The United States of America Meets the Planet Earth

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1 Summary of Conclusions

1. There is no Philosopher's Stone out there that will magically create cheap, clean, and abundant energy. Instead, we will be facing increasingly harsh problems with energy conservation and supply.

2. In a year, all vegetation in the USA delivers less biomass energy than the fossil and nuclear energy we consume. Most of the annual biomass production is committed to food, feed, lumber, paper pulp, fiber, etc., and is heavily subsidized with fossil fuels. Most of the remaining land is covered with sparse and remote vegetation, but some of it could be used for biofuel production. Compared with current energy use in the U.S., the impact of biomass is almost negligible, regardless of its source.

3. Ms. THERESA SCHMALSHOF of NCGA, who testified on May 19, 2005, before the House Subcommittee on Energy and Mineral Resources, correctly stated that U.S. corn growers and ethanol producers heavily rely on fossil fuel subsidies: on natural gas, crude oil, and coal. The first two fossil fuels are in very short supply, the last is abundant. Ms. SCHMALSHOF concluded that more fossil energy from all sources must be produced *now* to save American corn growers and ethanol producers in the near future. See http://resourcescommittee.house.gov/archives/109/testimony/2005/-TheresaSchmalshof.htm

4. I conclude that we must start managing our agriculture with far less fossil energy.

5. Further increases in corn ethanol production from the 2003–2004 levels, will change nothing in our runaway consumption of fossil energy. At best, more ethanol will decrease motor gasoline consumption in 2012 by 2.5%, while increasing the total primary

energy consumption. More likely, costlier ethanol from marginal corn will destabilize corn grain prices.

6. Removal of the current 1 psi Reid Vapor Pressure (RVP) waiver for 10% gasohol, would reduce ethanol contribution to conventional gasoline by 30 or 40 percent. In other words, in 2012, without the waver, ethanol will displace the same fraction of gasoline as in 2004, with the waver.

7. Increasing the average mileage of passenger cars and SUVs by $3-5$ miles per gallon would dwarf the effects of all possible biofuel production from *all* sources of biomass available in the U.S.

8. Inflating passenger car tires properly *today* will have more impact on the energy independence of U.S. than the 7.5 billion gallons of corn ethanol in 2012 *with* the RVP waver.

9. There are fundamental physical and chemical reasons why industrial production of lignocellulosic ethanol may be an elusive goal. Thermodynamically and kinetically, lignocellulosic ethanol is the poorest choice in comparison with direct burning of biomass for electricity generation and with biomass gasification.

10. Biodiesel fuel from soybeans has a negligible chance of satisfying a discernible part of our fuel consumption.

2 Recommendations

1. It seems prudent to increase *now* the average mileage of U.S. passenger cars and SUV's by at least 3-5 mpg.

2. It also seems prudent to invest in efficient manufacturing technologies for photovoltaic cells. A mediocre photovoltaic cell is about 100 times more efficient in delivering work than corn ethanol.

3. We ought to take a deep breath and freeze corn ethanol production at or below the 2004 level for several years, while evaluating the long-term consequences of gasohol use.

4. I want to establish an independent *small* center in Berkeley to create the common thermodynamic, chemical, and biological language to describe all major solar (photovoltaic, wind, and biomass), fossil, and nuclear energy capture schemes. This interdisciplinary center will coordinate efforts of several engineers (chemical, mechanical, electrical and agricultural), physicists, chemists, biochemists, biologists, ecologists, geneticists, economists, applied mathematicians, psychologists, and political scientists across the U.S. and abroad. The proposed center ought to be funded in part with public money and in part by independent private foundations.

5. Because such a center will almost immediately start saving millions of dollars of taxpayers' money, it should happen as soon as possible. I would like to name this center after M. King Hubbert, a remarkable petroleum geologist, who in 1956 predicted that our petroleum and gas endowments would largely run out by 2020-2030. It took 20 years for the National Academy of Sciences to officially admit that he was right.

Table 1: Annual use of energy in the U.S. in the year 2003. Sources: U.S. DOE Energy Information Agency, www.eia.doe.gov, Patzek CE24 Class Notes, 2005

Source	Use EJ/year	Comments
Petroleum	41.8	Primary
Coal	26.1	Primary
Natural Gas	25.9	Primary
Nuclear	7.8	Primary
Biomass	2.0	Primary
Hydro	1.0	Primary
TOTAL	**104.6**	**Primary energy**
Food	1	Food products to live
Gasoline	18	All uses
Electricity	14	All sources
Nuclear	2.8	Electricity
Biomass	0.4[a]	Electricity
Wind	0.04[b]	Electricity
Photovoltaics	0.002[c]	Electricity

[a] The EIA data seem to be inconsistent. The summary statistics table lists biomass as the source of 3% (0.4 EJ/yr) of all electricity produced in the U.S. The detailed statistics list 37 and 22.9 billion kWh from wood and other biomass respectively (0.22 EJ/yr). The more optimistic estimate is used in the table

[b] The wind electricity was 10 260 150 000 kWh/year in 2002 or 0.04 EJ/yr according to www.mnforsustain.org/windpower_schleede_costs_of_electricity.htm, if the windmills operated with a 25% capacity factor (accessed March 5, 2005)

[c] The solar electricity was 0.003 EJ/yr in 2003 according to www.solarbuzz.com/StatsMarketShare.htm (accessed March 5, 2005)

Figure 1: Dr. M. King Hubbert (1903–1989), the most influential American-born geoscientist, creator and director of Shell Development Company, the Bell Labs of petroleum industry, 1943-1963; California Regents' Professor at U.C. Berkeley, 1973-1976. He was elected to the National Academy of Sciences in 1955 and the American Academy of Arts and Sciences in 1957; he received the Geological Society of America's Arthur L. Day Medal two years later and became the body's president in 1962. In 1977 he received the Rockefeller Public Service Award. In 1975, with the U.S. suffering from high oil prices, the National Academy of Sciences confirmed their acceptance of Hubbert's calculations of oil and natural gas depletion, and after 20 years acknowledged that their earlier, more optimistic estimates had been incorrect. I am also a petroleum engineer, who spent 7 year at Shell Development.

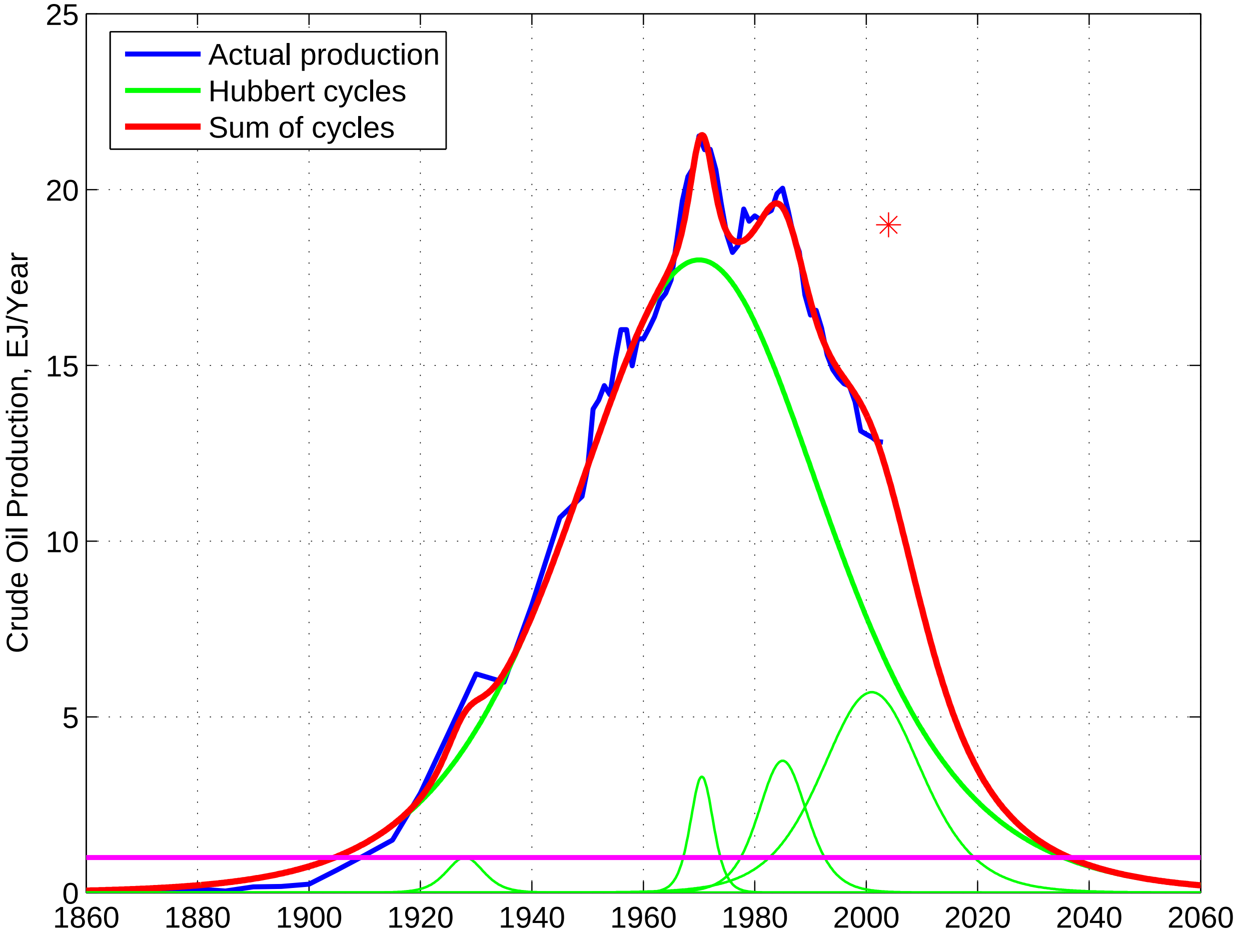

Figure 2: The HUBBERT cycle analysis of the U.S. crude oil endowment, my calculation. The total endowment is 230 billion barrels of oil, less than 1/2 of the U.S. Geological Survey's 1961 estimate of 590 billion barrels. The largest green cycle was predicted by M. KING HUBBERT in 1956. The small cycles describe oil production from waterflood, thermal EOR, Alaska, Austin Chalk, Gulf of Mexico,…, and the new drilling technologies. The area underneath the small cycles is 200 Exa Joules (1 EJ = 10^{18} J), equal to 2 years of primary energy consumption by the U.S. This has been the value of petroleum R&D. The magenta line at 1 EJ/yr is the amount of energy necessary to feed the U.S. population for one year. The star is the energy consumed as motor gasoline, 19 EJ/yr in 2004. Note that in 2004 the U.S. produced as much oil as in 1950, when President Truman was in the White House. Also note that the energy in just the motor gasoline consumed in 2004 was about ~30% higher than the energy of all crude oil produced in the U.S.

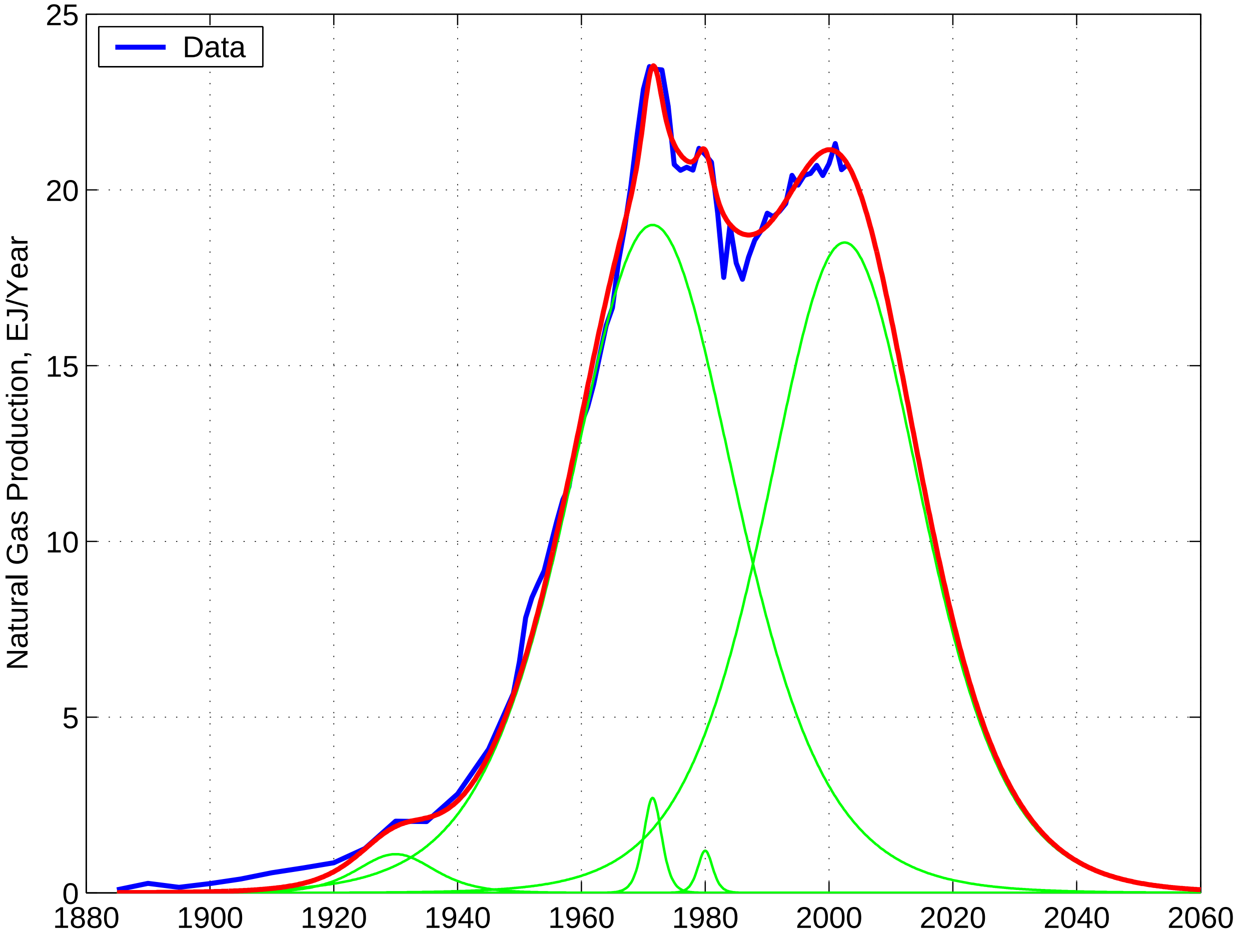

Figure 3: The Hubbert cycle analysis of the U.S. natural gas endowment, my calculation. There are two main cycles. The original Hubbert cycle for conventional natural gas peaked in 1973. The second comparable cycle, mostly from the Gulf of Mexico gas fields and unconventional gas fields, saw the peak drilling activity in 1981. Note that the domestic production rate of natural gas will be declining soon at 15-20% per year. The gas produced from the second main Hubbert cycle will be exhausted in the next 20 years. Therefore, Ms. Theresa Schmalshof of NCGA was correct when she testified before Congress that "Farmers face higher nitrogen fertilizer prices and the prospect that there might not be an adequate supply of nitrogen fertilizer to satisfy farmers demands at any price." She then appealed for drilling for gas everywhere in the U.S. and for the new natural gas pipeline from Alaska.

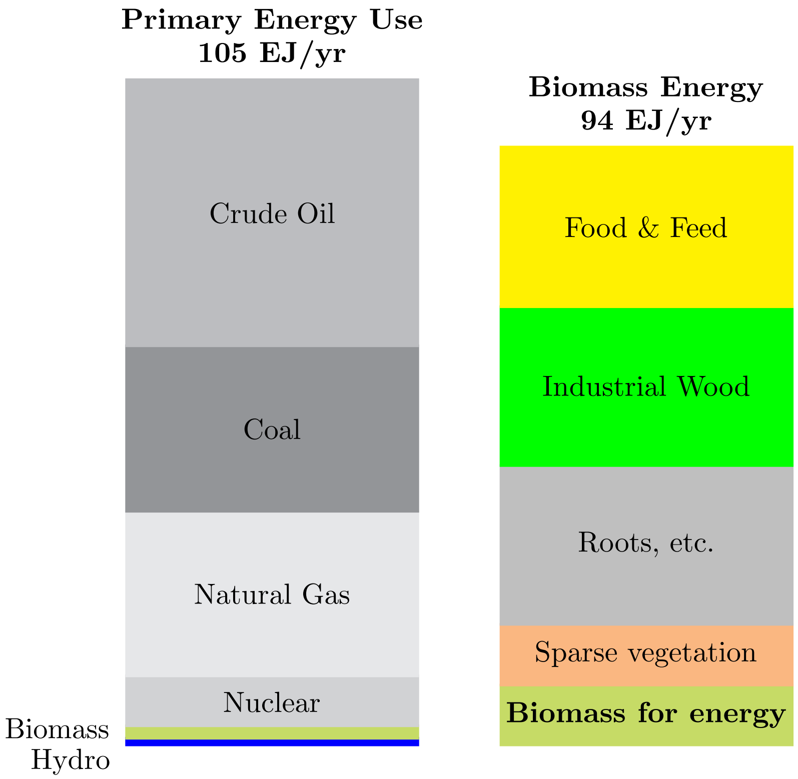

Figure 4: Annual fossil and nuclear energy consumption in the U.S. is larger than all biomass production. Sources: EIA; N. E. Good and D. H. Bell, Photosynthesis, *Plant Productivity and Crop Yield*, Academic Press, 1980; Patzek, 2005 calculations. **Left:** Primary energy use in the U.S. in 2003, see **Table 1**. Biomass burning provided about 2 percent of primary energy supply. **Right:** A very optimistic estimate of annual biomass production over the entire U.S. area. This biomass production has been converted to equivalent energy. Over 3/4 of the biomass production is committed to food and animal feed, wood for paper, lumber and fiber, or is energy stored in plant roots and other inaccessible parts. This part of biomass production is *heavily subsidized* with fossil fuels. One half of the remainder is remote and sparse vegetation. The other half may serve as the source of bioenergy, but a large part of it will be used to produce biofuels. So the ultimate sustained biofuel production capacity in the U.S. may be 2-3 percent of the U.S. consumption *today*. We already are at this level. Current proposals to replace a good part of the fossil energy devoured each year by us with the biomass-derived fuels are pure fantasy. The only way to *increase* the biomass share of primary energy use in the U.S. is to *decrease* the fossil fuel consumption. To make U.S. competitive with the rest of the developed world, we should strive to decrease our fossil energy consumption by a factor of *two*, so that each American uses daily only 50 times more energy than we need as food to live.

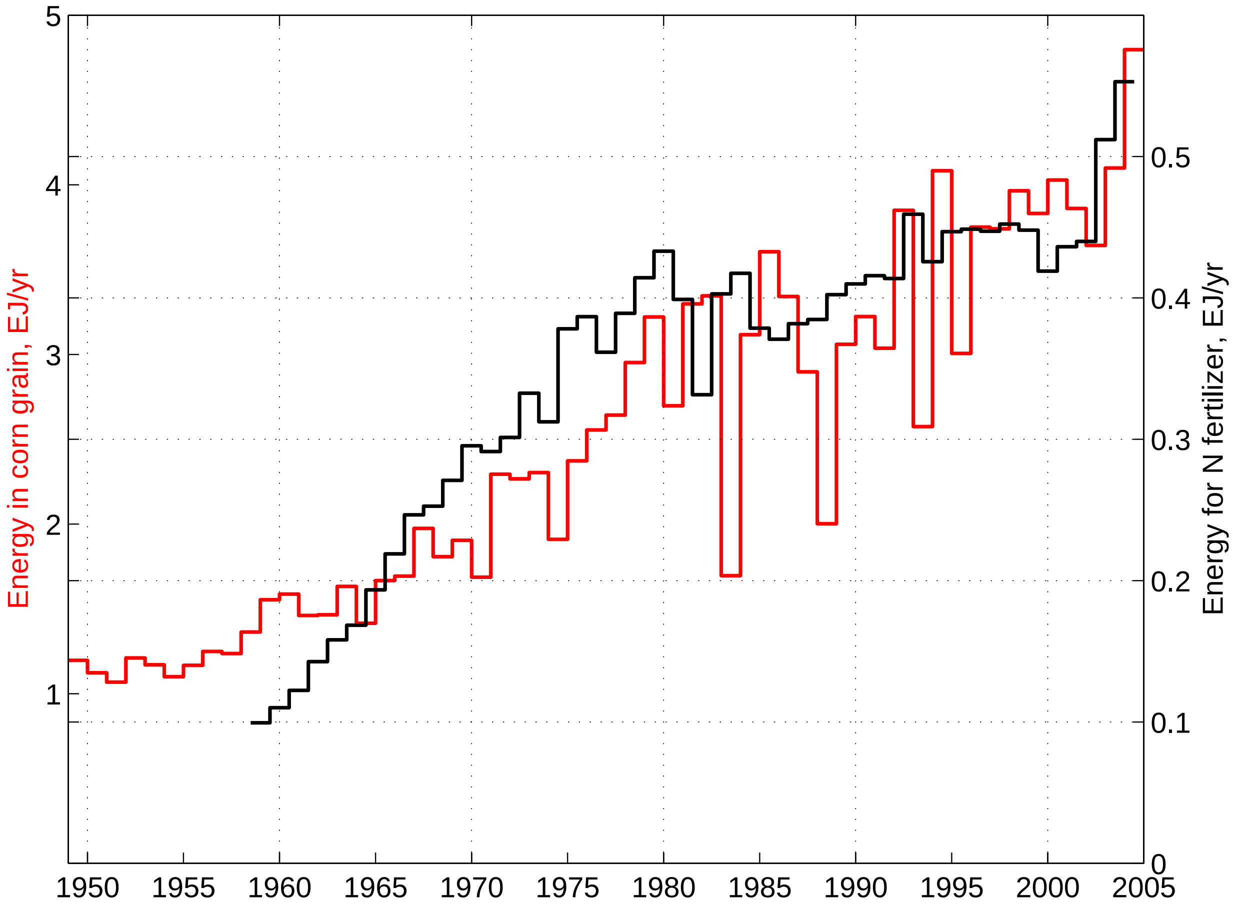

Figure 5: More corn = more nitrogenous fertilizer. Sources: USDA, The Fertilizer Institute, Patzek 2004. The high heating value of corn grain harvested in the U.S. each year between 1949 and 2004 (in red, left y-axis), and the cumulative free energy consumed to produce the nitrogenous fertilizers applied to grow the U.S. corn (black, right y-axis). Note that the 5-fold increase of corn grain yield corresponds to the 5-fold increase of the nitrogen fertilizer application rate. All nitrogen fertilizer in the U.S. is obtained from natural gas. In 2004, the highest crop ever in the U.S. was sufficient to feed the U.S. population for five years, or the population of China for one year. Says Ms. SCHMALSHOF: “Rising natural gas prices in the U.S. have caused domestic nitrogen fertilizer producers to severely curtail production. Of the 16.5 million tons of nitrogen capacity that existed in the U.S. prior to 2000, almost 20% has been closed permanently. Another 25% is at risk of closing within the next two years.” And it gets worse. Nitrogen imports accounted for nearly 50% of supplies for the 2004 fertilizer year and 85% of nitrogen fertilizer use. Historically, on a fertilizer-year basis, nitrogen imports only accounted for 20-25% of total nitrogen supplies during 1985-2000. Source: www.globalinsight.com/Perspective/PerspectiveDetail1609.htm.

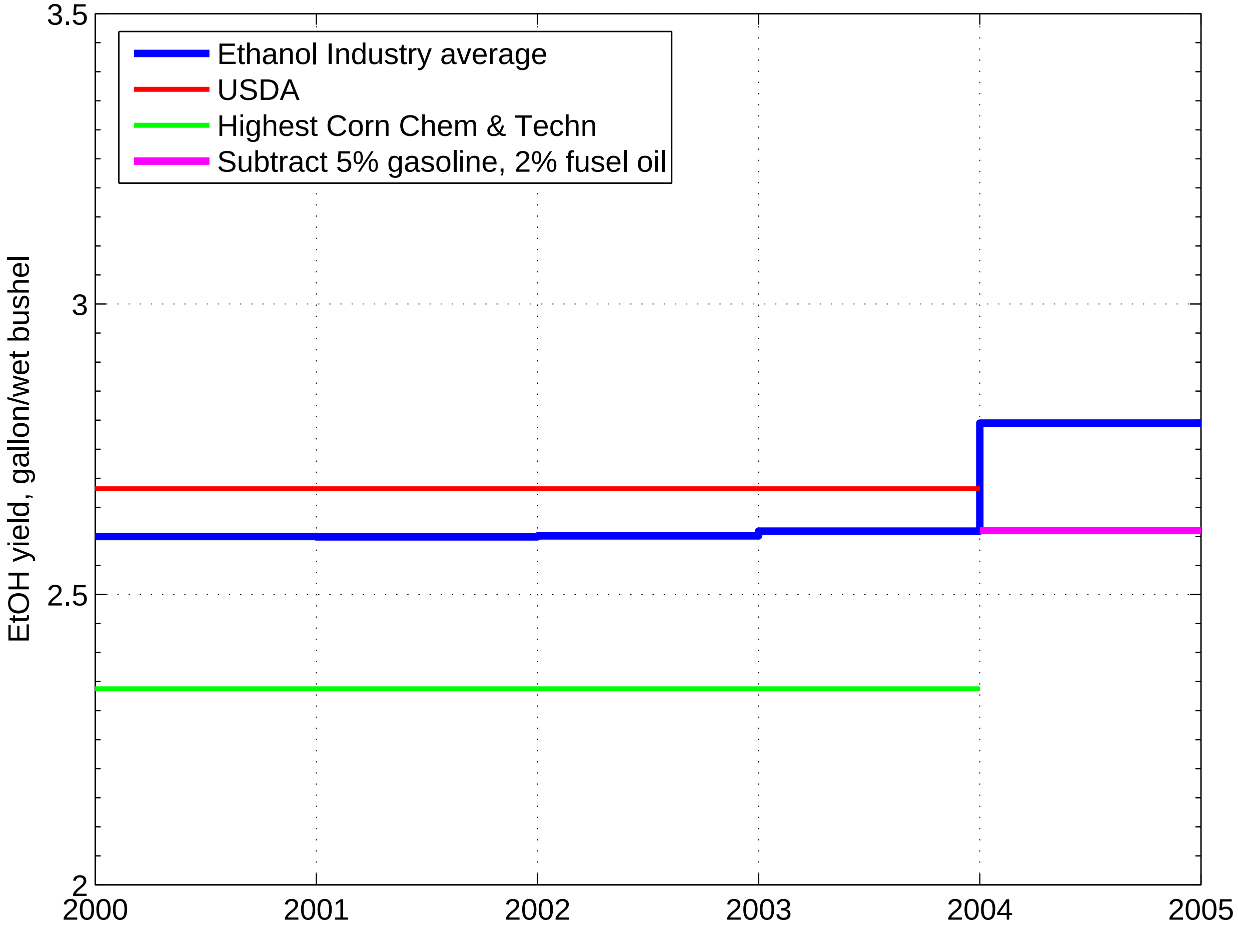

Figure 6: Source: Renewable Fuels Association, 2004 Ethanol Industry Outlook. Between 2000 and 2004, the average ethanol yield (the blue line) has been 2.6 gallons of anhydrous EtOH per bushel of corn grain delivered to the refineries. This bushel contains 15% of moisture on the average. In 2004, the ethanol industry seemed to have started counting 5 volume percent of #14 gasoline denaturant and 1–2 volume percent of fusel oil as ethanol. When these additives are accounted for, we return to the 2.6 gal EtOH/bushel (the magenta line). The USDA estimate of 2.682 gal EtOH/bushel has been consistently higher, and the highest 2002 Corn Chemistry and Technology Handbook estimate, page 709, has been lower than the ethanol industry's gross average.

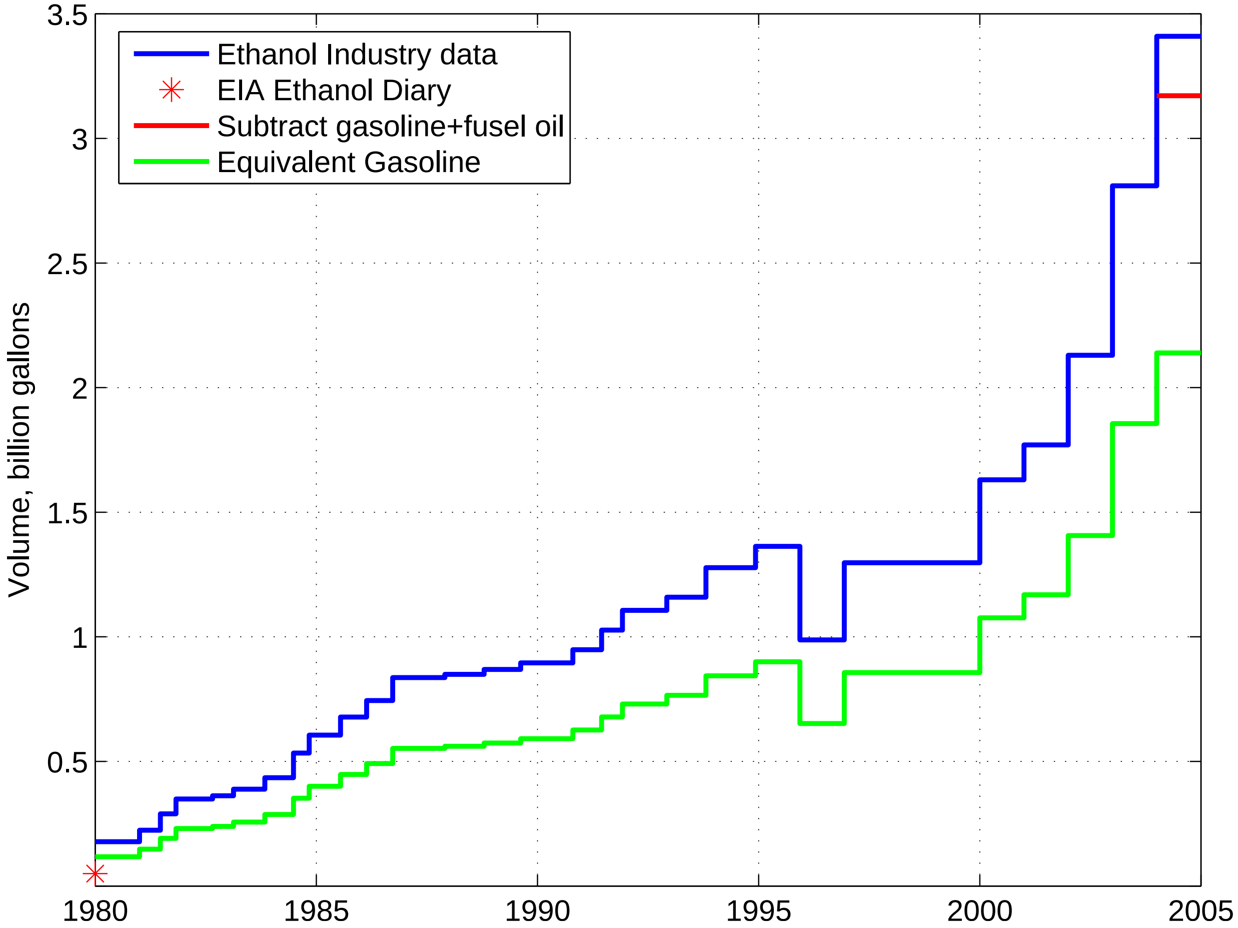

Figure 7: Sources: 1980 – 1992: Renewable Fuels Association; 1993 – 1998: Energy Information Administration, Form EIA-819M; 2004 Ethanol Industry Outlook. In 2004, the U.S. produced 3.2 billion gallons of anhydrous ethanol, fortified with 5 volume percent of #14 gasoline denaturant and 1–2 volume percent of fusel oil. I consider this volume to be an upper bound of what can be accommodated by the U.S. environment (water sources, natural gas supply, etc.) and economy without disrupting the corn market, and without major increases of ethanol price. Note that on energy-equivalent basis, 3.2 billion gallons of anhydrous ethanol equals 2.1 billion gallons of gasoline (the green curve). But the story does not end here…

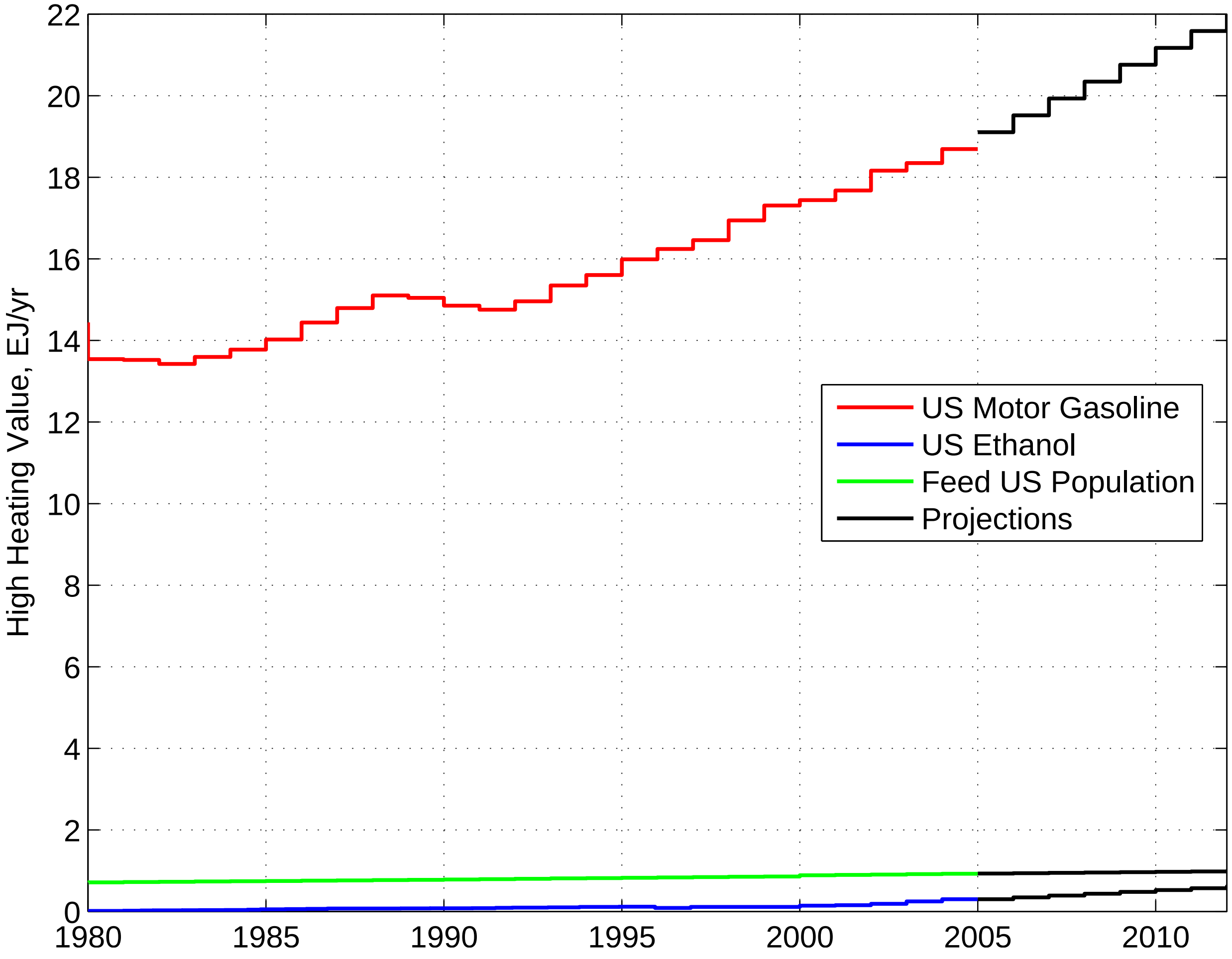

Figure 8: Sources: DOE EIA, 2004 Ethanol Industry Outlook, 2005 Energy Bill. The actual consumption of motor gasoline in the U.S. (the red curve), and its projected growth with the 2005 Energy Bill (the black curve). The historical ethanol production in blue, and its projected increase to 7.5 billion gallons in 2012 according to the 2005 Energy Bill (the black curve). The green curve is the amount of energy sufficient to feed the U.S. population for one year. Note how small the ethanol contribution is.

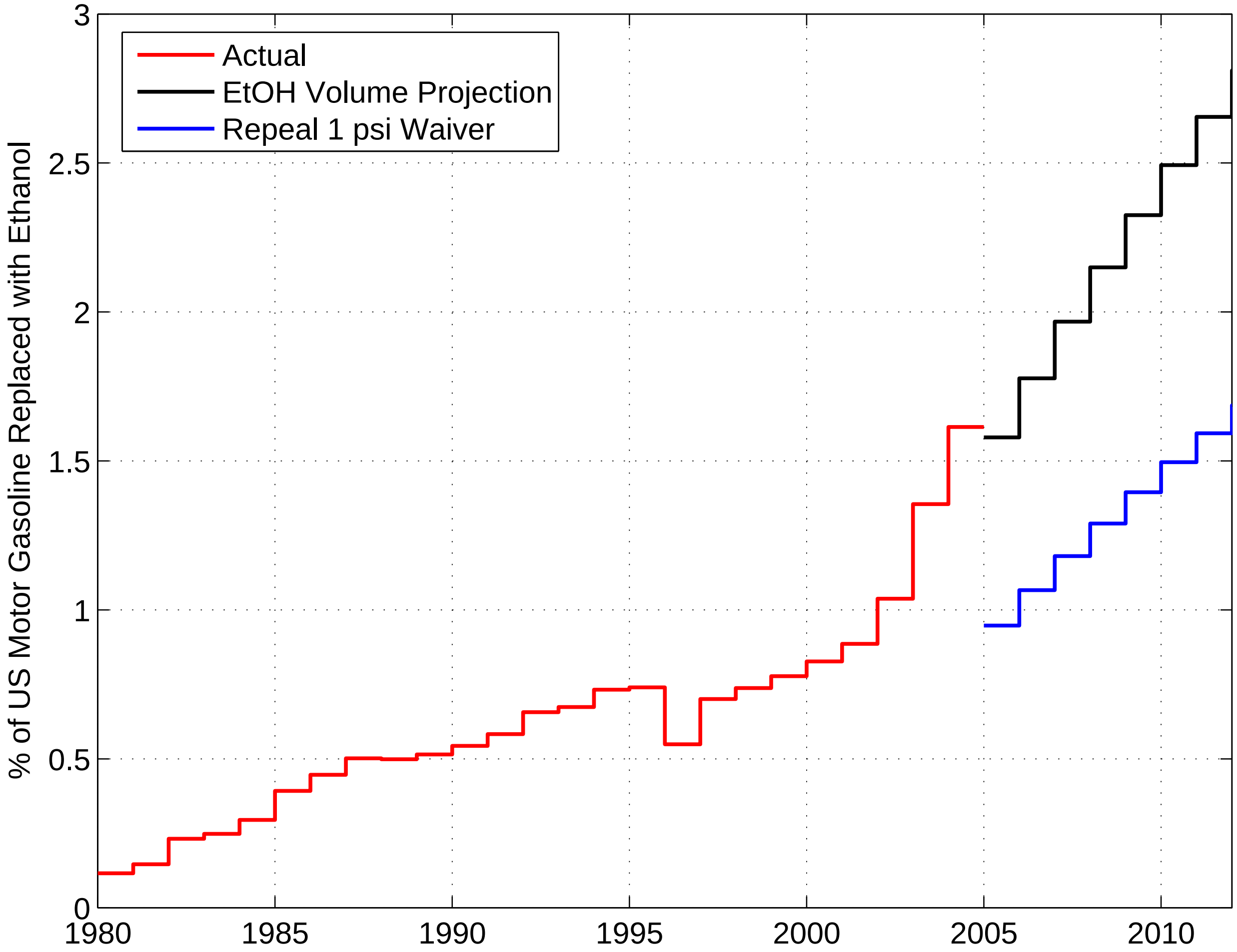

Figure 9: Sources: DOE EIA, 2004 Ethanol Industry Outlook, 2005 Energy Bill. After the correction for #14 gasoline and fusel oil (not shown), in 2004, corn ethanol satisfied less than 1.5% of U.S. motor gasoline consumption, provided that the 1 psi Reid Vapor Pressure (RVP) waver for gasoline-EtOH blends is *not* repealed by states fighting increased air pollution. In 2012, with the waiver, ethanol will displace another 1% of U.S. motor gasoline consumption on an energy-equivalent basis (the black curve). If the waiver is repealed, the lighter gasoline components will be removed in refineries to lower the RVP. The repeal of the waiver would reduce ethanol contribution to conventional gasoline by 30 or 40% (the blue curve) (Source: *Potential Supply Impacts of Removal of 1-Pound RVP Waiver*, September 2002, Office of Oil and Gas of the EIA, Mary J. Hutzler (202-586-2222, mhutzler@eia.doe.gov). The EIA study was requested by Senator Jeff Bingaman, Chairman of the Senate Committee on Energy and Natural Resources).

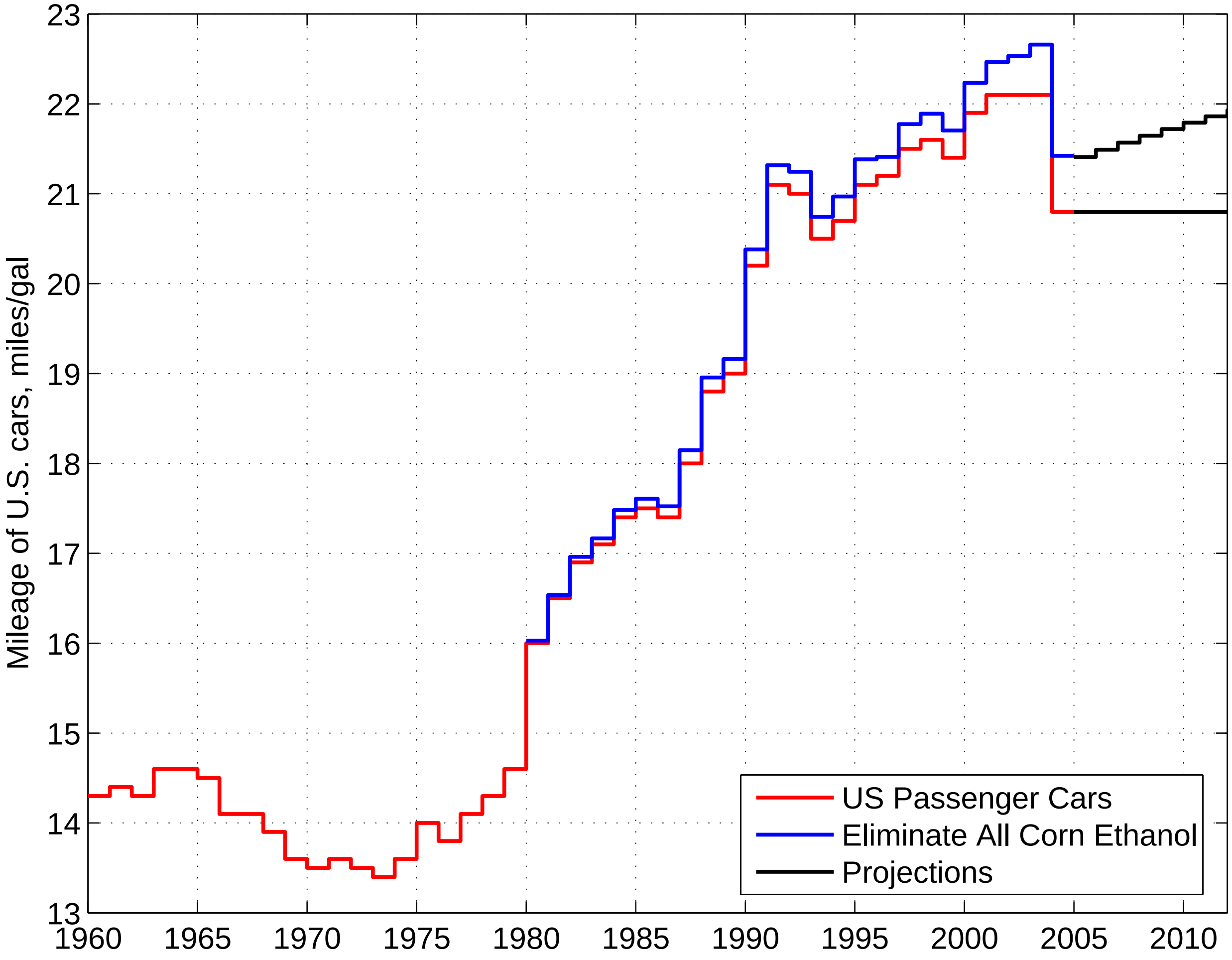

Figure 10: Sources: DOE EIA, U.S. Bureau of Transportation Statistics, EPA. The red curve is the historical mileage of U.S. passenger car fleet, *excluding* SUVs, light trucks and vans. Note the dramatic decrease from 21.2 miles per gallon (mpg) in 2001–2003 to 20.8 mpg in 2004. The blue curve is the calculated increase of mileage of the U.S. passenger car fleet sufficient to eliminate the use of ethanol altogether *with* the RVP waver. For example, the 7.5 billion gallons of ethanol – mandated by the 2005 Energy Bill by 2012 – could be compensated by an increase of car mileage by 1 mile per gallon, or going back to the average passenger car mileage in the year 2000. Thus the entire effect of corn ethanol is less than the effect of inflating car tires properly. Note that I have not considered here the gas-guzzling SUV's and light trucks.

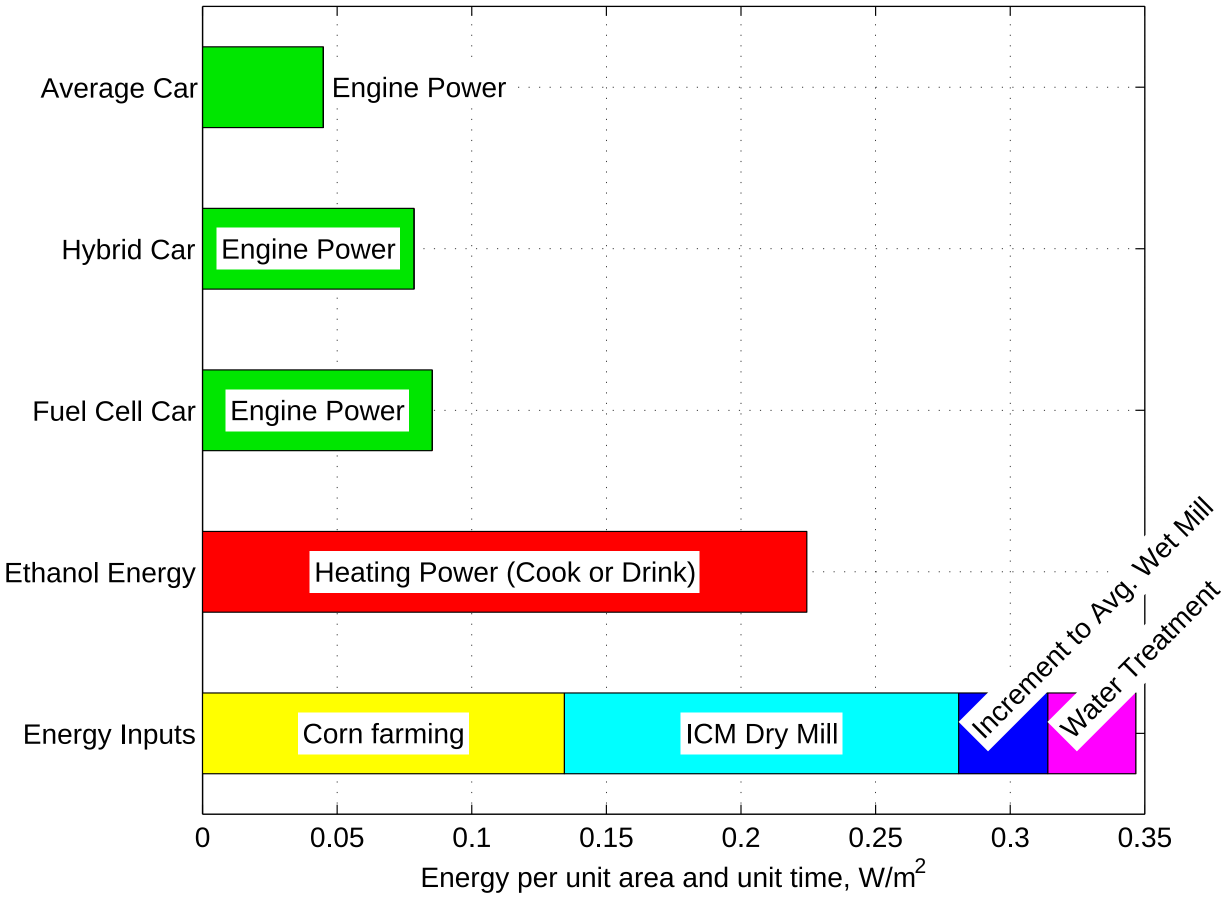

Figure 11: This chart summarizes my calculation of energy fluxes in the corn-ethanol cycle. The green bars illustrate engine power in different cars using corn ethanol from 1 m^2 of cornfield as fuel. The red bar is the energy one would get if one drank this ethanol and metabolized it, or burned it in a stove. Fossil fuels and environmental resources are depleted in corn farming (the yellow segment), and in subsequent production of corn ethanol in the best dry mill today (the light-blue segment), as advertised by ICM, Inc. Wet mills use somewhat more energy and more water, as illustrated by the dark blue and magenta segments, but deliver a wider variety of byproducts. It takes about seven times more energy to produce ethanol than ethanol can deliver as work to power an average passenger car. Hybrid and fuel cell engines are more efficient than the average passenger car, but it still takes about four times more energy to produce ethanol than the mechanical work this ethanol delivers. A 20 mpg gasoline truck driven only 10,000 miles per year consumes fuel energy at the rate of 102 gigajoules (GJ) per year, or 3,240 watts (W). From the two bottom bars it follows that if this truck were using ethanol fuel, it would need an equivalent of 8.8 acres of cornfield: To consume the 3,240 W of free energy as ethanol, the truck would require approximately 3.6 acres of cornfield. But it would also consume 5,000 W of free energy to recover the fossil energy used, and “undo” some of the environmental damage caused by the production of corn ethanol. These 5,000 W of free energy might be produced from an equivalent of 5.2 acres of cornfield. In contrast, an average wind turbine generates about 1 W per square meter (W/m^2) of electricity, which can be converted to mechanical work with 85 - 95 percent efficiency. A photovoltaic cell generates 5 - 20 W/m^2 of electricity. Thus, wind turbines and solar cells are at least 20 and 100 times more efficient in delivering mechanical work than corn ethanol.

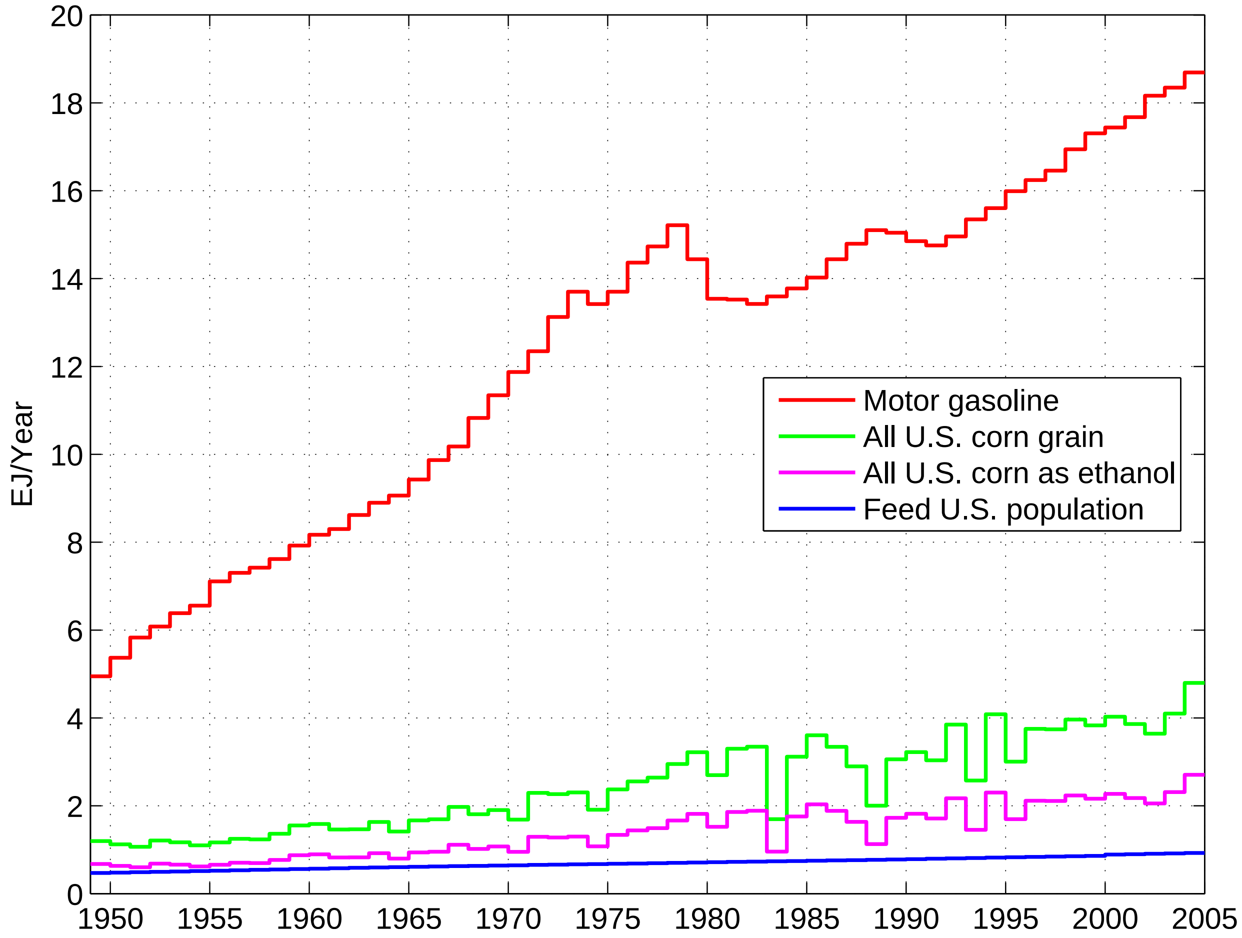

Figure 12: Sources: DOE EIA, USDA NASS, Patzek 2004. To see the limits of biofuel production, let us imagine converting all U.S. corn (the green curve) into ethanol (the magenta curve) with the yield of 2.6 gallons EtOH per wet bushel, see **Figure 6**. This of course cannot be done! The red curve is the energy consumed as motor gasoline, and the blue curve is the energy in food for the U.S. population. Corn is grown in the U.S. on 30 million hectares (a bit less that 1/4 of harvested agricultural land of 122 million hectares in 2002, U.S. Census.), and the record 300 million metric tonnes of corn grain were harvested in 2004. As of August 2005, the 2005 corn crop was predicted by USDA to be 40 million metric tonnes or 13% less. This corn conversion into ethanol would deplete far more energy than the calorific value of the ethanol, see **Figure 11**.

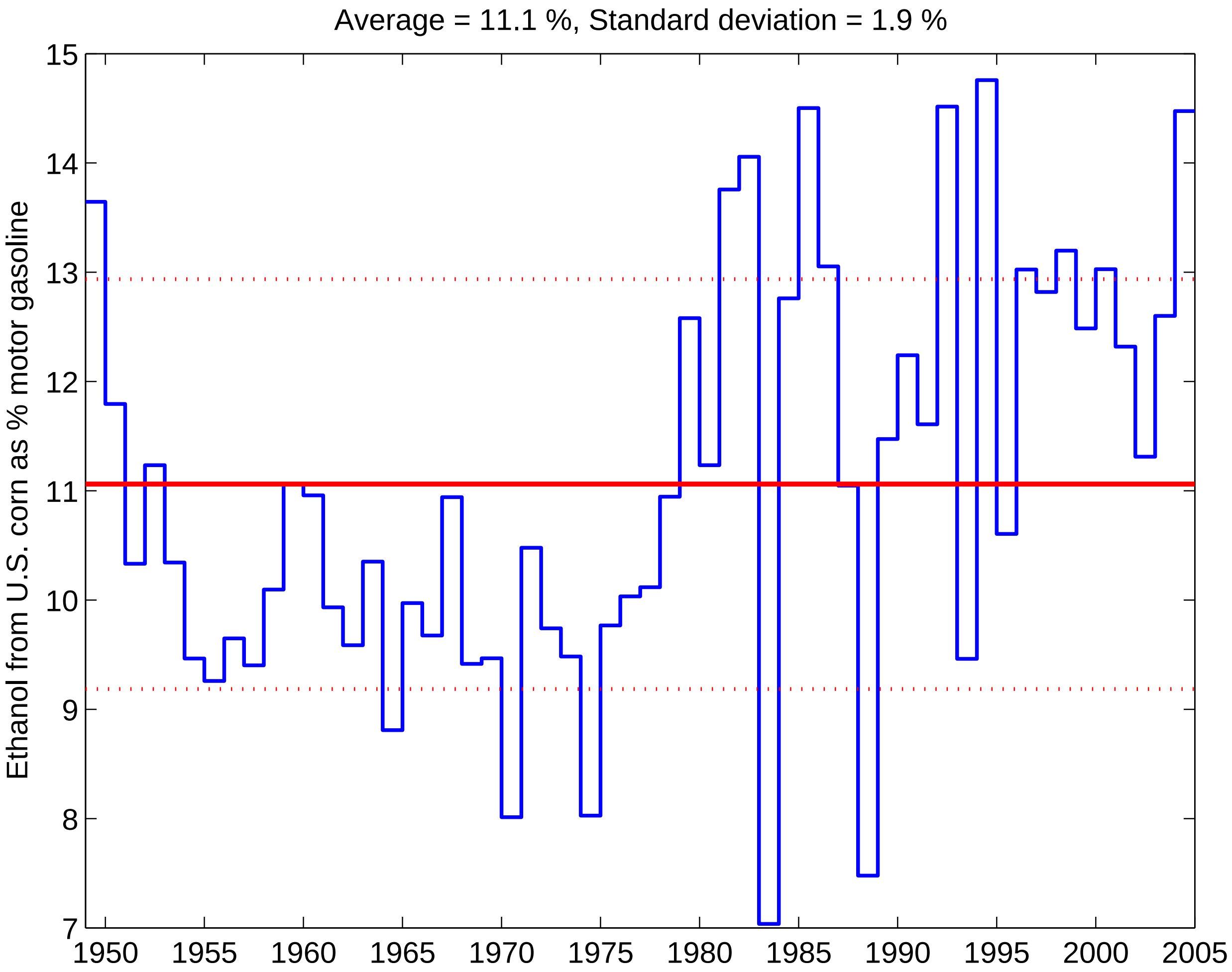

Figure 13: Sources: DOE EIA, USDA NASS, Patzek 2004. On the average, all U.S. corn converted to ethanol would eliminate 11 percent of U.S. gasoline consumption between 1949 and 2004. The average annual swings in energy supply, ±2 percent, were of the same size as the 7.5 billion gallons of ethanol in 2012, mandated by the 2005 Energy Bill. The catastrophic swings (drought, flooding, disease) were 2-3 times larger. Imagine running the national motor fuel supply market on corn.

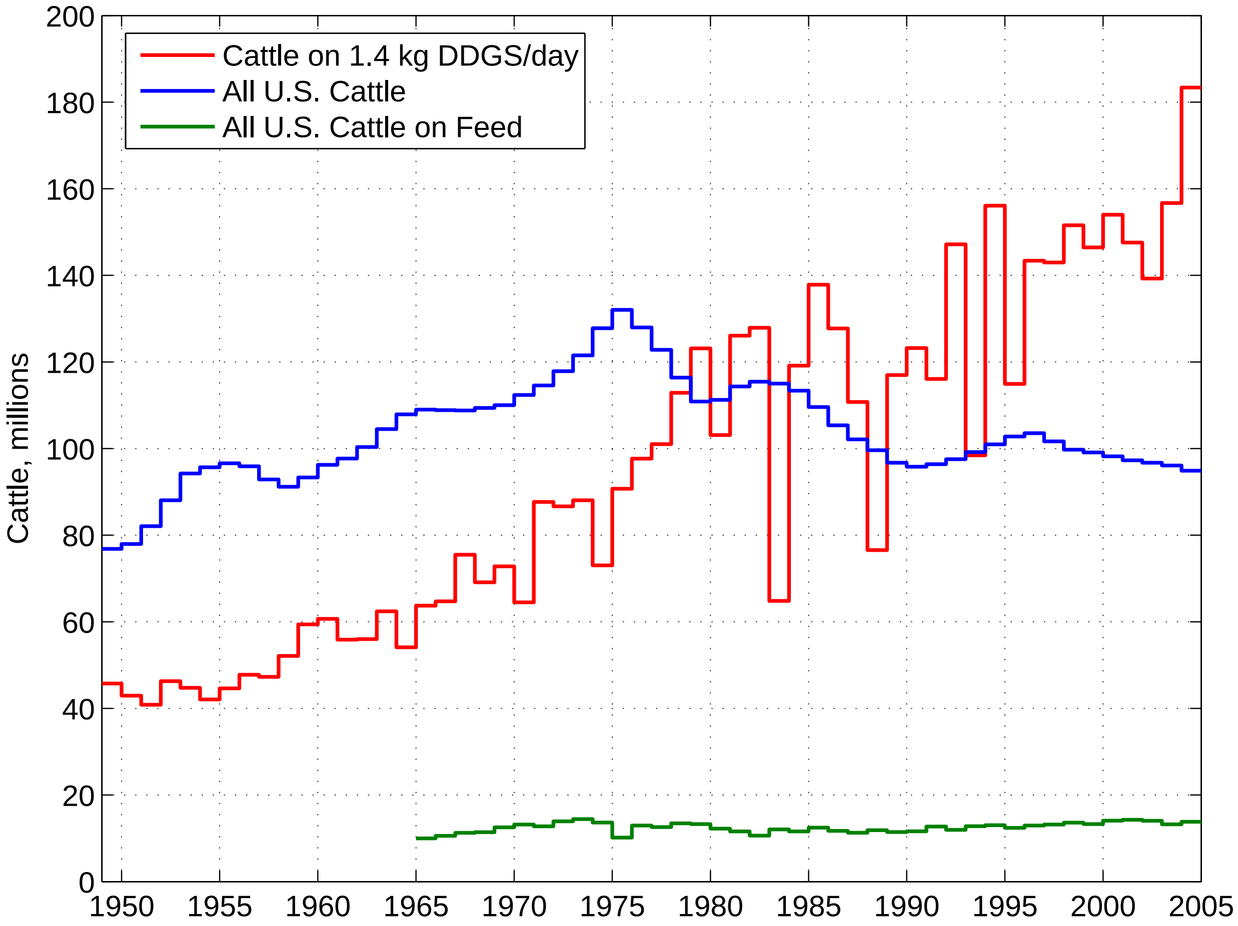

Figure 14: Sources: USDA NASS, Kansas Corn Growers, Patzek 2004. Suppose now that we wanted to feed cattle with the main by-product of transforming all U.S. corn into ethanol, the dried distillers grain & solubles (DDGS). There would be enough DDGS to feed 180 million cows, twice as much as the head count of all cows in the U.S. Cows have evolved to eat grass and cannot be fed DDGS alone. Cow feedlot managers suggest using up to 3 pounds of DDGS per day per cow to prevent the cows from getting sick.

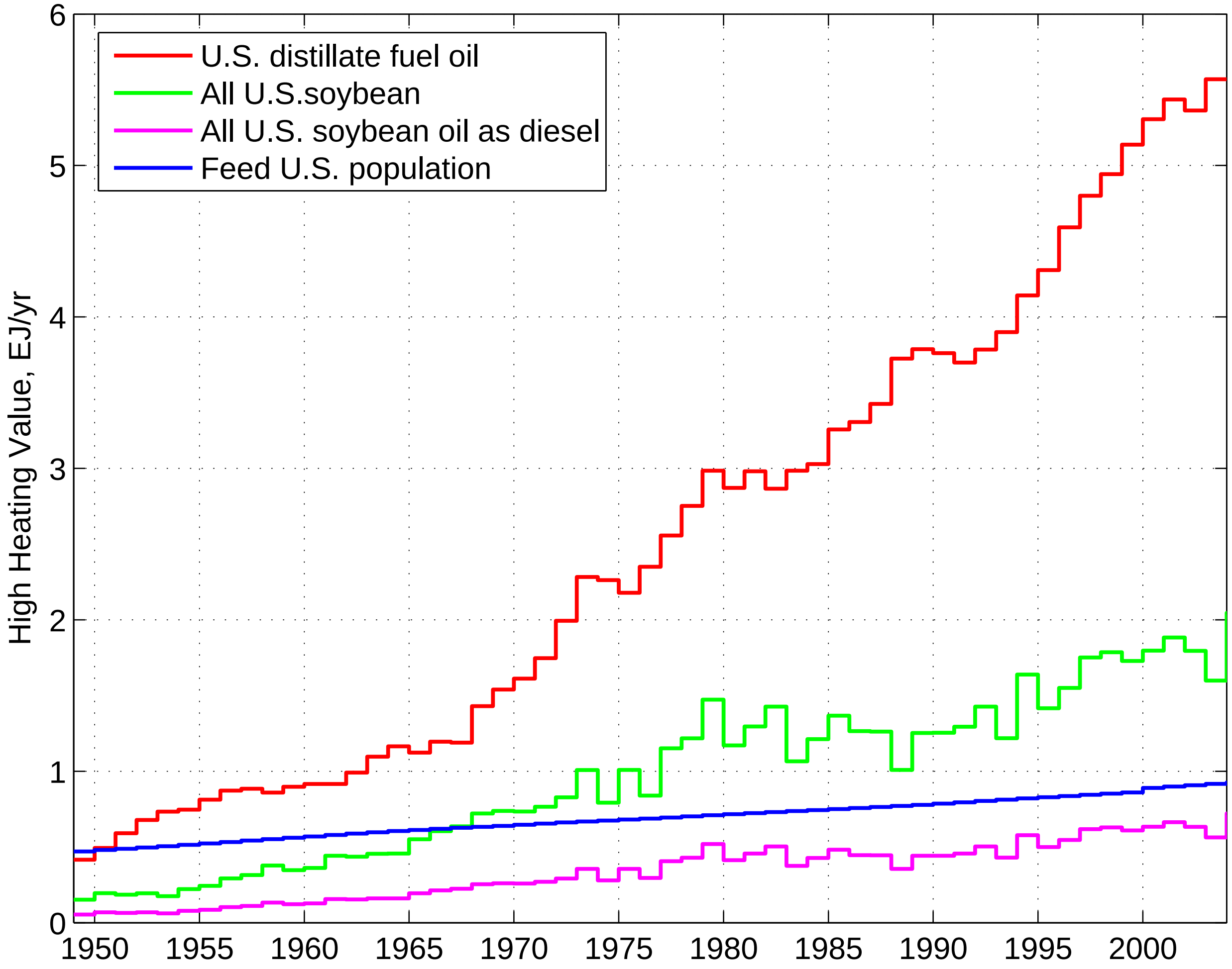

Figure 15: A hypothetical conversion of all U.S. soybeans to biodiesel with the National Renewable Energy Laboratory (NREL) yield. The net energy loss in this conversion would be about 30%. Soybeans are grown in the U.S. on 30 million hectares, just as corn. Soybeans and corn occupy roughly 1/2 of harvested agricultural land in the U.S. Sources: DOE EIA, www.eia.doe.gov/emeu/aer/txt/stb0513c.xls; USDA NASS www.nass.usda.gov:81/ipedb/-oilseeds.htm, Sheehan, J., Camobreco, V., Duffield, J., Graboski, M., and Shapouri, H. 1998, *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus*, Final Report NREL/SR-580-24089. Distillate fuel oil (the red curve) is one of the petroleum fractions produced in conventional distillation operations. It includes diesel fuels and fuel oils. Products known as No. 1, No. 2, and No. 4 diesel fuel are used in on-highway diesel engines, such as those found in cars and trucks, as well as off-highway engines, such as those in railroad locomotives and agricultural machinery. Products known as No. 1, No. 2, and No. 4 fuel oils are used primarily for space heating and electricity generation. Note that the fast increase of soybean production is no match for the exponentially growing demand for diesel fuel and heating oil.

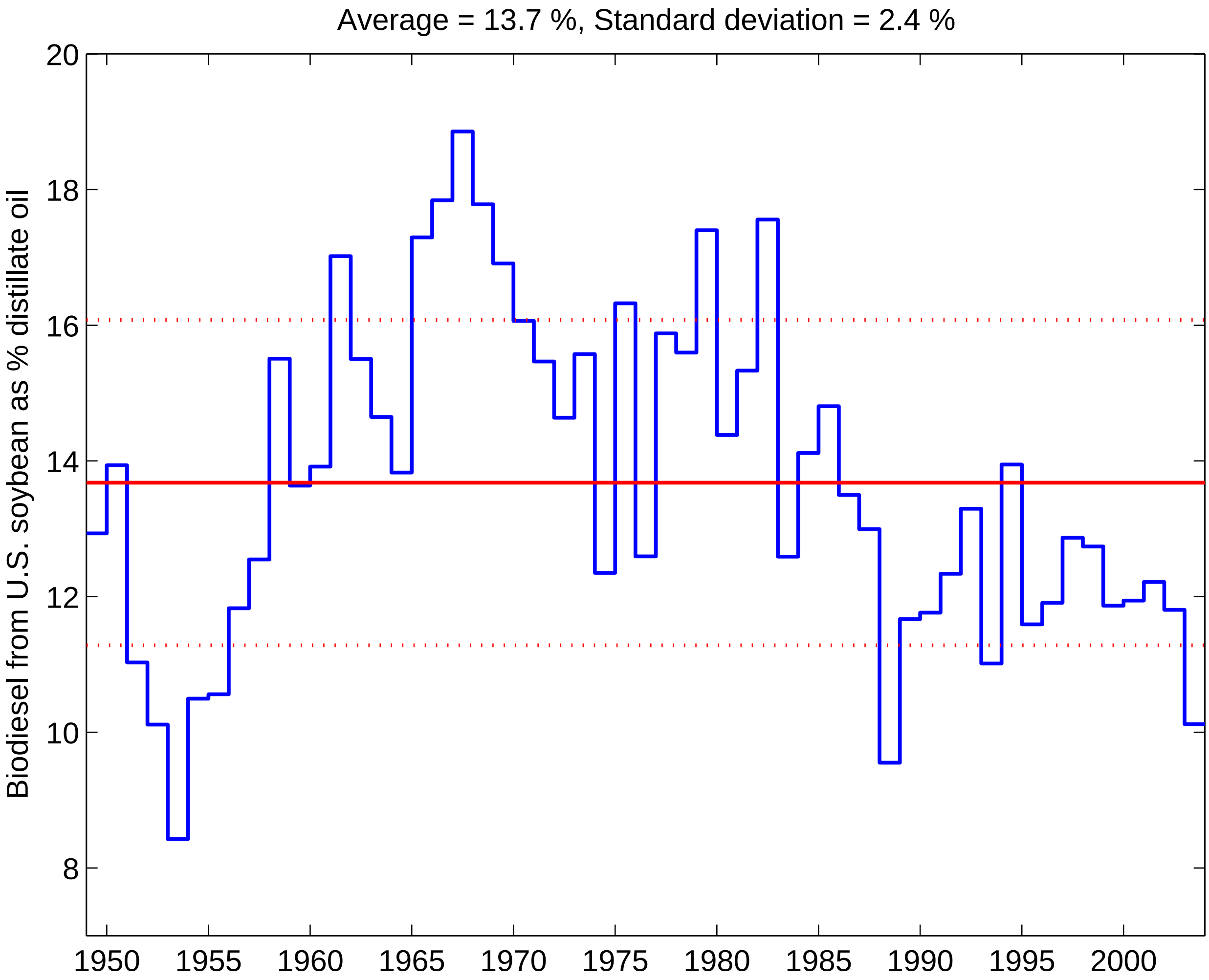

Figure 16: Sources: DOE EIA, USDA NASS, Sheehan et al, 1998. On the average, all U.S. soybeans converted to biodiesel would eliminate 14 percent of U.S. distillate oil consumption between 1949 and 2004. This percent has been steadily declining since 1967, down to 10% in 2004, mostly because of the explosive growth of consumption of distillate oil. In 2004, the two largest crops in the U.S., corn and soybeans, completely converted to ethanol and diesel fuel (and animal feed byproducts), would respectively eliminate 14.5% of motor gasoline and 10% of distillate oil. Of course, production of these two biofuels would cost more energy than their calorific values.

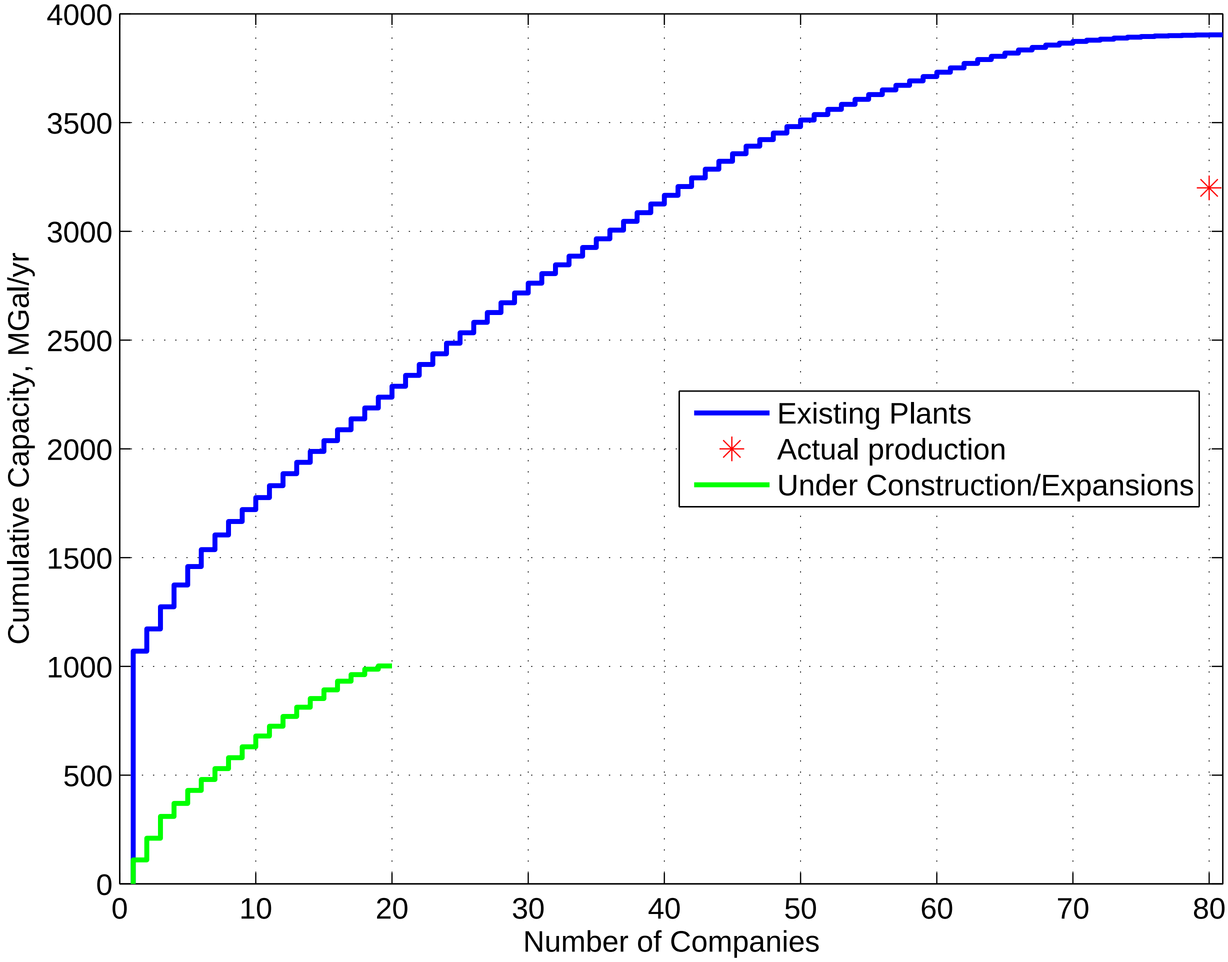

Figure 17: Nominal capacity of U.S. ethanol plants and their current expansions. The red star is the actual production of anhydrous ethanol, i.e., the gross volume reported by the industry minus 5 percent of gasoline denaturant (a fossil fuel additive) and minus 1-2 percent of fusel oil (not ethanol). Fifteen companies provide 50 percent of ethanol production capacity. Source: Renewable Fuels Association, July 2005. Note that only 82% of the existing capacity was utilized in 2004, with the best corn crop ever. An additional 26% production capacity will be added soon. Therefore, the idle capacity of U.S. ethanol plants will reach 45% of the 2004 ethanol production volume. Compared with the 2004 corn crop, the 2005 crop will be lower by at least 10–15%.

3 Cellulosic Ethanol

Biomass availability: Natural productivity of a mature ecosystem (an earth household, e.g., a forest or grassland) is *zero*. What is produced by autotrophic plants and algae, and by rock weathering and floods, is consumed by heterotrophs (bacteria, fungi, and animals that are continuously recycled as nutrients for the plants). Therefore, "biowaste" is an engineering classification of plant (and animal) parts unused in an industrial process. This dated human *concept* is completely alien to natural ecosystems, which must recycle their matter *completely* in order to survive. Excessive "biowaste" removal robs ecosystems of vital nutrients and species, and degrades them irreversibly. As discussed in **Figure 4**, those ecosystems from which we remove biomass at high rate (crop fields, tree plantations) must be heavily subsidized with fossil energy and earth minerals (see Theresa Schmalshof's testimony).

Contamination: For corn starch fuel ethanol, normal fermentation times in batch mode (there are no continuous reactors in operation) are 48 hours; up to 72 hours is acceptable. These estimates do not include downtime, cleaning, start up, etc. Over 72 hours the number of failures increases exponentially due to contamination with bacteria: acetogens and others. My information comes from a discussion with the ethanol plant personnel. As described in the literature, typical enzyme processes for lignocellulosic alcohol take 5 to 7 days. This spells big problems if lignocellulosic ethanol producers ever go outside the laboratory or pilot scale (sterile fermenters) to a conventional fermentation vessel, which can *not* be sterilized for 120–170 hours.

Enzyme Yield vs. Rate: The rate of lignocellulose hydrolysis and fermentation can be increased by enough pre-treatment (such as ball milling to exceedingly fine dust, at enormous energy costs, or steam exploding with acid pre-treatment), but rates will slow down rather rapidly before high yields are obtained. The main problem is the number of binding sites available; the outside-in rate limitation phenomenon. It simply takes time to chew into the sturdy lignocellulosic particles. Of course, one *could* run the lignocellulose through a paper process by Kraft, which is really good, but really energy-intensive. This cannot be done for lignocellulosic ethanol because net energy losses would be severe. One can get pretty good yields and rates if one performs energy-intensive and unaffordable pretreatment, or (relatively) high yields with modest pre-treatment if one waits long enough (ideally for weeks), or high rates if one only measures initial rates. But, despite claims to the contrary, we do *not* have a real industrial process for lignocellulosic ethanol, and may *never* have one with a sufficiently favorable energy balance.

Thermodynamics: Prof. Pimentel and I have studied the thermodynamics of lignocellulosic ethanol production and it is by far the worst biofuel option. For details, see http://petroleum.berkeley.edu/papers/patzek/CRPS-BiomassPaper.pdf

4 My NPC Presentation

VUG1: Thank you for inviting me here. The message I would like you to remember is this: When it comes to energy consumption, the United States is a huge country and the Earth is small.

VUG2: Each year, U.S. depletes more fossil and nuclear energy than our vegetation can sequester as biomass. In 2003, the U.S. used 105 times more energy than required to feed us. Over 90% came from fossil fuels and uranium, and 2% from biomass co-generation. To the right, you see a very optimistic estimate of biomass energy across the U.S. Over 3/4 of this biomass energy is committed to food and feed production, wood for lumber, paper and fiber, and as plant roots. This biomass is heavily subsidized with fossil fuels. One half of the remainder is covered by sparse and remote vegetation. The green strip at the bottom can produce biomass for energy, but 1/2 to 3/4 of it will be used to service biofuel production. Therefore, biomass cannot displace the astronomic quantity of fossil fuels we devour every year.

VUG3: This chart illustrates my calculation of energy fluxes in the corn-ethanol cycle. The green bars illustrate engine power in different cars using corn ethanol from 1 square meter of cornfield each year. The red bar represents the calorific value of the ethanol. Fossil energy is used in corn farming (the yellow bar), and in subsequent production of corn ethanol in the best dry mill today (the light-blue bar), as advertised by ICM, Inc. Wet mills use somewhat more energy and more water, as illustrated by the dark blue and magenta bars, but also deliver a larger variety of byproducts. All these values are tiny. In contrast, an average wind turbine generates about 1 W per square meter (W/m^2) of electricity, which can be converted to mechanical work with 85 - 95 percent efficiency. A photovoltaic cell generates 10 - 20 W/m^2 of electricity. Thus, wind turbines and solar cells are 20 and 100 times more efficient in delivering mechanical work than corn ethanol.

VUG4: As recently testified to by Ms. Theresa Schmalshof of NCGA, modern agriculture is heavily subsidized with fossil fuels, especially with natural gas. The most energy-intensive nitrogen fertilizer is produced from natural gas. Over the last 50 years, the total energy in corn grain, up to 5 EJ/yr in **red**, has increased in direct proportion to the nitrogen fertilizer application rate in **black**. The 5EJ/yr in corn grain in 2004 was sufficient to feed the population of China for 1 year.

VUG5: This is the yield of corn ethanol in gallons per wet bushel of corn. The **blue** line at 2.6 gallons/bushel is the industry average. In 2004, this line jumped up from the historical trend because the industry started counting an additional 5 % of gasoline and 1-2% of fusel oil as ethanol. After correction, we go back to the historical trend. The **red** line by USDA is consistently high, and the **green** line from the Corn Technology and Chemistry Handbook is low.

VUG6: The energy in motor gasoline consumed in the US since 1980 in **red** is compared with the industry reported-ethanol energy in **blue**. The **black** lines are projections of gasoline consumption until 2012, and ethanol production of 7.5 billion gallons by 2012. Note how small the ethanol contribution is.

VUG7: Therefore, in 2004, — on energy-equivalent basis – anhydrous ethanol replaced about 1.5% of motor gasoline, and it will replace an additional 1 percent by 2012. If the current 1 psi Reid Vapor Pressure waver for gasohol is removed by those states that fight air pollution, the impact of ethanol will go down 40%, the blue curve.

VUG8: Here we see in **red** the average mileage of the U.S. passenger car fleet since 1960. The black line is the projection until 2012 following the spirit of the do-nothing Energy Bill in 2005. The **blue** line is the calculated increase of car mileage necessary to displace all U.S. ethanol. An increase of 1/2 to 1 miles per gallon is tiny, and could be achieved with proper inflation of car tires.