Net Energy of Ethanol

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Outline

I. Introduction
II. Ethanol Production / Energy Inputs
III. Review of studies
IV. Cellulosic Ethanol

Ethanol Production (Corn)

- Enzymes convert starch to dextrose
- Fermentation
- Distillation
- Dehydration
- Coproducts: livestock feed, corn syrup

Energy Inputs

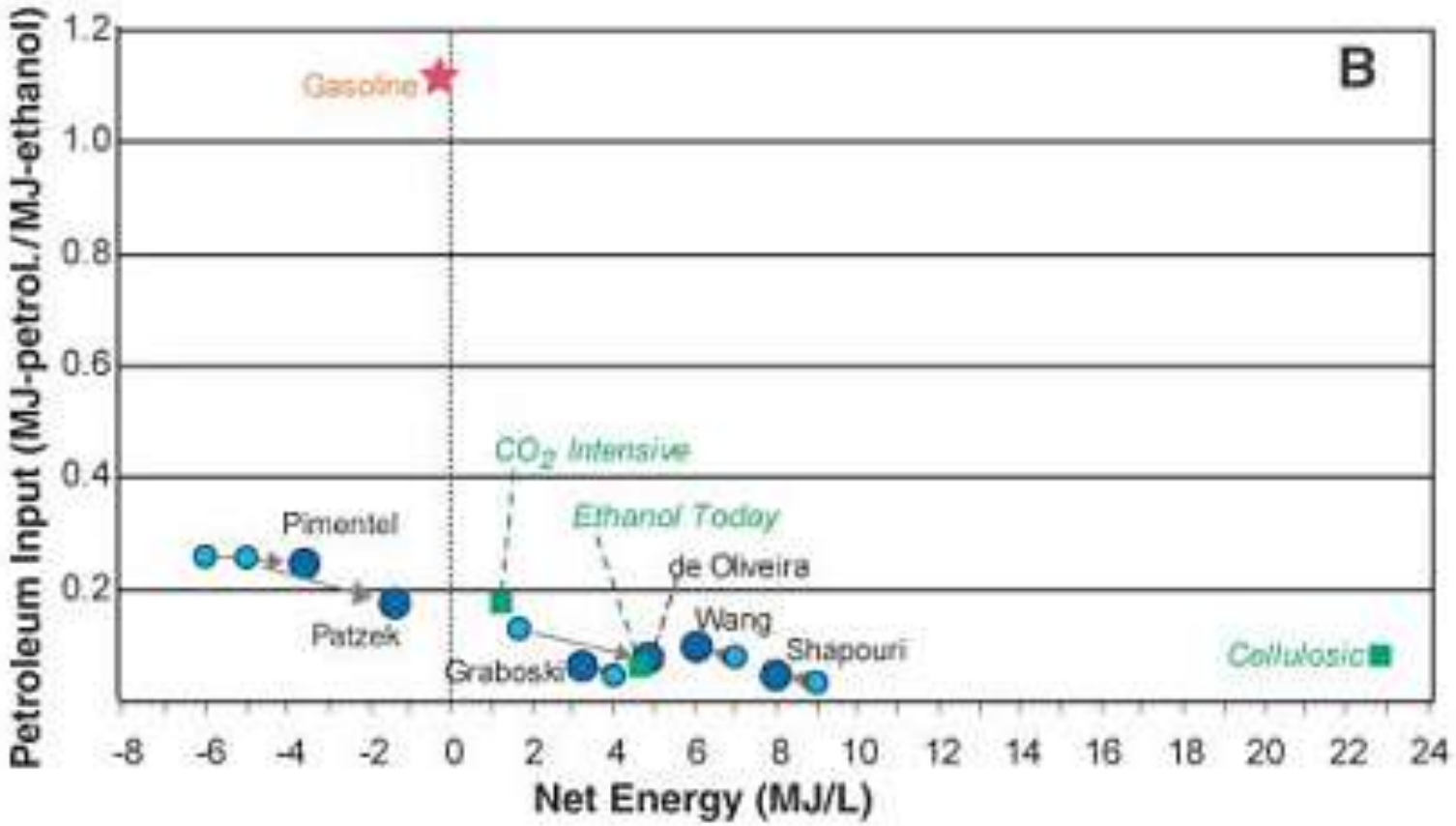
- Farm machinery fuel
- Fertilizer
- Irrigation
- Transport
- Electricity in Processing Plans
- Labor
- …

Corn ethanol is energy efficient, as indicated by an energy ratio of 1.24, that is, for every Btu dedicated to producing ethanol, there is a 24-percent energy gain.

Source: Shapouri, H., Duffield, J.A. & Graboski, M.S. Estimating the Net Energy Balance of Corn Ethanol. (1995). (sponsored by USDA)

Ethanol use in US gasoline should be banned, not expanded.

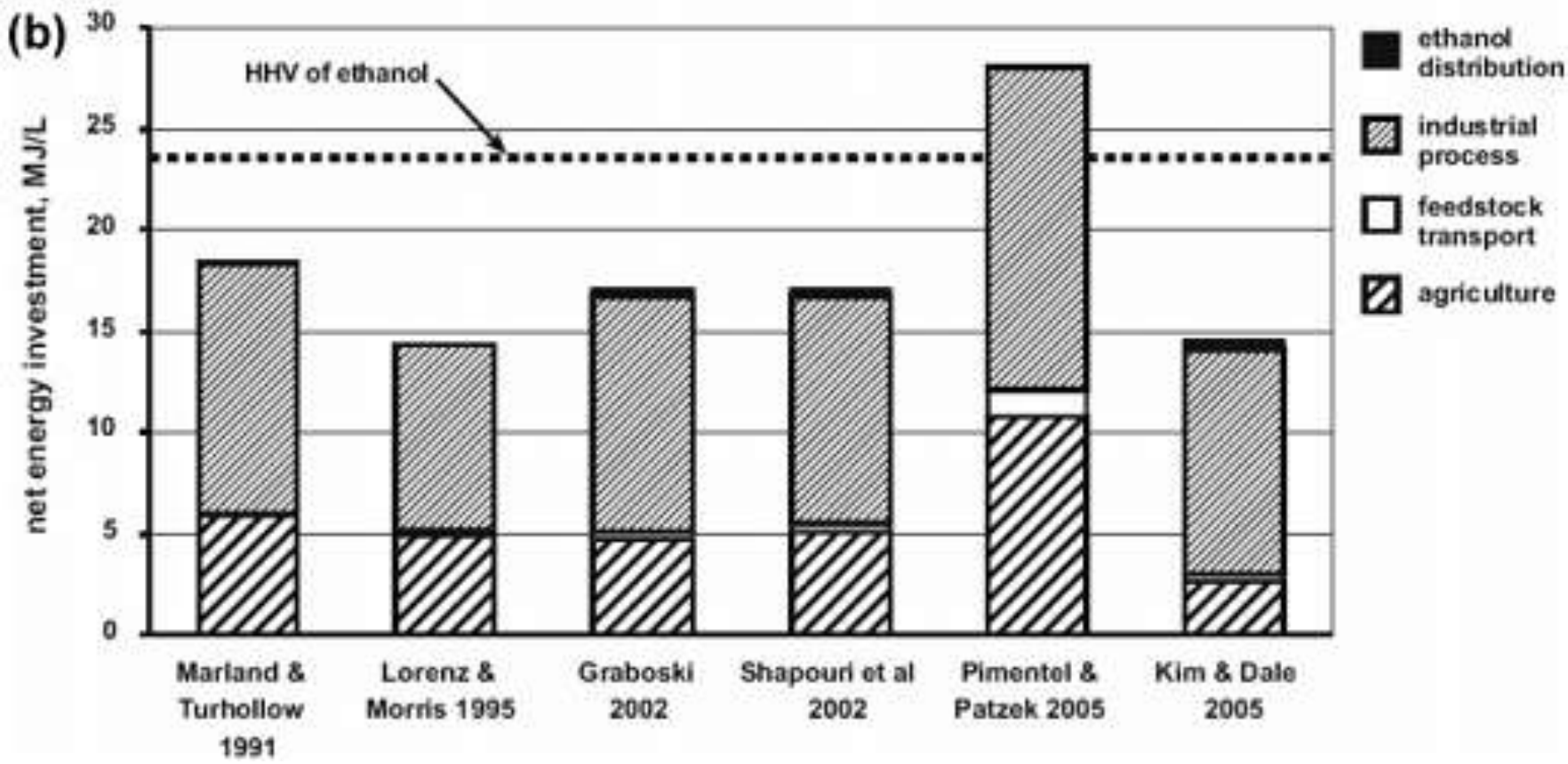
Source: Hodge, C. Ethanol use in US gasoline should be banned, not expanded. *Oil & Gas Journal* **100**, 20–30 (2002).



Source: Farrell, A.E. et al. Ethanol Can Contribute to Energy and Environmental Goals. *Science* **311**, 506-508 (2006).

	Marland & Turhollow 1991	Lorenz & Morris 1995	Graboski 2002	Shapouri et al. 2002	Pimentel & Patzek 2005	Kim & Dale 2005
milling technology:	wet	mixed	mixed	dry	dry	dry
	all values in MJ per liter ethanol unless otherwise noted					
	fuel and electricity					
agriculture						
fuel	2.0	0.7	2.2	2.7	2.0	0.8
electricity	0.2	2.0	0.5	0.6	0.5	0.1
feedstock transport		0.4	0.5	0.6	1.5	0.5
industrial process						
fuel	10.5	10.9	11.8	10.0	11.7	12.5
electricity	3.5	3.2	2.9	3.6	5.3	2.2
ethanol distribution			0.4	0.4		0.6
total fuel and electricity	16.1	17.1	18.4	17.9	21.0	16.8
	upstream energy					
agriculture						
fertilizer	4.2	3.6	2.6	2.3	4.7	2.0
biocides	0.3	0.3	0.2	0.4	1.3	0.4
other		0.9	0.3	0.1	3.1	0.1
other nonagriculture					0.1	
total upstream energy	4.5	4.9	3.2	2.8	9.2	2.5
	calculation of r_E					
gross energy input	20.6	22.0	21.6	20.7	30.1	19.3
coproduct energy input	(2.3)	(7.7)	(4.5)	(3.7)	(2.0)	(4.8)
net energy input	18.3	14.3	17.1	17.1	28.1	14.5
allocation factor (%)	89%	65%	79%	82%	93%	75%
r_E (unitless)	**1.29**	**1.65**	**1.38**	**1.38**	**0.84**	**1.62**
	reference data					
upstream fuel included?	yes	no	yes	yes	yes	yes
electricity heat rate	3.0	2.4	3.0	2.7	3.3	3.2–3.4
corn yield (Mg/ha)	7.5	7.5	8.8	7.7	8.7	9.0
ethanol yield (L/kg)	0.37	0.38	0.39	0.39	0.37	0.39
oil reduction (%)			94%	84%		
projected r_E (unitless)	1.67	2.51	1.40			1.91

Source: Hammerschlag, R. Ethanol's Energy Return on Investment: A Survey of the Literature 1990-Present. *Environmental Science & Technology* **40**, 1744-1750 (2006).



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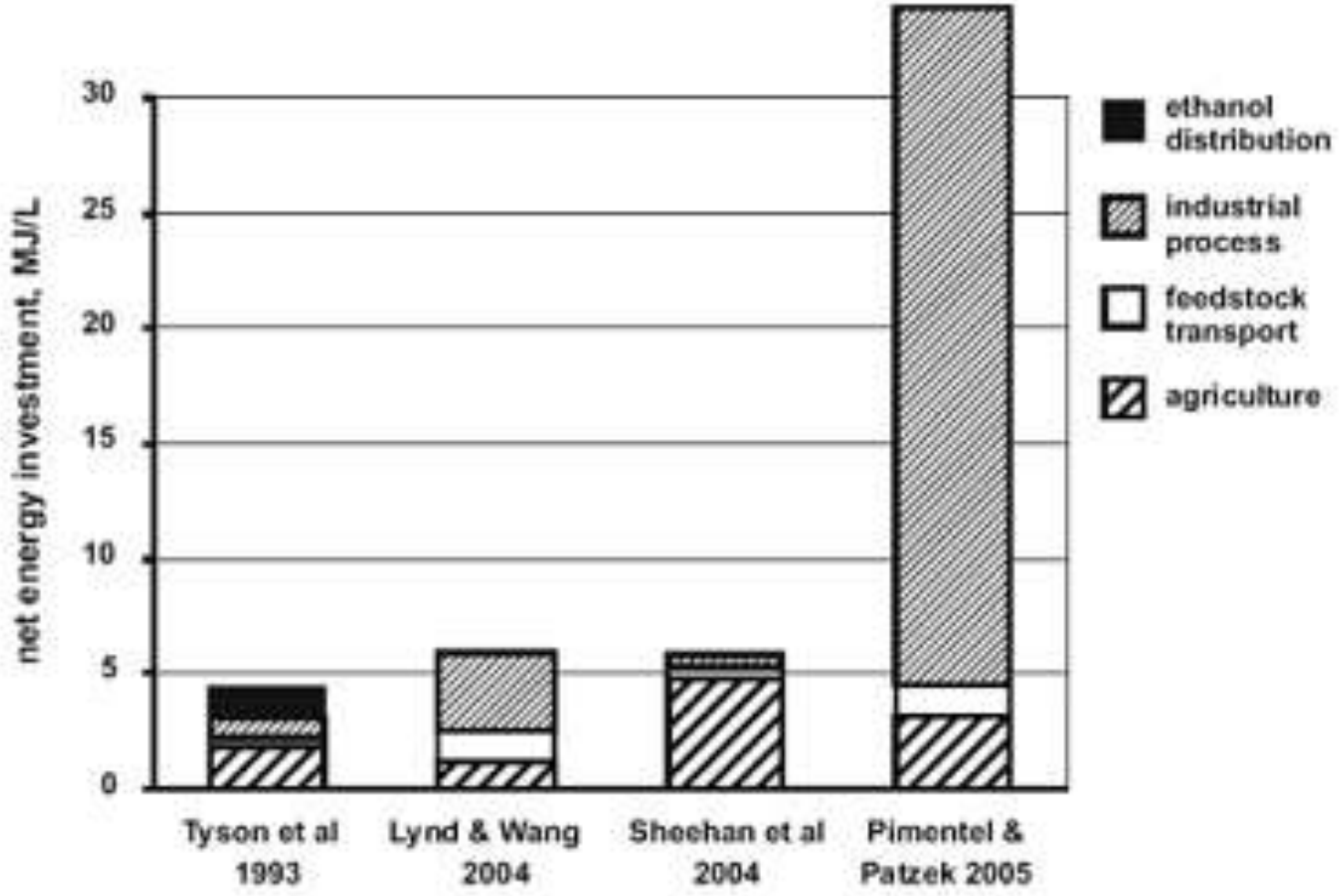
Cellulosic Ethanol

- Crops easier to grow
- Higher crop yields
- Uses entire plant
- Cellulose refined into ethanol
- Lignin burned to generate electricity (surplus)
- Not ready for large-scale production (Enzymes to break down cellulose inefficient)

	Tyson et al. 1993	Lynd & Wang 2004	Sheehan et al. 2004	Pimentel & Patzek 2005
fuel:	various	poplar	corn stover	switchgrass
	all values in MJ/L unless otherwise noted			
	fuel and electricity			
agriculture				
fuel	0.8	1.1	0.8	1.1
electricity				
feedstock transport	0.4	1.3	0.5	1.4
industrial process				
fuel	0.2	2.9		20.1
electricity	0.1		0.3	8.9
ethanol distribution	1.4			
total fuel and electricity	2.9	5.4	1.5	31.5
	upstream energy			
agriculture				
fertilizer	1.1	0.1	4.0	0.9
biocides		0.0		0.3
other				0.8
other nonagriculture	0.5	0.4	0.3	0.5
total upstream energy	1.5	0.5	4.3	2.5
	calculation of r_E			
gross energy input	4.4	5.9	5.8	34.0
surplus electricity	5.4	3.3	1.9	
gross energy output	29.0	26.9	25.5	23.6
r_E (unitless)	**6.61**	**4.55**	**4.40**	**0.69**
	reference data			
upstream fuel included?	yes	?	yes	yes
nominal electric multiplier	3.3	2.7	3.0	3.3
feedstock yield (Mg/ha-yr)	11.2–33.6		8.2	10.0
ethanol yield (L/kg)	0.37–0.41	0.34	0.34	0.40
oil reduction (%)			95%	

Source: Hammerschlag, R. Ethanol's Energy Return on Investment: A Survey of the Literature 1990-Present. *Environmental Science & Technology* **40**, 1744-1750 (2006).



Source: Hammerschlag, R. Ethanol's Energy Return on Investment: A Survey of the Literature 1990-Present. *Environmental Science & Technology* **40**, 1744-1750 (2006).

Conclusion

- No clear answer
- Cellulosic Ethanol looks promising

Sources

1. Shapouri, H., Duffield, J.A. & Graboski, M.S. Estimating the Net Energy Balance of Corn Ethanol. (1995).
2. 2. Farrell, A.E. et al. Ethanol Can Contribute to Energy and Environmental Goals. *Science* **311**, 506-508 (2006).
3. 3. Pimentel, D. & Patzek, T.W. Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower. *Natural Resources Research* **14**, 65-76 (2005).
4. 4. Hodge, C. Ethanol use in US gasoline should be banned, not expanded. *Oil & Gas Journal* **100**, 20–30 (2002).
5. 5. Hammerschlag, R. Ethanol's Energy Return on Investment: A Survey of the Literature 1990-Present. *Environmental Science & Technology* **40**, 1744-1750 (2006).
6. 6. Schmer, M.R. et al. Net energy of cellulosic ethanol from switchgrass. *Proceedings of the National Academy of Sciences* **105**, 464-469 (2008).