit of ethanol 'replaces' about 7 units of liquid fuels by turning coal, natural gas and LP into liquid ethanol, which is quite important if your goal is to reduce dependency on imports of liquid fuels or crude oil.

In conclusion, although results depend on what is counted, the more recent the data and the more up-to-date the bioethanol production process, the higher (more often positive) the resulting energy balance for the converting of fossil fuels to liquid bioethanol through corn is likely to be.

4. Energy balance in bioethanol production from sugarcane (Brazil)

There is little doubt that the energy balance for the production of bioethanol from sugarcane is positive. Here are the figures from the *Assessment of greenhouse gas emissions in the production and use of fuel ethanol in Brazil*, Isaias de Carvalho Macedo, March 2004.

Table 11: Energy consumption in sugar cane production

Level		Scenario 1	Scenario 2
		MJ/tonne of cane	MJ/tonne of cane
1	Fuel		
	Agricultural operations/harvesting	38.09	38.09
	Transportation	42.96	36.51
	Level total	**81.05**	**74.60**
2	Fertilizers	66.53	63.44
	Lime	7.14	7.14
	Herbicide	11.26	11.26
	Pesticides	0.80	0.80
	Seeds	5.88	5.59
	Level total	**91.61**	**88.23**
3	Equipment	29.18	29.18
	Level total	**29.18**	**29.18**
	Total	**201.84**	**192.01**

Notes: The energy flows have been considered in two situations: one (Scenario 1), based on the average values of energy and chemical utilizations, and the other (Scenario 2), based on the best existing values (minimum consumption values resulting from the application of the best technology in use by the sector). The use of these scenarios allows not only the characterization of the present situation (Scenario 1) but also the estimation of a situation that may become reality in the medium term (Scenario 2) by the widespread use of good practices already being used in some mills.

Level 1 – Only the direct consumptions of external fuels and electricity (direct energy inputs) are considered.

Level 2 – The energy required for the production of chemicals and materials used in the agricultural and industrial processes (fertilizers, lime, seeds, herbicides, sulfuric acid, lubricants etc.) is added.

Level 3 – The energy necessary for the fabrication, construction and maintenance of equipment and buildings is added.

Table 12: Energy consumption in the production of ethanol

Level		Scenario 1	Scenario 2
		MJ/tonne cane	MJ/tonne cane
1	Electric energy	0	0
2	Chemicals and lubricants (A9)	6.36	6.36
3	Buildings (A10)	11.97	9.29
	Heavy equipment	14.53	11.30
	Light equipment	16.54	12.85
	Total	**49.40**	**39.82**

Table 13: Energy generation and consumption in the production of sugar cane and ethanol

	Scenario 1		Scenario 2	
Activity	MJ/tonne cane			
Sugar cane production (total)	201.84		192.01	
Agricultural operations	38.09		38.09	
Transportation	42.96		36.51	
Fertilizers	66.53		63.44	
Lime, herbicides, pesticides etc.	19.20		19.20	
Seeds	5.88		5.59	
Equipment	29.18		29.18	
Ethanol production (total)	49.40		39.82	
Electricity	0.00		0.00	
Chemicals, lubricants	6.36		6.36	
Buildings	11.97		9.29	
Equipment	31.07		24.16	
External energy flows	**Input**	**Output**	**Input**	**Output**
Agriculture	202		192	
Factory	49		40	
Ethanol produced		1,922		2,052
Surplus bagasse		169		317
Total	**251**	**2,091**	**232**	**2,369**
Output:input (EPR)		**8.32**		**10.22**

Although the energy balance for the production of bioethanol from sugarcane is positive with respect to fossil energy resource inputs, can this production be carried out without the use of fossil fuels? This would necessitate the return of the bagasse to the soil as fertilizer and/or other sustainable fertilizer and soil protection methods. The process fuel would then have to come from the bioethanol produced. Making appropriate changes to Scenario 2 in the lower part of Table 13 above would result in the following "sustainable production" scenario.

Table 14: "Sustainable production" of bioethanol from sugarcane

External energy flows	**Output**
Ethanol produced	2,052
Ethanol used in Agriculture	-192
Ethanol used for process fuel	-40
Surplus bagasse	0
Total	**2,012**
% ethanol recycled	**6.43%**

The theoretical result is that by recycling the bagasse and about 6.5% of the ethanol produced into the production process, a "sustainable" production system is achieved. This does not take into account the energy savings from the substitution of bagasse (and other sustainable fertilizers) for the nitrogen fertilizer, so the final result might be a little better than this. In theory, any process with an energy balance (EPR) of more than 1 could be self-sustaining from its own production, once the system is up and running. In practice, however, and depending on the nature of the coproducts, it would probably be difficult to carry this out with a process whose EPR was lower than about 3.

Finally, a useful comparative table is to be found at: http://en.wikipedia.org/wiki/Ethanol_fuel_in_Brazil

Table 15: Comparison of key characteristics between the ethanol industries in the United States and Brazil

Characteristic	Brazil	U.S.	Units/comments
Feedstock	Sugarcane	Maize	Main cash crop for ethanol production, the US has less than 2% from other crops.
Total ethanol production (2007)	5,019.2	6,498.6	Million U.S. liquid gallons Brazil: 18,000 m litres U.S.: 24,600 m litres
Total arable land	355	270[1]	Million hectares.
Total area used for ethanol crop	3.6 (1%)	10 (3.7%)	Million hectares (% total arable)
Productivity per hectare	7,500	3,000	Liters of ethanol per hectare. Brazil is 727 to 870 gal/acre (2006), US is 321 gal/acre (2005/06)
Energy balance (input energy productivity, ERP, EROEI)	8 to 10 times	1.3 to 1.6 times	Ratio of the energy obtained from ethanol/energy expended in its production
Estimated greenhouse gas emission reduction	86-90%[2]	10-30%[2]	% GHGs avoided by using ethanol instead of gasoline, using existing crop land.
Ethanol fueling stations in the country	33,000 (100%)	873 (0.5%)	As % of total fueling gas stations in the country. U.S. has 170,000 (see Inslee, op cit pp. 161)
Fuel ethanol used by the road transport sector	20%[3]	3.6%	As % of the sector's total on a volumetric basis for 2006.
Cost of production (USD/gallon)	0.83	1.14	2006/2007 for Brazil (22¢/liter), 2004 for U.S. (35¢/liter)
Government subsidy (in USD)	0	0.51/gallon	U.S. as of 2008-04-30. Brazilian ethanol production is no longer subsidized.
Import tariffs (in USD)	0	0.54/gallon	As of April 2008, Brazil does not import ethanol, the U.S. does
Notes: (1) Only contiguous U.S., excludes Alaska. (2) Assuming no land use change. (3) Excluding diesel-powered vehicles, ethanol consumption in the road sector is more than 40%			

Blume also gives interesting background to sugarcane production in his book (pp.166-171).

5. Energy balance in biodiesel production

This is by no means a full review of the energy balance of biodiesel fuel, but rather a comparison of energy balance results from Pimentel (2003, 2005) and a study of the energy balances from various fuels by Woods and Bauen (2003).

Table 16: Summary of energy balances for some bioethanol and biodiesel crops (Pimentel 2003, 2005)

Raw material	Energy cost of crop production (MJ/tonne)	EPR of crop production	EPR of biofuel production	Biofuel Product
Corn (2002)	4.16	3.65	0.777	95% ethanol
Corm (2005)	3.93	3.84	0.777	99.5% ethanol
Switchgrass	1.153	14.52	0.69	99.5% ethanol
Wood Cellulose	-	-	0.64	99.5% ethanol
Soybeans	5.88	2.56	0.76	Biodiesel
Sunflower	17.08	0.76	0.46	Biodiesel

Again Pimentel appears to be extremely pessimistic, possibly assigning high values for the energy cost of the crop production and, as can be seen from Table 17 below, low or 'worst case' energy values for biofuel production. Note that Graboski states that, "The energy ratio for corn production in 2000 is about 7.4. Thus, the energy embodied in corn is more than seven times the fossil energy inputs required for growing."

Table 17: Summary of energy balances for biofuel and hydrogen production processes (Wood and Bauen)

No.	Chain	Description	End fuel	EPR (Low – [Best Estimate] – High)
1	Ethanol from Sugar Beet	C6 fermentation	Ethanol	No co-product credits: 0.29-0.32 Co-products used as fuel: 1.36-1.61 No co-product credits: 0.52-0.84 Co-products used as fuel: 1.4-2.1
2	Ethanol from Wheat (grain)	Starch hydrolysis, C6 fermentation	Ethanol	Straw not used as fuel: 0.69-1.67 Straw used as fuel: 1.84-2.72
3	Ethanol from Straw (Wheat)	Hydrolysis, C5 & C6 fermentation	Ethanol	Lignin not used as fuel: 0.78-1.79 Lignin used as fuel: 1.34-2.33
4	Ethanol from Wood (Short Rotation Coppice, SRC)	Hydrolysis, C5 & C6 fermentation	Ethanol	Lignin not used as fuel: 0.55-0.56 Lignin used as fuel: 1.23-2.24 Lignin not used as fuel: 0.19-2.33 Lignin used as fuel: 0.4-3.73
5	Rape Methyl Ester (RME)	Oil extraction and esterification	Biodiesel	No co-product credits: 0.7-1.9-3.3 Straw used as fuel: 1.8-3.1-4.4
6	Vegetable Oil Methyl Ester (VME) from waste oils	Filtration / purification & esterification	Biodiesel	6.6-8.0
7	Fischer-Tropsch (FT) Biodiesel from Wood (SRC - willow)	Gasification & catalytic gas upgrading	Biodiesel	18.05-62.43 (Biofuel energy produced per unit of non-renewable energy)
8	Methanol from Wood (SRC - willow). Biomass gasification.	Gasification & catalytic gas upgrading	Methanol	7.33-65.51 (Biofuel energy produced per unit of non-renewable energy)
9	Hydrogen from Wood (SRC) Biomass gasification.	Gasification and gas upgrading. Compressed H_2 storage.	Hydrogen	5.73-17.97 (Biofuel energy produced per unit of non-renewable energy)
10	Hydrogen from Off-shore wind	Regional electrolysis – compressed H_2 distribution	Hydrogen	23.8 (H_2 energy produced per unit of non-renewable energy)
11	Hydrogen from Off-shore wind	Regional electrolysis – liquid H_2 distribution	Hydrogen	625 (H_2 energy produced per unit of non-renewable energy)
12	Hydrogen from Off-shore wind	Regional electrolysis – pipeline distribution	Hydrogen	Very Large (H_2 energy produced per unit of non-renewable energy)
13	Hydrogen from Off-shore wind	Forecourt electrolysis – compressed local storage	Hydrogen	Very Large (H_2 energy produced per unit of non-renewable energy)

The conclusions that can be drawn from this study are:

1. Bioethanol production results in a positive energy balance in cases of efficient (recent, state-of-the-art) bioethanol processing, and that use of the coproducts (as process fuel or other use) improves the energy balance, sometimes resulting in the conversion of a negative energy balance to a positive one. This appears to be true also for biodiesel production from rape (rapeseed, canola).
2. Biodiesel from waste oils or wood have a good positive energy balance as the energy content of the raw material is not counted in the balance.
3. Hydrogen also looks promising as a future transport fuel. However, storage and transport of H_2 is difficult, and the use of the fuel depends on the fuel cell, which is not a simple article to manufacture.

One further point about biodiesel is that there is one form of this fuel for which an EPR is not necessary; *Jatropha curcas L*. This is a low tree, two to three metres in height. The fruit looks like a black plum, and it contains a nut that is 33-35% oil. The nut can be chopped, dried, pressed and filtered to give a diesel fuel. No processing, and no machinery is necessary, except for the hand-operated press and the end-use diesel engine. The process is incredibly low-tech, and the remains of the nut after pressing can be used as a fertilizer for the trees. Planting 1,250 *Jatropha* trees/ha, gives 10,000 kg of nut per harvest, 4 kg gives 1 litre of diesel oil, so 2,500 litres are harvested per ha for each harvest. However, the tree is often planted as a hedgerow around fields or gardens, or along roadsides, taking up no cropland whatsoever. This means that small rural communities far from sources of conventional diesel fuel can quite easily be self-sufficient in this kind of fuel.

6. Local, small-scale production of bioethanol and biodiesel fuel

It is appropriate to mention local, small-scale (e.g. single-person or small group) production of biofuels. However, I do not recall ever seeing an energy accounting for such a process. Please alert me if you know of one. Assuming some producers use some fossil fuels in their process, an energy accounting might be possible, though it might not have much meaning. Small-scale producers may be more interested in obtaining the fuel than what the EPR is, rather similar to the notion of replacing liquid gasoline by ethanol through the use of coal and natural gas in the USA. If no fossil fuels are used, it might still be possible to do an energy balance based on the energy inputs to produce the raw material and the energy content of the fuel used to heat the boilers, e.g. wood. However, current small producers may be more interested in the money values of the inputs in comparison with the outputs. The cost of the inputs can be compared with the selling price of the biofuel (e.g. ethanol) and the coproducts, or the cost-effectiveness of the process can be gauged by the value of the biodiesel in comparison with the purchase cost of what it replaces, i.e. gasoline or diesel fuel. Blume, though not giving energy balance details for biofuels, gives the table on the following page (Table 18).

The processes are obviously profitable in money terms and look profitable in terms of energy, i.e. relatively small amounts of wood and electricity are used. Rather than what the EPR might be, what we need to know for the future is how easily we might make the equipment (could a blacksmith do it, for instance?) and how sustainable the process for obtaining the input raw material and the process energy material is. If there is wood available locally in a sustainably managed way, and if the raw materials are obtained or grown in an appropriate way (not using cropland that would normally be used for growing human food, sustainable harvesting, etc.) then small-scale bioethanol may have a big part to play in our energy future.

A final word.

This is not an exhaustive or definitive review of biofuel production, but it does give the basic facts of biofuel production process energy balances as they stand in 2008. Although not negative, the conversion of fossil energy resources to bioethanol through corn grown in conventional agriculture in the USA can probably not look forward to an EPR of much over 3 in the mid-term future. The negative aspects of soil erosion and water pollution probably make the whole effort not really worthwhile in terms of environmental burdens. Biofuel from sugarcane production has a much higher EPR, and it looks as if it can be made to run in an environmentally sustainable and non-fossil-fuel form without any great reduction in the amounts of bioethanol produced. Some countries, Brazil, but perhaps only Brazil, may be able to continue to run their cars on bioethanol for centuries to come, but the problem then is will they have cars to run – will it still be possible to mass-produce (or even hand-produce) engines for the alcohol to run? The same may be true of small-scale biofuel production. It can probably be made to be sustainable and ‘profitable’, but will there be any engines to run on it?

Table 18: Expenses and Credits for Three Feedstocks per Gallon of Ethanol

Input Costs	Fruit Cull	Donuts	Corn
Feedstock	0.15	0.10	0.96
Yeast	0.01	0.01	0.01
Enzymes	0.10	0.05	0.06
Miscellaneous Consumable	0.03	0.03	0.03
Energy	0.07	0.00	0.10
Electricity	0.035	0.035	0.035
Cost of Distillery	0.083	0.083	0.083
Maintenance	0.02	0.02	0.02
Labor	0.60	0.60	0.60
Total Input Costs to Produce One Gallon (3.7854 l)	**0.80**	**0.93**	**1.90**
Tax Credits, Reimbursable as Cash			
Federal Producer's Small Plant Credit	-0.10	-0.10	-0.10
VEETC	-0.51	-0.51	-0.51
Gross Production Cost Per Gallon after Credits	**0.19**	**0.32**	**1.29**
Credits for Direct Byproducts			
Hot Water over 180°F, stored	-0.50	-0.70	-0.50
Wet Mash Sold for Dairy or Cattle	-0.20	0.00	-0.87
Carbon Dioxide, 6.5 pounds	-0.65	-0.65	-0.65
Net Cost per Gallon after Direct Byproducts	**-0.71**	**-0.40**	**-0.30**
Secondary Product Potential			
Type of Mash Byproduct	Skins/Pulp	Liquid	Wet distillers grains
Mash Byproducts per Gallon (approximate)	8 lbs.	10 gals.	7 lbs.
Potential for Mushrooms	40.00	25.00	42.50
Potential for Worm Castings	16.00	0.00	16.00
Potential for Fish	50.00	60.00	43.75

(US$ except where stated) Source: Blume p.460

Note: Energy for donut process provided by donut fat. Fruit cull uses less energy due to simpler process than corn. Assumes 200 proof final ethanol product and wood at $160 per cord and starting from room temperature.

References

Blume, David, "*Alcohol Can Be a Gas!*" The International Institute for Ecological Agriculture, 2007, ISBN 9780979043772

Brazil Institute, *The Global Dynamics of Biofuels*, Brazil Institute Special Report, April 2007, Issue No.3, http://www.wilsoncenter.org/topics/pubs/Brazil_SR_e3.pdf

Graboski, Dr. Michael S., Colorado School of Mines, Fossil Energy Use in the Manufacture of Corn Ethanol, Prepared for the National Corn Growers Association, August 2002 http://www.ncga.com/ethanol/pdfs/energy_balance_report_final_R1.PDF

Lorenz, David, and David Morris *How Much Energy Does It Take to Make a Gallon of Ethanol?* ©1995 Institute for Local-Self Reliance (ILSR) http://www.carbohydrateeconomy.org/library/admin/uploadedfiles/How_Much_Energy_Does_it_Take_to_Make_a_Gallon_.html

Macedo, Isaias de Carvalho, *Assessment of greenhouse gas emissions in the production and use of fuel ethanol in Brazil*, March 2004.
Morris, David, *The Carbohydrate Economy, Biofuels and the Net Energy Debate*, Institute for Local Self-Reliance, August 2005, http://www.newrules.org/agri/netenergyresponse.pdf

Pimentel, David, *Ethanol Fuels: Energy Balance, Economics, and Environmental Impacts are Negative*, *Natural Resources Research, Vol. 12, No. 2, June 2003* http://www.ethanol-gec.org/netenergy/neypimentel.pdf

Pimentel, David and Tad W. Patzek, *Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower*, *Natural Resources Research, Vol. 14, No. 1, March 2005.* http://petroleum.berkeley.edu/papers/Biofuels/NRRethanol.2005.pdf

Shapouri, Hosein, James A. Duffield and Michael S. Graboski, *Estimating the Net Energy Balance of Corn Ethanol*, United States Department of Agriculture Agricultural Economic Report Number 721, July 1995. http://www.ers.usda.gov/publications/aer721/AER721.PDF

Shapouri, Hosein, James A. Duffield, and Michael Wang, *The Energy Balance of Corn Ethanol: An Update (July 2002)* Office of Energy Policy and New Uses */ AER-813* _ iii http://www.transportation.anl.gov/pdfs/AF/265.pdf

Shapouri, Hosein, James Duffield, Andrew McAloon, and Michael Wang, *THE 2001 NET ENERGY BALANCE OF CORN-ETHANOL*, 2004. http://www.ncga.com/ethanol/pdfs/netEnergyBalanceUpdate2004.pdf

Woods, J. and Bauen, A. *Technology Status Review and Carbon Abatement Potential* of. *Renewable Transport Fuels* (RTF) in the *UK.DTI*; AEAT. 1-150 *2003*. www.berr.gov.uk/files/file15003.pdf