

28
9-24-80
25 to 41 LS

ORNL/CON-54

omni MASTER

OAK
RIDGE
NATIONAL
LABORATORY



**Projection of Energy Use in
Agricultural Production by
Fuel Type and at the
State Level**

Austin Fox
Hoang D. Nguyen
Benjamin Thomas

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A04; Microfiche A01

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Contract No. W-7405-eng-26

Energy Division

PROJECTION OF ENERGY USE IN AGRICULTURAL PRODUCTION
BY FUEL TYPE AND AT THE STATE LEVEL

Austin Fox^{*}
Hoang D. Nguyen
Benjamin Thomas[†]

Date Published - September 1980

Department of Energy
Office of Energy Information Administration
and
Office of Conservation and Solar Energy

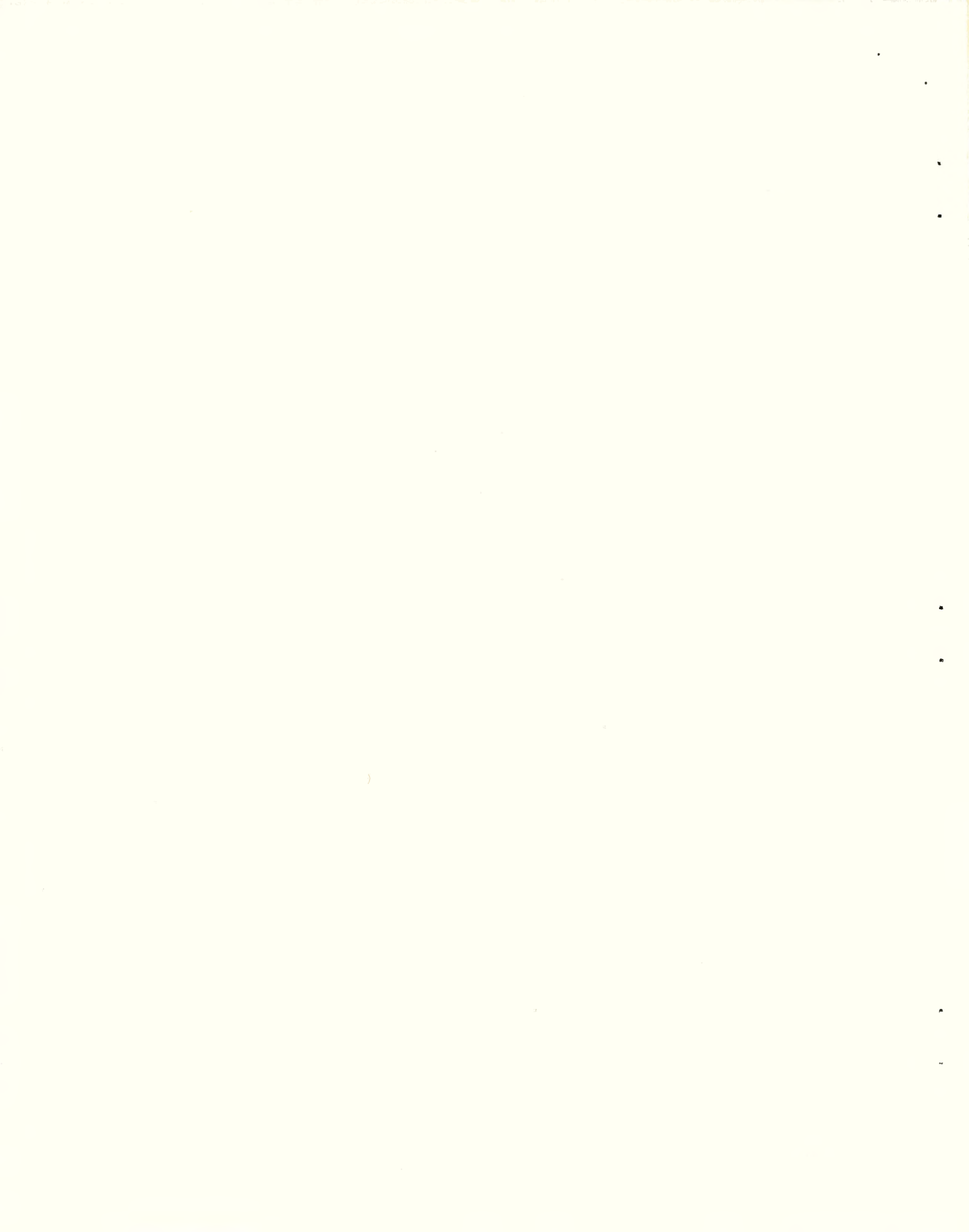
* Food and Agricultural Policy Branch, U.S. Department of Agriculture.
† Computer Sciences Division.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED



CONTENTS

	<u>Page</u>
Abstract	v
1. Introduction	1
2. Energy Use in Agricultural Production	2
2.1. Crop Production	2
2.2. Livestock Production	5
2.3. State Comparison	5
3. Projection Methodology	8
3.1. Review of Existing Models	8
3.1.1. The Iowa State University Model (ISU)	8
3.1.2. The AGRIMOD Model	11
3.1.3. The Penn-Irwin (PI) Model	11
3.1.4. The Miranowski and Mensah Study (MM)	12
3.2. Theoretical Structure	13
3.3. Updating the State Energy Coefficients	15
3.3.1. Substitution Among Fuels	20
3.3.2. Changes in Irrigation Practices	21
3.3.3. Changes in Crop Drying Practices	24
3.3.4. Changes in Tillage Practices	25
3.3.5. Changes in Fertilizer and Pesticide Uses	27
4. Projection Results	29
5. Conclusions	36
Acknowledgments	39
References	41
Appendix	43



PROJECTION OF ENERGY USE IN AGRICULTURAL PRODUCTION
BY FUEL TYPE AND AT THE STATE LEVEL

Austin Fox
Hoang D. Nguyen
Benjamin Thomas

Abstract

Energy is essential for U.S. agricultural production. It is consumed either as a direct input (fuel for tractors, grain drying, irrigation, etc.) or as an indirect input (such as energy invested in fertilizers and pesticides).

This study examines the use of energy in agricultural production in recent years and projects future direct and indirect energy inputs in agricultural production for each state in the U.S. Alternative projections under various assumptions of production levels and production practices are presented.

The projections are based on estimated 1974 state energy input-output matrices which are adjusted for possible future changes in production technology and fuel choices.

1. INTRODUCTION

Energy use in agricultural production has received increasing attention* in recent years due to many factors. First, the U.S. agricultural sector consumes a large amount of energy. In 1974, about 2.1 EJ (Exajoule or 10^{18} joules which is equal to 1.0548 quadrillion Btu's) of energy was used in agricultural production. This number represents approximately 3% of total U.S. energy consumption and includes both direct energy use (fuel for tractors, grain drying, irrigation, etc.) and indirect energy use (energy invested in fertilizers and pesticides). Secondly, energy is essential for agricultural production. Energy shortages could lead to serious disruption of future food and livestock production. Since the 1973 oil crisis, disruption of energy supply has become a likely scenario in the near future.

The objectives of this study are twofold: (1) to examine the nature of energy use in U.S. agricultural production in recent years and (2) to project future energy use in the agricultural sector for each state.

There are few models in the literature which project energy use in agricultural production at the state level. Furthermore, the previous models suffer from either lack of reliable and consistent data or limitations of production possibilities.

The projections in this study are based on a state-level energy input-output model for the agricultural sector. The energy input-output coefficients were estimated from 1974 data.[†] However, the input-output coefficients were adjusted to reflect possible changes in future agricultural production technology.

The following section of this study (Section 2) discusses the nature of energy use in agriculture in recent years; Section 3 presents the structure of the model and explains the adjustment process; Section 4 presents

*See Pimentel et al,¹ Hirst,² Steinhart and Steinhart,³ Leach,⁴ and Pimentel and Terhune⁵ for an account of the current U.S. food-energy situation.

[†]The data base was originally developed by the Economic Research Service (ERS) of the U.S. Department of Agriculture (USDA) in cooperation with the Federal Energy Administration.

alternative projections of energy use in the agricultural sector under various assumptions of production levels and production practices; and finally, Section 5 summarizes the results and discusses future research directions.

2. ENERGY USE IN AGRICULTURAL PRODUCTION

Agricultural production can be divided into two categories: crop and livestock production. Each type of production, in turn, involves many commodities which differ greatly in production practice, land use, yield, energy intensity, fuel type, etc. Furthermore, energy use per unit of production by commodity, by state varies significantly due to different production practices, land characteristics, weather, etc. This section provides an overview of energy use in crop and livestock production and the variation in energy use in agricultural production by state.

2.1. Crop Production

Energy use in crop production accounted for nearly 90% of total energy use in agriculture in 1974 (Table 1). Sixty percent of the energy used in crop production is classified as direct energy (for tillage, irrigation, harvesting, and crop drying...). The other forty percent is for indirect energy use which includes the energy required to manufacture fertilizers and pesticides (including herbicides and fungicides).

Gasoline and diesel are the major fuels in crop production, accounting for approximately 64% of direct energy input. Less important fuels are natural gas, liquid petroleum gas, and electricity. Direct coal use in crop production is insignificant (Table 1).

The detailed energy use in crop production by major end-uses is shown in Table 2. As expected, fertilizer is the most important end-use due to large amounts of embedded energy (35% of energy use in crop production). The other major end-uses by order of importance are: irrigation (15%), harvest (8%), preplant (8%), farm pickup (7%), crop drying (6%), and the rest (21%).

Table 1. Total U.S. energy use in agricultural production in 1974
(10¹⁵ joules)

	Gasoline	Diesel	Fuel oil	L.P. gas	Natural gas	Coal	Electricity	Invested energy	Total
Crop	380	334	43	116	172	--	79	756	1880
Livestock	108	52	1	34	5	1	36	--	236
Total U.S.	488	386	44	149	177	1	115	756	2116

Source: Computed from USDA-ERS.⁶

Table 2. Energy use in agriculture by operation, 1974
(10¹⁵ joules)

Operation	Gasoline	Diesel	Fuel oil	LP gas	Natural gas	Coal	Electricity	Invested energy	Total
Crops									
Preplant	8	135	--	2	--	--	--	--	145
Plant	3	35	--	1	--	--	--	--	39
Cultivate	3	41	--	1	--	--	--	--	45
Fertilizer application	4	9	--	1	--	--	--	--	14
Fertilizers	--	--	--	--	--	--	--	655	655
Pesticide application	4	11	--	1	--	--	--	--	16
Pesticides	--	--	--	--	--	--	--	100	100
Irrigation	9	26	--	24	142	--	69	--	270
Frost protection	6	6	32	--	--	--	1	--	45
Harvest	65	65	--	18	--	--	--	--	148
Farm truck	71	1	--	--	--	--	--	--	72
Grain handling	2	--	--	--	--	--	--	--	2
Crop drying	--	--	11	67	29	--	3	--	110
Farm pickup	136	--	--	--	--	--	--	--	136
Farm auto	58	--	--	--	--	--	--	--	58
Electric overhead	--	--	--	--	--	--	6	--	6
Miscellaneous	8	5	--	--	--	--	--	--	13
Total crops	380	334	43	116	172	--	79	756	1880
Livestock									
Lighting	--	--	--	--	--	--	6	N/A	6
Feed handling	20	29	--	--	--	--	4	N/A	53
Waste disposal	13	7	--	1	--	--	--	N/A	21
Water supply	--	4	--	--	--	--	6	N/A	10
Livestock handling	3	--	--	--	--	--	--	N/A	3
Space heating	--	--	--	6	--	--	1	N/A	7
Ventilation	--	--	--	--	--	--	7	N/A	7
Water heating	--	--	--	7	--	--	4	N/A	11
Milking	--	--	--	--	--	--	3	N/A	3
Milk cooling	--	--	--	--	--	--	5	N/A	5
Egg handling	--	--	--	--	--	--	--	N/A	--
Brooding	--	--	1	19	5	1	--	N/A	26
Farm vehicles	31	10	--	--	--	--	--	N/A	41
Farm auto	26	--	--	--	--	--	--	N/A	26
Other	16	2	--	1	--	--	1	N/A	20
Total livestock	108	52	1	34	5	1	36	N/A	236
Total agriculture	488	386	44	149	177	1	115	756	2116

Notes: Preliminary data developed by the Economic Research Service, U.S. Department of Agriculture, Washington, D.C. 20250, under a jointly funded cooperative agreement with the Federal Energy Administration. (A) Data include all energy used directly on the farm for crop and livestock production. Numbers may not add up exactly due to rounding. (B) Invested energy includes the energy required to manufacture fertilizers and pesticides including carrier solution.

Source: USDA-ERS.⁶

Energy use in crop production is highly concentrated in a few crops. The six most energy consuming crops are corn, winter wheat, cotton, soybeans, alfalfa, and sorghum. They account for nearly 65% of total energy use in crop production. These crops, however, are among the least energy intensive* ones. Their average energy use per hectare was only 12 gigajoules (5 million Btu/acre) in 1974. In contrast, the more energy intensive crops (i.e., tobacco, citrus fruits) averaged about 155 gigajoules per hectare (59 million Btu/acre) in the same year (Table 3).

2.2. Livestock Production

Livestock production accounts for only about 10% of total energy use in agriculture in 1974. Most of the energy use in livestock production is for feed handling, brooding chicks, farm auto and vehicles, and waste disposal (Table 2). The dominant fuel in livestock production is gasoline (46%). Other important fuels are: diesel (22%), electricity (15%), and LP gas (14%) (Table 1).

Energy use in livestock production is highly concentrated. The three categories of livestock beef — cow, calves, and feedlot — along with milk cows and hogs, account for approximately 81% of the total energy use in livestock production. The average energy use per kilogram of these livestock was 2.6 million joules (1.1 thousand Btu/lb). The two most energy intensive livestock categories are sheep and lambs (10.7 million joules/kg or 4.6 thousand Btu/lb) and turkeys (7.0 million joules/kg or 3.0 thousand Btu/lb) (Table 3).

2.3. State Comparison

Energy use in agriculture varies significantly across states (Fig. 1). The top five states are Texas, Iowa, Nebraska, Illinois, and California. Their annual energy use in farm production in 1974 was .21, .14, .14, .13, and .12 EJ respectively (.20, .14, .13, .12, and .11 quads). The annual energy use by the three least energy consuming states (i.e., Alaska, Rhode

*Energy intensity in crop production is defined as energy use per harvested hectare.

Table 3. Fuel use in the production of selected agricultural commodities in 1974
(10^{15} joules)

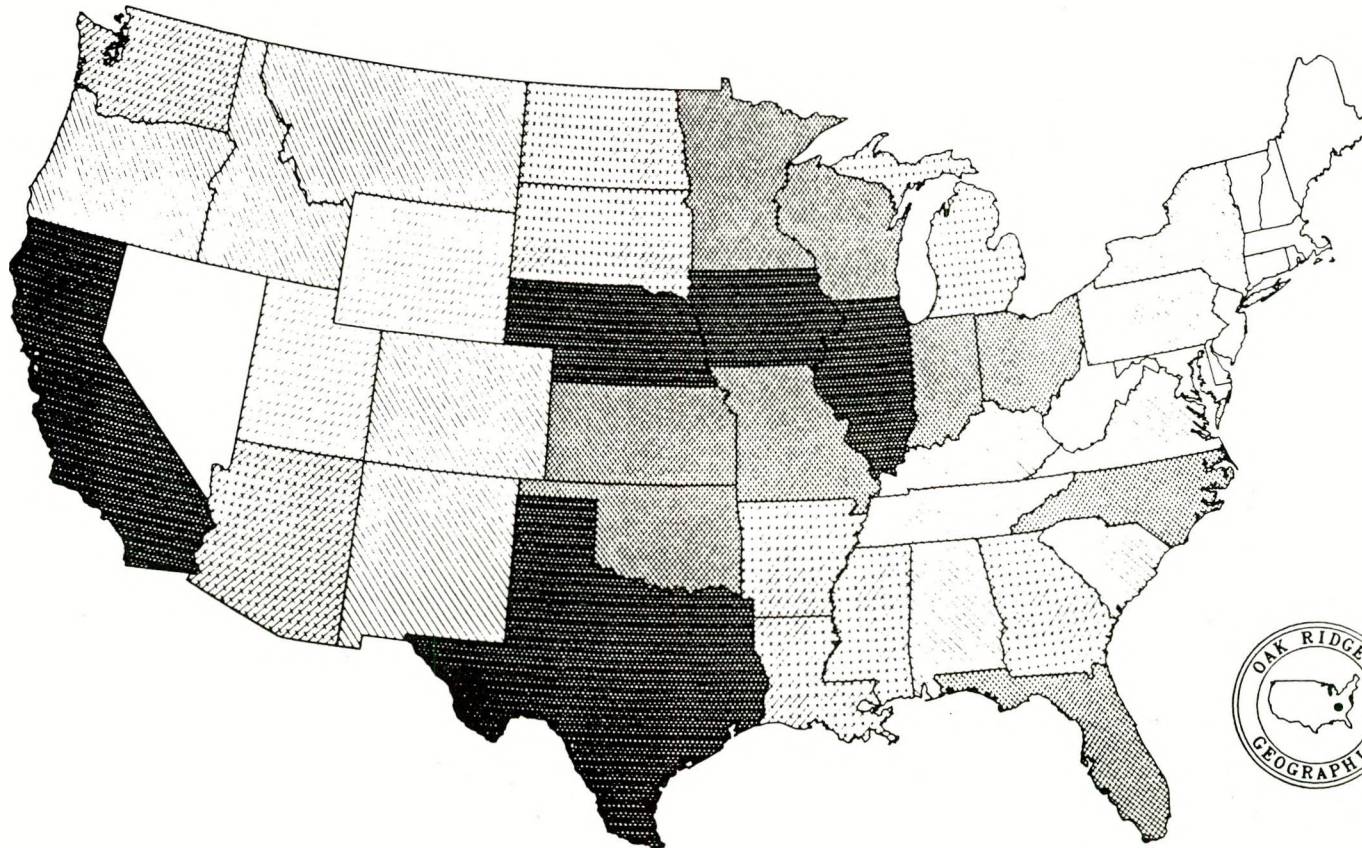
	Gasoline	Oil	L.P. Gas	Natural Gas	Electricity	Indirect Energy	Intensity*
<u>Crops</u>							
Corn	90.3	70.6	58.9	27.9	7.2	270.6	20.0
Soybeans	51.1	50.1	3.8	2.1	1.3	24.8	6.2
Winter wheat	26.5	28.6	3.3	15.3	4.5	76.4	7.9
Alfalfa	49.8	19.5	7.2	29.4	13.4	7.9	11.9
Cotton	14.1	29.7	2.8	22.0	7.2	80.3	26.2
Sorghum	13.0	15.0	4.1	31.0	3.7	39.0	19.0
Flue-cure tobacco	3.4	12.4	17.3	0	0.6	5.8	155.0
Oranges	6.2	26.3	0.3	0.6	1.3	9.3	119.8
Grapefruit	1.2	4.7	0.1	0.3	0.2	1.9	114.9
Lemons	0.5	1.6	-	0.2	0.2	0.5	113.2
<u>Livestock</u>							
Beef-cows & calves	41.4	25.7	1.1	0	1.3	0	3.6
Beef-feedlot	10.1	12.6	0	-	4.1	0	NA
Milk cows	28.8	0	7.7	0	18.4	0	1.1
Hog	15.2	11.7	5.1	0	7.2	0	4.3
Turkey	1.3	0.3	4.3	1.3	0.2	0	6.9
Sheep & lambs	2.9	1.0	0	0	0.1	0	10.7

*Defined as total energy use per unit of production. The unit used is gigajoules (10^9 joules) per hectare for crop and megajoules (10^6 joules) per kilogram for livestock.

Source: USDA-ERS⁶.

Figure 1.

ENERGY USE IN AGRICULTURAL PRODUCTION IN 1974 BY STATE (TRILLIONS OF BTU)



Island, and New Hampshire) in 1974 was only .001, .002, and .008 EJ respectively (.001, .002, and .008 quads). This variation can be attributed to several factors.

First, the characteristics of the inputs (including weather) differs by state. For instance, land in Arizona is much drier than land in California; thus, it takes much more energy to irrigate and fertilize a hectare of corn in Arizona to obtain the same yield as in California.

Another important factor is the diversity of production activities by state (Fig. 2).

The difference in the level of production activity is probably the most important factor explaining the difference in energy use among states. Thus the states with high production values are generally associated with higher energy use (Table 4).

3. PROJECTION METHODOLOGY

3.1. Review of Existing Models

Rising energy prices and the importance of energy input in agricultural production have prompted a number of studies on modeling and projections of energy use in agricultural production. Several major models* are described briefly below.

3.1.1. The Iowa State University model⁸ (ISU)

The ISU model is a static, annual, linear-programming, interregional model which was originally designed to assess the water use and environmental impact of agricultural production. The U.S. is divided into 105 production areas and 28 demand markets which are connected through transport linkages. The model has 10,700 activities simulating crop rotations, water transfer and distribution, commodity transportation, and nitrogen

*For a detailed listing of food and agricultural models, see G. Boss, et al (Ref. 7). Most studies of energy use and conservation in agricultural production are at the regional level. Since we are interested in projecting energy use for each state in the U.S., we list only the models which cover the whole U.S. or all regions in the U.S.

Figure 2.
 PREDOMINANT FARM TYPE BY STATE

1974

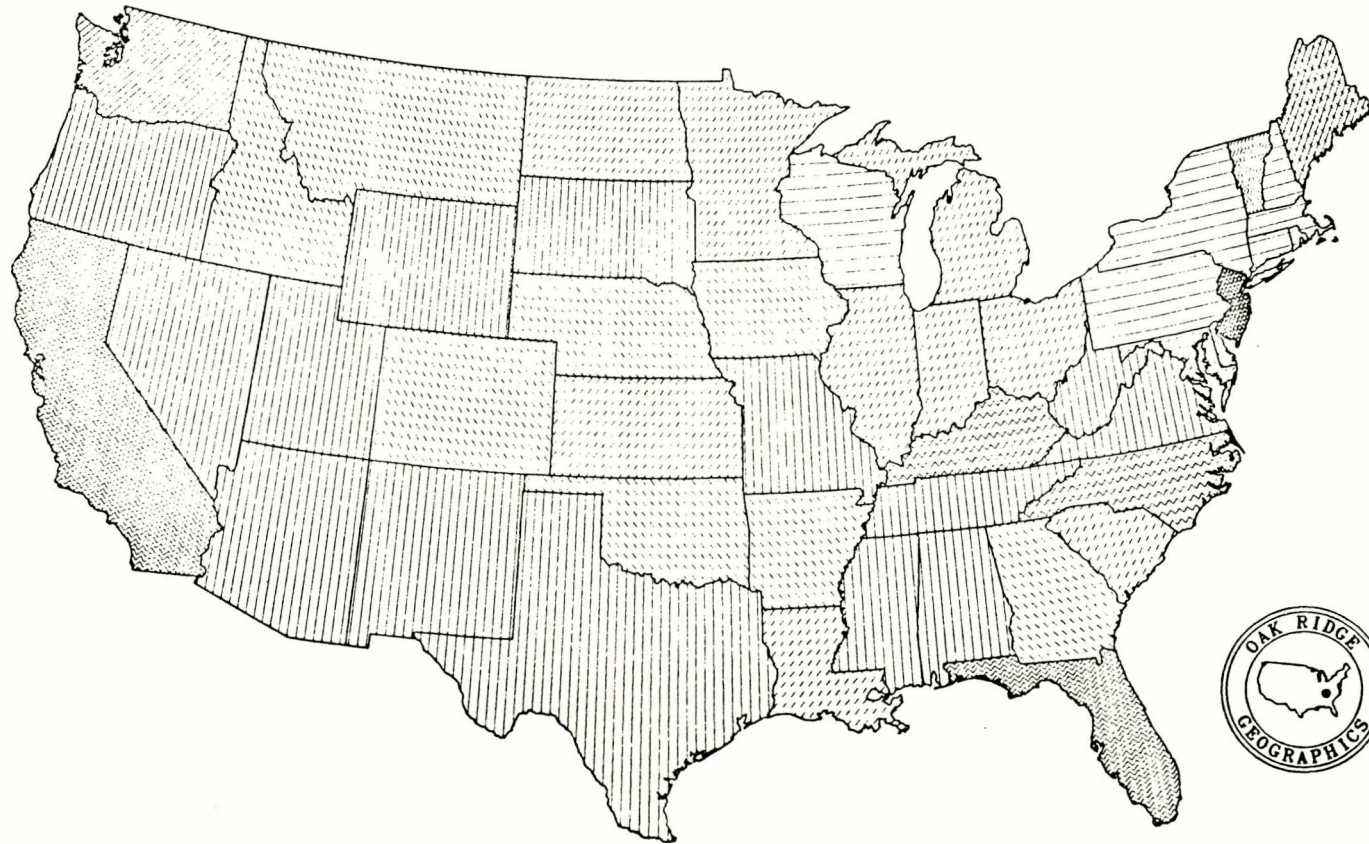
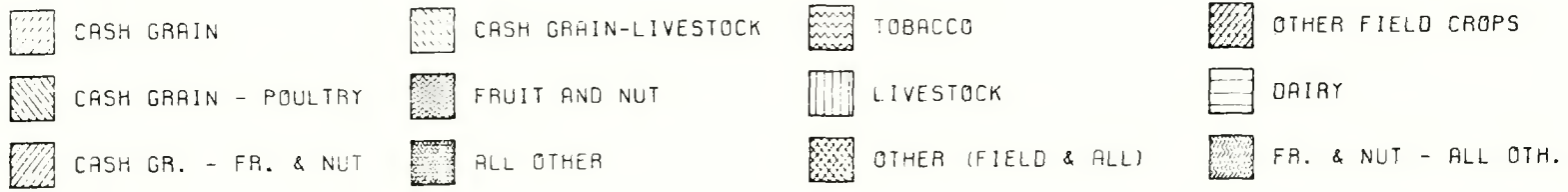


TABLE 4. ACTUAL 1974 FUEL USE IN CROP PRODUCTION

(10**15 JOULES)

STATE	GASOLINE	DIESEL	FUEL OIL	LP GAS	NAT. GAS	COAL	ELECTRICITY	INV. ENERGY
MAINE	0.682	0.432	0.0	0.035	0.0	0.0	0.011	1.404
NEW HAMPSHIRE	0.137	0.078	0.0	0.015	0.0	0.0	0.004	0.347
VERMONT	0.619	0.210	0.0	0.080	0.0	0.0	0.011	1.462
MASSACHUSETTS	0.348	0.256	0.089	0.037	0.0	0.0	0.007	0.614
RHODE ISLAND	0.043	0.022	0.0	0.003	0.0	0.0	0.0	0.095
CONNECTICUT	0.279	0.191	0.0	0.133	0.0	0.0	0.004	0.551
NEW YORK	7.490	4.086	0.657	0.470	0.0	0.0	0.000	10.737
NEW JERSEY	1.776	0.972	0.0	0.112	0.0	0.0	0.032	2.052
PENNSYLVANIA	7.361	4.420	0.351	1.006	0.468	0.0	0.119	11.139
DELAWARE	1.052	0.722	0.0	0.067	0.0	0.0	0.014	1.371
MARYLAND	2.636	1.563	0.011	0.408	0.103	0.0	0.043	3.897
VIRGINIA	3.067	3.386	1.250	2.313	0.066	0.0	0.110	9.772
WEST VIRGINIA	0.856	0.375	0.117	0.106	0.0	0.0	0.014	2.130
NORTH CAROLINA	6.530	7.668	7.393	12.304	0.528	0.0	0.569	18.370
KENTUCKY	5.255	3.942	0.212	1.311	0.254	0.0	0.112	12.530
TENNESSEE	4.358	4.592	0.079	0.585	0.336	0.0	0.112	11.950
SOUTH CAROLINA	3.140	4.121	1.459	2.339	0.071	0.0	0.191	3.547
GEORGIA	6.422	8.181	1.495	3.177	0.560	0.0	0.248	17.211
FLORIDA	8.857	12.342	19.183	1.707	0.043	0.0	1.109	15.670
ALABAMA	3.258	4.669	0.067	0.423	0.070	0.0	0.083	10.600
MISSISSIPPI	5.727	9.537	0.079	0.053	0.113	0.0	0.202	18.135
MICHIGAN	9.553	6.565	1.005	1.768	0.412	0.0	0.310	15.743
WISCONSIN	18.238	5.767	0.007	3.492	0.442	0.0	0.458	17.547
MINNESOTA	27.317	13.531	0.023	6.267	0.394	0.0	0.637	40.556
OHIO	13.111	6.230	0.549	3.177	1.200	0.0	0.338	25.074
INDIANA	16.204	7.397	0.003	6.629	0.159	0.0	0.403	36.308
ILLINOIS	31.500	15.873	0.012	12.822	0.346	0.0	0.767	59.655
ARKANSAS	7.319	13.104	0.0	3.006	2.703	0.0	0.511	17.425
LOUISIANA	5.425	9.543	0.0	0.787	2.056	0.0	0.227	11.737
OKLAHOMA	8.558	8.989	0.0	1.876	6.744	0.0	0.635	20.857
TEXAS	22.301	25.728	1.629	5.706	71.097	0.0	5.598	62.854
NEW MEXICO	1.967	2.706	0.0	1.776	16.473	0.0	1.493	2.604
IOWA	35.900	17.287	0.020	11.618	0.591	0.0	0.750	55.371
MISSOURI	14.541	7.430	0.029	3.332	0.468	0.0	0.367	30.615
NEBRASKA	15.371	31.466	0.002	14.782	13.744	0.0	4.097	47.353
KANSAS	17.010	16.393	0.0	4.307	23.526	0.0	1.044	33.931
NORTH DAKOTA	15.017	11.625	0.0	0.438	0.120	0.0	0.443	13.414
SOUTH DAKOTA	9.020	11.827	0.001	2.944	0.162	0.0	0.522	9.625
MONTANA	6.738	4.293	0.0	0.439	0.360	0.0	0.832	11.159
WYOMING	1.440	1.587	0.0	0.162	0.131	0.0	0.735	2.386
COLORADO	4.548	4.956	0.109	0.643	5.759	0.0	1.570	6.943
UTAH	1.199	1.685	0.0	0.089	0.302	0.0	1.228	1.497
ARIZONA	1.871	2.227	0.042	0.047	15.804	0.0	7.553	7.338
NEVADA	0.479	1.235	0.0	0.120	0.112	0.0	1.336	0.445
CALIFORNIA	13.826	19.891	7.391	0.814	4.490	0.0	16.643	38.525
HAWAII	0.930	0.947	0.0	0.002	0.0	0.0	2.513	3.155
IDAHO	3.522	5.971	0.0	0.387	0.957	0.0	5.796	10.407
WASHINGTON	4.232	4.568	1.256	0.298	0.340	0.0	13.644	12.920
OREGON	2.694	3.395	1.177	0.200	0.249	0.0	5.792	6.470
ALASKA	0.028	0.000	0.0	0.004	0.0	0.0	0.0	0.027
UNITED STATES TOTAL	379.753	334.524	46.596	115.708	171.774	0.0	79.412	755.718

and energy supplies at the regional level. Given the production levels of all crops and livestock, the model determines the level of production activities; the use of nitrogen fertilizer, livestock residue, water, and energy which minimizes production cost* under a set of factor inputs (land, water, energy, and fertilizer) and fixed demand constraints.

From the perspective of forecasting fuel uses in agricultural production at the state level, the ISU model suffers the following drawbacks:

- (1) it is large and expensive to operate, and
- (2) it is not a state level model.

3.1.2. The AGRIMOD model⁹

The AGRIMOD is a dynamic simulation model of the U.S. food production system developed by System Control, Inc. The model was originally designed to provide a framework for analyzing the effects of alternative policies on food supply and the impacts of technical changes, energy and resource constraints on production and prices. The model covers 7 regions of the U.S., 10 crops, and 5 livestock categories. The food production system is divided into four sectors: pre-production, crop production, food supply, and consumption. Input materials and outputs move between sectors through three markets in which prices are determined. The model consists of 17 submodels fully integrated through material and information flows into four sectors and three markets.

From the perspective of projecting fuel uses in agricultural production at the state level, the AGRIMOD model suffers several drawbacks:

- (1) it is not designed to project fuel use in agricultural production,
- (2) it is not a state level model, and
- (3) it is large and expensive to operate.

3.1.3 The Penn-Irwin (PI) model¹⁰

The PI model is a static, annual, linear-programming model of the U.S. food and fiber system. The model is designed to assess the impact of alternative energy availabilities on the food and fiber sector in the

*The model can be modified to minimize energy cost rather than production cost.

context of the total economy setting. The 85 sector I/O matrix of the U.S. economy in 1967 is used to establish the resource independence between the food and fiber sector and others.

The simulation results indicate that: "fuel allocation to agricultural production may be of little assistance if other needed inputs are unobtainable. The results further suggest that, of input industries, the fertilizer and chemical sectors are relatively more severely affected by the shortages than others. Food processing is also a potential bottleneck, especially in specific product sectors. ...The agricultural production sectors are not more severely affected relative to many others..."*

Even though the PI model is rather attractive in taking into consideration the interdependence between the food production and other sectors, it can not be used to project state energy use in agricultural production due to the following drawbacks:

- (1) it is not designed to forecast energy use, and
- (2) it is a national, not state-level model,
- (3) it does not have detailed production processes in the agricultural sector, and
- (4) the model's 1967 I/O table is not adjusted for future changing conditions.

3.1.4. The Miranowski and Mensah study (MM)¹¹

In this study, Miranowski and Mensah combine annual time series data (1964, 1969, and 1974) with cross-sectional data (state) to estimate econometrically the derived demand for energy and non-energy inputs in the U.S. agricultural sector. The demand functions are derived from a trans-log cost function. The preliminary econometric results indicated that energy inputs in agricultural production are responsive to own price as well as to the prices of other factor inputs. This result is in contradiction with most process analyses which indicate highly inelastic response. Furthermore, the MM study indicates that as energy prices rise, capital and land will substitute for energy while fertilizer and labor intensity will decrease.

*J. Penn and G. Irwin¹⁰, p. 14.

The MM study is rather appealing since it provides the own- and cross-price elasticities of demand for energy in a manner consistent with economic theory. However, the application of the MM approach in the projection of state energy use in agricultural production is limited due to the following drawbacks:

- (1) The data and estimation method is far from desirable. The study does not account for the structural difference between time periods, as well as the nonhomogeneity of the input factors. For instance, land is treated as a homogenous factor input in the MM study, but in reality, land quality varies significantly across states.
- (2) The study assumes the price responses to be identical across states. The lack of consistent data at the state level prevent a more detailed econometric study.
- (3) The study deals with national rather than state energy use, and does not contain any technical information on agricultural production processes.

In the rest of this section, we will present a simple model designed specifically to forecast energy use in agricultural production by fuel and commodity at the state level.

3.2. Theoretical Structure

The energy used for each crop and livestock category was divided by the units of production in 1974 to get fuel use per acre of crops grown and per unit of livestock production. Energy use projections by fuel type are then a production of the projected per unit fuel requirements – by production operations, commodity and state – and the projected acres of crops or units of livestock production. The nonhomogeneity of input factors between states are then accounted for.

The energy consumed in the making of fertilizer and pesticides is also projected.

The projections of invested energy in fertilizer used in farm production are the product of the percent change in fertilizer use from 1974 to the projected year and the invested energy in fertilizer used in the 1974 data base described earlier. The projections assume the proportion of nitrogen, phosphates, and potash used on each crop in 1974 will be unchanged. These chemical shares have remained fairly stable for several decades.

The projections of invested energy in pesticides used in food production are the product of the percent change in pesticide use from 1974 to the projected year and the invested energy in pesticides in the 1974 data base. The projections currently assume continuing changes in the relative importance of fungicides, insecticides, and herbicides.

The projection methodology can be explained in further detail. The energy consumption by the agricultural sector for a given state and year can be broken down into energy consumption in the production of crop and livestock:

$$E_A = E_C + E_L \quad (1)$$

Where E denotes energy use and the subscripts A, C, and L denote total agricultural sector, crop, and livestock production activity, respectively.

Energy consumption in the crop production can be represented as:

$$E_C = \sum_i \sum_j \sum_k e_{ijk}(t) \cdot A_i(t) \quad (2)$$

where $e_{ijk}(t)$ is the energy coefficient at time t which denotes the amount of fuel j used in the type of production operation k (or the amount of energy invested in fertilizers and pesticides applied to a hectare of crop i) per hectare of the crop i harvested at t . $A_i(t)$ = number of hectares of the crop i harvested at time t . It should be noted that e and A are different for each state.

Similarly, energy consumption in the production of livestock can be expressed as:

$$E_L = \sum_l \sum_j \sum_m e_{ljm}^*(t) L_l(t) \quad (3)$$

where

- e^* = energy use per million kilograms of livestock produced,
- l = type of livestock,
- j = type of fuel,
- m = type of livestock production operation, and
- L_l = the production of livestock l in million kilograms.

Combining Eqs. (1), (2), and (3), the total energy consumption in crop and livestock production can be presented as:

$$E_A = \sum_i \sum_j \sum_k e_{ijk}(t)(A)_t + \sum_l \sum_j \sum_m e_{ljm}^*(t)L_l(t) \quad (4)$$

The energy coefficients e_{ijk} and e_{ljm}^* are estimated based on a 1974 state energy data base developed by the Economic Research Service, USDA in cooperation with the Federal Energy Administration.⁶ This data base covers 1974 monthly and annual energy use by the farm business for six fossil fuels, electricity, and the energy invested in fertilizers and pesticides, for 70 crop and livestock commodities. The information includes quantities of energy used for each of 17 crop operations and 15 livestock operations, by crop and livestock category, by fuel type, and by state. Crop operations relate to tillage, irrigation, harvesting, hauling, and crop drying practices. Livestock operations relate to feeding, watering, waste disposal, livestock handling, heating and ventilation. Both crop and livestock operations also include all transportation related to the farm business. They do not include residential or non-business uses of energy. Tables 5 and 6 illustrate the 1974 matrices of energy coefficients for crop and livestock production.

For projection purposes, the 70 crop and livestock commodities were aggregated to the 32 commodities (24 crops and 8 livestock). The energy coefficients, e_{ijk} , are adjusted to reflect future possible changes in production practices. The adjustment process is described in the next section.

3.3. Updating the State Energy Coefficients

The demand for energy in agricultural production is a derived or input demand. The fuel requirements per unit of production, or the energy input-output coefficients e_{ijk} vary over time, depending on the relative fuel prices versus other input prices, relative price of one fuel versus others, changes in production technology, and other factors such as weather, conservation effort, etc.

Table 5. 1974 fuel consumption per hectare of silage in Maine
(10⁶ joules)

Operation	Gasoline	Diesel	Fuel oil	LP gas	Natural gas	Coal	Electricity	Joule
Preplant	0.0	852.9	0.0	0.0	0.0	0.0	0.0	0.0
Plant	0.0	334.6	0.0	0.0	0.0	0.0	0.0	0.0
Cultivate	35.0	277.5	0.0	11.1	0.0	0.0	0.0	0.0
Harvest	613.0	2711.4	0.0	173.0	0.0	0.0	0.0	0.0
Pickup	1628.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fertilizer application	93.6	0.0	0.0	26.7	0.0	0.0	0.0	0.0
Pesticide application	47.2	0.0	0.0	12.1	0.0	0.0	0.0	0.0
Truck	508.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Farm auto	714.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Invested energy – fertilizer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6398.6
Invested energy – pesticide	0.0	0.0	0.0	0.0	0.0	0.0	0.0	984.4
Electric overhead	0.0	0.0	0.0	0.0	0.0	0.0	44.5	0.0
Miscellaneous	0.0	77.6	0.0	0.0	0.0	0.0	0.0	0.0
Total	3639.2	4255.0	0.0	222.9	0.0	0.0	44.5	7303.0

Source: Derived from 1974 USDA-ERS⁶.

Table 6. 1974 fuel consumption per unit of hog production in Maine
(10⁶ joules/kg)

Operation	Gasoline	Diesel	Fuel oil	L.P. gas	Natural gas	Coal	Electricity
Lighting	0	0	0	0	0	0	33
Feed Handling	0	534	0	0	0	0	30
Waste Disposal	0	267	0	0	0	0	0
Water Supply	0	0	0	0	0	0	233
Space Heating	0	0	0	368	0	0	23
Ventilation	0	0	0	0	0	0	256
Farm Vehicles	602	400	0	0	0	0	0
Farm Auto	602	0	0	0	0	0	0
Other	0	0	0	0	0	0	7
Total	1,204	1,202	0	368	0	0	582

Source: USDA-ERS⁶.

Evaluating the impact of changing energy price on energy intensity and therefore energy coefficients in the agricultural sector has been rather difficult. The two most common evaluating methods in the literature are econometric, and mathematical programming analyses; neither of which yield satisfactory and conclusive results. The econometric analysis has been limited by the lack of reliable and continuous time-series data on fuel consumption, fuel prices, and other inputs in the agricultural sector. This lack of data is particularly serious at the state or lower regional levels. Mathematical programming analysis, on the other hand, suffers from the lack of accurate detail on production processes, as well as limited representation of the production possibilities. These two methods, in some cases, yield contradicting results. For instance, recent econometric studies by J. Miranowski and E. Mensah,¹¹ and J. Yanagida and R. Conway,¹² indicated that energy inputs in agricultural production are quite responsive to energy prices. In contrast, the mathematical programming studies reviewed in the previous section (ISU, AGRIMOD, and PI models) tended to support the view that energy demand in agriculture is relative price inelastic.

In this study, we do not attempt to estimate the response of energy use in agricultural production to energy prices. Instead, we focus our attention on the impact of changing agricultural production practices on the energy requirement in agriculture.

The popular methods of updating the input-output matrix such as biproportional or RAS, Almond and Friedlander*, are not applicable to our case, simply due to the lack of consistent control total data. Thus, we rely on ex ante information on changing production practices (discussed below) to adjust the energy input-output coefficients.

Changes in fuel requirements are associated with the substitution of one type of fuel for another, improvements in irrigation, crop drying, tillage practices, and fertilizer and pesticide uses. The remainder of this section will discuss adjustments in fuel requirements for each of these sources of change. The production practices where the changes take place are summarized in Table 7.

*For a review and critics of RAS and other popular methods of updating the input-output matrix, see R. I. Allen and W. F. Gosling.¹³

Table 7. Production practices for which projected unit fuel requirements were changed, by production operation and fuel type

Crop and livestock production practices	Production practice codes ^a							Invested BTU
	Gasoline	Diesel	Fuel oil	LP gas	Natural gas	Coal	Electric	
Crops								
Preplant	1,2,5	1,2,5	2,5	1,2,5	2,5	--	2,5	--
Plant	1	1	--	1	--	--	--	--
Cultivate	1,2	1,2	2	1,2	2	--	2	--
Harvest	1	1	--	1	--	--	--	--
Farm pickup	1	1	--	1	--	--	--	--
Fertilizer application	1	1	--	1	--	--	--	--
Pesticide application	1	1	--	1	--	--	--	--
Farm truck	1	1	--	1	--	--	--	--
Farm auto	1	1	--	1	--	--	--	--
Grain handling	--	--	--	--	--	--	--	--
Crop drying	3	3	3,4	3,4	3	3	3	--
Irrigation	5	5,6	5	5	5,6	5	5,6	--
Frost protection	--	--	--	--	--	--	--	--
Fertilizer	--	--	--	--	--	--	--	7
Pesticides	--	--	--	--	--	--	--	8
Electricity	--	--	--	--	--	--	--	--
Miscellaneous	--	--	--	--	--	--	--	--
Livestock								
Lighting	--	--	--	--	--	--	--	--
Feed handling	1	1	--	1	--	--	--	--
Waste disposal	1	1	--	1	--	--	--	--
Water supply	--	--	--	--	--	--	--	--
Livestock handling	1	1	--	1	--	--	--	--
Space heating	--	--	--	--	--	--	--	--
Ventilation	--	--	--	--	--	--	--	--
Water heating	--	--	--	--	--	--	--	--
Milking	--	--	--	--	--	--	--	--
Milk cooling	--	--	--	--	--	--	--	--
Egg handling	--	--	--	--	--	--	--	--
Brooding	--	--	--	--	--	--	--	--
Farm vehicles	1	1	--	1	--	--	--	--
Farm auto	1	1	--	1	--	--	--	--
Other	--	--	--	--	--	--	--	--

^aProduction practice codes: 1 - dieselization; 2 - reduced tillage; 3 - crop drying; 4 - change in fuel type to dry tobacco; 5 - irrigation; 6 - change in fuel type for irrigation; 7 - fertilizers; 8 - pesticides.

3.3.1. Substitution among fuels*

Most of the substitution among fuels relate to using more diesel fuel in place of gasoline and some of the LP gas. We assume that the historical substitution of diesel fuel for gasoline will continue in the near future. Diesel engines require less maintenance, have longer operating lives, use a cheaper fuel, and use less energy than gasoline engines. Diesel fuel is more efficient in terms of number of liters and joules needed to perform a given amount of work. In terms of liters of fuel use, the same work can be done with diesel fuel with 27 percent fewer liters than with gasoline and 40 percent fewer liters than with LP gas. In terms of joules the same work can be done with diesel fuel with about a fifth fewer joules than with gasoline and 40 percent fewer joules than with LP gas.

The projected substitution of diesel fuel for gasoline and LP gas fuel is assumed to be proportional to changes in the stock of tractors, combines, and other farm vehicles and engines used for specific types of farm operations. A gradual switch to diesel power machines is being made even though the cost of these units is higher. The switch to diesel is assumed to be uniform across the United States for all uses. The projections do not allow for any substitution of diesel fuel for gasoline and LP gas used in crop drying and frost protection. The projected shift to diesel suggests that by 1990 diesel powered units will account for nearly 95 percent of the tractor and combine power used on farms. Gasoline will continue to provide most of the fuel for farm autos, trucks, and other vehicles.

The general form of the equation used to estimate the substitution of diesel fuel for gasoline and LP gas is:

$$e_{ig}(t) = (1 - PN)e_{ig}(74) \quad (5)$$

where

$e_{ig}(t)$ = gasoline use per hectare or per unit of production of commodity i at time t ,

*See USDA¹⁴ for a more detailed explanation of the adjustment scheme.

PN = percent of gasoline and LP powered units in 1974 that switched to diesel between 1974 and t, and

$$e_{id}(t) = e_{id}(74) + PN* [.73*e_{ig}(74) + .605 e_{il}(74)] \quad (6)$$

where

.73 and .605 are conversion factors converting gasoline and LP gas to diesel equivalents,
 $e_{id}(t)$ = diesel use per hectare or per unit of production of commodity i at time t, and
 $e_{il}(74)$ = LP gas in 1974 per hectare or per unit of production of commodity i

$$e_{il}(5) = (1 - PN)e_{il}(74) \quad (7)$$

These equations are applied to selected operations. The operations and PN's associated with each operation over time are included in the Appendix Table A1.

Natural gas has been used extensively for irrigation particularly in the areas where natural gas is produced. There was little if any switching from natural gas prior to 1974. With the passage of the Natural Gas Policy Act of 1978,¹⁵ natural gas for agricultural uses, which include irrigation, were given a number 2 priority. This means that natural gas would be made available for agricultural uses and that for these uses there would not be subject to any incremental pricing. Thus, it is not likely that the increases in prices we have seen from 1974 to 1979 for natural gas for farm use will continue.

To date, there has not been much experience related to further adjustments in the use of natural gas as they might relate to the Natural Gas Policy Act of 1978. At this time, the best judgment is that there will not be a significant adjustment or shift in the use of natural gas.

3.3.2. Changes in irrigation practices*

There is some irrigation of nearly all farm crops. Fruits and vegetables are most often irrigated – over half the fruit and Irish potatoes

*See Young et al¹⁶ and G. Sloggett¹⁷ for a more detailed explanation of the adjustment scheme for irrigation practice.

and a third of the other vegetables. Also, about a fourth of the cotton and sorghum is irrigated. Corn, wheat, other grains, and soybeans are not generally irrigated. The proportion of hectares that are irrigated will continue to increase over time, although at a slower rate than before. Fuel requirements are greater on irrigated hectares. Fuel requirements for some irrigated crops are greater than for others because of the different irrigation practices and because some crops commonly grown in arid sections of the country require extensive irrigation.

Energy for irrigation includes that used for on-farm pumping of irrigation water. It does not include energy used for off-farm pumping of irrigation organizations. Trends in energy requirements for irrigation reflect changes in irrigated hectares and in energy use per hectare irrigated. In these projections the energy use per hectare for all hectares is adjusted to reflect the change in the relative importance of irrigation. As the percentage of irrigated hectares increases in each state, the fuel for irrigation per hectare for all crops is increased by the same percentage.

Over time, the energy use per hectare also is changed to reflect increases in height that the water must be pumped. Much of the irrigation water must be pumped either from underground wells or from ground level water sources such as lakes, rivers, and streams. In this study, it is assumed that there will be proportional increases in irrigation with both groundwater and surface water and that the amount of water applied per hectare will remain the same over time. There will be more energy needed for pumping water from deeper wells because of the falling level of groundwater, but it is assumed that the wells are sufficiently deep so no additional energy will be needed to drill deeper wells. It is assumed that the average groundwater pumping height will increase about 0.3 meter (1 foot) a year between 1974 and 1990 for all regions (Sloggett¹⁷). Surface water pumping requirements will remain the same through time. The additional energy required for pumping the water from deeper wells is added to the total energy for pumping irrigation water.

Because of increases in irrigated areas, more fuel is needed for tillage operations, particularly for preplant operations. Research studies indicate that an additional 20 percent more fuel per hectare is required for preplant operations on irrigated hectares. The projected fuel use

coefficients for irrigation increase through time as the proportion of hectares irrigated increases. It is assumed that no additional energy is required for cultivation as the proportion of hectares irrigated increases. Any additional energy needed for cultivation with furrow irrigation probably is offset by the reduced energy needed to apply herbicides with water via sprinkler irrigation.

In these projections, adjustments are made over time in the preplant and irrigation operations. We assumed 20 percent more energy is needed on additional irrigated hectares than on the nonirrigated hectares. The general form of the equation showing increases in energy use per hectare for preplant operations due to increases in hectares irrigated is:

$$e_{ijp}(t) = e_{ijp}(74) \left[1 + \left(\frac{1}{.2PI_{74}+1} \right) \left(\frac{PI_t}{PI_{74}-1} \right) \right] \quad (8)$$

where

$e_{ijp}(t)$ = fuel used per hectare of crop i at time t for preplant operation, and
 PI = percent of hectares of crop i irrigated.

The general form of the equation showing increases in fuel for the irrigation operations is:

$$e_{ijr}(t) = e_{ijr}(74) \left[(PG) \left(\frac{FL_t}{FL_{74}} \right) + (1-PG) \left(\frac{PI_t}{PI_{74}} \right) \right] \quad (9)$$

where

$e_{ijr}(t)$ = fuel j use per hectare of crop i at time t for irrigation,
 PG = percent of irrigation energy used to pump ground water,
 FL = meters of lift, and
 PI = percent of hectare irrigated.

The percent of energy used to pump groundwater and the meters of lift for each state are shown in the Appendix, Table A2.

3.3.3. Changes in crop drying practices*

Crop drying always has been a part of crop production. Grasses, legumes, and grains have been cut and allowed to dry naturally. Corn and small grains were cut and stacked to allow the grain to dry, and corn was stored in upright bins which allowed the flow of air to dry it even more. Grasses and legumes cut for silage are generally allowed to wilt before ensiling and when cut for hay are allowed to dry naturally. Today, many crops are being dried artificially with heated air that often comes directly from the burning of fuels or from electric heaters. With artificial drying, more of the crops can be harvested in a shorter time with fewer losses and a higher quality of product. High capacity driers and low fuel costs encouraged more drying.

Projected increase in fuel use for crop drying is assumed to be proportional to the increase in the proportion of the crop artificially dried. In these projections, the fuel per unit of production is held constant and, as discussed earlier, there were no adjustments made to allow for shifts in types of fuel used except for tobacco where there is a continuing shift from fuel oil to propane. The formulae and coefficients for estimating changes from fuel oil to LP gas for drying tobacco are in Appendix Table A3.1.

The general form of the equation for projecting changes in fuel used for crop drying is:

$$e_{ijd}(t) = e_{ijd(74)} \left(\frac{f_{ijd}(t)}{f_{ijd(74)}} \right) \left(\frac{d_j(t)}{d_j(74)} \right) \left(\frac{Y_i(t)}{Y_i(74)} \right) \quad (10)$$

where

$e_{ijd}(t)$ = fuel j per harvested hectare of crop i at time t for crop drying purpose,

$f_{ijd}(t)$ = fuel j used to dry a liter of commodity i ,

d = percent of yield dried, and

Y = crop yield in liter per hectare.

*See USDA¹⁴ for a more detailed explanation of the adjustment scheme of crop drying practice.

The same formula is used for all types of fuel. There are different coefficients for each crop over time and they vary by state. The percentages of the crop dried are shown in the Appendix, Table A3.

3.3.4. Changes in tillage practices*

Reduced tillage is becoming important in farm production. Such practices vary widely, ranging from eliminating one of the conventional tillage practices to "no-till" where there is no preparation of the land ahead of planting and no cultivation of the crop. Generally, reduced tillage requires less fuel for preplant production operations. With reduced tillage there is a difference in the types and quantities of pesticides used, but often the amount of fuel used to apply the pesticides is almost the same. In this study it is assumed that the amount of fuel used for applying pesticides does not vary with alternative tillage practices.

No-till only recently has become feasible because of the historical lack of availability of planters that work in untilled fields. No-till first was used primarily with row crops such as corn and sorghum. However, now it is also being used extensively on soybeans and small grains. In 1974 no-till was being used on only about 2 percent of the total hectare of corn, sorghum, silage, soybeans, wheat, oats, barley, and rye. We assume that this practice will increase so that its use will be 7 percent, 14 percent, and 32 percent for 1980, 1985, and 1990, respectively.

Forms of reduced tillage other than no-till always have been used by some farmers, but increases in use have become much more important recently. Reduced tillage other than no-till is used on most field crops. In 1974 it is estimated that on almost 8.5 percent of the acreage of all field crops some form of reduced tillage other than no-till was being used. We are assuming that this practice will increase on all field crops so that it will be 16 percent, 24 percent, and 30 percent for 1980, 1985, and 1990, respectively. Over time, many of the reduced tillage acreages will go into no-till. By 1990 either no-till or some form of reduced tillage will be used on about half of the field crop acreage.

*See USDA.¹⁸

Changes in fuel use for alternative tillage practices are assumed to be directly related to the extent of the reduction in tillage. For no-till practices it is assumed that there are no tillage operations prior to planting and that there is no cultivation. Then for preplant production practices and for cultivation the fuel use per acre is reduced the same proportion as the increase in the percentage of acres on which no-till is being used.

With reduced tillage there is a general reduction in the number of preplant production operations. This lower fuel use is offset partly by an increase in fuel needed for additional cultivation. For reduced tillage it is assumed that the tillage operations prior to planting will have fuel use per hectare reduced to 50 percent of conventional practices. Fuel for cultivation will increase a third on those areas where reduced tillage is practiced.

The reduced tillage operations affect preplant and cultivation operations. The general formulas are as follows:

$$e_{ijk}(t) = e_{ijk}(74) \frac{PC_t + .50 (PR)_t}{PC_{74} + .50(PR)_{74}} \quad (11)$$

where

$e_{ijk}(t)$ = fuel j used per hectare of crop i at time t for preplant operation k ,
 PC = percent conventionally tilled, and
 PR = percent reduced tillage.

$$e_{ijl}(t) = e_{ijl}(74) \frac{PC_{74} + 1.33(PR)_t}{PC_t + 1.33(PR)_{74}} \quad (12)$$

where

$e_{ijl}(t)$ = fuel j used per hectare of crop i at time t for cultivation.

The same formulas are used for all states and all fuel types. The percentages that are conventionally tilled and reduced tilled vary by groups of crops and over time. This information is included in the Appendix, Table A4.

3.3.5. Changes in fertilizer and pesticide uses*

The energy consumed in making fertilizers and pesticides and in delivering them to farmers is also projected separately from the fuel used for applying them. It is shown as invested energy.

The projections of invested energy in fertilizer used in farm production are the product of the percent change in fertilizer use from 1974 to the projected year and the invested energy in fertilizer used in the 1974 data base described earlier. The projections assume the combinations of nitrogen, phosphates, and potash used in 1974 will continue to be used in those proportions, as these have remained fairly stable for several decades.

In projecting fertilizer, it is assumed application rates will continue to increase over time. The increase in the overall fertilizer application rates reflects changes in the percent of hectare treated and in the application rate per hectare treated. Total fertilizer use is the summation of projected use on individual crops.

Fertilizer use on corn, soybeans, wheat and cotton was estimated separately for each State by fitting a logistic function to time series data where fertilizer use was expressed as a function of time. The maximum value used in the logistic function was the highest quantity that would be expected to be applied. Higher and lower maximum values were tested and the one selected generally had the lowest standard error.

These fertilizer application rates were then adjusted to more nearly agree with the derived demand for fertilizer for the crop as estimated by multiplying the average revenue of product times the marginal physical product from fertilizer use .

The general form of the fertilizer equations for State estimates of nitrogen (P_2O_5 for soybeans) per hectare treated (N/A_T) are:

$$N/A_T^\dagger = D \text{ Max} - e^{B_1} + B_2^t \text{ (Adj. factor)}$$

*See Fox¹⁹ (1975) for more detailed explanation of the adjustment scheme for fertilizer and pesticide uses.

† P_2O_5/A_T for soybeans.

where

D Max = the highest quantity that might be applied,

B_1 and B_2 = coefficients derived from fitting the curve to historical data for 1954, 1959, and 1964-73,

t = the last two digits for the year. Projections for 2000 and beyond, the years are 100 for 2000, 101 for 2001, etc.,

Adj. factor = description noted above.

Projected changes in fertilizer application rates for the other crops were assumed to be lower than for wheat and corn but higher than soybeans and cotton.

Pesticides are now an integral part of agricultural production. Fungicides and insecticides control diseases and insects that damage crops and livestock. Herbicides control undesirable weeds and are a partial substitute for labor, fuel, and machinery. Other pesticides are used to fumigate the soil, defoliate plants and to control plant growth.

In the projections of pesticide use it was assumed that the percentage of acres treated and the application rates would vary over time. Some of these changes over time are related to more pest problems. Other changes relate to shifts in pesticide use practices over time.

Fungicides, herbicides, and insecticides were projected separately for 24 crop groupings. Miscellaneous pesticides were assumed to continue to be as important as they were in 1974. Total pesticides are the summation of projected fungicides, herbicides, insecticides, and miscellaneous pesticides, after they were adjusted to include noncrop farm uses.

The projections of invested energy in pesticides used in farm production are the product of percent change in pesticide use from 1974 to the projected year and the invested energy in pesticides in the 1974 data base. The projections currently assume continuing changes in the relative importance of fungicides, insecticides, and herbicides.

4. PROJECTION RESULTS

To project energy consumption in the agricultural sector, we need to specify the future values of the exogeneous variables which are the number of hectares harvested and livestock production for 24 crops, 8 livestock, and 50 states. Varying assumptions on the values of the model's parameters, the energy coefficients, also affect the projection results. In this section we describe the three scenarios resulting from different combinations of future values of the exogeneous variable and energy coefficients, and the projection results of each scenario. The differences between the three scenarios are briefly described in Table 8.

In scenario 1, which is the base scenario, the projections of crops (harvested hectares) and livestock productions are taken from a preliminary USDA projection.¹⁴ The full projected values of crop and livestock production by commodity and by state are aggregated and listed in the Appendix, Table A5. The energy coefficients are adjusted to reflect possible future changes in production technology as described in Section 3.

In scenario 2, we assume that the future levels of harvested areas and livestock production are 10% higher than the levels in scenario 1. The energy coefficients are also adjusted as in scenario 1.

In scenario 3, we assume the future levels of harvested areas and livestock production are the same as scenario 1. In contrast, the energy coefficients are unadjusted, assuming that production technology is unchanged from 1974. Specifically, the fuel used per hectare in crop production and per kilogram of livestock production in 1980, 1985, 1990, 1995, and 2000, are the same as 1974. It should be noted that the future crop yield response function would have to be higher to get the same projected production from the same areas with fewer inputs than in scenario 1. More likely, with the same number of harvested areas, the future levels of crop yields and also crop production in scenario 3 would be lower than in scenario 1.

Table 8. Assumptions on future agricultural production and energy coefficients in the three scenarios

Scenario	Agricultural production	Energy coefficients
1	As projected by USDA	Adjusted for future trend
2	10% higher than those in in scenario 1	Same as scenario 1
3	Same as scenario 1	1974 coefficients

Some projection results under scenario 1 are shown in Tables 9, 10, and 11. Comparing the projection of energy use in the year 2000 (Table 9) with actual energy use in 1974 (Table 4), we can note:

1. The use of diesel, LP gas, coal, electricity, and energy embodied in fertilizers and insecticides are projected to increase significantly while the use of gasoline and fuel oil are projected to stay rather unchanged.
2. Projected growth rates of direct energy use in agricultural production vary widely across states. The states with highest projected growth rates are traditionally predominant agricultural states such as Kansas, Kentucky, Alabama, Oklahoma, Arizona, and New Mexico. The states with lowest projected growth rates are the northeast and other northern states such as Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Montana, Idaho, North Dakota, South Dakota, and Michigan (Table 10).
3. Direct energy use in agricultural production in the U.S. is projected to increase slowly, approximately at the annual rate of 0.5% between 1974 and 2000. Total energy use (direct plus indirect energy use) is projected to increase at an annual rate of about 1% at year and reach 2.7 EJ (2.6 quads) by the year 2000.

The projection results under the assumptions of scenarios 2 and 3 are shown in Table 11 and Fig. 3. Under the scenario 2 assumption of using the adjusted energy coefficients for future trends and a 10% increase in agricultural production, total energy use in the U.S. is projected to reach 2.9 EJ (2.8 quads) by 2000, an annual compounded growth rate of 1.3% from 1974. Under scenario 3 where fuel use per hectare of crop production remains unchanged from 1974 onward, and agricultural production and the future number of acres harvested is the same as in the first scenario, total energy use in agricultural production is projected to reach 2.4 EJ (2.3 quads) in 2000, an annual compounded growth rate of 0.5%. It should be noted that projected direct energy use in scenario 3 is higher than those in scenario 1, reflecting the direct energy conservation trend which is incorporated into the model under scenario 1. In contrast, indirect energy use in scenario 3 is lower than those in scenario 1, reflecting the current trend toward more application of fertilizers and insecticides.

Table 9.

Table 9. 2000 FJEL USE IN AGRICULTURAL PRODUCTION

(10**15 JOULES)

STATE	GASOLINE	DIESEL	FUEL OIL	LP GAS	NAT. GAS	COAL	ELECTRICITY	INV. ENERGY
MAINE	0.922	0.445	0.945	0.074	0.0	0.0	0.354	1.450
NEW HAMPSHIRE	0.189	0.135	0.016	0.033	0.0	0.0	0.091	0.395
VERMONT	0.939	0.435	0.005	0.208	0.0	0.0	0.373	1.632
MASSACHUSETTS	0.409	0.359	0.159	0.074	0.0	0.0	0.105	0.681
RHODE ISLAND	0.059	0.039	0.003	0.008	0.0	0.0	0.014	0.121
CONNECTICUT	0.444	0.295	0.028	0.097	0.0	0.0	0.162	0.622
NEW YORK	7.451	6.079	1.071	0.746	0.305	0.033	2.173	13.788
NEW JERSEY	1.504	1.100	0.007	0.093	0.001	0.0	0.094	2.528
PENNSYLVANIA	8.333	6.783	0.578	2.350	0.650	0.157	2.003	16.664
DELAWARE	1.281	0.855	0.079	1.035	0.0	0.0	0.236	1.370
MARYLAND	3.363	2.152	0.137	2.068	0.201	0.0	0.586	6.169
VIRGINIA	5.328	6.131	0.666	4.688	0.216	0.263	0.883	13.431
WEST VIRGINIA	0.844	1.027	0.216	0.226	0.010	0.045	0.123	3.217
NORTH CAROLINA	8.274	10.397	2.352	22.554	0.953	0.352	1.405	24.806
KENTUCKY	8.647	9.548	0.380	1.562	0.448	0.020	1.011	19.404
TENNESSEE	5.856	7.982	0.131	1.095	0.372	0.042	0.734	14.820
SOUTH CAROLINA	3.907	5.337	0.765	3.758	0.151	0.016	0.543	10.648
GEORGIA	9.611	11.685	0.764	6.710	2.010	0.0	1.556	23.156
FLORIDA	12.503	18.271	23.876	3.165	0.080	0.0	2.039	29.549
ALABAMA	6.928	9.527	0.138	4.289	0.431	0.361	1.026	17.276
MISSISSIPPI	7.355	14.198	0.228	2.612	0.822	0.000	0.940	22.829
MICHIGAN	8.651	8.217	1.708	2.601	0.480	0.0	1.410	21.890
WISCONSIN	16.164	12.194	0.037	4.620	0.540	0.0	4.774	25.058
MINNESOTA	27.296	22.748	0.054	11.844	0.513	0.010	3.930	71.325
OHIO	15.051	11.058	0.950	4.528	1.779	0.022	1.597	43.395
INDIANA	17.221	12.762	0.038	11.592	0.320	0.038	1.774	53.718
ILLINOIS	30.971	23.119	0.033	22.137	0.565	0.015	3.161	89.169
ARKANSAS	13.029	15.403	0.0	11.886	6.977	0.0	2.078	31.382
LOUISIANA	8.691	13.079	0.0	1.378	4.522	0.0	0.928	19.080
OKLAHOMA	15.140	9.686	0.0	2.301	8.441	0.0	1.500	35.502
TEXAS	41.049	29.306	3.309	7.272	107.687	0.0	9.376	112.433
NEW MEXICO	4.258	4.361	0.031	2.056	17.285	0.001	2.293	1.055
IDAHO	39.709	32.510	0.046	21.022	0.967	0.007	5.636	76.342
MISSOURI	16.978	14.881	0.072	6.089	0.863	0.0	2.118	41.643
NEBRASKA	16.769	44.285	0.007	26.005	10.229	0.0	7.794	59.518
KANSAS	20.239	44.832	0.004	11.536	34.141	0.0	7.717	65.667
NORTH DAKOTA	14.361	12.583	0.001	0.210	0.101	0.001	0.758	21.847
SOUTH DAKOTA	10.921	12.913	0.003	3.697	0.136	0.005	0.974	10.544
MONTANA	6.733	4.596	0.023	0.290	0.395	0.002	0.770	19.044
WYOMING	2.193	2.534	0.0	0.096	0.159	0.000	0.476	3.807
COLORADO	7.277	7.203	0.072	1.118	7.969	0.009	1.327	14.775
UTAH	2.119	1.829	0.000	0.352	0.520	0.071	1.337	2.483
ARIZONA	3.955	4.265	0.739	0.164	21.503	0.000	11.819	14.524
NEVADA	1.160	1.532	0.0	0.185	0.115	0.0	1.552	0.700
CALIFORNIA	22.676	28.265	6.786	3.182	9.152	0.0	21.951	55.920
HAWAII	0.614	0.578	0.006	0.021	0.0	0.0	1.137	1.628
IDAHO	5.665	7.067	0.0	0.574	0.929	0.001	4.938	17.207
WASHINGTON	4.663	4.069	0.650	0.626	0.315	0.0	11.821	17.006
OREGON	3.911	4.905	1.344	0.572	0.263	0.0	5.059	10.240
ALASKA	0.031	0.017	0.000	0.003	0.0	0.0	0.005	0.102
UNITED STATES TOTAL	471.493	500.168	49.427	212.924	240.576	1.437	137.516	1168.843

Table 10. Growth rate of agricultural production and total energy consumption

State	1974-1985			1985-1990			1990-2000		
	Crop	Live-stock	Energy use	Crop	Live-stock	Energy use	Crop	Live-stock	Energy use
Maine	-1.84	0.69	-0.35	-0.04	1.00	0.88	0.32	0.91	0.97
New Hampshire	-2.81	0.34	-0.72	-0.12	0.60	0.13	0.30	0.53	0.51
Vermont	-2.43	0.95	-0.59	-0.14	1.06	0.45	0.38	0.91	0.83
Massachusetts	-2.05	-1.18	-0.61	-0.34	-0.66	-0.27	0.17	-0.50	0.19
Rhode Island	-0.93	-0.38	0.47	-0.97	-0.33	-0.36	-0.34	-0.02	0.03
Connecticut	-1.54	-0.20	-1.25	-0.41	0.31	-0.21	0.03	0.31	0.24
New York	-1.58	0.45	-0.67	0.18	0.72	-0.02	0.48	0.64	0.54
New Jersey	-1.59	-4.21	-1.63	0.74	-3.80	-0.31	0.77	-3.40	0.15
Pennsylvania	-0.90	0.86	-0.27	0.61	0.99	0.54	0.73	0.87	0.92
Delaware	-0.89	1.39	-0.19	0.32	1.68	0.54	0.82	1.47	1.01
Maryland	-0.16	1.16	0.27	1.71	1.26	1.06	1.12	1.10	1.12
Michigan	-1.56	0.07	-0.57	0.45	0.57	0.08	0.47	0.55	0.48
Wisconsin	-1.85	0.67	-0.96	0.30	0.86	0.18	0.47	0.76	0.74
Minnesota	-0.33	0.31	-0.34	1.42	0.75	0.56	1.11	0.72	0.93
Ohio	-0.00	0.36	0.25	1.58	0.37	0.58	1.21	0.44	0.87
Indiana	-0.48	0.25	0.39	1.30	0.58	0.59	0.90	0.62	0.73
Illinois	-0.30	0.23	0.39	0.58	0.47	0.21	0.75	0.57	0.62
Iowa	-0.09	0.17	0.31	1.29	0.29	0.57	0.97	0.42	0.77
Missouri	-0.88	0.47	-0.16	1.47	1.03	0.79	1.13	1.00	1.00
North Dakota	-1.10	-1.19	-1.33	0.59	0.63	-0.25	0.30	0.72	0.23
South Dakota	-1.89	0.12	-1.59	0.87	1.11	0.44	0.60	1.06	0.69
Nebraska	-0.97	0.27	0.32	0.50	1.11	0.52	0.79	1.11	1.07
Kansas	0.18	0.63	1.19	1.05	1.17	1.84	0.87	1.16	2.21
Virginia	-1.15	2.11	1.56	0.96	1.21	0.70	0.93	1.12	0.94
West Virginia	-1.53	-0.39	-0.76	0.69	0.31	0.35	1.00	0.44	0.95
North Carolina	-0.65	2.03	0.10	1.60	1.87	0.78	1.02	1.65	0.90
Kentucky	0.86	0.56	0.91	2.29	1.03	1.25	1.97	0.96	1.55
Tennessee	0.15	0.78	0.44	1.55	0.83	0.65	1.25	0.82	0.99
South Carolina	-0.79	1.83	-0.31	2.37	1.76	0.96	1.24	1.56	0.95
Georgia	-0.19	1.31	0.10	2.00	1.17	1.11	1.64	1.02	1.12
Florida	1.26	1.35	0.87	1.54	2.30	1.18	1.35	1.88	1.06
Alabama	1.08	2.24	1.66	2.68	1.80	1.58	2.39	1.58	1.71
Mississippi	1.10	1.29	0.77	1.78	1.29	0.84	1.25	1.23	0.97
Arkansas	0.68	2.19	1.56	2.62	2.37	1.91	0.55	2.03	1.28
Louisiana	2.07	1.26	1.31	2.46	1.29	1.31	1.77	1.16	1.19
Oklahoma	-0.92	0.82	-1.03	1.30	1.75	0.62	1.02	1.62	1.34
Texas	0.21	1.21	-0.70	1.25	2.01	0.61	0.78	1.76	1.18
Montana	-0.89	0.58	-1.30	1.05	0.94	-0.13	0.90	1.01	0.68
Idaho	-0.44	0.32	-0.68	0.63	0.96	0.57	-0.19	0.69	0.24
Wyoming	-0.64	0.08	-0.77	1.40	0.81	0.61	1.52	0.90	1.04
Colorado	-0.47	1.64	-0.85	1.28	1.74	0.23	1.24	1.57	1.20
New Mexico	-0.93	1.42	-2.42	0.73	1.67	0.98	1.13	1.46	1.89
Arizona	0.71	1.76	-1.29	2.08	2.32	1.20	2.02	1.90	2.14
Utah	-0.52	1.30	-0.41	1.36	1.61	0.42	1.34	1.30	0.92
Nevada	-1.22	0.74	-0.62	0.64	1.38	1.00	0.97	1.30	1.24
Washington	-1.45	1.21	-2.51	0.27	1.52	0.42	0.28	1.26	0.67
Oregon	-0.72	0.18	-0.82	0.85	0.61	0.55	0.77	0.59	0.85
California	0.22	1.75	0.25	1.11	1.77	0.70	0.76	1.45	0.88
Alaska	8.78	-1.45	-1.70	2.75	0.70	1.51	1.62	-0.12	1.39
Hawaii	-3.83	-2.98	-8.09	-0.01	0.88	-0.15	0.16	0.79	0.07
U.S. total	-0.42	0.79	0.10	1.18	1.13	0.73	0.93	1.05	1.05

Table 11. Projections of energy use in U.S. agricultural production
(10^{18} joules)

	Actual 1974	1980	1985	1990	1995	2000
Scenario 1						
Direct energy use	1.37	1.35	1.34	1.39	1.47	1.55
Indirect energy use	0.70	0.83	0.91	1.02	1.09	1.17
Total	2.12	2.25	2.25	2.41	2.56	2.72
Scenario 2						
Direct energy use	1.37	1.43	1.48	1.53	1.61	1.70
Indirect energy use	0.76	0.88	1.00	1.12	1.20	1.29
Total	2.12	2.18	2.31	2.65	2.82	2.99
Scenario 3						
Direct energy use	1.37	1.38	1.38	1.46	1.53	1.60
Indirect energy use	0.75	0.74	0.72	0.75	0.77	0.79
Total	2.12	2.11	1.10	2.20	2.30	2.39

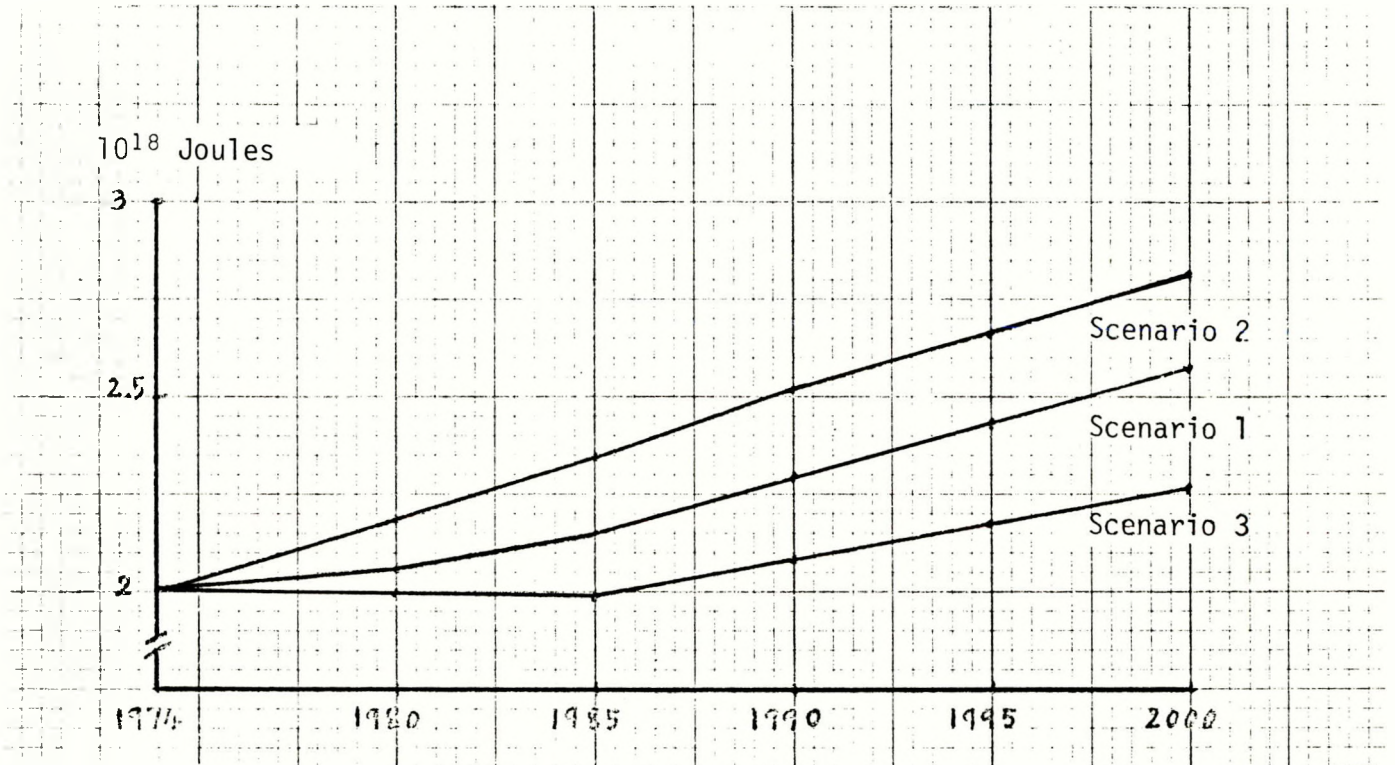


Figure 3. Projected energy consumption in agricultural production.

5. CONCLUSIONS

In this study we examined the use of energy in agricultural production in recent years and presented a simple model designed to project future fuel use (direct and indirect fuel use) in agricultural production separately for crops, livestock, for different fuel types, and at the state level.

The model is an accounting system based on estimated 1974 state fuel-use-per-unit-of-crop-and-livestock-production matrices. The matrices are adjusted to reflect possible future changes in production technology such as irrigation techniques and fuel choices. The exogeneous variables of the model are the numbers of hectares harvested for 24 crop categories, and production for 8 livestock categories at the state level.

For illustration purposes, three projections of energy use in agricultural production are made based on various assumptions of agricultural production levels and production practices.

As previously stated (in Section 4) the projection results indicate:

1. The use of diesel, LP gas, coal, electricity, and energy embodied in fertilizers and insecticides are projected to increase significantly while the use of gasoline and fuel oil are projected to stay unchanged.
2. The above projection results are consistent with the current trends toward conservation of oil and natural gas; increasing use of coal and electricity; and greater application of fertilizers and pesticides in agricultural production.
3. Total (direct plus indirect energy use) energy use in agricultural production in the U.S. is projected to increase slowly, approximately at the annual rate of 1% between 1974 and 2000. Total energy use is projected to reach 2.7 EJ (2.6 quads) by the year 2000.
4. Projected growth rates of direct energy use in agricultural production varies widely across states. The states with the highest growth rates are the traditionally predominant agricultural states such as Kansas, Kentucky, Alabama, Oklahoma, Arizona, and New Mexico. The states with the lowest projected growth rates are the northeast and other northern states such as Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Montana, Idaho, North Dakota, South Dakota, and Michigan.

One obvious drawback of this study is that the model is not sensitive to changes in fuel prices. This drawback is not easy to overcome since the farm fuel prices and consumption data at the state level are not easily available. Our future research efforts will be concentrated in the following five areas:

1. Collect and/or develop time-series data on fuel prices and consumption in agricultural production at the state level.
2. Perform statistical analyses based on obtained data to estimate the responses of farm fuel consumptions to changes in fuel prices. If the price responses are found to be significant in the short- and medium-run, they will be incorporated into our model.
3. Use the improved model to evaluate the input of the following relevant energy conservation options:

Soil and crop working

- Crop rotation
- Minimum tillage
- Tractor efficiency
- Fuel from farm residue

Irrigation

- Pump efficiency
- Wells with minimum drawdown
- More efficient distribution and sprinkler systems

Crop drying

- Heat recovery systems
- Heat pumps
- Dryeration
- Solar heat systems
- Regenerated desiccate systems
- Industrial or utility waste heat
- Coal fuel for dryers

Frost protection

- Optimum heater use
- Fans

Livestock and poultry production

- Building design and construction
- Feed handling
- Solar heat

Alternative farming systems

- Decentralization of feedlot operations to substitute natural manure for chemical fertilizers (Pimentel¹)
- Greenhouses and waste heat
- Soil heating from waste heat
- Nonchemical farming (Chapman²⁰)

4. Talk to agricultural engineers and agronomists about potential for new machines or practices which may affect future energy intensity in agricultural production.
5. Energy use in the agricultural sector is directly related to the level of agricultural production which depends on domestic consumption, international trade, federal farm income support policies, etc. (Nguyen²¹). Our model currently establishes the linkage between energy use and agricultural production level. Future research to establish the linkage between agricultural production and domestic food consumption, food trade, and farm policies would improve the model greatly.

ACKNOWLEDGMENTS

The authors appreciate the helpful comments on an earlier draft of the report by R. W. Barnes, S. M. Cohn, K. R. Corum, R. J. Maddigan, and T. J. Wilbanks.

40

REFERENCES

1. D. Pimentel, et al., "Food Production and the Energy Crisis," *Science* 182, pp. 443-449, Nov. 1973.
2. E. Hirst, "Food Related Energy Requirements," *Science* 184, pp. 134-138, April 1974.
3. J. S. Steinhart, and C. E. Steinhart, "Energy Use in the U.S. Food System," *Science* 184, pp. 307-316, April 1974.
4. G. Leach, *Energy and Food Production*, IPC Science and Technology Press Limited, Guildford, Surrey, 1976.
5. D. Pimentel and E. C. Terhune, "Energy and Food," *Annual Review of Energy*, Annual Review, Inc., 1977.
6. U.S. Department of Agriculture, Economic Research Service, *Energy and U.S. Agriculture: 1974 Data Base*, Government Printing Office, Washington, D.C., 1977.
7. G. Boss et al., "Food and Agriculture Models for Policy Analysis" in: A. H. Lewis and C. L. Quance, eds., *System Theory Applications to Agricultural Modeling*, ESCS-07, Washington, D.C., 1978.
8. D. Dvoskin and E. Heady, *U.S. Agricultural Production Under Limited Energy Supplies, High Energy Prices, and Expanding Agricultural Exports*, CARD Report 69, Iowa State University, 1976.
9. A. Levis, et al., *Energy in Agriculture: On Modeling Energy Inputs in Agrimod*, Systems Control, Inc., SAN/1314-1, 1977.
10. J. B. Penn and G. D. Irwin, *Constrained Input-Output Simulations of Energy Restrictions in the Food and Fiber System*, Economic Research Service, U.S. Department of Agriculture, Agricultural Economic Report No. 280, 1977.
11. J. Miranowski and E. Mensah, *Derived Demand for Energy in Agriculture: Effects of Price, Substitution, and Technology*, paper presented at the 1979 Annual Meetings of the American Agricultural Economic Association.
12. J. Yanagida and R. Conway, *Impact of Rising Energy Prices on Livestock Prices and Production*, unpublished paper, U.S. Department of Agriculture, 1979.
13. R. G. Allen and W. Gossling, eds., *Estimating and Projecting Input-Output Coefficients*, Input-Output Publishing Company, London, England, 1975.

14. U.S. Department of Agriculture, *Adjustment Potential in U.S. Agriculture*, Vol. I, Economics, Statistics, and Cooperative Service (ESCS), Scenario, Production Price, and Income Projections to 1985, 1985, and 2000. Unpublished working materials, Washington, D.C., Sept. 1979.
15. U.S. Congress, The National Energy Act, Oct. 15, 1978.
16. K. B. Young and J. M. Coomer, *Effects of Natural Gas Price Increases on Texas High Plains Irrigation, 1976-2025*, U.S. Department of Agriculture, Economics, Statistics, and Cooperatives Service, Agricultural Economic Report No. 448, 1980.
17. G. Sloggett, *Energy and U.S. Agriculture: Irrigation Pumping, 1974*, U.S. Department, Economics Research Service, Agricultural Economic Report No. 376, Sept. 1977.
18. U.S. Department of Agriculture, Office of Planning and Evaluation, *Minimum Tillage: A Preliminary Technology Assessment*, 1975.
19. A. S. Fox, *Projecting Fertilizer Use in Crop Production*, paper presented at the AMA Ag-Chem Marketing Research Conference, Washington, D.C., Oct. 27, 1975.
20. D. Chapman, "An End to Chemical Farming?" *Environment* 15, No. 2, 1973.
21. H. D. Nguyen, *A Market-Oriented World Food Model with Policy Implications*, paper presented at the 1980 American Statistical Association Meeting, Houston, Texas, Aug. 14, 1980.

APPENDIX

Table A1. Percent of gasoline and/or LP units on farms in 1974 that converted to diesel in projected years (t), by machine type for selected operation, United States^a

Machine	Operation ^b	1980	1985	1990
Tractor	1, 2, 3, 6, 7, 19, 20, 22	.375	.622	.777
Combine	4	.306	.522	.725
Pick up	5	.005	.010	.020
Truck	8	.020	.050	.090
Auto	9, 31	.005	.010	.020
Farm vehicle	30	.200	.350	.500

^aAssures an increase in use of diesel fuel is directly related to the number of diesel power machines on farms.

^bThe names of these operations are defined in Table 7.

Table A2. Percent of energy used to pump irrigation groundwater and feet of lift

State	Percent of energy used to pump groundwater (same over time)	Feet of lift			
		1974 ^a	1980	1985	1990
Maine	0	0			
New Hampshire	0	0			
Vermont	0	0			
Massachusetts	0.20	80	86	91	96
Rhode Island	0	0			
Connecticut	0.34	80	86	91	96
New York	0.77	80	86	91	96
New Jersey	0.96	175	181	186	191
Pennsylvania	0.34	150	156	161	166
Delaware	0.89	50	56	61	66
Maryland	0.56	50	56	61	66
Michigan	0.84	100	106	111	116
Wisconsin	0.82	45	51	56	61
Minnesota	0.91	60	66	71	76
Ohio	0.71	100	106	111	116
Indiana	0.89	150	156	161	166
Illinois	1.00	30	36	41	46
Iowa	0.90	35	41	46	51
Missouri	0.89	75	81	86	91
North Dakota	0.76	75	81	86	91
South Dakota	0.18	70	76	81	86
Nebraska	0.98	100	106	111	116
Kansas	1.00	180	186	191	196
Virginia	0.16	30	36	41	46
West Virginia	0	0			
North Carolina	0.17	150	156	161	166
Kentucky	0.10	75	81	86	91
Tennessee	0.69	100	106	111	116
South Carolina	0.88	300	306	311	316
Georgia	0.92	250	256	261	266
Florida	0.95	85	91	96	101
Alabama	0.83	150	156	161	166
Mississippi	0.95	110	116	121	126
Arkansas	0.93	45	51	56	61
Louisiana	0.91	100	106	111	116
Oklahoma	1.00	250	256	261	266
Texas	0.96	200	206	211	216
Montana	0.15	100	106	111	116
Idaho	1.00	275	281	286	291
Wyoming	0.95	150	156	161	166
Colorado	1.00	115	121	126	131
New Mexico	1.00	350	356	361	366
Arizona	1.00	350	356	361	366
Utah	0.97	225	231	236	241
Nevada	0.98	250	256	261	266
Washington	0.16	250	256	261	266
Oregon	0.30	200	206	211	216
California	1.00	110	116	121	126
Alaska	0.97	100	106	111	116
Hawaii	1.00	700	706	711	716

^aEstimated from data in USDA-ESCS, references 14 and 17.

Table A3. Percentages of crops dried for selected crops by state

State	Corn				Sorghum grain				Soybean				Tobacco				Peanuts				Rice				Alfalfa Hay						
	1974	1980	1985	1990	1974	1980	1985	1990	1974	1980	1985	1990	1974	1980	1985	1990	1974	1980	1985	1990	1974	1980	1985	1990	1974	1980	1985	1990			
Maine																															
New Hampshire																															
Vermont																															
Massachusetts										75	75	75	75																		
Rhode Island																															
Connecticut										75	75	75	75																		
New York																															
New Jersey																															
Pennsylvania	25	29	32	35						10	10	10	10											1	1	1	1				
Delaware																															
Maryland	25	29	32	35						10	10	10	10											1	1	1	1				
Michigan	60	62	64	65					15	15	15	15												1	1	1	1				
Wisconsin	60	62	64	65						10	10	10	10											0.4	0.4	0.4	0.4				
Minnesota	69	71	73	75					15	15	15	15												0.4	0.4	0.4	0.4				
Ohio	83	84	85	85					15	15	15	15	10	10	10	10								1	1	1	1				
Indiana	88	88	88	88	10	10	10	10	15	15	15	15	10	10	10	10								0.5	0.5	0.5	0.5				
Illinois	80	82	84	85	10	10	10	10	15	15	15	15												0.5	0.5	0.5	0.5				
Iowa	63	67	69	79	10	10	10	10	15	15	15	15												0.4	0.4	0.4	0.4				
Missouri	85	85	85	85	90	90	90	90	15	15	15	15	10	10	10	10					100	100	100	100							
North Dakota									15	15	15	15													0.4	0.4	0.4	0.4			
South Dakota	61	63	64	65	20	22	24	25	15	15	15	15												0.4	0.4	0.4	0.4				
Nebraska	61	63	64	65	20	22	24	25	15	15	15	15												14	14	14	14				
Kansas	65	67	68	70	63	66	68	70	15	15	15	15												6	6	6	6				
Virginia	25	29	32	35	10	10	10	10					80	80	80	80	85	85	85	85											
West Virginia										10	10	10	10																		
North Carolina	65	67	69	70	10	10	10	10	10	10	10	10	100	100	100	100	85	85	85	85											
Kentucky	25	29	32	35	10	10	10	10	10	10	10	10	10	10	10	10									0.5	0.5	0.5	0.5			
Tennessee	25	29	32	35	10	10	10	10	10	10	10	10	10	10	10	10								2	2	2	2				
South Carolina	25	29	32	35	10	10	10	10	10	10	10	10	100	100	100	100	86	86	86	86											
Georgia	55	59	62	65					10	10	10	10	100	100	100	100	86	86	86	86											
Florida	25	29	32	35					10	10	10	10	100	100	100	100	86	86	86	86											
Alabama	25	29	32	35	10	10	10	10	10	10	10	10				86	86	86	86					2	2	2	2				
Mississippi	25	29	32	35	10	10	10	10	10	10	10	10									100	100	100	100							
Arkansas					10	10	10	10	10	10	10	10												2	2	2	2				
Louisiana	25	29	32	35	10	10	10	10	10	10	10	10									100	100	100	100							
Oklahoma					10	10	10	10									70	76	79	80						0.1	0.1	0.1	0.1		
Texas					10	10	10	10	10	10	10	10				80	80	80	80	100	100	100	100			0.1	0.1	0.1	0.1		
Montana																								1	1	1	1				
Idaho																								1	1	1	1				
Wyoming																															
Colorado	25	29	32	35	10	10	10	10																1	1	1	1				
New Mexico					10	10	10	10									80	80	80	80					0.1	0.1	0.1	0.1			
Arizona					10	10	10	10																	0.5	0.5	0.5	0.5			
Utah																								1	1	1	1				
Nevada																									0.5	0.5	0.5	0.5			
Washington																									0.5	0.5	0.5	0.5			
Oregon																									0.5	0.5	0.5	0.5			
California					10	10	10	10																100	100	100	100	2.6	2.6	2.6	2.6

Table A3.1

The general formulas for estimating changes from fuel oil to LP gas for drying tobacco are:

$$FO_t = \frac{PFO_t}{PFO_{74}} (FO_{74}) \quad (1)$$

and

$$LP_t = LP_{74} \left[1 + \frac{1.652(FO_{74} - F_t)}{LP_{74}} \right] \quad (2)$$

where

FO = fuel oil,
 PFO = percent fuel oil, and
 LP = LP gas or propane

The 1.652 is the conversion factor from fuel oil to propane. The same conversion factor was used to convert from fuel oil to diesel fuel.

Percentages of fuel oil and propane used in drying tobacco in 1974 and projected years are:

	Fuel oil (%)	Propane (%)
1974	35	65
1980	25	75
1985	15	85
1990	10	90

Table A4. Extent of reduced tillage in 1974 and in projected years

Items	No Tillage	Conventional	Reduced Tillage	Total
	-----Percent-----			
No Tillage and ^a Reduced Tillage				
1974	2	90	8	100
1980	7	77	16	100
1985	14	62	24	100
1990	32	38	30	100
Reduced Tillage Only ^b				
1974	--	92	8	100
1980	--	84	16	100
1985	--	76	24	100
1990	--	70	30	100

^a Corn, soybeans, grain sorghum, silage.

^b Rice, vegetables, hay, flaxseed, peanuts, cotton, sugar cane, sugar beets, sweet potatoes, dry beans, and dry peas.

Table A5. Projections of agricultural production levels and energy use by state

		CROP 1000 HECTARES	LIVESTOCK 1000 MT	DIRECT ENERGY USE 10**12 JOULES	INDIRECT ENERGY USE 10**12 JOULES
		-----	-----	-----	-----
MAINE					
	1974	187.4	455.7	2414.2	1403.9
	1985	152.7	491.3	2323.6	1244.7
	1990	152.4	516.4	2427.3	1327.6
	2000	157.3	565.2	2673.3	1450.4
NEW HAMPSHIRE					
	1974	45.9	164.0	463.3	347.0
	1985	33.6	170.3	428.1	330.2
	1990	33.4	175.5	430.9	355.4
	2000	34.4	185.0	453.2	395.4
VERMONT					
	1974	233.9	917.8	1904.2	1462.0
	1985	178.4	1018.9	1783.4	1357.2
	1990	177.1	1074.3	1823.6	1457.6
	2000	184.0	1176.1	1980.4	1632.5
MASSACHUSETTS					
	1974	74.5	298.0	1165.0	613.9
	1985	59.3	261.5	1088.7	601.1
	1990	58.3	253.0	1074.0	631.6
	2000	59.3	240.6	1094.8	681.1
RHODE ISLAND					
	1974	7.0	31.5	118.0	94.9
	1985	6.4	30.2	124.2	111.2
	1990	6.0	29.7	122.0	115.3
	2000	5.8	29.7	122.4	120.5
CONNECTICUT					
	1974	66.2	301.4	1152.2	550.6
	1985	55.8	294.9	1003.3	555.9
	1990	54.6	299.5	992.6	583.0
	2000	54.8	308.8	1016.2	621.5

Table A5. (cont'd) Projections of agricultural production levels and energy use by state

	CROP 1000 HECTARES	LIVESTOCK 1000 MT	DIRECT ENERGY USE 10**12 JOULES	INDIRECT ENERGY USE 10**12 JOULES
NEW YORK				
1974	1805.4	4672.4	18163.4	10736.8
1985	1514.9	4909.3	16877.3	11468.8
1990	1528.4	5088.0	16856.4	12393.5
2000	1603.6	5424.8	17797.7	13787.6
NEW JERSEY				
1974	252.0	280.0	3365.3	2051.6
1985	211.3	174.4	2808.9	2096.8
1990	219.2	143.7	2765.1	2277.5
2000	236.8	101.6	2806.3	2527.8
PENNSYLVANIA				
1974	1893.6	3619.1	19059.0	11138.7
1985	1714.1	3891.7	18494.7	13111.4
1990	1766.7	4087.8	19002.6	14562.9
2000	1899.2	4459.1	20829.4	16663.5
DELAWARE				
1974	236.5	342.4	3129.8	1391.3
1985	214.4	398.7	3065.9	1530.7
1990	217.8	433.4	3150.4	1661.7
2000	236.3	501.5	3482.2	1870.2
MARYLAND				
1974	655.0	1096.4	7005.2	3806.8
1985	643.9	1244.9	7218.1	4622.6
1990	701.0	1325.2	7609.5	5290.9
2000	783.6	1477.7	8503.9	6169.1
VIRGINIA				
1974	1286.3	1098.2	13458.2	9771.7
1985	1132.0	1381.4	15961.3	10632.4
1990	1187.7	1467.1	16526.4	11765.4
2000	1303.5	1639.4	18141.8	13430.7
WEST VIRGINIA				
1974	333.2	266.7	2410.4	2188.7
1985	281.3	255.3	2215.8	2442.7
1990	291.1	259.3	2254.4	2718.6
2000	321.7	271.0	2477.1	3216.5

Table A5. (cont'd) Projections of agricultural production levels and energy use by state

		CROP 1000 HECTARES	LIVESTOCK 1000 MT	DIRECT ENERGY USE 10**12 JOULES	INDIRECT ENERGY USE 10**12 JOULES
PENNSYLVANIA					
	1974	1893.6	3619.1	19059.0	11138.7
	1985	1714.1	3891.7	18494.7	13111.4
	1990	1756.7	4057.8	19002.6	14562.9
	2000	1899.2	4459.1	20829.4	16663.5
DELAWARE					
	1974	236.5	342.4	3129.8	1391.3
	1985	214.4	398.7	3065.9	1530.7
	1990	217.8	433.4	3150.4	1661.7
	2000	236.3	501.5	3482.2	1870.2
MARYLAND					
	1974	655.0	1095.4	7005.2	3905.8
	1985	643.9	1244.9	7218.1	4622.6
	1990	701.0	1325.2	7609.5	5290.9
	2000	783.6	1477.7	8503.9	6169.1
VIRGINIA					
	1974	1286.3	1098.2	13458.2	9771.7
	1985	1132.0	1391.4	15961.3	10632.4
	1990	1187.7	1407.1	16526.4	11765.4
	2000	1303.5	1639.4	18141.8	13430.7
WEST VIRGINIA					
	1974	333.2	256.7	2410.4	2188.7
	1985	281.3	255.3	2215.8	2442.7
	1990	291.1	259.3	2254.4	2716.6
	2000	321.7	271.0	2477.1	3216.5

Table A5. (cont'd) Projections of agricultural production levels and energy use by state

	CROP 1000 HECTARES	LIVESTOCK 1000 MT	DIRECT ENERGY USE 10**12 JOULES	INDIRECT ENERGY USE 10**12 JOULES
	-----	-----	-----	-----
NORTH CAROLINA				
1974	2072.5	1770.9	40552.7	18370.4
1985	1928.3	2210.0	40992.5	19798.7
1990	2087.9	2424.3	42569.0	22015.8
2000	2310.6	2855.6	46545.2	24805.9
KENTUCKY				
1974	1960.4	1716.0	15766.8	12530.0
1985	2155.1	1825.3	17413.2	14400.6
1990	2412.9	1921.0	18531.8	15900.4
2000	2932.1	2113.6	21611.9	18404.3
TENNESSEE				
1974	1952.3	1406.5	14306.3	11859.1
1985	1985.2	1529.2	15018.1	12225.8
1990	2144.3	1593.5	15510.3	13290.1
2000	2426.9	1729.4	17122.3	14819.7
SOUTH CAROLINA				
1974	1261.1	477.1	12868.6	8547.0
1985	1155.5	592.3	12431.5	8234.1
1990	1299.3	635.4	13040.8	9272.9
2000	1469.9	741.8	14334.7	10647.9
GEORGIA				
1974	2256.5	1789.1	27063.0	17211.2
1985	2211.0	2065.0	27365.8	18139.9
1990	2441.2	2188.8	28917.2	20077.5
2000	2872.5	2423.0	32310.4	23156.5
FLORIDA				
1974	986.1	1346.7	44978.8	15678.5
1985	1132.1	1647.7	49468.8	22139.7
1990	1222.1	1946.2	52456.8	25039.7
2000	1397.2	2224.1	58273.8	29547.5
ALABAMA				
1974	1427.3	1404.6	14141.6	10808.5
1985	1605.6	1792.4	16942.8	12729.4
1990	1832.2	1959.8	18327.8	14334.1
2000	2319.4	2292.0	21710.2	17276.4
MISSISSIPPI				
1974	2324.6	1207.0	20935.2	18134.7
1985	2622.8	1390.4	22785.1	18991.9
1990	2864.6	1492.7	23759.6	20652.3
2000	3244.6	1674.8	26170.8	22829.4

Table A5. (cont'd) Projections of agricultural production levels and energy use by state

		CROP 1000 HECTARES	LIVESTOCK 1000 MT	DIRECT ENERGY USE 10**12 JOULES	INDIRECT ENERGY USE 10**12 JOULES
		-----	-----	-----	-----
MICHIGAN	1974	2695.2	2426.8	23218.8	15943.3
	1985	2266.3	2446.7	21798.5	17893.4
	1990	2318.2	2517.8	21883.9	19720.9
	2000	2428.6	2660.7	22966.4	21889.6
WISCONSIN	1974	3993.1	9116.7	39266.9	17546.6
	1985	3170.9	9808.1	35301.0	20888.5
	1990	3218.5	10239.0	35624.7	22734.6
	2000	3372.6	11049.2	38359.8	25058.4
MINNESOTA	1974	8418.3	5741.3	61109.1	40556.0
	1985	8121.5	5938.2	53884.4	49250.6
	1990	8716.0	6164.5	60554.7	58404.9
	2000	9737.0	6620.6	66456.8	71324.5
OHIO	1974	4429.6	2560.7	30297.2	26004.0
	1985	4428.7	2662.8	31129.3	31575.8
	1990	4790.7	2712.3	32039.1	36629.5
	2000	5404.2	2832.9	34936.9	43385.1
INDIANA	1974	5036.5	2114.7	37947.9	36308.3
	1985	4775.0	2173.7	39612.0	42444.7
	1990	5092.6	2237.0	40802.5	49568.3
	2000	5568.9	2380.5	43876.3	58317.7
ILLINOIS	1974	9271.5	2875.1	71299.9	58655.3
	1985	8967.5	2948.5	74437.3	72610.1
	1990	9232.8	3019.1	75228.1	80127.6
	2000	9944.4	3195.7	80060.9	89168.9

Table A5. (cont'd) Projections of agricultural production levels and energy use by state

		CRUP 1000 HECTARES	LIVESTOCK 1000 MT	DIRECT ENERGY USE 10**12 JOULES	INDIRECT ENERGY USE 10**12 JOULES
		-----	-----	-----	-----
ARKANSAS					
	1974	3178.9	1666.0	33279.9	17434.8
	1985	3425.1	2113.7	39575.4	23078.7
	1990	3898.7	2376.5	43513.6	28142.9
	2000	4119.2	2906.2	49411.4	31382.1
LOUISIANA					
	1974	1653.8	817.2	20368.7	11736.7
	1985	2071.7	937.8	23707.2	14736.3
	1990	2338.9	1000.0	25343.5	16564.0
	2000	2788.4	1121.8	28520.0	19080.4
OKLAHOMA					
	1974	4472.1	1664.7	33020.7	20867.1
	1985	4039.9	1821.3	31214.2	25196.3
	1990	4310.0	1986.2	32459.2	29396.4
	2000	4770.9	2331.6	37094.3	35502.2
TEXAS					
	1974	9589.1	4639.6	149283.8	62854.4
	1985	9813.8	5296.4	163941.6	89230.9
	1990	10442.4	5851.4	173511.3	100132.8
	2000	11287.8	6966.1	193842.2	112432.9
NEW MEXICO					
	1974	482.5	442.4	26336.1	2604.3
	1985	435.4	516.7	23905.2	3132.1
	1990	451.5	561.4	25443.8	3416.9
	2000	505.4	649.2	30284.0	4055.1

Table A5. (cont'd) Projections of agricultural production levels and energy use by state

		CROP 1000 HECTARES	LIVESTOCK 1000 MT	DIRECT ENERGY USE 10**12 JOULES	INDIRECT ENERGY USE 10**12 JOULES
		-----	-----	-----	-----
IOWA	1974	9794.7	5230.4	86956.9	55370.6
	1985	9702.8	5329.3	89999.2	67354.4
	1990	10344.6	5406.6	92603.4	71576.5
	2000	11390.1	5636.2	100028.9	76342.4
MISSOURI	1974	5499.0	3042.5	36374.8	30614.5
	1985	4991.8	3203.1	35723.1	32474.6
	1990	5370.7	3372.2	37157.9	36364.1
	2000	6011.2	3725.3	41033.4	41642.7
NEBRASKA	1974	7248.1	2609.0	87327.6	47353.1
	1985	6512.3	2688.0	92198.4	48406.3
	1990	6678.0	2841.2	94727.7	52167.1
	2000	7222.1	3173.4	105190.7	59518.2
KANSAS	1974	8784.5	2233.1	69132.4	33930.8
	1985	8961.6	2393.6	87317.0	50405.3
	1990	9443.0	2537.2	96390.7	56906.5
	2000	10301.5	2846.1	118573.1	66666.9

Table A5. (cont'd) Projections of agricultural production levels and energy use by state

	CROP 1000 HECTARES	LIVESTOCK 1000 MT	DIRECT ENERGY USE 10**12 JOULES	INDIRECT ENERGY USE 10**12 JOULES
	-----	-----	-----	-----
NORTH DAKOTA				
1974	8067.4	1022.9	32159.4	13413.9
1985	7144.6	896.6	27746.0	16289.6
1990	7357.6	925.2	27397.5	18837.6
2000	7577.9	993.6	28046.8	21846.7
SOUTH DAKOTA				
1974	6530.0	2004.0	31251.4	8625.1
1985	5293.2	2031.0	26205.3	8148.9
1990	5528.0	2146.3	26785.7	9196.5
2000	5988.6	2389.2	28680.2	10544.1
MONTANA				
1974	3815.8	647.9	13918.7	11158.7
1985	3459.7	690.2	12058.6	13666.4
1990	3645.0	723.4	11983.6	15853.2
2000	3987.9	799.6	12819.1	19044.4
WYOMING				
1974	728.1	319.2	5532.5	2386.0
1985	678.1	322.1	5122.2	2735.1
1990	726.9	335.4	5286.6	3111.2
2000	845.0	366.8	5864.9	3807.1
COLORADO				
1974	2489.8	1266.6	21996.7	6942.7
1985	2364.2	1515.0	21557.3	10465.5
1990	2519.1	1651.1	22113.6	11954.3
2000	2850.2	1930.2	24988.4	14774.9
UTAH				
1974	493.9	588.5	5796.3	1496.8
1985	466.5	678.3	5564.9	1861.9
1990	499.0	731.1	5686.8	2115.5
2000	569.8	832.2	6232.7	2488.5

Table A5. (cont'd) Projections of agricultural production levels and energy use by state

		CROP 1000 HECTARES	LIVESTOCK 1000 MT	DIRECT ENERGY USE 10**12 JOULES	INDIRECT ENERGY USE 10**12 JOULES
		-----	-----	-----	-----
ARIZONA					
	1974	566.7	707.0	30335.4	7338.2
	1985	612.7	856.7	31724.5	9054.6
	1990	679.1	960.9	34488.9	10860.4
	2000	829.6	1160.0	42302.3	14523.9
NEVADA					
	1974	211.4	170.0	4100.4	445.1
	1985	184.7	184.5	3827.5	465.3
	1990	190.7	197.6	4022.2	545.9
	2000	210.2	224.8	4548.3	699.8
CALIFORNIA					
	1974	3692.2	6078.1	80090.8	35524.6
	1985	3784.3	7360.2	82613.6	43064.3
	1990	3998.7	8035.6	85578.2	48759.5
	2000	4311.3	9276.4	91606.6	55920.2
HAWAII					
	1974	90.7	94.2	4707.6	2155.0
	1985	59.0	67.5	2358.1	1494.4
	1990	58.9	70.5	2340.6	1550.7
	2000	59.9	76.3	2356.3	1628.2

Table A5. (cont'd) Projections of agricultural production levels and energy use by state

		CROP 1000 HECTARES	LIVESTOCK 1000 MT	DIRECT ENERGY USE 10**12 JOULES	INDIRECT ENERGY USE 10**12 JOULES
		-----	-----	-----	-----
IDAHO	1974	1831.9	1038.7	19498.7	10406.6
	1985	1744.6	1075.6	18204.1	13353.1
	1990	1800.7	1128.1	18744.0	14914.3
	2000	1766.0	1232.8	19190.8	17207.0
WASHINGTON	1974	2198.2	1307.3	26780.1	12800.0
	1985	1872.1	1492.3	20247.7	13381.3
	1990	1897.1	1609.1	20674.4	14902.1
	2000	1951.5	1823.4	22107.7	17005.7
OREGON	1974	1362.5	727.3	15632.9	6470.1
	1985	1258.6	741.5	14277.2	7795.9
	1990	1312.7	764.4	14673.7	8856.6
	2000	1417.5	810.8	15970.3	10239.8
ALASKA	1974	6.8	8.9	54.9	27.4
	1985	17.1	7.6	45.4	65.7
	1990	19.5	7.9	49.0	80.7
	2000	22.9	7.8	56.2	101.7

INTERNAL DISTRIBUTION

- | | | | |
|-----|-----------------|--------|---|
| 1. | D. J. Bjornstad | 18. | W. R. Mixon |
| 2. | R. W. Barnes | 19-23. | H. D. Nguyen |
| 3. | R. S. Carlsmith | 24. | S. C. Parikh |
| 4. | P. J. Carroll | 25. | A. M. Perry |
| 5. | W. S. Chern | 26. | G. Samuel |
| 6. | S. M. Cohn | 27. | R. B. Shelton |
| 7. | K. R. Corum | 28. | D. N. Stuckwish |
| 8. | R. M. Davis | 29-33. | B. Thomas |
| 9. | W. Fulkerson | 34. | D. P. Vogt |
| 10. | C. A. Gallagher | 35. | T. J. Wilbanks |
| 11. | E. Hirst | 36-38 | Central Research Library |
| 12. | R. B. Honea | 39. | Document Reference Section |
| 13. | C. R. Kerley | 40. | Laboratory Records (RC) |
| 14. | G. Lawson | 41-42. | Laboratory Records |
| 15. | H. M. Long | 43. | ORNL Patent Section |
| 16. | R. J. Maddigan | 44-89. | Economic Analysis Section |
| 17. | J. B. Mills | 90. | Energy and Environmental
Response Center |

EXTERNAL DISTRIBUTION

91. Institute of Energy Analysis, ORAU Library, Oak Ridge, TN 37830
- 92-118. Technical Information Center, Department of Energy, Oak Ridge, TN 37830
119. Office of Assistant Manager for Energy Research and Development, Department of Energy, Oak Ridge Operations, Oak Ridge, Tn 37830
- 120-124. Dr. Austin Fox, U.S. Department of Agriculture, Food and Agriculture Policy Research Branch, 500 12th St., S.W., GHI Building, Room 253 Washington, D.C. 20250
125. Dr. Terry Morlan, Department of Energy, Demand Analysis Division, 12th and Pennsylvania Avenue, N.W., Room 4518, Washington, D.C. 20461
126. Dr. Leroy Quance, U.S. Department of Agriculture, Agriculture and Trade Policy Branch, 500 12th Street, S.W., GHI Building, Room 248, Washington, D.C., 20250
127. Korea Energy Research Institute Library, P.O. Box 339, Dae Jeon, Chung Nam, Korea, Attention: Sun-Young Yoon.