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Folke Dovring and Donald R. McDowell

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Department of Agricultural Economics
University of Illinois at Urbana-Champaign
305 Mumford Hall, Urbana, IL 61801

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Pesticides are a sizeable item of expenditures for American farmers. Accoding to recent statistics, agricultural chemicals (other than fertilizers) amounted to about 2½ percent of farmers' production expenses; this is one-fourth of their expenses for fertililzers and not far behind those for seed, for instance [1/] Pesticides are high-energy goods, per unit of weight; they are also high priced per unit of weight, and therefore much less energy intensive per dollar than per pound. Hence, farmers' use of pesticides represent only a minor share in their use of indirect energy. However, different pesticides require very different levels of energy for their production, as will be seen below. This renders any generalized finding on the energy intensity of pesticides uncertain, and it is worthwhile to search for and analyze the facts that can be found, in order to illustrate what levels, and what ranges of variation, we have to reckon with.

The subject will be pursued on two levels. One is based on aggregate statistics from the United States: the main source is the Census of Manufactures, analyzed by help of existing input-output studies foremost the Energy Analysis Handbook (EAH),[2/] and other pertinent statistics. The other level draws on process data - those on individual pesticides from a British inquiry and those on formulation and packaging developed in the United States, of which further below.

U.S. manufacturing data. The Census of Manufactures, 1967, gives very few details on Industry 2879, "Agricultural chemicals, n.e.c.". Hence, the EAH energy intensity coefficient for this industry (for 1967) is based on residuals and will not be used here. Instead we combine data from the 1972 and 1977 censuses with other relevant sources.

The 1972 Census data on energy used in Industry 2879 refer to 1971 and will be combined with the industry output of that year (1.21 billion pounds). Data on fuels and electricity used in Industry 2879 in this census are mostly in physical units (tons, barrels, cubic feet. kwh) and are added up through a common key on "kilowatt-hour equivalents" of fuels.[3/] A residual in dollars is also given a key which does not always appear to fit consistently. From these data, direct energy use in the industry under scrutiny comes to 13.6 trillion Btu. Adding the indirect (or, backward-linkage) requirements of the energy supplying industries,[4/] the sum comes to 20 trillion Btu. Dividing with the output of the industry in 1971, we obtain 16,500 Btu per pound of active pesticide ingredient.

Other indirect energy (other than that used for production of direct energy) include the pesticide factories' purchases of chemical ingredients, formulating materials and packaging materials, and their use of capital. Between the factory gate and farm gate, there are also costs of marketing.

Purchase of chemical ingredients (intermediate goods) are specified for the first time (for Industry 2879) in the 1977 Census of Manufactures. The total of materials purchased came to $1,227.2 million, of which only $679.7 million were specified. Of the specified amount, $422.9 million were for chemical ingredients, $126.6 million for formulating materials, and $130.2 million for packaging. Assuming the unspecified portion to represent the same commodity mix, we obtain a raised total of $764.2 million as the likely total for purchased chemical materials in 1977. Dividing by the volume of output in 1977, which was 1.33 billion pounds,[6/] we find 57.46 cents worth of chemical materials per pound of pesticides in 1977. To apply the findings of the input-output studies for 1967, we first divide through by the price index for chemical products which is 292 for 1977 (1967=100) and obtain 19.70 cents worth of chemical materials per pound of pesticide, in 1967 materials prices. To this we apply the 1967 energy intensity coefficient for all chemical industry (sector 30), which was 244,711 Btu per dollar's worth of output (Wall poster)[2/], and obtain 48,200 Btu as the estimate of energy used for chemical ingredients per pound of pesticide.

The same procedure is applied to the purchases of formulating materials, much of which also originates in other chemical industries. The result is 14,400 Btu per pound of pesticide, active ingredient.

Packaging materials are analyzed in the same way, applying the energy intensity coefficients for the Plastics, Glas containers, Paperboard containers, and Metal containers industries (sectors 2801, 3502, 2500, and 3901, EAH), resulting in an estimate of 7,400 Btu per pound of pesticide active ingredient.

Capital expenditures are harder to capture. According to data from recent years (1972-77)[7/], gross value of fixed asets in Industry 2879 has been about 40 percent of (gross) value of shipments. Thus this industry, as a processor of already much processed intermediate goods, is not very capital intensive. New capital expenditures in the same years have varied between 3½ percent and 9 percent of gross value of shipments per year. Since there was some expansion in the years we are concerned with, we may choose a value close to the lower bound and assume depreciation to be on the order of 4 percent of annual shipment value, or one-tenth of fixed asset value. Applying this to 1967, we obtain an annual capital cost of $40 million. To estimate embodied energy, we assume this investment to be new construction, non-residential(sector 1102, EAH) with an energy intensity coefficient of 75 728 Btu per dollar's worth. This leads to an estimate of 3 Trillion Btu as annual use of indirect energy through the use of capital. Dividing this by 1.14 billion pounds (the 1967 production), we find 2,600 Btu per pound of pesticide active ingredient.

To calculate energy cost of marketing, we use the guidelines of the EAH and find that the marketing margin for pesticides is 12 percent of the retail price. The distribution of this cost on railroad and motor transportation, and on wholesale and retail trade, shows these costs to be 6,500 Btu per dollar's worth of pesticide in 1967;[8/] with the average 1967 price of 80 cents per pound, this gives 5,200 Btu per pound of pesticide active ingredient.

The above calculations can now be summed:

Direct energy (including the backward-linkage, or "energy cost of energy")	16,500
Chemical ingredients	48,200
Capital charge	2,600
Sub-total: Manufacturing	67,300
Formulating Materials	14,400
Packaging materials	7,400
Sub-total: Formulation and packaging	(21,800)
Double, because of coverage (see below)	43,600
Marketing	5,200
Total	116,100

The total includes double the amounts calculated for formulating and packaging materials, because it is know that much of this phase in production is done by wholesalers, only part of it takes place in the chemical factories which manufacture the active ingredients. The proportion is not know with any precision and is likely to change over time. A USDA source says that in 1971, basic manufacturers did 71 percent of the formulation of farm herbicides and 48 percent of the insecticides.[9/] This may not include the quantities exported, and also says nothing of fungicides, fumigants, etc. Assuming half is formulated in the basic factories is a crude assumption but it is as close as the information will allow us.

The above relates to the industry sector which makes pesticides in the United States. That is far from coinciding with the pesticides that American farmers use. Exports vastly exceed imports in American pesticide trade, and pesticides are used by many other people besides farmers. The commodity composition of farmers' use, as we shall soon see, is as important for total energy consumption in farm pesticides as any precision in the detailed estimates.

British process data. Energy input into pesticides was studied several years ago by scientists working for Imperial Chemical Industries.[10/] Energy input into several processes were studied separately, backward-linkage energy was computed, as were also several indirect energy costs; capital charges were considered insignificiant. For 21 specified pesticides, data were given as summarized in Table 1.

The most striking feature is the wide dispersion of energy costs for individual products; from Toxaphene to Paraquat, the range is almost as 1:8. Clearly, the commodity composition of aggregate consumption (or production) will have far reaching consequences for over-all energy intensity.

The British data are believed to be accurate with an error margin of plus or minus 15 percent. For comparison with U.S. data, additions need to be made for formulation, packaging, and marketing. The British figures are for 100 percent active ingredient, "naked, ex works"[11/], assuming energy for formulation to be insignificant.

U.S. data on formulation and packaging. The British assumption on formulating material does not appear to hold in the United States. Estimates put together by David Pimentel are much higher and also somewhat more detailed[12/]. Distinguishing three classes of formulating agent, with consequent differences in packaging, gave the following estimates (per pound of pesticide active ingredient):

Miscible oil (30 percent formulation)	77,100 Btu
Wettable powder (50 percent formulation)	10,400 Btu
Granules and dusts (5 percent formulation)	43,600 Btu

Weighting these three or four categories (granules and dusts are estimated to have the same requirements) is problematic. Trade literature shows that most if not all pesticides can be formulated in more than one way, and many of them are sometimes formulated in all available ways. Statistics on pesticide use are not explicit on these proportions. USDA survey data give the bulk (70 percent) to liquid formulations but are less precise on the distribution of these between miscible oils and

Table 1. Energy Used for Specified Pesticides, in gigajoules per metric ton, and thousand Btu per pound, of pure content.

Herbicides	GJ/ton	Btu/ton	Fungicides	Gj/ton	Btu/l
Atrazine	190	82	Captan	115	49
Chloramben	170	73	Ferbam	61	26
Dicamba	295	127	Maneb	99	43
Dinoseb	80	34			
Diquat	400	172	Insecticides:		
Diuron	270	116	Carbaryl	153	66
Glyphosate	454	195	Carbofuran	454	195
MCPA	130	56	Methyl parathion	160	69
Paraquat	460	198	Toxaphene	58	25
Propachlor	290	125			
Propanil	220	95			
Trifluralin	150	64			
2,4-D	85	37			
2,4,5-T	135	58			

Source: Maurice B. Green, "Energy in Agriculture," Chemistry and Industry August 7, 1976, p. 642.

Conversion factors: 1 joule = .0009477 Btu; 1 Btu = 1055.20 joules

1 pound = .4536 kilogram

water based formulations.[8/] Illinois agricultural statistics appear to indicate proportions between wettable powder, miscible oils, and granules of 51:41:7.[13/] From such indications we may conclude that the weighted average would be likely in the range of 40,000 -45,000 Btu per pound of pesticide active ingredient, for formulation and packaging materials. This comes close to the estimate given above, based on Census of Manufactures and inout-output data. In Pimentel's data, packaging appears to come to about one-fourth of the total for formulatin and packaging; in the above calculations based on Census of Manufactures, the same proportion is a third. The difference is not large, given the many uncertainties in data and computations. Rather the results are close enough so that the two sets of estimates support each other.

Evaluation. Based on the above, Table 2 shows energy intensities for individual pesticides including the British process data for manufacturin (as in Table 1) and the sum of coefficients for formulating, packaging and marketing based on U.S. Census data. This means that 49,000 Btu per pound of active ingredient have been added to the data in Table 1. Table 2 further shows rates of usage for those pesticides listed both in the British data and in U.S. statistics.

Despite the cushioning effect of a constant addition to each item, differences between individual pesticides are still large, ranging from 74 to 244. It is easy to see that, over time, some of the more energy intensive ones have increased while low-intensive items have lost ground, absolutely or relatively. The coverage is less than half, and the weight of a few large items brings to mind how much could be changed if some large ones had been added to the specified list, such as DDT in 1966 or Alachlor in 1976.

The sub-total shown for manufacturing only (the British data in) Table 1) show a variation from 51 to 74 thousand Btu per pound of active ingredient. This compares with 67,300 as computed above, from Census of Manufactures data. Despite the variation, this indicates that also the British process data are tolerably close to the realities of U.S. chemical factories. Thus we have double sets of estimates,

Table 2. U.S. Farmers' Use of Specified Pesticides and Their Energy Intensity, 1966 and1976.

	Energy intensity, a/ 000 Btu/lb	1966 000 lb.	% of total	1976 000 lb.	% of total
Herbicides:					
Atrazine	131	23,521	6.66	90,300	13.67
Dicamba	176	222	.06	3,600	.54
Diuron	165	1,624	.46	900	.14
MCPA	105	1,669	.47	--	--
Propachlor	174	2,269	.64	11,000	1.67
Propanil	144	2,589	.73	6,900	1.04
Trifluralin	113	5,233	1.48	28,300	4.28
2,4-D	86	40,144	11.36	38,400	5.81
2,4,5-T	107	760	.22	--	--
Fungicides:					
Captan	98	6,869	1.94	--	--
Ferbam	75	2,945	.83	100	.015
Maneb	92	4,443	1.26	100	.015
Insecticides:					
Carbaryl	115	12,392	3.51	9,300	1.41
Carbofuran	244	--	--	11,600	1.76
Methyl parathion	118	8,002	2.27	22,800	1.76
Toxaphene	74	34,605	9.80	30,700	4.65
Totals		353,241 b/ 502,502 c/		660.6 d/ -- d/	
Coverage, percent			41.69		38.45
Energy intensity, weighted average, 000 Btu/lb		100		122	
Sub-total or average:					
Energy intensity for manufacturing only e/		51		73	

a/ Data from Table 1, augmented by 49,000 Btu/lb for formulative packaging, and marketing.
b/ Excludes petroleum and sulfur.
c/ Includes petroleum and sulfur.
d/ Does not specify petroleum or sulfur.
e/ Reflects data in Table 1 without additions.
Sources: Col. 1 from Table1, augmented by 49,000 Btu/lb. Col. 2 from Paul A. Andrilenas, Farmers' Use of Pesticides in 1971-quantities, USDA, ERS, Afr. Econ. Report No. 252. Col. 4 from Theodore R. Eichers, Paul A. Andrilenas and Thelma W. Anderson, Farmers' Use of Pesticides in 1976, USDA, ESCS, Ag. Econ. Report no. 418, Dec. 1978

both sets compatible, for all the numbers except marketing, which is minor. We will therefore maintain an established range of energy cost of pesticide, from 100 to 120 thousand Btu per pound of pure content Multiplying this with the consumption of pesticides, we get a figure in excess of 70 trillion Btu's embodied in pesticide supplies at the farm gate. This comes to about 7 percent of the energy used for American farmers' fertilizers which was close to 1 quad (1000 trillions) recently.

The increase in weighted average from 1966 to 1976 is worth noting, in any event. How much, or how little, farmers' pesticides will draw on our national energy budget in the future will depend on any continuation or reversal of the trend indicated by the data for those two years.

1/ Agricultural Prices (Crop Reporting Board, SRS, USDA), May 1977 and May 1980, give the index weight of this group as 1.6 and 1.4 percent, out of a total 59.4 and 57.9 percent for production expenses, which raises the share of agricultural chemicals among production expenses to 2.7 and 2.4 percent, respectively, in June 1977 and June 1980.

2/ Clark W. Bullard, Peter S. Penner and David A. Pilati, Net energy analysis: Handbook for combining process and input-output analysis, University of Illinois at Urbana-Champaign, Energy Research Group, Center for Advanced Computation, CAC Document 214, October 1976. Further information in David Simpson and David Smith, Direct energy use in U.S. economy 1967. CAC Technical Memo No. 39; and Energy flow through the United States economy (wall poster) by Clark Bullard, Bruce Hannon and Robert Herendeen, Urbana 1975.

3/ 1972 Census of Manufactures, Industry statistics, Agricultural Chemicals, 28G-23, Table 7B; and 1972 Census of Manufactures, Special Reports, SR 6-16, Table 3 and Explanatory Text, p. SR 6-4.

4/ Coefficients from EAH Table A5, p. 48: Coal 1.0092, Petroleum refinery product 1.2227, Electricity 4.0683, Gas utilities 1.1166.

5/ 1977 Census of Manufactures, Industry Series, MC 77-1-28G-4 (P), Issued September 1979, Table 4, p. 7.

6/ Agricultural Statistics (USDA), annual data.

7/ 1977 Census of Manufactures (note 5), Table 1, p. 3.

8/ Donald R. McDowell, Direct and indirect energy analysis of Illinois corn and soybean production, 1976, Unpublished M.S. thesis, University of Illinois, 1979, p. 38.

9/ Letter from T.R. Eichers (USDA), December 1, 1980.

10/ Procedure, and some results, in Maurice B. Green and Archie McCulloch, "Energy considerations in the use of herbicides", Journal of the Science of Food and Agriculture, 1976, 27, pp. 95-100; results from

21 individual pesticides in Maurice B. Green, "Energy in agriculture", Chemistry and Industry, 7 August 1976, pp 641-646.

11/ Green and McCulloch, op.cit., p. 97.

12/ David Pimentel, "Energy inputs for the production, formulation, packaging and transportation of various pesticides", in Handbook of Energy Utilization in Agriculture, ed. David Pimentel, CRC Press, Inc., Boca Raton, Florida, 1980, pp 45-48 (previously circulated in mimeo form, 1977).

13/ Pesticide use by Illinois farmers 1976, IIEQ Document No 77/1 (Springfield), pp 12, 18.

14/ Folke Dovring and Donald R. McDowell, Energy Used for Fertilizers, Illinois Agricultural Economics Staff Paper, 80 E-102, February 1980, p. 14.