6-7-2006

SLIDES: The Real Biofuel Cycles and The Earth, Biofuels, and Reality

Tad W. Patzek

Tad W. Patzek, *The Real Biofuel Cycles* and *The Earth, Biofuels, and Reality*, *in* CLIMATE CHANGE AND THE FUTURE OF THE AMERICAN WEST: EXPLORING THE LEGAL AND POLICY DIMENSIONS (Natural Res. Law Ctr., Univ. of Colo. Sch. of Law 2006).

The Real Biofuel Cycles

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This short example of astronomical scale-up problems with biofuel systems builds on the similar calculations described at http://zfacts.com/p/60.html, see **Table 1** for details. My conference presentation will cover a broad range of physical, biological, and ecological problems with the real corn-ethanol, switchgrass-ethanol, and sugarcane-ethanol systems.

Suppose that one accepted the unrealistically high ethanol yield[1] used by the USDA and their nonphysical coproduct energy credits[2], and one claimed that the net energy ratio of corn ethanol production were as high[3] as 1.34. Consistently with this claim, for each 1 unit of input fossil energy, one would get 1.34 units of output fossil energy as ethanol, or for 3 units of input energy, one would get 4 units of output energy. This means that one would have to use the amount of fossil energy equivalent to 3 gallons of ethanol to produce one extra gallon of automotive fuel ethanol. Therefore, it would take the energy in $4/(0.95 \times 0.64 + 0.05) = 6.1$ gallons of denatured ethanol to eliminate 1 gallon of gasoline. The current cost of these 6.1 gallons EtOH is $6.1 \times \$3.73 = \$22.67$, but one would save one gallon of premium high-octane gasoline retailing at \$3.24 as of 05/06/06. So the net cost of displacing one gallon of premium gasoline with corn ethanol would be $\$22.67 - \$3.24 = \$19.43$.

In 2005, the U.S. burned ∼140 billion gallons of gasoline. If one wanted to run a "sustainable" corn-ethanol transportation system[4], one would have to produce $6.1 \times 140 = 851$ billion gallons of denatured ethanol, with 5% gasoline by volume, or 808 billion gallons of pure ethanol. The unrealistically[5] low cost of producing this ethanol would be \$15.71 trillions, more than the 2005 U.S. GDP of \$12.4 trillions.

At 2.48 gallons EtOH/bushel, one would have to produce 327 billion bushels of corn per year (34 times the mean annual U.S. corn production over the last decade) to replace gasoline currently used in the U.S. Let's suppose that this corn were produced every year at the all-time record yield of 180 bushels/acre in Iowa[6]. One would have to grow corn on 1.8 billion acres, year-after-year, for decades. There are about 400 million acres of arable land now in cultivation in the U.S. Therefore, one would

[1] This yield of 2.682 gal EtOH/bushel counts 5% of gasoline denaturant, fusel alcohol, and Brazilian imports of ethanol as parts of the true yield of ethanol produced in the U.S.

[2] To separate starch from the remainder of corn kernels (coproducts), one does not have to spend the enormous amount of fossil energy necessary to distil ethanol beer.

[3] Without the coproduct energy credits the USDA net energy ratio hovers at about 1.0.

[4] A system in which corn ethanol would serve as the main fossil energy source to drive corn agriculture and ethanol refineries. Physics makes such a system clearly impossible.

[5] One would have to spend additional \$ trillions to expand industrial farming (35-fold if all corn went to ethanol) and ethanol refining (200-fold), and protect the entire national water and food supplies, public health, and the environment. Water shortage and pollution, and soil destruction would become extreme across the U.S.

[6] Such consistently high yields are absolutely impossible if one cultivated only corn on all arable land, including marginal fields, and expanding agriculture to non-agricultural land. Also the hybrid corn seed production would take an enormous additional land area and fossil energy.

have to use the land area equal to 4.5 times the current arable land area just to satisfy the automotive gasoline use in the U.S. There would never be enough water and soil, and other environmental services to support this madness.

Alternatively, one may claim that the U.S. car drivers receive a subsidy of $15.71 trillion - $0.45/0.83 trillion for premium gasoline = $15.1 trillion per year from ancient solar energy and the world. This amount of wealth would disappear *every year*, once the latter subsidy stops. Since continuous disappearance of wealth at this rate is impossible, the U.S. economy will have to shrink dramatically and reconnect with its natural resource foundation. Enter energy efficiency and lifestyle modifications.

I have not discussed here the 45 billion gallons per year of diesel fuel and 25 billion gallons per year of jet fuel used in the U.S. Oh, and then there are naphtha for heating and natural gas for cooking. . .

Table 1: True cost of corn ethanol to taxpayers

Line	Fact	Value	Units
1	2005 EtOH production capacity[a]	4486	10^6 gallons denatured per year
2	"Small producers"[b] EtOH capacity	2597	10^6 gallons denatured per year
3	Mean ethanol tax credit[c] for "small producers"	0.0579	$/gallon denatured
4	VEETC tax credit[d]	0.5100	$/gallon denatured
5	Mean ethanol tax credits	0.5679	$/gallon denatured
6	Cumulative corn subsidies[e] in US from 1995 to 2004	41.90	$ Billion
7	Cumulative corn produced[f] in US from 1995 to 2004	95.309	Billion Bushels
8	Average[g] corn subsidies from 1995 to 2004	0.4396	$/bushel
9	Mean rack price[h] of EtOH (05/05/06)	2.8303	$/gallon denatured
10	Mean EtOH yield[i] from 2000 to 2004	2.4776	gallons EtOH/bushel
11	Mean subsidy[j] of EtOH from corn subsidies	0.1774	$/gallon EtOH
12	Mean state subsidies[k] for EtOH	0.1535	$/gallon EtOH denatured
13	Total mean subsidy[l] of EtOH	0.8988	$/gallon EtOH denatured
14	**Mean cost[m] of EtOH to taxpayer**	**3.7292**	**$/gallon EtOH denatured**
15	Mean tax bias[n] against ethanol	-0.1347	$/gallon EtOH denatured
16	**Energy equivalent[o] cost of EtOH to taxpayer**	**5.4626**	**$/gallon GGE**

[a] http://www.ethanolrfa.org/industry/locations/, updated 04/12/06
[b] As in *a*. A "small-producers" tax credit of $0.10/gallon for the producers of up to 60 million gallons EtOH per year
[c] Line 2/1 × 0.10
[d] The Federal Volumetric Ethanol Excise Tax Credit, http://www.irs.gov/irb/2005-02_IRB/ar14.html
[e] http://www.ewg.org/farm/region.php?fips=00000, accessed 4/14/06
[f] http://www.ers.usda.gov/Briefing/Corn/, accessed 04/14/06
[g] Line 6/7
[h] http://www.axxispetro.com/ace.shtml, accessed 05/06/06. The mean rack price in the largest ethanol producing states in the Midwest. The rack price of ethanol delivered to both coasts will be at least $0.15 higher because of transportation costs
[i] The mean of (Industry-reported yields - Brazilian imports), multiplied by 0.95 to remove gasoline denaturant
[j] Line 8/10
[k] Source: http://www.opisnet.com/headlines.asp, *Sunny Forecast for Summer Ethanol Blending*, accessed 02/21/05
[l] Lines 5 + 11 + 12
[m] Lines 9 + 13
[n] Ethanol has less energy per unit volume than gasoline, but taxes collected on both are equal. Federal excise tax on gasoline is 18.4 cents, and mean state excise tax is 21 cents (DOE EIA). The energy-equivalent tax bias against ethanol is $39.4 \times (1 - 0.95 \times 0.64 - 0.05)$
[o] Direct cost, excluding environment subsidies. Lines $(14 + 15)/(0.95 \times 0.64 + 0.05)$. GGE = Gallon Gasoline Equivalent

The Earth, Biofuels, and Reality

Netherlandish Proverbs by PIETER BRUEGHEL, 1525 – 1569

Tad Patzek, Civil & Environmental Engineering, U.C. Berkeley

June 7, 2006, Boulder, CO

This is What We Do...

In addition to extracting ancient plants (oil, gas, and coal) from the earth and burning them, we now burn the earth surface in real time:

- Corn, soybeans, sugarcane, wheat, sorghum, rapeseed, beats, potatoes, switchgrass, rice, ...
- Tropical forests, palm oil, pines, acacias, eucalypts, poplars, ...
- Wood chips, bagasse, rice straw, corn stover, hay,...
- Leftovers of animal carcasses, fish oil, human fat,...

Is there anything else left we might burn
to further our lifestyles?

They Spoke So Well For Us...

"I perceived it to be possible to arrive at knowledge highly useful in life ... and thus render ourselves the lords and possessors of Nature."

"I am come in very truth leading you to Nature with all her children to bind her to your service and make her your slave... The mechanical inventions of recent years do not merely exert a gentle guidance over Nature's course, they have the power to conquer her and subdue her, to shake her to her foundations."

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“I perceived it to be possible to arrive at knowledge highly useful in life …and thus render ourselves the lords and possessors of Nature.”

RENÉ DESCARTES, 1596-1650, *Discourse on Method* (1637)

“I am come in very truth leading you to Nature with all her children to bind her to your service and make her your slave… The mechanical inventions of recent years do not merely exert a gentle guidance over Nature’s course, they have the power to conquer her and subdue her, to shake her to her foundations.”

SIR FRANCIS BACON, 1561-1626, *Cogitata et Visa* (1607)

They Also Speak For Us. . .

- Aggressive action to develop advanced biofuels . . . could virtually eliminate our demand for gasoline
- Farmers will plant energy crops on a large scale
- Fast-growing, cost-efficient trees such as poplar and eucalyptus, and grasses such as alfalfa and switchgrass, [are] to be harvested as biofuels
- More power plants will burn biomass along with coal to produce electricity

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Natural Resources Defense Council, 2006

The Fundamental Incompatibility...

- The rate at which we use fossil energy, makes replacing it by biomass impossible
- Colonizing all available land on the earth will be insufficient
- If we really want to switch to solar cells, biofuels, wind, etc., we will have to shrink our energy use by a factor of 10
- US will have to look and act more like China or India

Talk Outline. . .

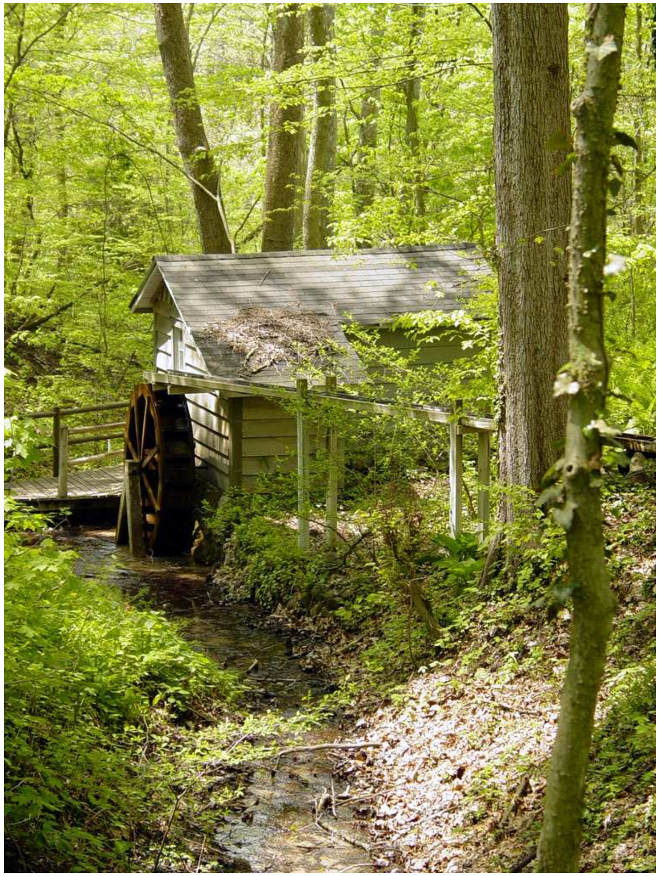
- The new and old agriculture
- The new and old machines
- The developing and developed countries
- Energy use in US: Homo Colossus Americanus
- Energy flows in US agriculture
- Endo- and exosomatic energy use
- Conclusions

Old and New Agriculture

Old Agriculture = Many People, Small Energy Inputs, Small Harvests, No Pollution
New Agriculture = Few People, Huge Energy Inputs, Large Harvests, High Pollution

Old Agriculture = Diverse, almost sustainable ecosystems powered by the sun
New Agriculture = Unsustainable deserts paved with single plants running on fossil fuels

Old and New Machines



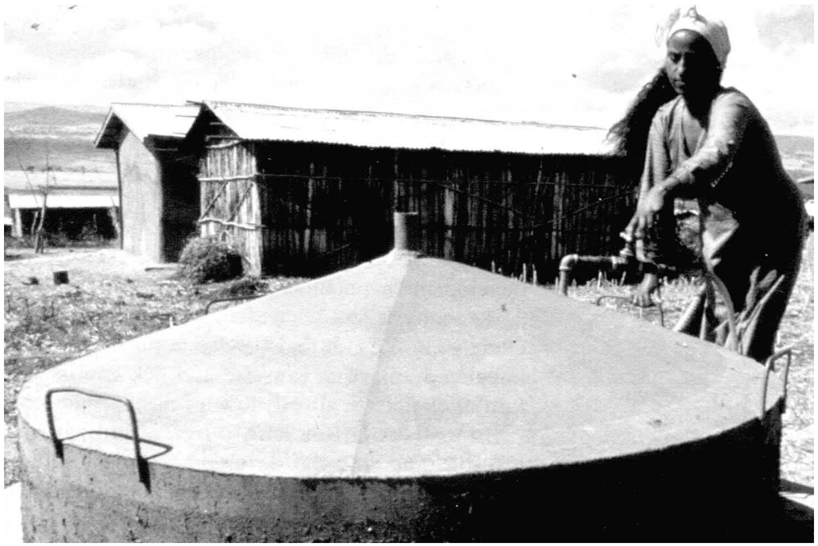
Old Machines = Small and Few, Powered by Animals, Water or Wind, No Pollution
New Machines = Gigantic and Many, Powered by Fossil Fuels, High Pollution

Developing and Developed Countries

Developing = Huge Poor Farming Populations, Low Agricultural Productivity
Developed = Tiny Farming Populations, High Agricultural Productivity

Agricultural workers in China = 40% of population can barely feed China
Agricultural workers in US = 0.17% of population can feed US, China, and Bangladesh

Developing and Developed Countries



Developing = Tiny Chemical Waste Fluxes, Low Environmental Impact, Sustainable
Developed = Large Chemical Waste Fluxes, High Environmental Impact, Unsustainable

CO_2 emissions in Kenya = 0.2 tonnes/person
CO_2 emissions in US = 20.2 tonnes/person

Units in My Presentation. . .

- The fundamental unit of energy is 1 exa Joule (EJ)

1EJ = 1,000,000,000,000,000,000 J
is the amount of metabolized energy in food sufficient to sustain the entire U.S. population for one year

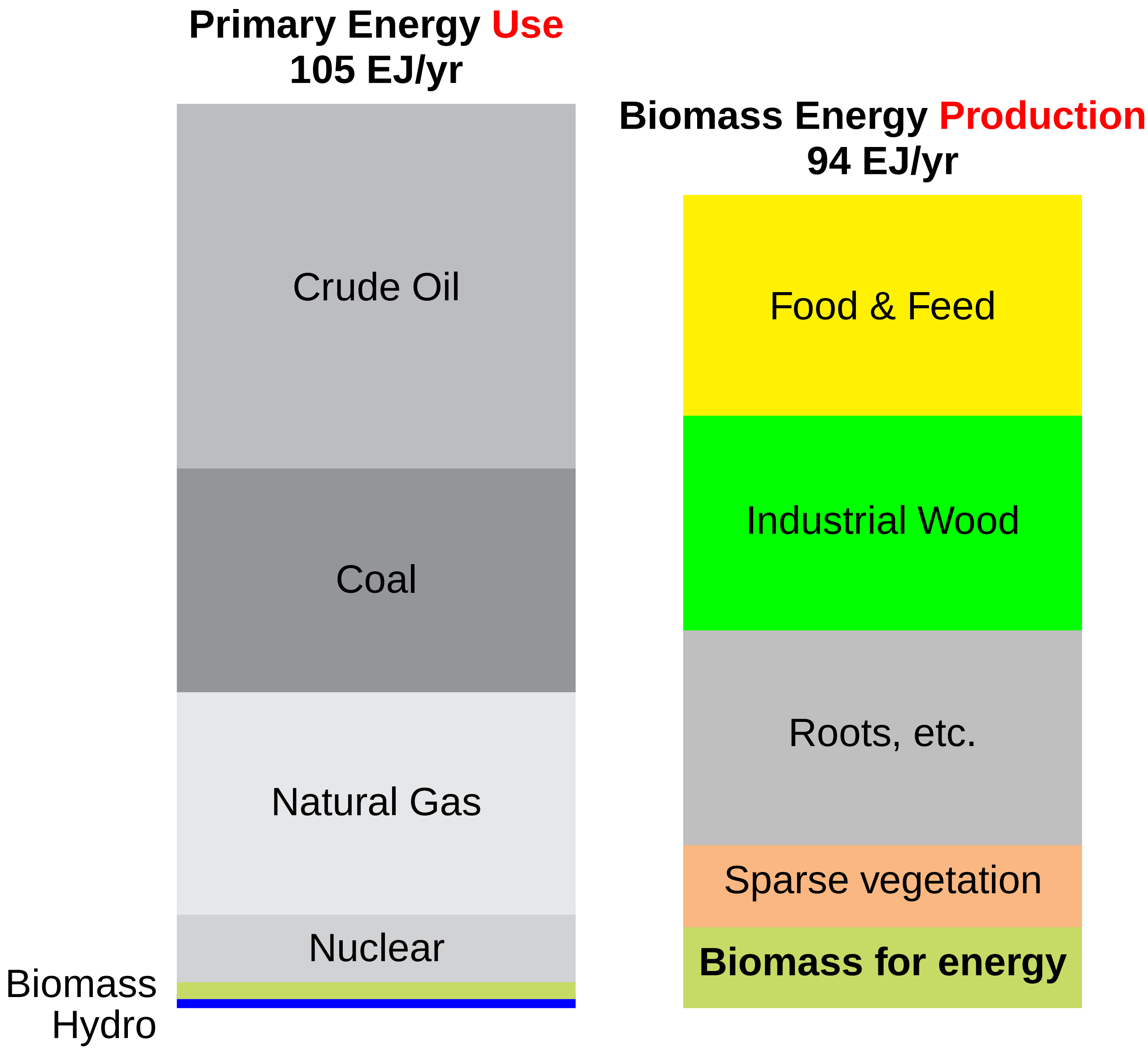
- Currently the U.S. uses 105 EJ/year; one hundred and five times more than we need to live
- If we were to metabolize this amount of energy, we would be 15 m long sperm whales, each weighing 40 tonnes. There are $\sim$1.9 million of sperm whales worldwide and 300 million Americans

Homo Colossus Americanus. . .

1 Statistical American = 1 Sperm Whale

EUGENE ODUM, *Ecological Vignettes*, 1998

We Burn More Than Plants Produce



Sources: Good & Bell, 1980; Patzek, 2005

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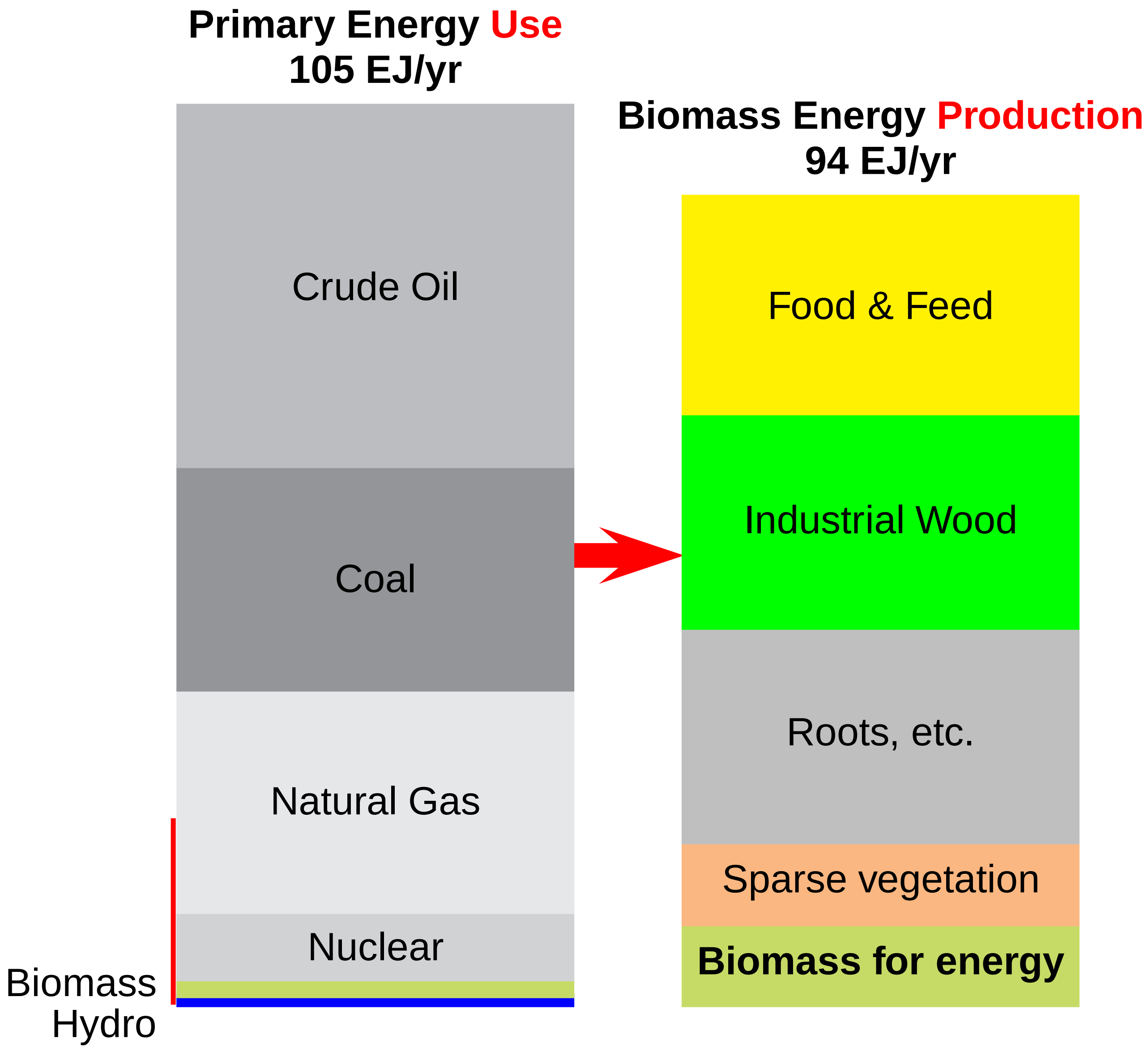
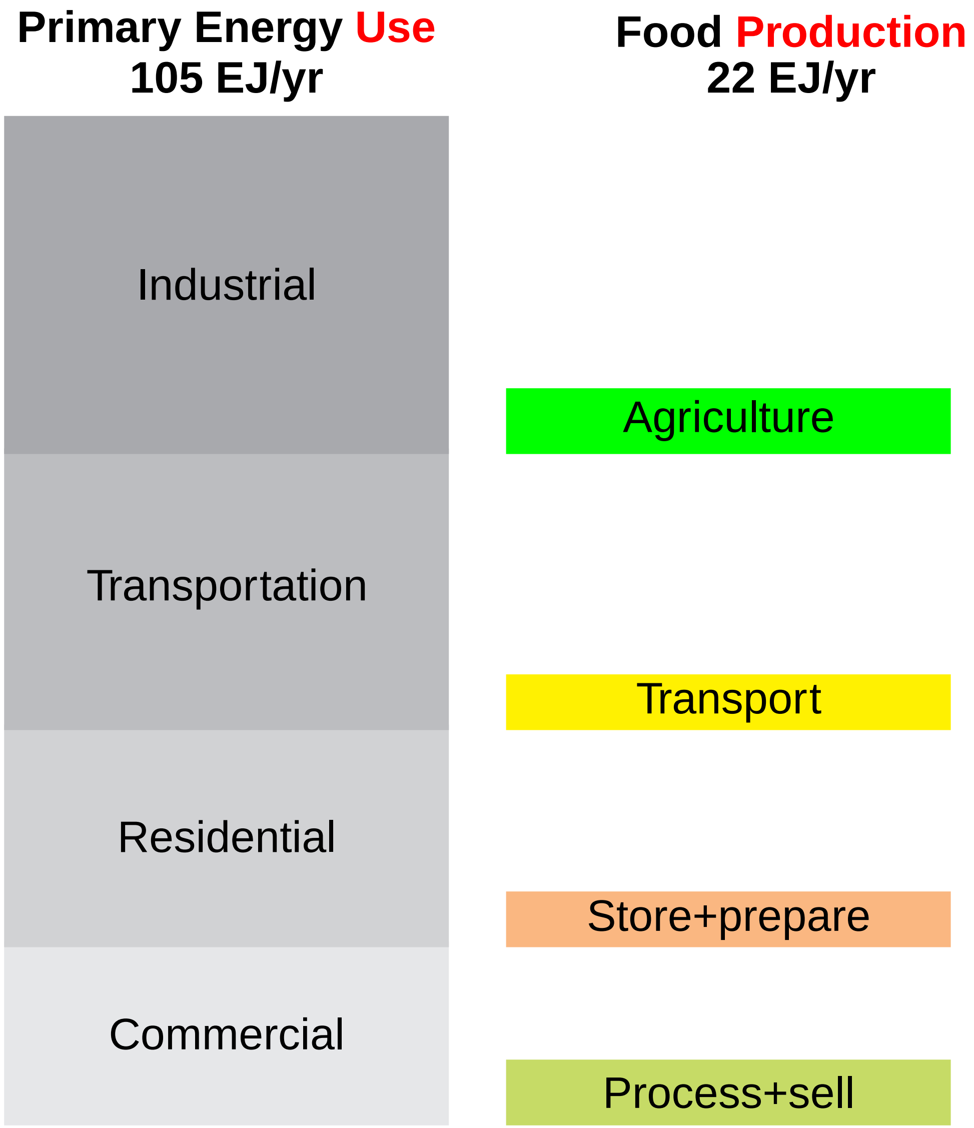


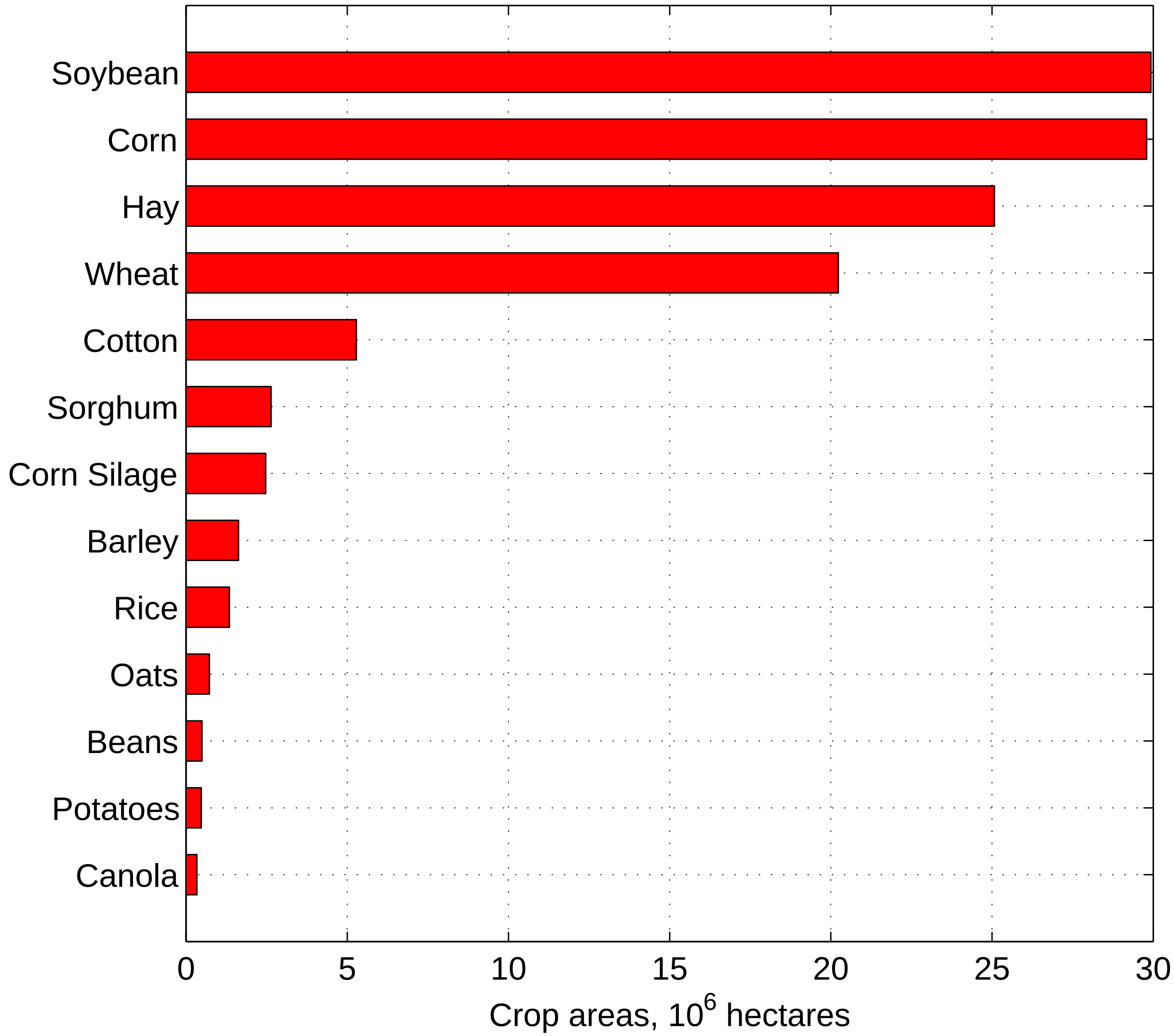
Sources: Good & Bell, 1980; Patzek, 2005

Energy Use in Agriculture



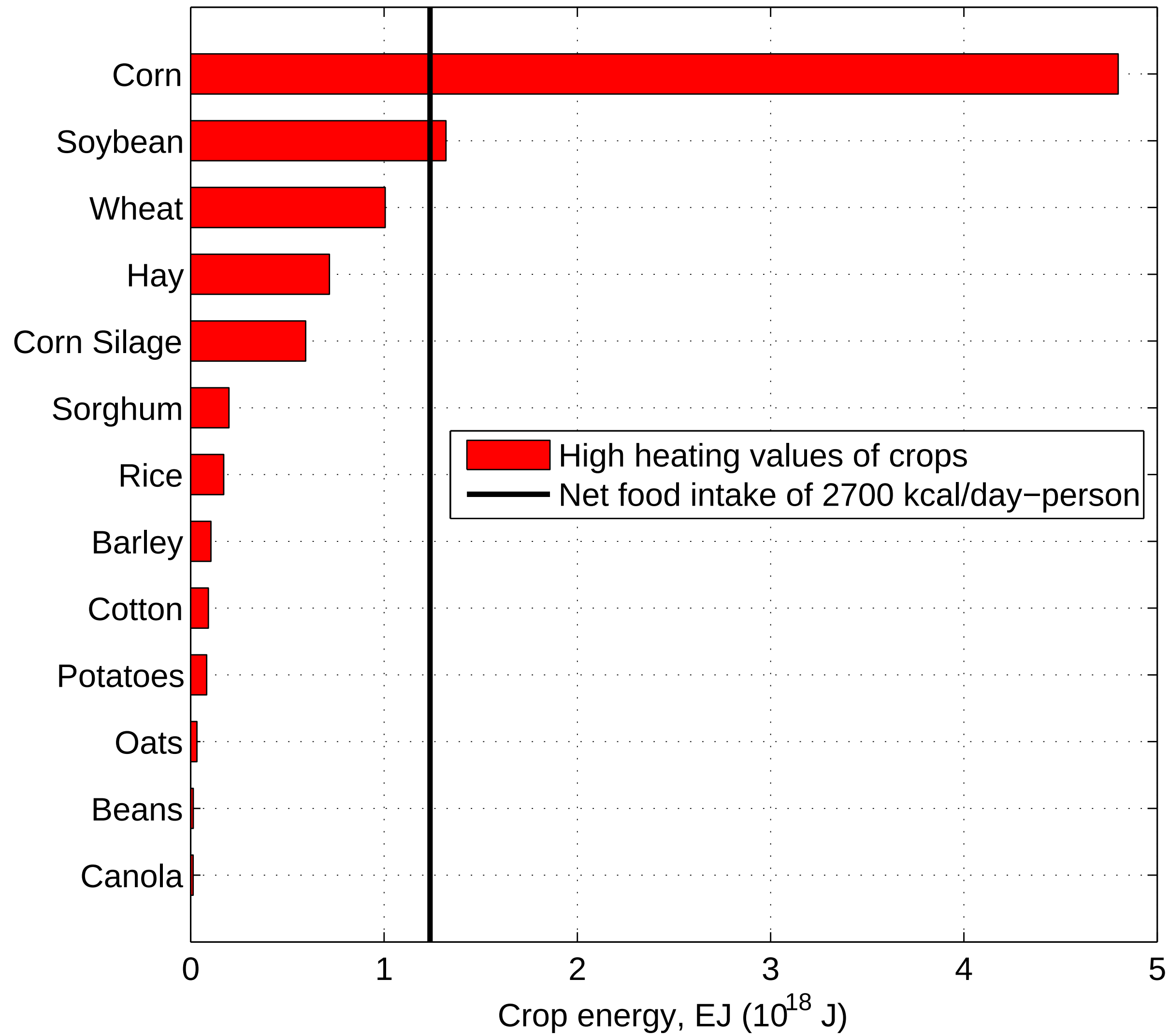
Sources: USDA; Miller, Environmental Science, 1995, p. 377

US Agriculture: Crop Areas



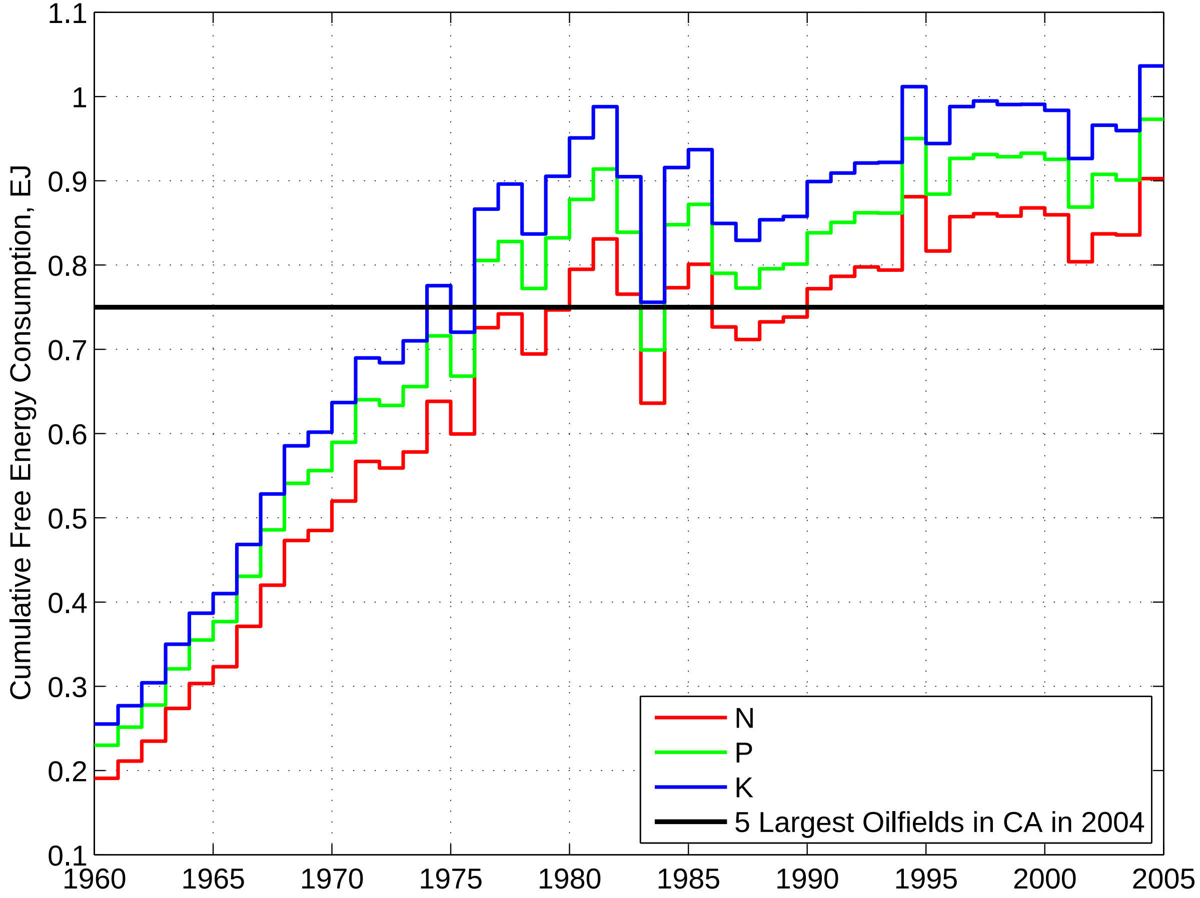
Source: USDA NASS. Total crop area 120 Mha (300 million acres)

US Agriculture: Crop Energy



Sources: USDA NASS, Patzek (2004). Total crop energy 9.14 EJ (9 quads)

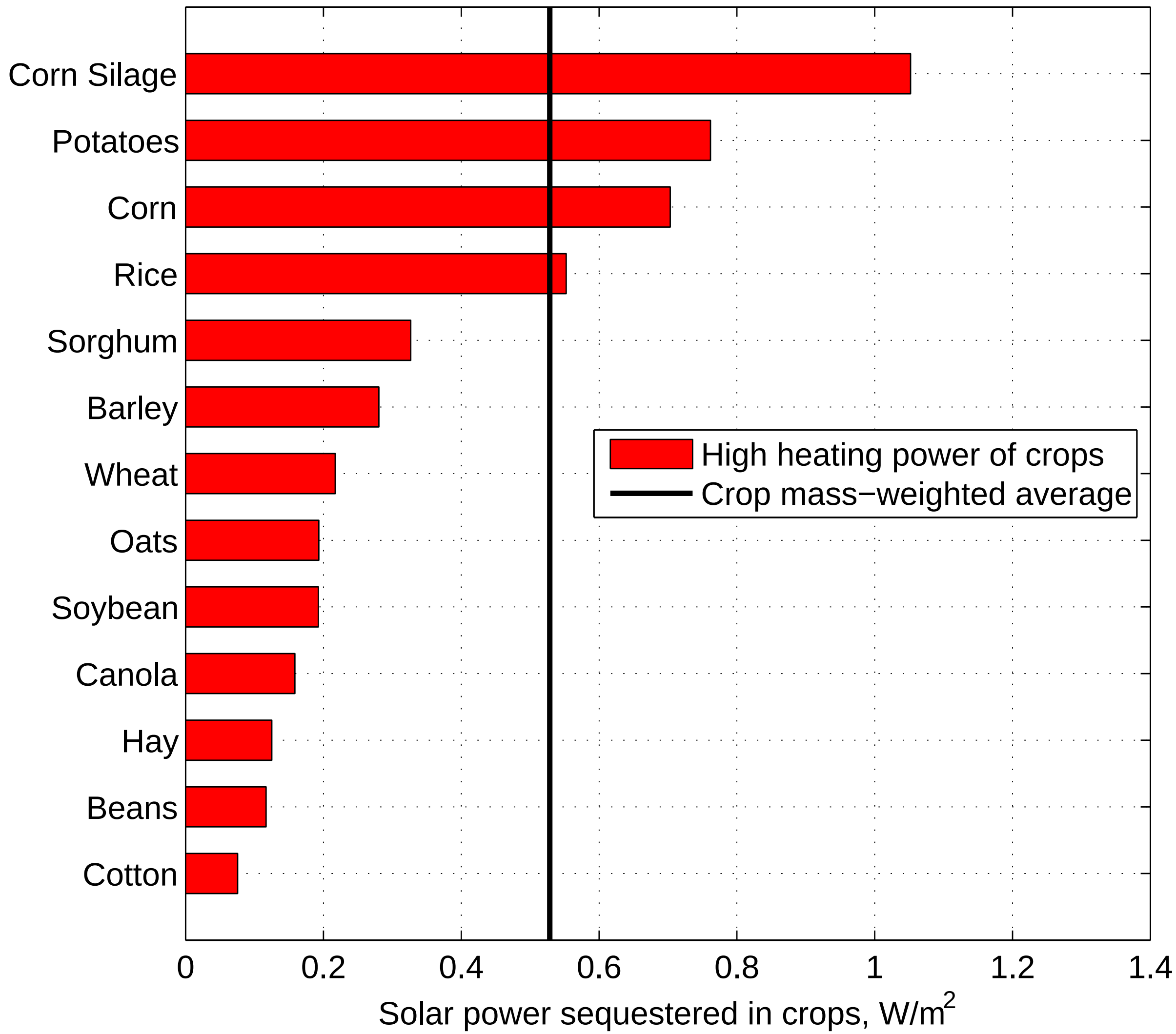
US Agriculture: Fertilizer Energy



Sources: USDA NASS, Patzek (2004)

Oilfields are: South Belridge, Cymric, Kern River, Midway Sunset, and Elk Hills

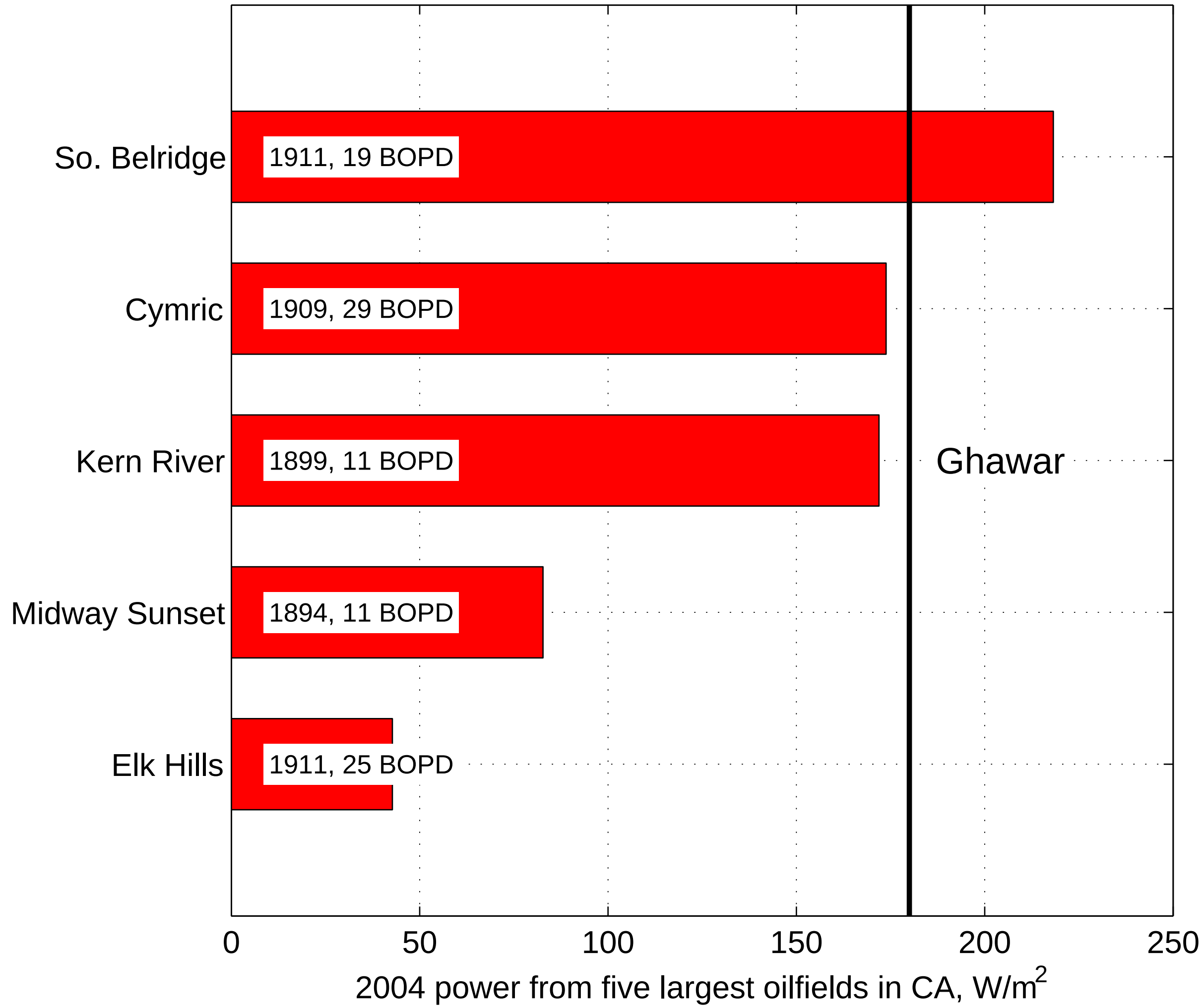
US Agriculture: Power Flux



Sources: USDA NASS, Patzek (2004). Mean crop power flux 0.53 W/m^2

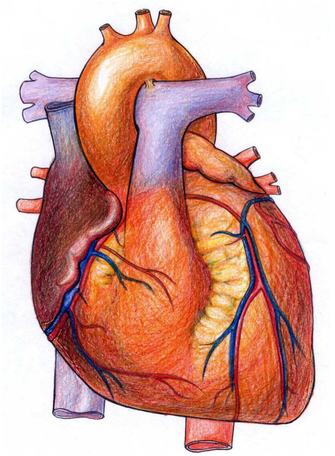
Each person in US uses 11,250 W of primary energy + Imported goods

US Petroleum: Power Flux



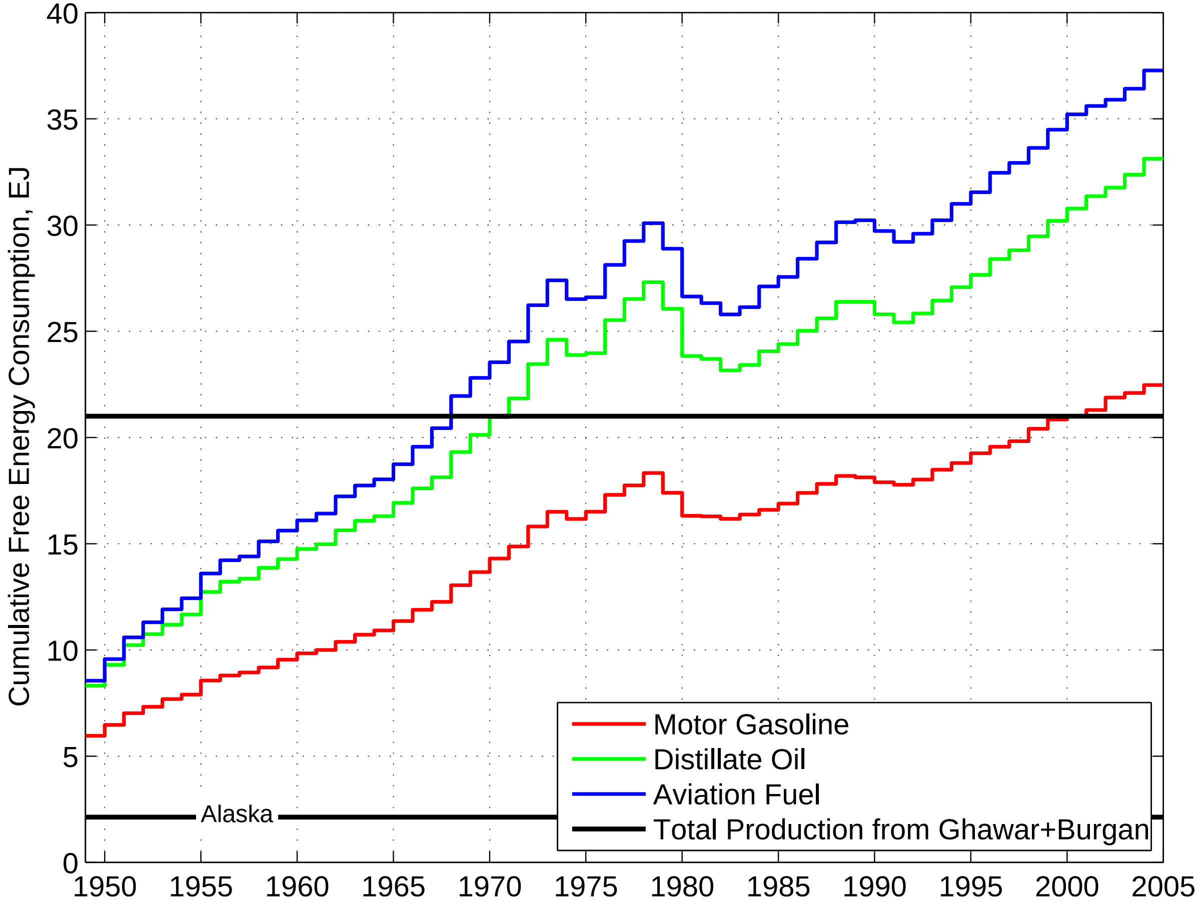
Sources: US DOE EIA, Patzek (2004)

Endo- and Exosomatic Energy Use



Human Metabolism	Societal Metabolism
0.0001 MW/average person	0.012 MW/average person
0.02 ha/avg. person to live	2 ha/avg. person to function
6×10^6 very productive ha to live	6×10^6 km^2 to function
	Ag worker inputs 0.8 MW
	Ag worker outputs 3 MW
	Oil&Gas worker inputs 2.8 MW
	Oil&Gas worker outputs 14.5 MW

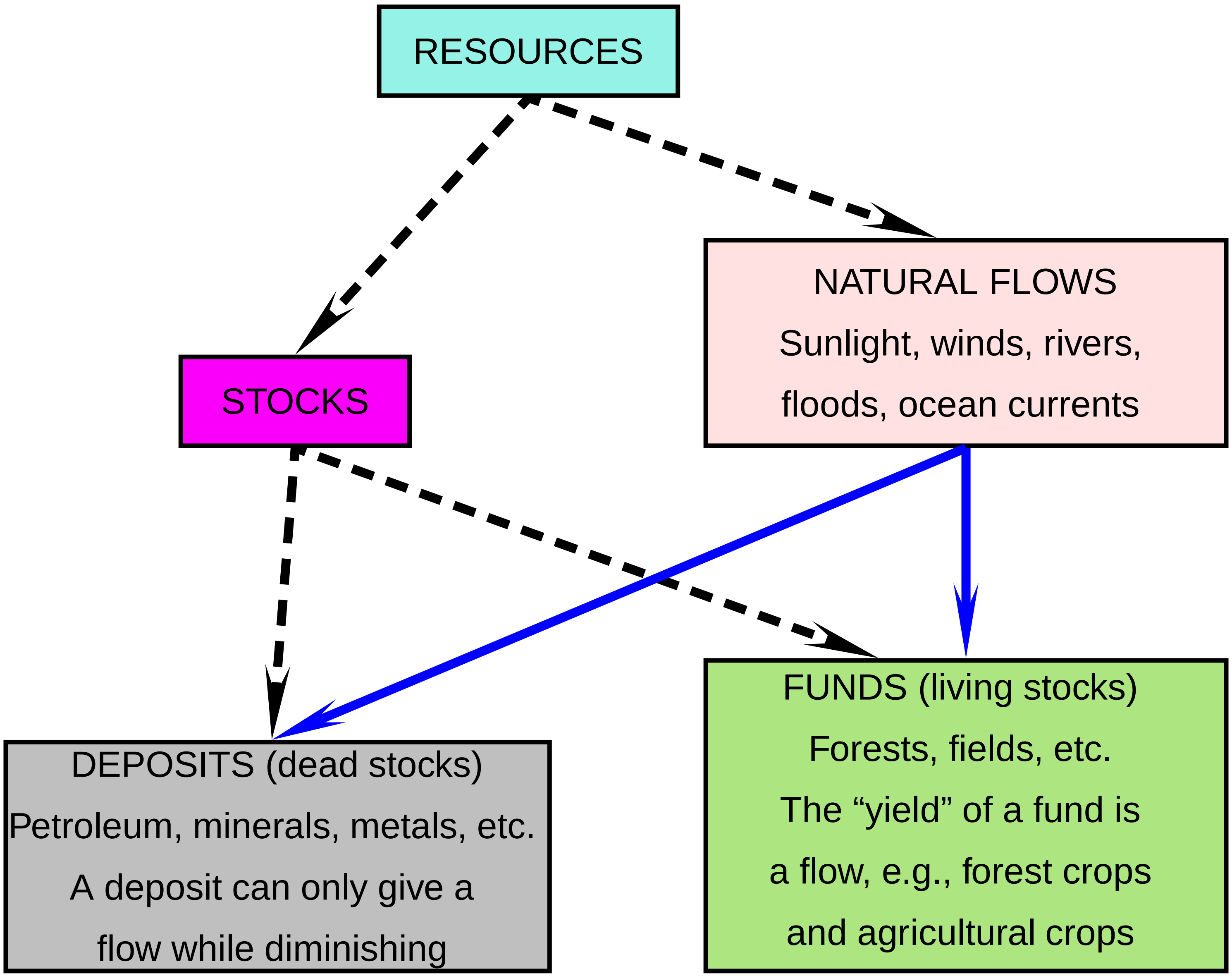
US Fuel Use: Energy Flux



Sources: US DOE EIA, Patzek (2004)

Ghawar and Burgan are two most productive oilfields on the earth

Resource Classification. . .



True Cost of Ethanol

Fact	Value	Units
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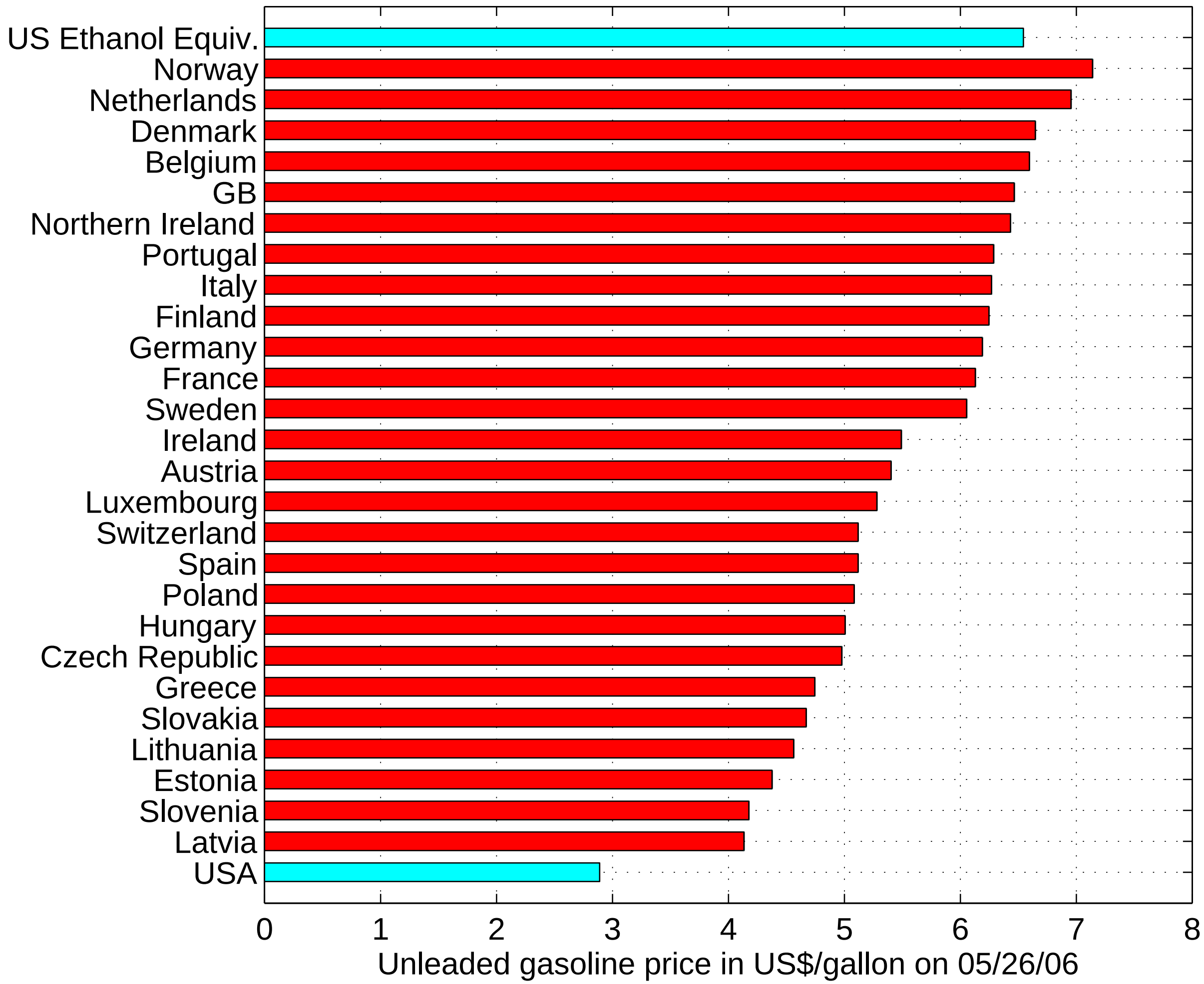
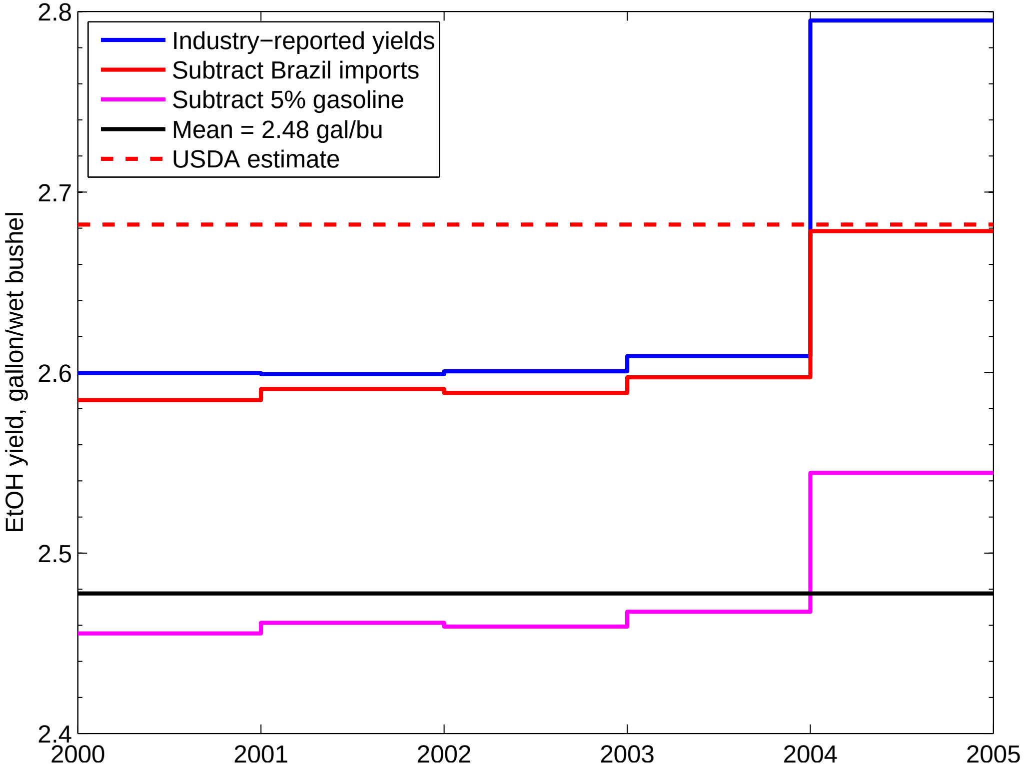
Mean cost of EtOH to taxpayer	**4.3060**	**$/gallon EtOH denatured**
Energy equivalent cost of EtOH to taxpayer	**6.5440**	**$/gallon GGE**

Current Gasoline Prices



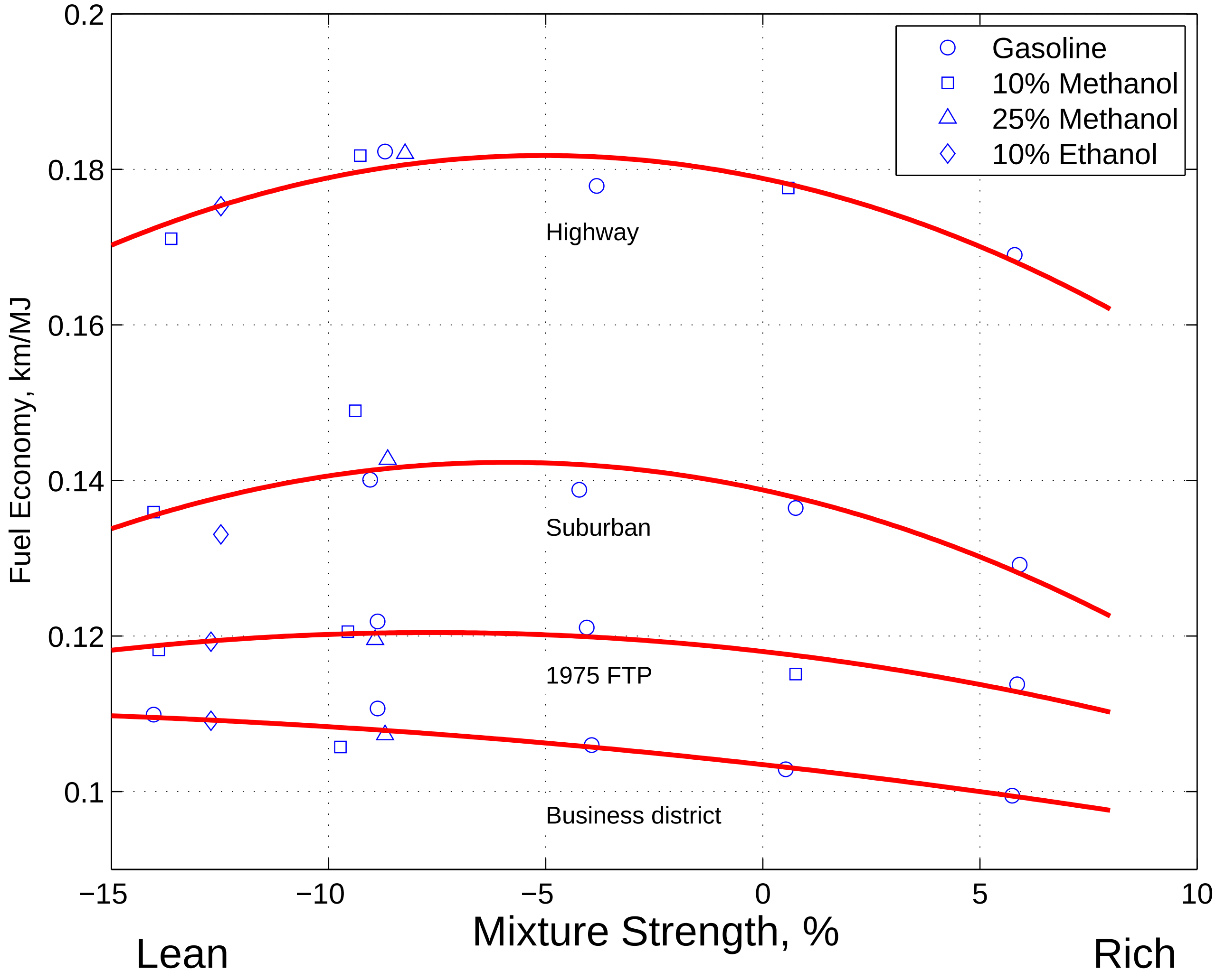
Data sources: www.aaroadwatch.ie/eupetrolprices/ and tonto.eia.doe.gov/oog/info/gdu/gasdiesel.asp

Ethanol Yield



Source: petroleum.berkeley.edu/patzek/BiofuelQA/Materials/RealFuelCycles-Web.pdf

Distance Driven Per MJ in Fuel



One needs 35% more ethanol to drive the same distance!

Source: BRINKMAN *et al.*, *Exhaust Emissions, Fuel Economy, and Driveability of Vehicles Fueled with Alcohol-Gasoline Blends*, Paper 750120, Soc. Automotive Eng., 1975