THE NET ENERGY BALANCE OF CORN ETHANOL

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Comparison of the Pimental and Patzek results to the USDA results

Process	Pimentel and Patzek [2]	USDA [3]	Difference
	Btu per Gallon of Ethanol		
Corn Production	**37,860**	**18,713**	**-19,147**
Corn Transportation	**4,834**	**2,120**	**-2,714**
Ethanol Conversion	**56,399**	**51,220**	**-5,179**
Energy Input Excluding Coproducts	**99,093**	**72,053**	**-27,040**
Coproduct Value	**6,680**	**26,250**	**19,570**
Energy Input Including Coproducts	***92,413***	***45,803***	***-46,610***
Total Energy Output	***77,011***	***76,330***	***-681***
Net Energy Balance	**-15,402**	**30,527**	**45,929**

[1] The study by Shapouri and McAloon, "The 2001 Net Energy Balance of Corn-Ethanol" is available at the USDA, Office of Energy Policy and New Uses web site: http://www.usda.gov/oce/oepnu/. The Wang study can be found at the following web site: http://www.transportation.anl.gov/research/systems_analysis/fuel_ethanol.html.

[2] Pimentel and Patzek report their results (Table 2 of their paper) in kcal x 1000 per 1000 litres of ethanol. Converted to Btu per gallon using 1 litre = 0.26 gallons and 1 kcal = 3.96 Btu.

[3] Estimates are based on a weighted average of dry and wet milling. Ethanol conversion includes 1,588 Btu per gallon for ethanol distribution.

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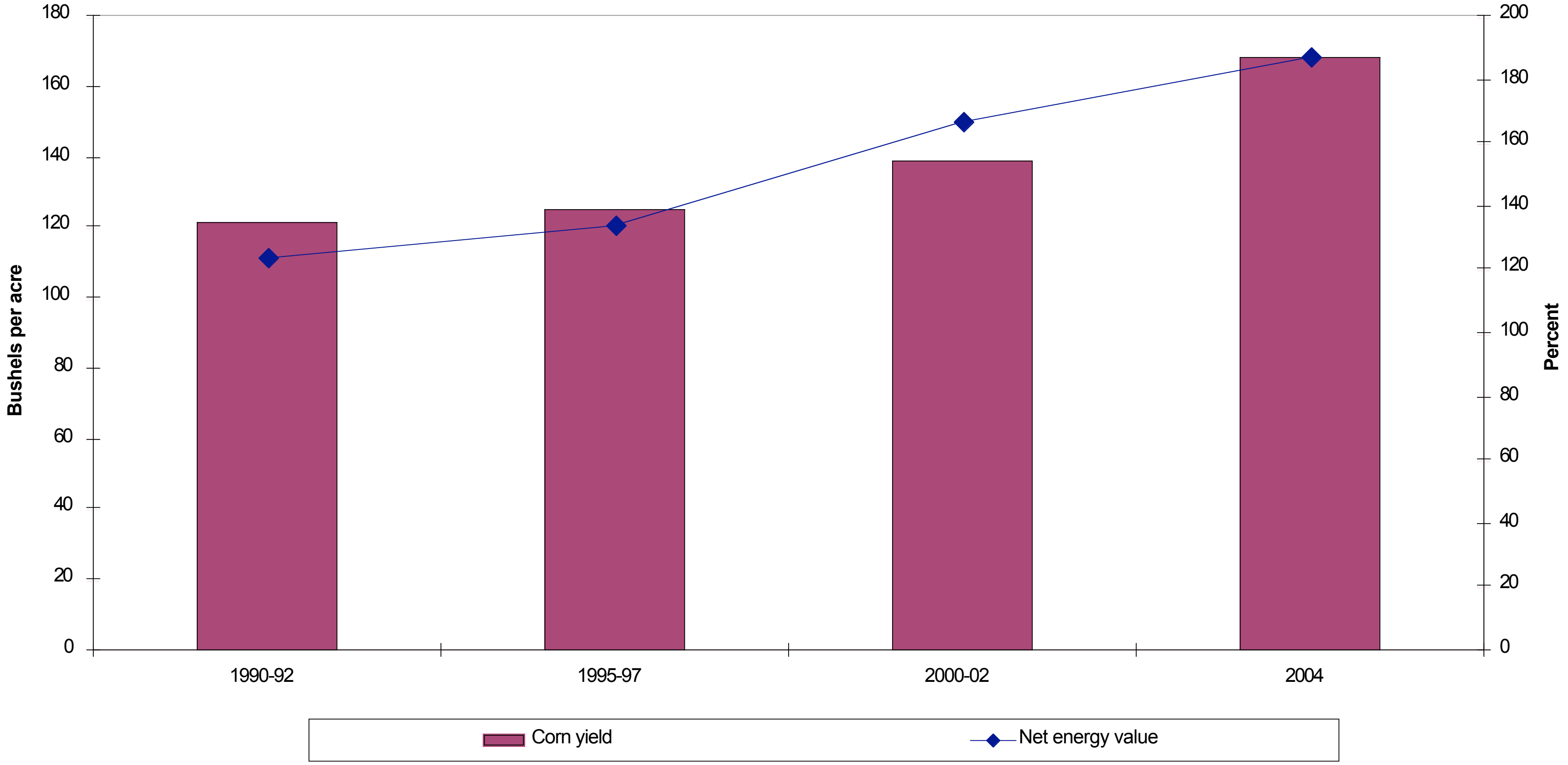
Net Energy Balance of Corn-Ethanol and 9-State Average Corn Yield per Acre



Net Energy Balance Results

- Data quality
- Feedstocks, grains, sugar, biomass materials
- New technologies:
  - Crop production
  - Processing
- Methodology used to allocate total energy to ethanol and by products

Sources of Data

- USDA/ Economic Research Service (ERS), 2001 Agricultural Resources Management Survey (ARMS)
- USDA/ National Agricultural Statistics Service (NASS), 2001 Agricultural Chemical Usage and 2001 Crop Production
- Stokes Engineering Company, energy used in production of fertilizers

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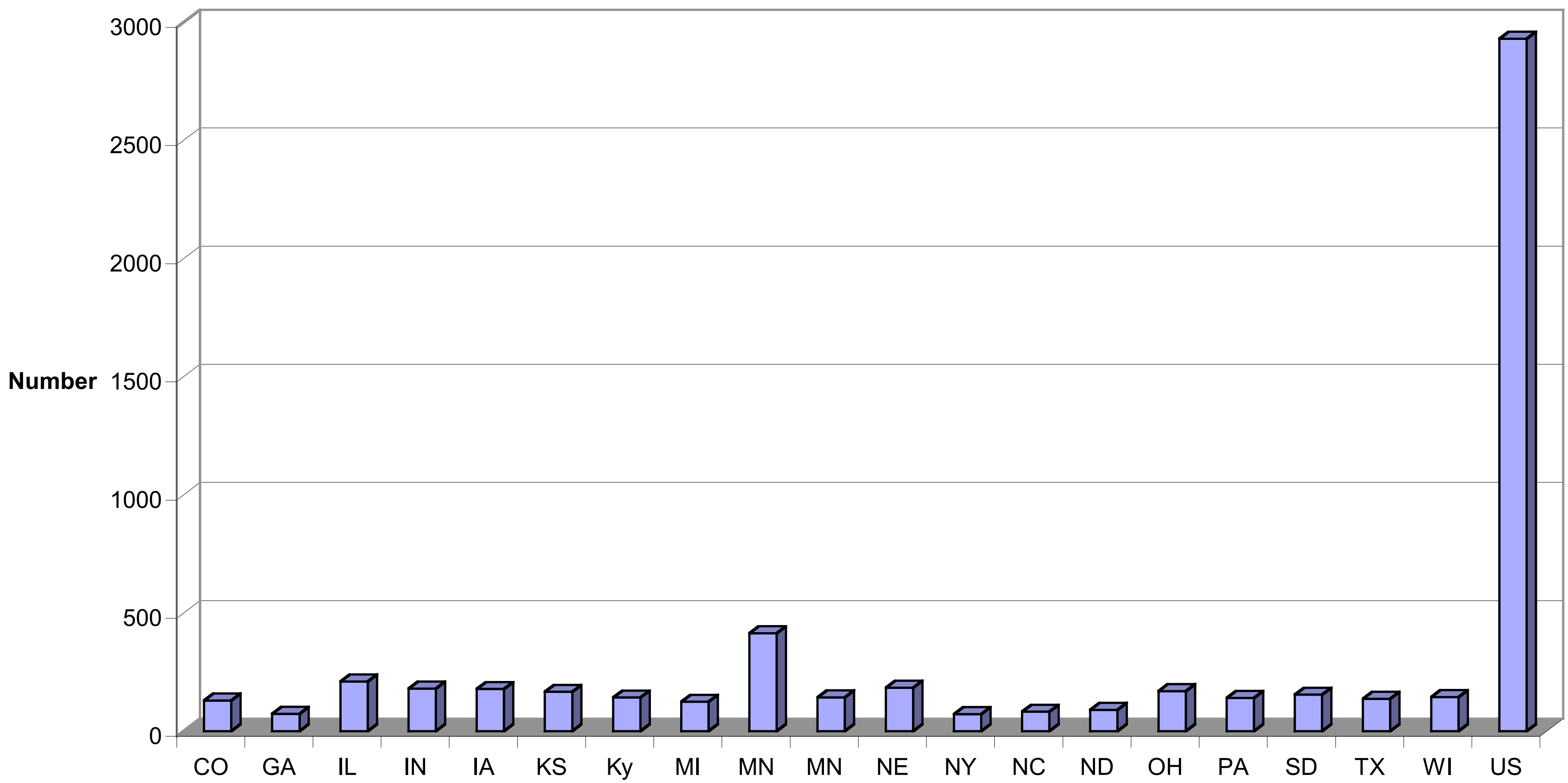
Sources of Data--Continued

- Greenhouse Gas Regulated Emissions and Energy Use in Transportation (GREET) model, energy used in production of chemicals
- 2001 survey of ethanol plants, BBI International, thermal and electrical energy used in ethanol plant
- ASPEN Plus, a process simulation program, to allocate energy used in ethanol plant to ethanol and byproducts

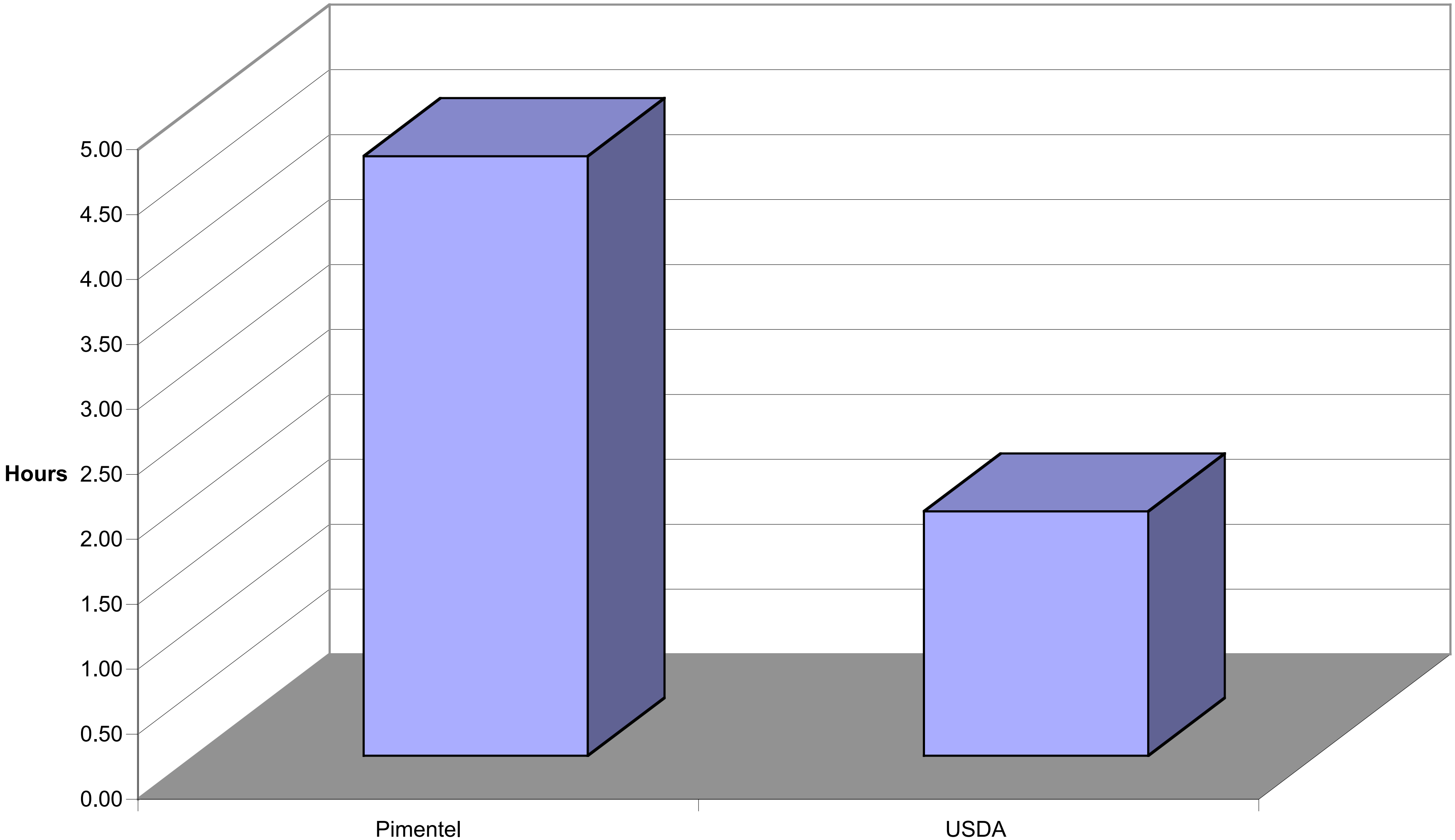
Sample Size, the 2001 ARMS Corn Survey



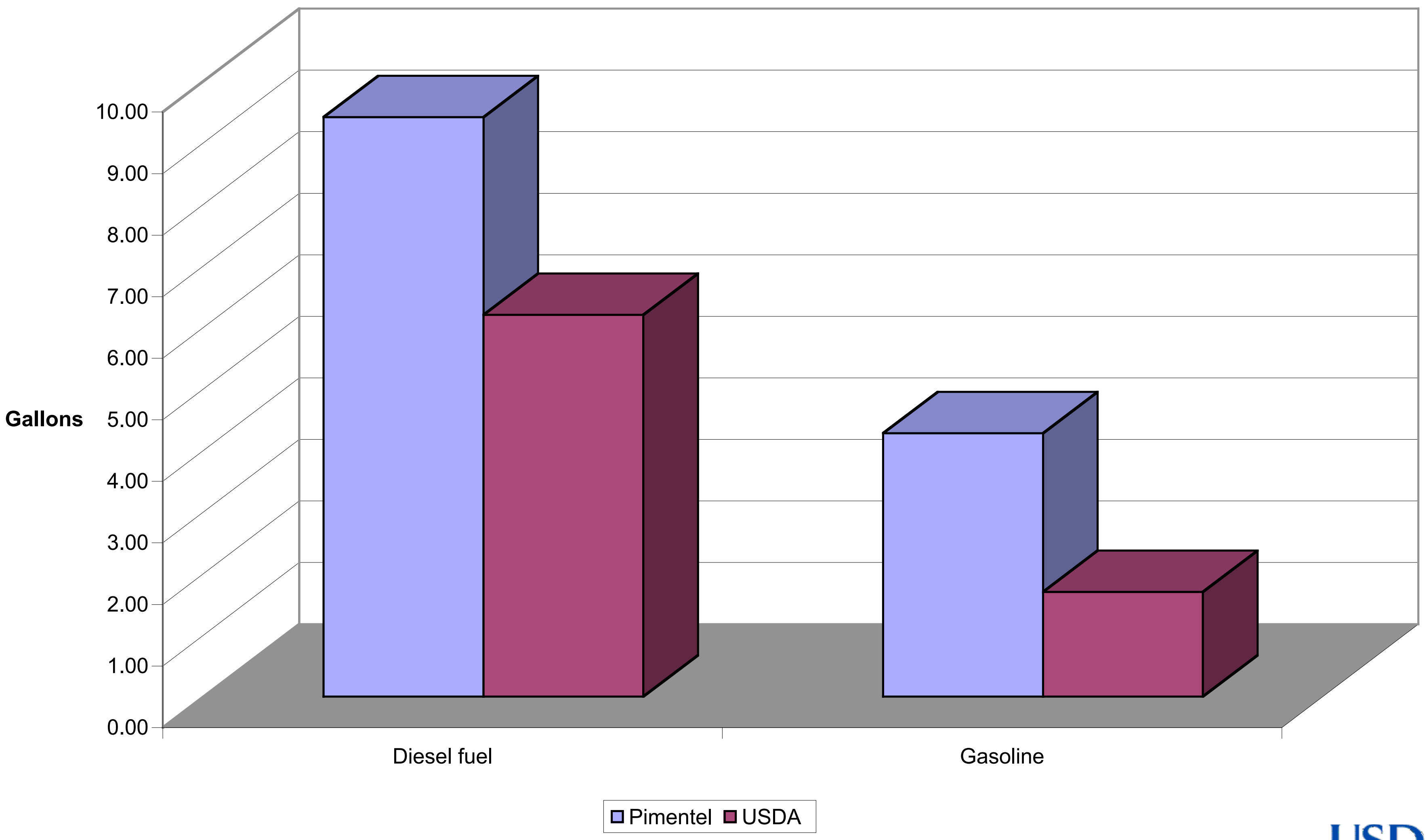
Energy inputs used per acre of corn, 2001

	Pimentel, 2005	USDA/U.S. ave.
Labor, hours	4.62	1.88
Diesel, gallons	9.41	6.2
Gasoline, gal.	4.28	1.7
Nitrogen, lbs	136.28	122
Phosphate, lbs	57.89	34.8
Potash, lbs	68.58	36.21
Lime, lbs	997.57	393
Herbicides, lbs	5.52	2.18
Insecticides, lbs	2.49	0.04

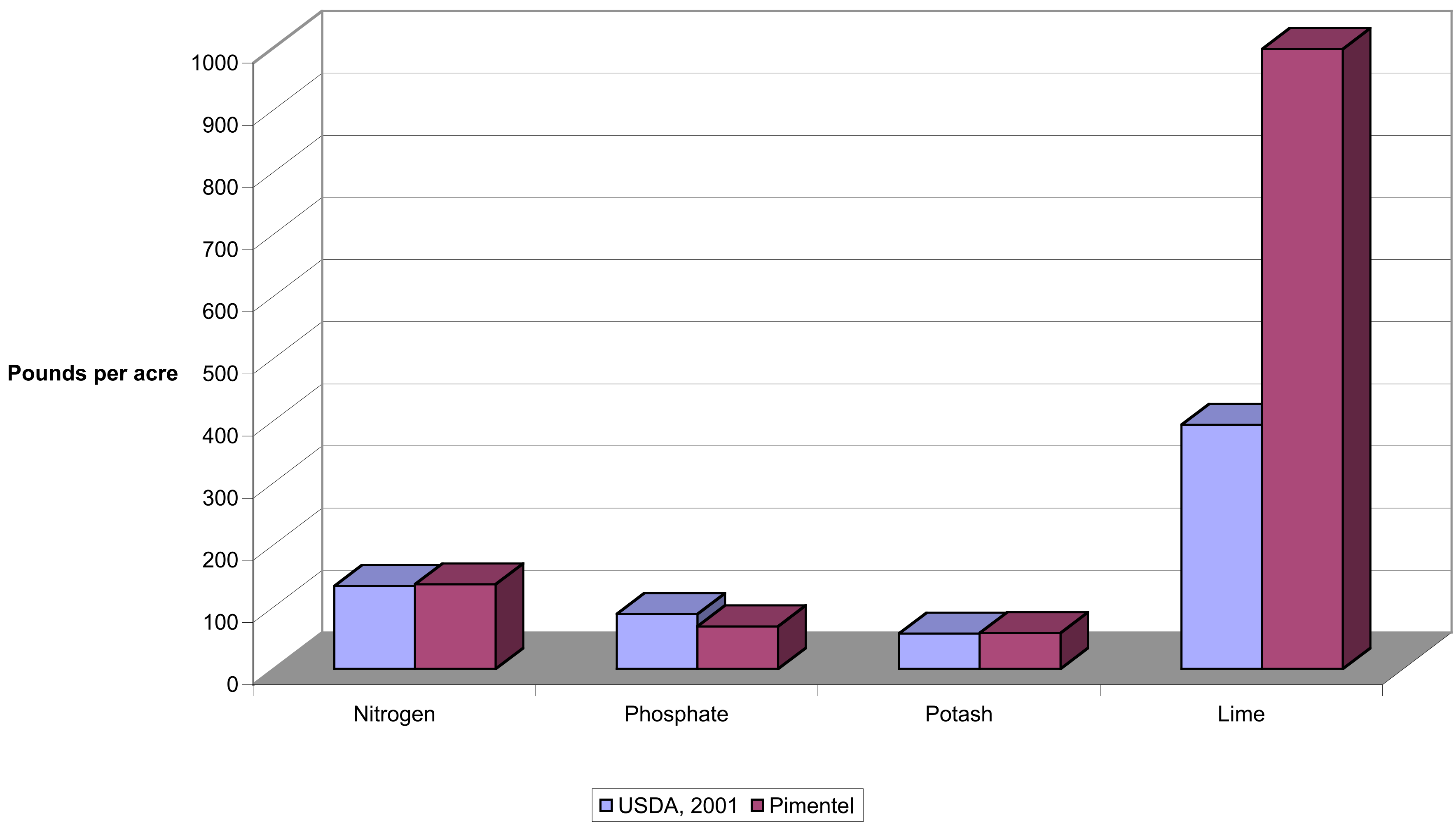
Labor Use per Acre of Corn, 2001



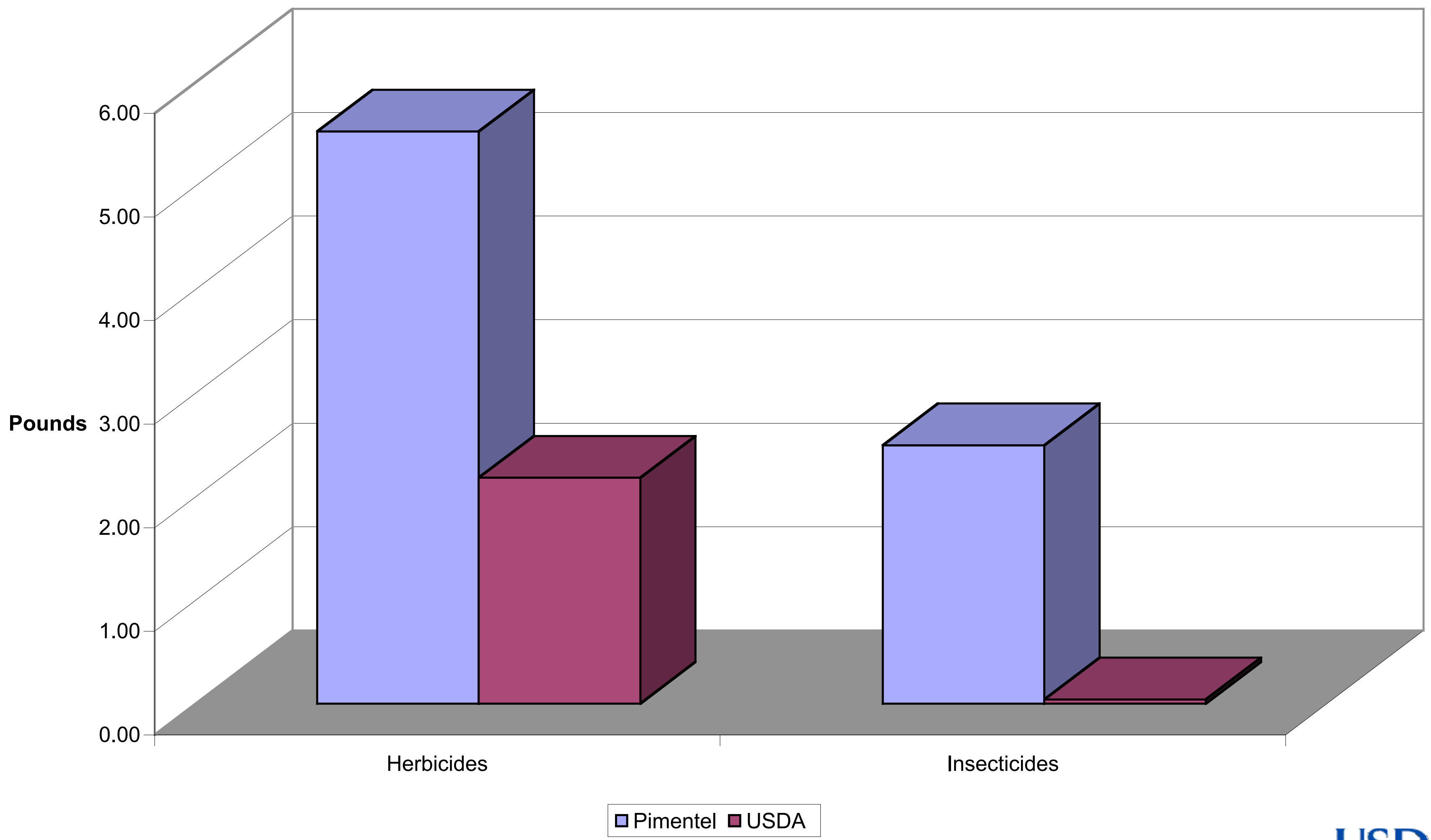
Fuel Use per Acre of Corn, 2001



Fertilizer and Lime use per acre of Corn



Pesticides Use per Acre of Corn, 2001



Comparison of Amount of Energy Used to Produce Corn

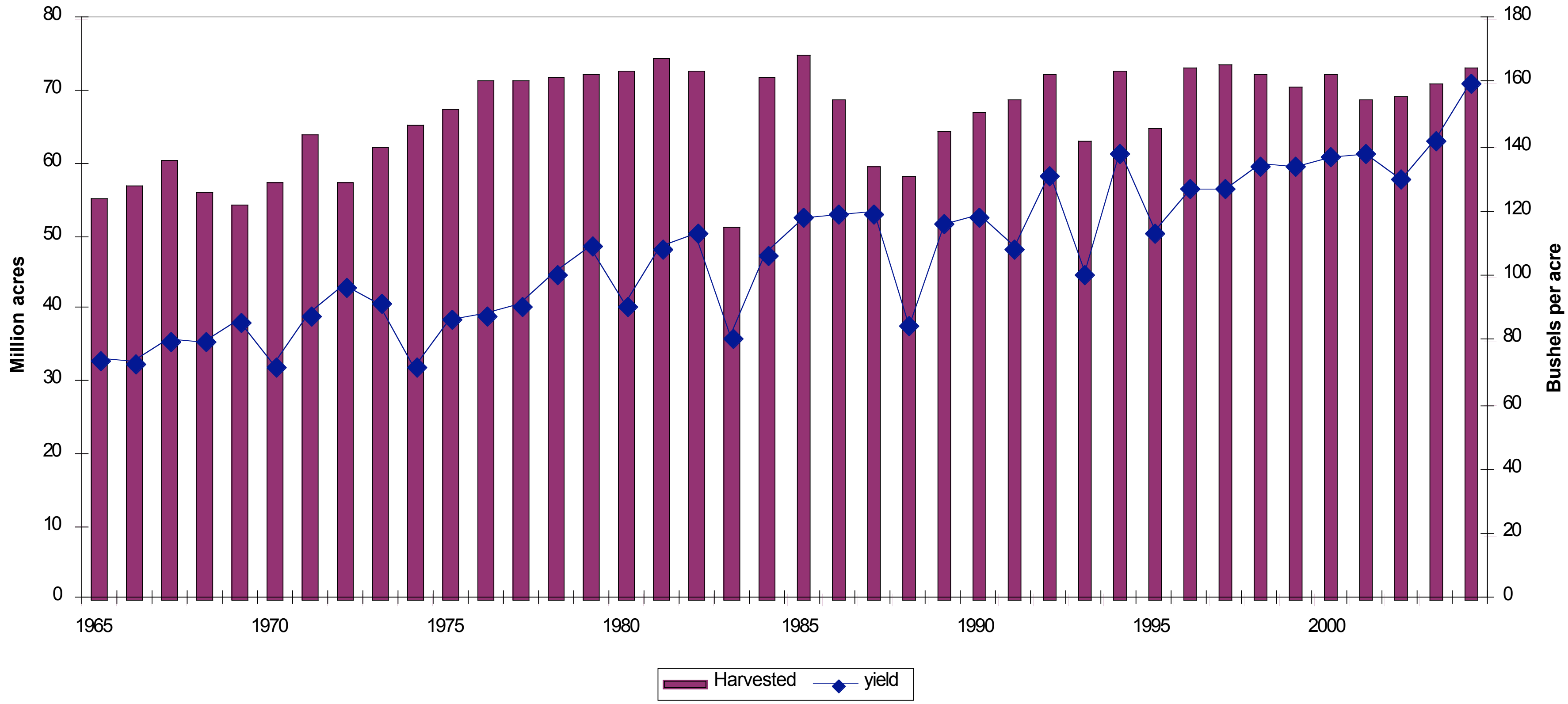
Input	Pimentel and Patzek[1]	USDA	Difference
	Btu per Gallon of Ethanol from Corn Production		
Labor	2,155	0	-2,155
Machinery	4,749	0	-4,749
Diesel	4,679	2,816	-1,864
Gasoline	1,890	1,323	-567
Nitrogen	11,421	8,824	-2,597
Phosphorus	1,260	613	-647
Potassium	1,171	714	-457
Lime	1,470	24	-1,446
Seeds	2,426	227	-2,199
Irrigation	1,493	62	-1,431
Herbicides	2,893	1,105	-1,787
Insecticides	1,306	--	-1,306
Electricity	159	849	690
Transport	788	76	-713
LP Gas		792	792
Natural Gas		694	694
Custom Work		594	594
Total	37,860	18,713	-19,147

[1] The amount of Btu per gallon of ethanol for each corn input is calculated by taking the share of energy used to produce corn (Table 1 in Pimentel and Pazek) and applying that share to the total amount of energy from corn in ethanol production (Table 2 in Pimentel and Pazek).

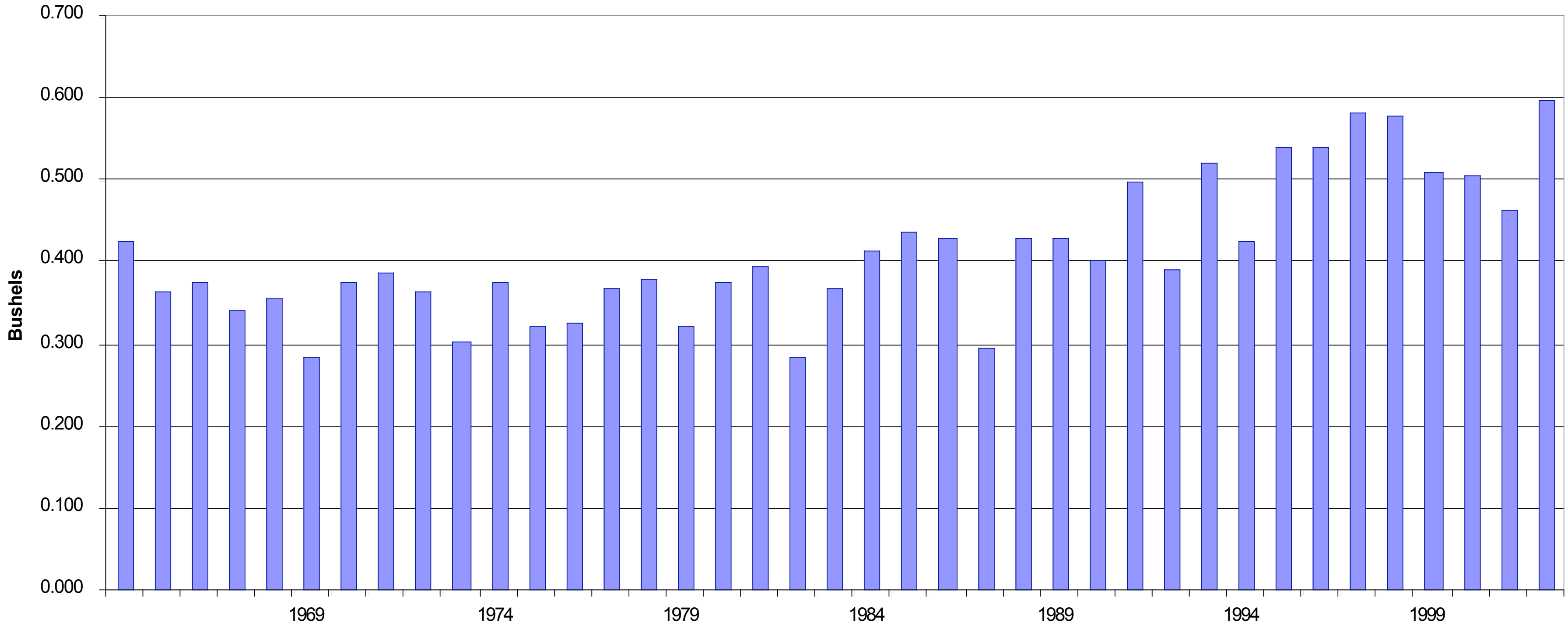
New Technologies

- Crop Production:
  - Genetically modified crops, yield map, global positioning system, slow release fertilizer, and more efficient irrigation system
- Ethanol plants:
  - Heat exchanger, heat tolerance yeast, Molecular sieves, cold cook, dry fractionation, new enzymes, process automation, Combined heat and power, and nano filtration

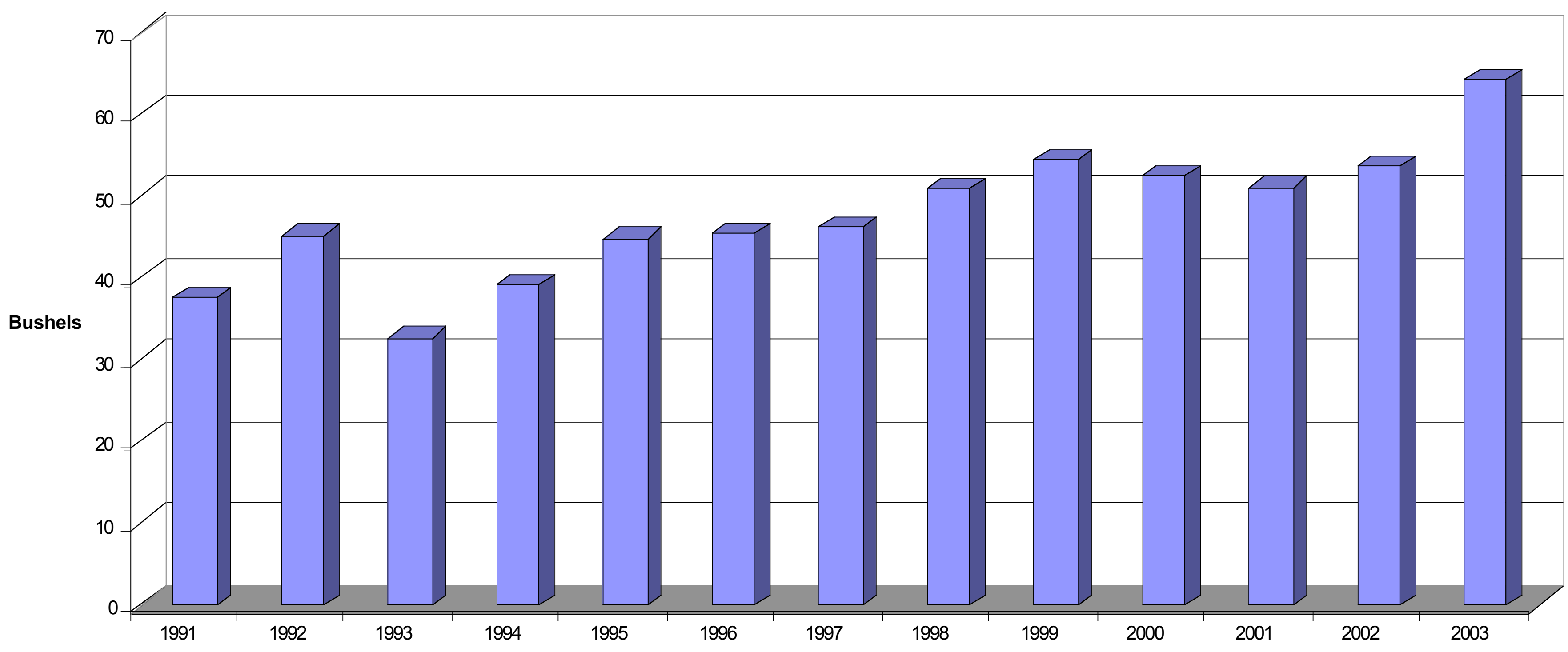
Corn: Harvested Area and Yield per Acre, 1965-04



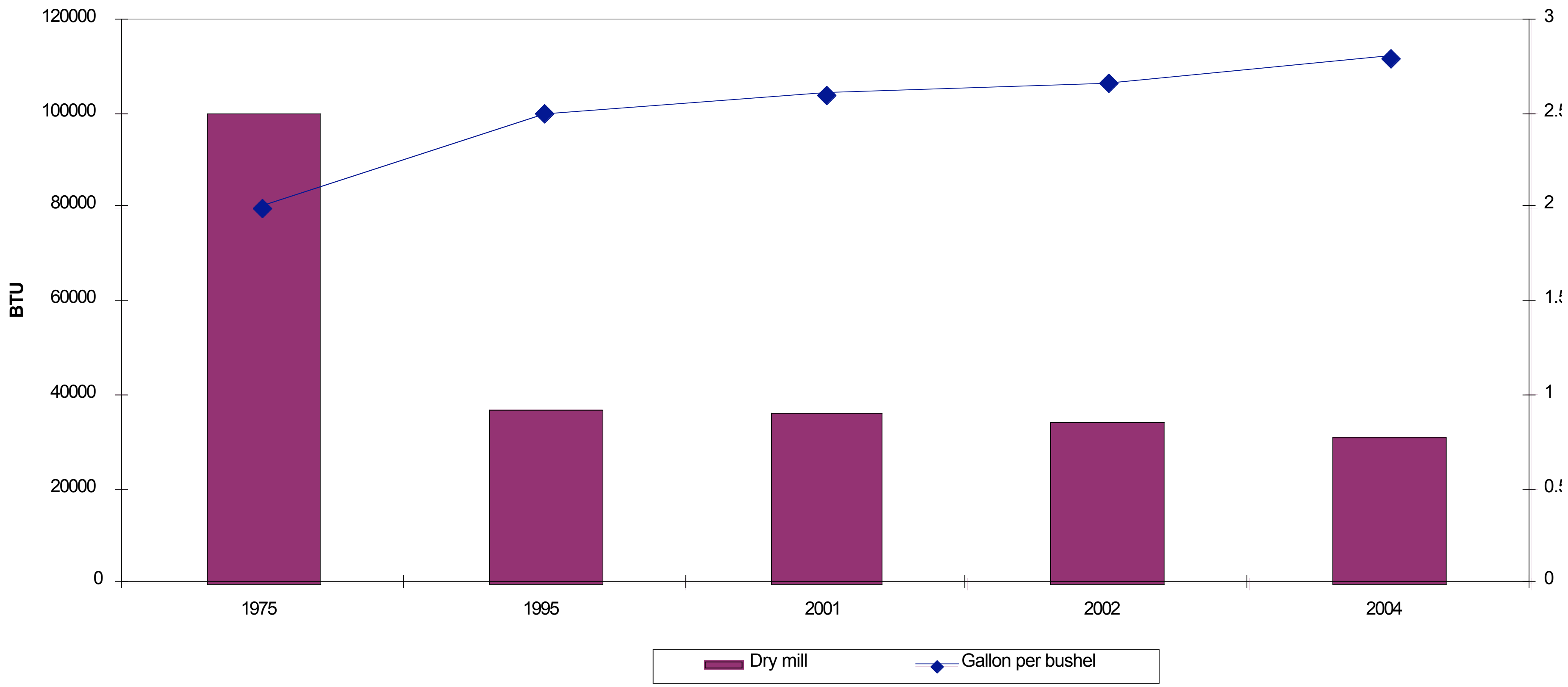
Bushels of Corn per Pound of Fertilizer, 1966-03



Bushels of Corn per Pound of Pesticides, 1991-03



Dry-Mill: Thermal Energy Use per Gallon of Ethanol and Ethanol Yield per Bushel



How to Allocate Total Energy to Ethanol and Byproducts

- Methodology:
  - Energy content
  - Market value
  - Output weight basis
  - Replacement value
  - Process energy for energy used in plant and % weight of starch and non-starch for energy used to grow corn and transport corn to ethanol plant

Allocation Rules

- Energy used in corn production:
  - 66% to ethanol and 34% to byproducts
- Energy used in transporting corn to ethanol plant:
  - 66% to ethanol and 34% to byproducts
- Energy used in conversion of corn to ethanol and byproducts, ASPEN Plus:
  - Wet mill, 64% to ethanol and 36% to byproducts
  - Dry mill, 59% to ethanol and 41% to byproducts

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Conclusions

- Corn yield per acre will continue to increase
- Fertilizer industry has become more energy efficient
- Energy used to produce a bushel of corn will continue to decline
- Ethanol yield per bushel of corn will increase to its theoretical limit
- Ethanol plants will become more energy efficient
- Net energy value of corn-ethanol will continue to improve

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