The Oil Drum: Net Energy

Discussions about Energy and Our Future

The Effect of Natural Gradients on the Net Energy Profits from Corn Ethanol

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Scaling biofuels from the level of the laboratory or pilot-plants to commercial production is the Achilles' Heel of almost all biofuels. One major problem is that biofuels use feedstocks that are invariably less energy dense than their fossil fuel counterparts. For example, there are approximately 45 MJ per kilogram contained in both the finished product of gasoline and crude oil, while ethanol has an energy density of about 26 MJ per kilogram and corn has only 16 MJ per kilogram. In general, this means that large amounts of corn must be grown and harvested to equal even a small portion of our gasoline consumption on an energy equivalent level, which will undoubtedly expand the land area that is impacted by the production process of corn-based ethanol.

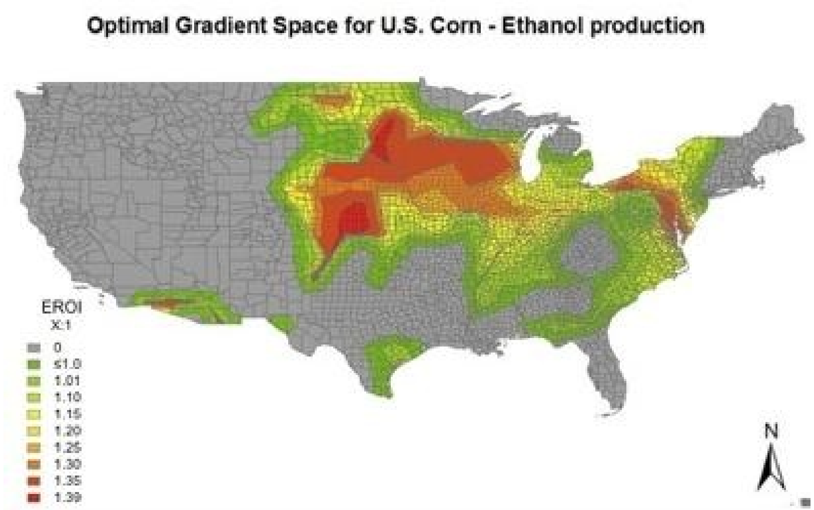

Figure 1. Map of the optimal gradient space for the production of corn-based ethanol within the United States. Colors correspond to EROI numbers listed in the figure caption. The grey areas represent locations without a significant amount of corn-production.

There is a definite hierarchy of corn productivity by state. For example, in 2005, 173 bushels per acre (10859 kg/ha) were harvested in Iowa, while only 113 bushels per acre were harvested in Texas (7093 kg/ha). This is consistent with the general principal of gradient analysis in ecology, which states that individual plant species grow best near the middle of their gradient space; that is near the center of their range in environmental conditions such as temperature and soil moisture (Whittaker 1956, Hall et al. 1992). The climatic conditions in Iowa are clearly at the center of corn's gradient space. What is understood less is that corn production is also less energy-intensive at or near the center of corn's gradient space.

Ethanol producers are privy to this information, which is why most of the first corn-ethanol refineries were located in the "corn-belt", defined here as the four states in the U.S. with the highest corn production: Iowa, Illinois, Minnesota, and Nebraska. The Renewable Fuel Standard that was signed into law as part of the Energy and Independence Security Act of 2007 mandated that 36 billion gallons of ethanol be produced by 2022, which led to the expansion of the ethanol industry and by 2008 over half of the new plants under construction or expansion were in areas located outside the corn-belt.

Using state-specific data for lime, fertilizer (N,P,K) and irrigation and county-specific data for yield (bushels per acre), I have calculated the EROI for corn-based ethanol for each county across the U.S. to see how the natural ecological gradients across the U.S. might impact the EROI of corn-based ethanol production. I used values taken from Farrell et al. (2006) for all other costs, which are not geographically variable in this analysis, including: herbicides, insecticides, seed, transport energy, gasoline, diesel, natural gas, LPG, electricity, farm labor, labor transportation, farm machinery, and inputs packaging.

My results show diminishing returns for EROI as distance from Iowa increases, meaning that the geographic expansion of corn production will produce lower yields at higher costs (Table 1, Figure 1). For example, ethanol production in Iowa and Texas yield enormously different energy balances. In Iowa, the production of a bushel of corn costs 43 MJ, while in Texas it costs 71 MJ (Table 1). Using those energy yields, the gross costs of producing 36 billion gallons of ethanol would be 576 x 10^9 MJ in Iowa and 952 x 10^9 MJ in Texas (0.4 liters ethanol/kg corn, 25.4 kg/bushel of corn). The difference in gross energy costs between Iowa and Texas is 376 x 10^9 MJ, which is the energy equivalent of 8.4 billion liters, or 2.2 billion gallons, of gasoline. In reality, the proportion of corn used for corn-based ethanol production will come from both optimal and marginal land, but some marginal land will be required.

Table 1. Summary statistics of the costs and gains of corn-based ethanol production for states that produced at least 1% of the United States 2005 harvest, ranked by decreasing Refinery Gate EROI.

State	Gains			Costs by Category											
	Yield (Bu/acre,Kg/Ha)		Yield (MJ/Ha)*	N Fertilizer (MJ/Ha)	P Fertilizer (MJ/Ha)	K Fertilizer (MJ/Ha)	Lime (MJ/Ha)	Irrigation (MJ/Ha)	Spatial Production Cost (MJ/Ha)	Non-Spatial Production Costs (MJ/Ha)	Total Cost (MJ/Ha)	Total Cost per Bushel (MJ/Bu)	Farm-Gate EROI (X:1)	Refinery-Gate EROI (X:1)	No Co-products EROI (X:1)
Minnesota	174	10921	174740	7058	597	416	17	11	8100	9442	17542	41	9.96	1.33	1.11
Iowa	173	10858	173736	7944	424	404	80	2	8654	9442	18296	43	9.50	1.32	1.10
Wisconsin	148	9289	148630	5449	362	359	94	25	6289	9442	15731	43	9.45	1.31	1.10
Pennsylvania	122	7657	122519	4305	399	183	63	1	4951	9442	14393	48	8.51	1.28	1.08
Michigan	143	8976	143608	6951	460	597	70	47	8125	9442	17567	50	8.17	1.27	1.07
North Dakota	129	8097	129549	6130	375	63	63	24	6655	9442	16097	51	8.05	1.27	1.06
Nebraska	154	9666	154655	9479	299	19	8	694	10498	9442	19940	52	7.76	1.25	1.05
Colorado	148	9289	148630	8671	325	40	63	642	9741	9442	19183	52	7.75	1.25	1.05
Indiana	154	9666	154655	9668	675	887	97	11	11339	9442	20781	55	7.44	1.24	1.04
South Dakota	119	7469	119506	6256	374	64	0	19	6713	9442	16155	55	7.40	1.24	1.04
Illinois	143	8976	143608	9763	692	703	103	9	11270	9442	20712	59	6.93	1.22	1.02
Ohio	143	8976	143608	10340	662	629	79	1	11711	9442	21153	60	6.79	1.21	1.02
Kansas	135	8473	135574	9383	293	48	63	1006	10792	9442	20234	61	6.70	1.21	1.01
Kentucky	132	8285	132562	9542	692	340	63	7	10644	9442	20086	62	6.60	1.20	1.01
Texas	114	7155	114485	9258	399	59	63	797	10575	9442	20017	71	5.72	1.15	0.97
Missouri	111	6967	111472	9447	496	461	63	38	10505	9442	19947	73	5.59	1.14	0.96

Note Yield (MJ/Ha) was calculated using 16 MJ/Kg corn-energy conversion ratio. Values for non-spatial costs include: herbicides, insecticides, seed, transport energy, gasoline, diesel, natural gas, LPG, electricity, farm labor, labor transportation, farm machinery, and inputs packaging. We calculated Farm-Gate EROI by dividing yield (MJ/Ha) by the sum of spatial and non-spatial production costs. We calculated Refinery-Gate EROI using values of 15.24 (MJ/L) for refinery costs, 21.46 (MJ/L) as the energy content of a liter of ethanol produced, and 4.13 (MJ/L) as the co-product credit. No Co-products EROI was calculated the same as Refinery-Gate EROI excluding the co-product credit of 4.13 (MJ/L).*

More important than the gross costs and gains of ethanol production are the net costs and gains. The gross amount of fuel produced must be adjusted by the EROI of that fuel to estimate the net energy profit that is added to the economy. For example, if the production of 2 MJ of ethanol requires 4MJ of fertilizer inputs, then the process ceases to provide a net energy profit to society, rather a loss of 2 MJ, even though the gross ethanol gain is 2 MJ. If we assume fertilizers are the only input and ethanol is the only output, the EROI of this process would be 0.5. The following equation can be used to calculate the net energy added to the economy using just the gross energy gains for society and the EROI of the fuel production process.

Net Energy Profit = Gross Energy Gains * (1 - (1 /EROI))

By substituting 2 MJ for the "Gross Energy Gains", and 0.5 for the EROI, the Net Energy Profit calculates to -2, which means that the production of ethanol is a net energy loss, even though it has a gross energy gain of 2MJ, in this example. Using this method the net energy gains will always be lower than the gross energy gains, which complies with the Second Law of Thermodynamics, which implies that no energy conversion process can operate at 100% efficiency. The question then becomes: How much of the 36 billion gallons mandated by the RFS is an net energy profit? The answer depends, in part, on where the ethanol is produced. If the mandate was fulfilled only by ethanol produced in Iowa, which has a refinery-gate EROI of 1.32:1 (Table 1), the net energy profit provided by the ethanol is actually 9 billion gallons. On the other hand if the ethanol were produced in Texas, then the net energy profit is only 4.7 billion gallons.

Clearly, the net gains from this process are less appealing than the gross. The net gains are even lower if co-product credits are removed. Co-products are dry or wet distiller's grains, which are a very contentious subject in the literature on corn-ethanol. This matter is significant because the energy credits allotted to the use of co-products as a by-product of the corn-based ethanol process account for 19% of the total energy gains of the corn-based ethanol process (co-products are allotted 4.13 MJ/L while ethanol is 21.46 MJ/L). More importantly, when this 19% is removed from the EROI calculation, the EROI of corn-based ethanol for marginal lands (e.g. Texas) is less than 1. Which is to say that the net energy profits from the production of 36 billion gallons of ethanol in Texas, for example, would be -1.08 billion gallons [36 billion gallons * (1-(1/0.97))]. In other words, without the energy contained in the co-products, the production of corn-based ethanol on marginal lands creates net energy losses rather than profits.

Whether or not co-products should be included in the calculation of the EROI is a topic for a different discussion, but the impact of excluding them is profound. The primary message to be gleaned from this post is that “scaling-up” corn-based ethanol or other similar biofuel projects usually have complications, such as lower corn yields on marginal lands, and these complications tend to increase the costs, not the gains, associated with converting feedstocks with low energy densities to final products with higher energy densities.

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