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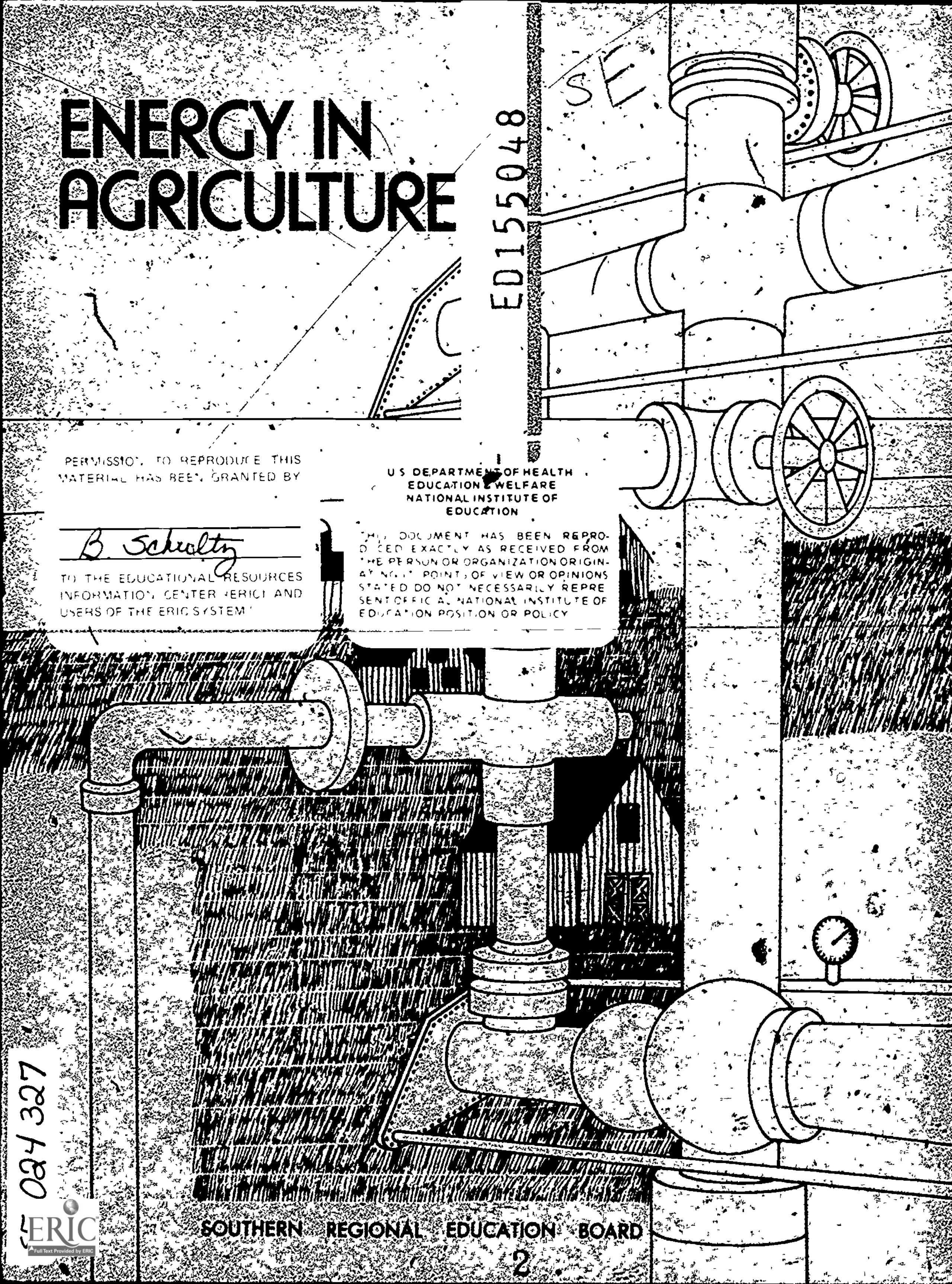
ABSTRACT

This publication is the proceedings of a conference-workshop held in Atlanta, Georgia in October 1975. At this conference 13 papers were presented on various aspects of energy use in agriculture. Also included are the final reports of the extension, the teaching, and the research workshop groups. Title of papers include Energy in Agriculture and Food, Energy Use in Crop Systems, Energy Utilization in Pest Management, Using Solar Energy in Agriculture, and Energy and the U.S. Food System. Papers discuss such topics as agricultural policy, energy efficiency in agriculture, energy conservation techniques, energy requirements for fertilizer production and distribution, alternative energy sources for agriculture, and energy conservation in food processing industries. Workshop group reports identify areas of extension work, education, and research that are in need of increased emphasis or that would yield better energy conservation results. (MR)

ENERGY IN AGRICULTURE



SOUTHERN REGIONAL EDUCATION BOARD

ENERGY IN AGRICULTURE

PROCEEDINGS OF CONFERENCE-WORKSHOP

ATLANTA, GEORGIA

OCTOBER 1-3, 1975

Sponsored by

Council of Higher Education in the Agricultural Sciences

of the

Southern Regional Education Board

in cooperation with

Deans and Directors of Colleges of Agriculture

SOUTHERN REGIONAL EDUCATION BOARD 130 Sixth Street, N.W. Atlanta, Georgia 30313

TABLE OF CONTENTS

FOREWORD

Agriculture is by far the largest industry in the Southern region. Production of agricultural products from the vast land resources and uniquely favorable climate of the region is essential in meeting the food and fiber needs of the states and the nation with some left over for export to help feed and clothe the under priviledged of the world The region's geographic location, close on the north and west to the major population centers of the nation and with the east and south having excellent deep water ports, facilitates rapid movement of its agriculture and forest products to the consumer at home or abroad

The availability of energy in the form of cheap fossil fuel enabled the region's farmers to mechanize their operations and increase their output above that of most farmers of other nations. Such a sustained rate of production can be maintained only through continuing availability of an effective energy supply. Though agriculture uses only a small percentage of the nation's total energy consumption it still amounts to millions of barrels of crude oil, therefore, it is a challenge to agriculturists to conserve energy wherever efficiencies can be made in producing, processing and marketing food and fiber

Realizing that the energy situation has already affected every person in the nation and recognizing the need for assessing the energy situation in agriculture the Council for Higher Education in the Agricultural Sciences recommended that a regional conference be conducted to acquaint agriculturists with the situation and begin formulation of plans to increase energy efficiency in agriculture A regional planning committee of 10 members representing extension, research and teaching assisted the project director in planning the conference The conference involving 122 participants from college of agriculture administrations, faculty members from extension, research and teaching, USDA, state agency and industry representatives was held in Atlanta, Georgia, October 1-3, 1975 This conference partially supported by the W K. Kellogg Foundation provided an excellent overview of energy usage in agriculture, with many challenging ideas for conserving our dwindling resources In addition these proceedings will serve as an excellent source of reference material on energy usage in agriculture for personnel involved with energy efficiency whether it be in extension, research or teaching activities. The Council of Higher Education in the Agricultural Sciences commends these Proceedings for use by agriculturists and others concerned with improving the efficiency of energy usage in agricultural production in the South..

T J. Horne, Project Director
Agricultural Sciences

THE UNITED STATES ENERGY SITUATION: ITS IMPLICATIONS FOR PERSONAL AND INSTITUTIONAL PLANNING

S. A. Trumbower, Consultant
Advanced Systems Technology Division
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East Pittsburgh, Pa. 15112

For several reasons, I was glad to accept your invitation to be the opening speaker at this conference on energy in agriculture. In the first place, your conference is timely because the energy crisis has already affected every individual and institution in the nation, and will have far more profound effects in the future.

But your conference is timely from another point of view. On June 30, a Westinghouse task force, which I directed, completed a very comprehensive long-term energy analysis under contract to the Federal Energy Administration. I think you will find the results of this study – which I will overview for you this morning – quite helpful in putting the energy situation into perspective.

Federal Energy Administration Study Framework

Time Period: 1972 to 2000

Population: Series F:	1972	208×10^6
	2000	251×10^6

Energy Import Objectives – Percent of Domestic Use

Oil	10%
Gas	0%
Coal	0%
Uranium	0%

GNP Growth Rate:	3.2% in Constant $
GNP per Capita Growth Rate:	2.5% in Constant $

I'll begin my presentation by outlining the study framework. The period of concern is from 1972 through 2000. 1972 is significant as a starting point because it represents the last year free of energy supply constraints. You will recall that the oil boycott started in October of 1973.

The time horizon extends to the year 2000, a period long enough to identify short-term, mid-term and long-term energy problems and policy implications.

The current population trend – technically called Series F – will cause our population to rise from 208 million in 1972 to 251 million by 2000.

National energy policy was assumed directed toward reducing oil imports to 10% of domestic consumption – a level that could, with some disruption accommodate a future oil boycott. Self-sufficiency was taken as the national policy objective for natural gas, coal and uranium.

The constant dollar GNP annual growth rate used was a moderate 3.2%. This translates to 2.5% annual growth of per capita GNP, enough for our citizens as a whole to make a little economic progress and enough for our society to continue to make progress against poverty.

Structure of Energy Use
1972 Data – 10^{15} BTU

	Gas	Oil	Coal	Nuclear	Renewable	Total	(Memo) Electricity
End Uses							
Residential	6.5	3.3	0 2		0.2	10.2	2.1
Commercial	1.1	3.4	0.2			4 7	1 0
Manufacturing	7.3	3 5	4 0		0.9	15.7	2.1
Transportation	0 8	17.3				18 1	0 2
Energy Processing							
Fuel Processing	3 3	2 4	0 2			5 9	0 1
Electricity Processing	4 1	3.1	7 8	0 6	1 0	16 6	0.6
Total	23 1	33.0	12.4	0.6	2 1	71 2	(T&D Loss) 6.0 (Output)

Renewable Includes Hydro(@ 3.413 BTU/KWH), Solar, Geothermal, Wind, Tidal, Wood, etc.

Now consider the structure of energy use Note that the really useful applications of energy, called *End Uses* in this chart, are to supply the Residential, Commercial, Manufacturing and Transportation Sectors of the economy. *Energy Processing*, on the other hand, represents the energy expended to prepare energy for delivery to the end use sectors The energy processing category therefore includes energy required to extract and refine gas, oil, coal and uranium, synthetic fuel conversion losses, and losses incurred in generating electricity.

Residential Sector
1972 Data – 10^{15} BTU

	Gas	Oil	Coal	Nuclear	Renewable	Total	(Memo) Electricity
Central Air Conditioning							.159
Room Air Conditioning							.138
Lighting							.275
Refrigerators							.311
Freezers							118
Television							.153
Dish Washers							.027
Clothes Washers							.023
Clothes Dryers	.076					076	.082
Cooking	.346	.061				407	.112
Other Appliances							.146
Water Heating	1,154	.300				1 455	.278
Space Heating: Elec. Resistance							257
Heat Pumps					.013	.013	.022
Non-Electric	4.630	2,740	0.240		150	7.760	
Miscellaneous	.310	.155				.465	052
Total	6.526	3.256	0.240		0.163	10.176	2.153

By recognizing the structure of energy use, it is possible to avoid the pitfalls inherent in making future energy use estimates by simply projecting historical growth rate data

We avoided this pitfall by analyzing each significant use of energy, exactly which forms of energy supply each use, and took into account factors such as saturation effects and efficiency trends.

For each use category, energy requirements were determined at 5-year intervals through the year 2000. The use categories analyzed are evident from these tabulations which show 1972 data for the residential sector, the commercial sector, the manufacturing sector, the transportation sector, and the energy processing sector

Commercial Sector
1972 Data – 10^{15} BTU

	Gas	Oil	Coal	Nuclear	Renewable	Total	(Memo) Electricity
Space Heating	.814	1.025	.014			1.853	.038
Water Heating	048	.070	.002			.120	.004
Air Conditioning							.225
Commercial Lighting							.518
Street Lighting							.042
Irrigation	.036	.048				.084	.036
Crop Drying	.015	.084				.099	
Agriculture Vehicles		.580				.580	
~~Road Tar and Asphalt~~		1.137				1 137	
Miscellaneous	.213	468	.131			.812	.131
Total	1.13	3.41	0.15			4.69	.994

Manufacturing Sector
1972 Data – 10^{15} BTU

	Gas	Oil	Coal	Nuclear	Renewable	Total	(Memo) Electricity
Chemicals	1.833	.204	.550			2.587	308
Paper	.557	.371	.233		.854	2.015	.118
Durable Goods	.689	.148	.169			1.006	.360
Food	.590	.163	.140			.893	.123
Steel	637	.197	2.203			3.037	.134
Aluminum	.345	.012	.083			.441	192
Cement	.227	.070	.167			.463	.031
Glass	.237	.008	.003			.248	.02[illegible]
Feedstock and Raw Material	1.470	1.025	.105			3.501	
Miscellaneous	.742	.387	.369		.012	1.510	.825
Total	7.33	3.48	4.02		0.87	15.70	2.11

8

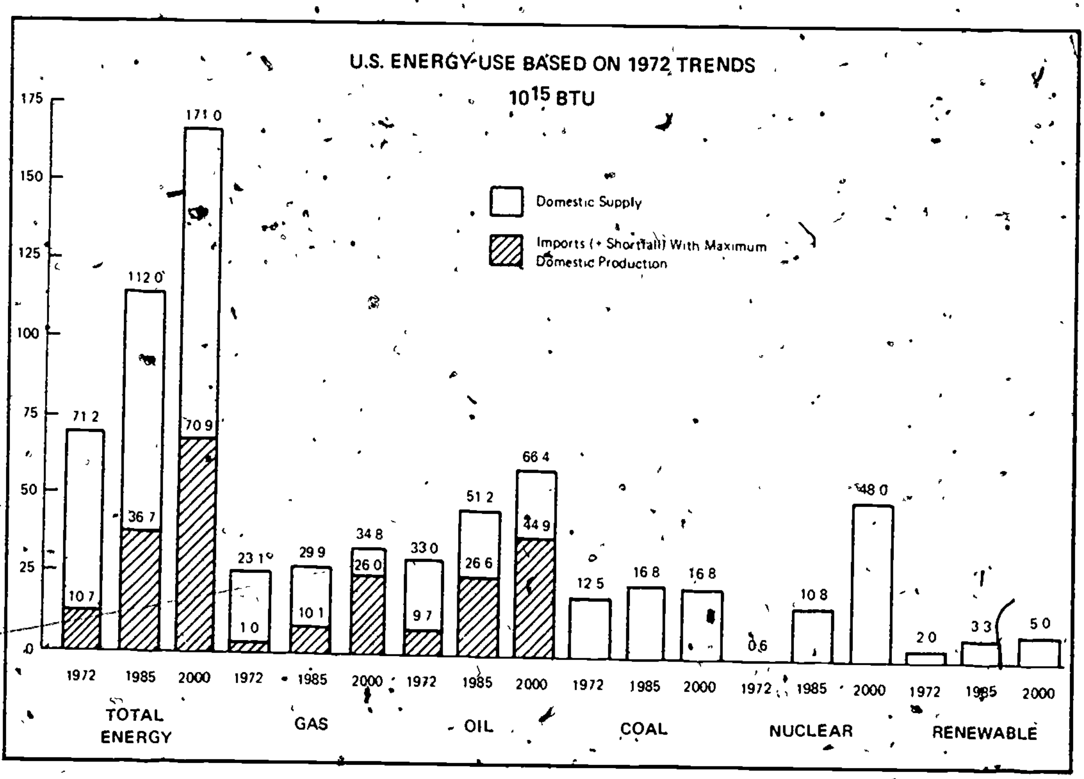
Transportation Sector — 1972 Data — 10^{15} BTU

		Gas	Oil	Coal	Nuclear	Renewable	Total	(Memo) Electricity
Auto	Urban		5.252				5.252	
	Rural		3.680				3.680	
Bus:	Urban		.058				.058	
	Intercity		.028				.028	
	School		.039				.039	
Truck	2 Axle, 4 Tire		1.299				1 299	
	Other Single Unit		1.002				1.002	
	Combinations		1 227				1.227	
Rail:	Freight		527				.527	.009
	Passenger Intercity		033				.033	.001
	Passenger Urban							007
Air:	Passenger Domestic		.968				.968	
	Passenger International		.256				.256	
	Cargo Domestic		.168				.168	
	Cargo International		.099				.099	
	General		.100				.100	
	Military		.609				.609	
Water.	Domestic		.429				429	
	Overseas		.820				.820	
Pipeline:	Gas	.791					791	
	Oil		132				.132	
Miscellaneous			.539				.539	
	Total	.791	17.255				18 055	.017

Energy Processing Sector — 1972 Data — 10^{15} BTU

	Gas	Oil	Coal	Nuclear	Renewable	Total	(Memo) Electricity
Fuel Processing							
Synthetic Fuels							
Coal Gasification							
Coal Liquification							
Extraction and Refining							
Gas	1.453	.080				1.533	
Oil	1.463	2.078	.004			3 545	093
Coal	.003	022	025			.050	.024
Uranium							.024
Handling Losses							
Gas	347					.347	
Oil		.234				.234	
Coal			.225			.225	
Subtotal	3.27	2.41	.25			5.93	.141
Electricity Processing							
Electricity Sold							5.416
T & D Losses							.572
Electrical Output							5.988
Fuel Input	4.10	3.13	7.83	.58	.96	16.60	
Total	7.37	5.54	8.08	.58	.96	22.53	

Now let's move to the bottom line



Adding all sectors together reveals the energy plight that the trend existing in 1972 was getting us into.

Our total energy would rise from 71 to 171 quads, a growth rate of 3.2% annually Relating the information given in Btu's to percentages, we find that of our total needs, imports would rise from 15% in 1972, to 33% in 1985, and reach 41% by 2000 even with a successful program of maximizing U.S. oil and gas production along with a moderate program of producing synthetic oil and gas from coal.

A glance at the gas situation reveals our most severe short term problem. Gas imports would have to rise from 4% of 1972 consumption, to 34% by 1985 and hit 75% by 2000. Gas in these quantities is simply not available for import. Even the 1 quad we are now importing is in jeopardy as our major supplier, Canada, has served notice it wishes to discontinue supplying us

Turning to oil, imports would rise from 29% of consumption in 1972, to 52% in 1985 and reach 68% by 2000. This is obviously intolerable; it threatens our national security, places an intolerable burden on our balance of payments, and adds to our already serious inflation problem.

Is conservation the answer? Let's see! Suppose we adopt a very aggressive national energy conservation program.

Residential Sector Conservation Actions

(Higher Energy Prices – All Sectors – Price Elasticity)

Improve Home Insulation

Improve Efficiency of Utilization Devices
- Gas and Oil Furnaces
- Heat Pumps
- Water Heaters
- Appliances
- Lighting (More Fluorescent)
- Air Conditioners
- Electric Ignitors for Gas Pilots

"Use Less" Ethic
- Turn Off Lights
- Lower Thermostat in Winter
- Higher Thermostat in Summer

In the *Residential Sector* we can improve home insulation, improve efficiency of utilization devices, and infuse a "use less ethic" into our society.

Commercial Sector Conservation Actions

Improve Building Insulation

Improve Efficiency of Utilization Devices

- Gas and Oil Furnaces
- Heat Pumps
- Water Heaters
- Appliances
- Lighting (More Fluorescent)
- Air Conditioners
- Crop Dryers
- Reduce Tillage in Agriculture
- Dieselize More Off Highway Agricultural Vehicles

"Use Less" Ethic

- Turn Off Lights
- Delamp
- Lower Thermostat in Winter
- Higher Thermostat in Summer

In the *Commercial Sector* we can improve building insulation, improve efficiency of utilization devices, and infuse the "use less ethic"

Manufacturing and Fuel Processing Sectors Conservation Actions

- Reduce Heat Losses
- Reduce Energy Needs of the Basic Process
- Apply Heat Recovery Techniques
- Shift to Less Energy Intensive Materials
- Recycle More
- Co Generate Electricity and Process Steam
- Infuse the Conservation Ethic

Similar conservation principles can be applied to the *Manufacturing and Fuel Processing Sectors*, and a few new ones as well Here we can reduce heat losses, reduce energy needs of the basic processes, apply heat recovery techniques, shift to less energy intensive materials, recycle more, co-generate electricity and process steam in very large industries, and infuse the conservation ethic.

Transportation Sector Conservation Actions

Shift Traffic to More Efficient Modes

Passengers – By 2000

12% Urban Auto PM to Bus

12% Urban Auto PM to Rapid Transit

15% Domestic Air PM to Rail

Freight – By 2000

25% Domestic TM to Rail

50% of Combi TM to Rail

Reduce Energy Intensiveness of Transportation Equipment By 2000

Auto	25 mpg
Bus	12% Less
Air	25% Less
Water	10% Less
Truck	10 25% Less

Improve Load Factors

In the *Transportation Sector* we can shift some passenger and freight traffic to more efficient modes Basically this means shifting passengers from auto and air to buses, rapid transit and rail It means shifting freight from truck and air to rail

We can also reduce energy intensiveness of transportation equipment, and improve load factors

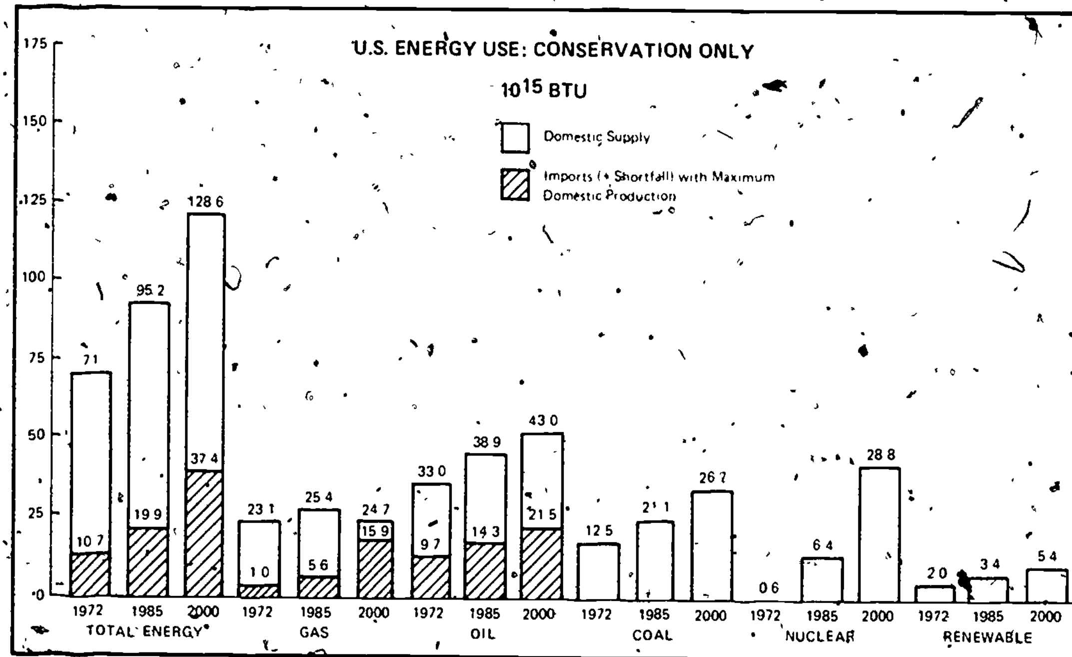
Electric Utility

Oil By 2000 Used for Peaking Only (1 5 quad) None for Base Load

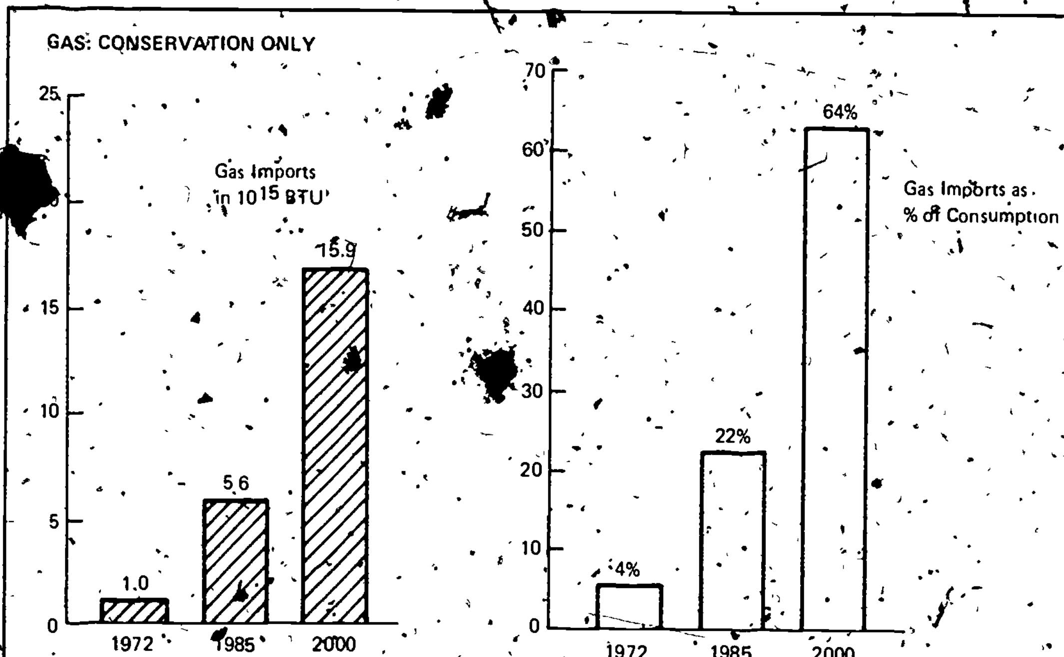
Gas. By 2000 All Gas is from Coal Gasification (3 0 quad) and Burned In Combined Cycle Plants

Turning to the *Electric Utility Sector*, by 2000 only a small amount of oil will be burned and that for peaking duty only All gas burned will then come from coal via gasification plants

Looking again to the bottom line, let's see if conservation alone solves our national energy problem

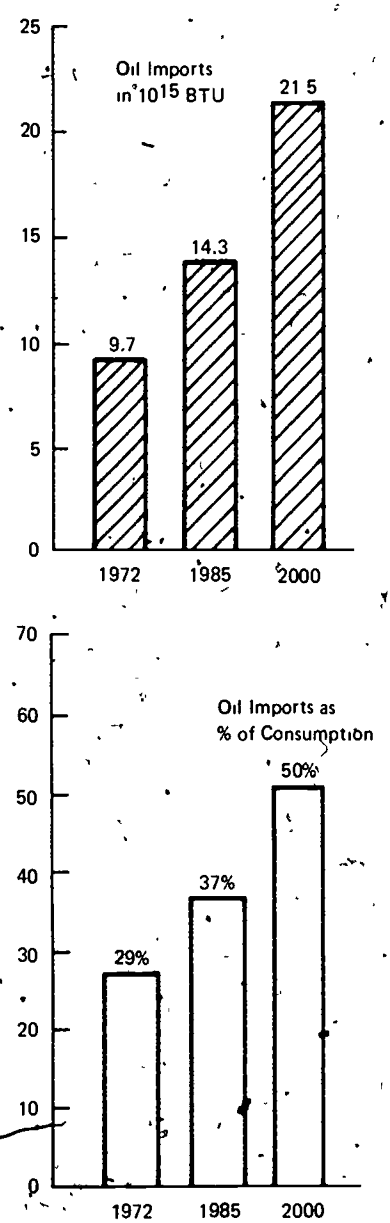


Our total energy use rises to only 128 quads in 2000 compared to 171 without conservation. Again, relating Btu's to percentages, we see that our dependence on imports rises from 15% in 1972, to 21% in 1985 and reaches 29% by 2000. Not only has our percentage dependence on imports doubled between 1972 and 2000, but in absolute terms *the amount of energy being imported in 2000 is 3-1/2 times what it was in 1972.*



The gas problem is still with us. Gas imports would represent 22% of consumption in 1985 and 64% of consumption in 2000 compared with 4% of 1972 consumption. In absolute terms, gas imports by 2000 would need to be 16 times what they were in 1972, while the real world situation is that it is doubtful we will be able to maintain imports even at 1972 levels.

OIL: CONSERVATION ONLY



The oil situation is still impossible. Imported oil's share of consumption appears to rise from 29% in 1972, to 37% in 1985, and reach 50% by 2000. But in practice we would be depending on imports for *more than* half of our needs because even more oil would be used to replace the natural gas shortfall. Even today this trend is becoming widespread in industry.

Quite obviously then, conservation alone is no solution to our energy problems.

Major World Energy Resources	
Fossil 10^{18} BTU	
Gas	10
Oil	33
Coal	170
Nuclear 10^{18} BTU	
Uranium-Fission Reactor	70
Uranium-Breeder Reactor	420,000
Fusion Reactors	10,000,000,000
Renewable 10^{15} BTU Per Year	
Wind	3
Geothermal	9
Tidal	48
Solar	540,000

To begin to come to grips with our energy problems we need to first review the world's energy resources. The resource base here is defined in terms of ultimately recoverable resources, including both *known* reserves and estimates of all future finds.

In the *fossil* category there is about four times as much coal energy as in oil and gas combined.

In the *nuclear* category, if we had to rely exclusively on the present generation of nuclear reactors – fission reactors – there would only be enough uranium available to fuel reactors for about 50 years.

Breeder reactors, now being developed, will extend uranium supplies for hundreds of years.

After the turn of the century fusion reactors are expected to become available and make available an essentially limitless supply of energy.

Renewable sources of energy – such as wind, geothermal, tidal and solar – have been highly publicized lately as the final solution to the world energy problem. Except for solar, however, these forms will make only a minor contribution to our energy supplies by 2000. The basic problem is that they are enormously expensive to harness, often remote from sites where the energy is needed, and intermittent in nature.

Even solar, which has potential for home space heating and hot water heating, seems out of the question for electrical generation. A typical analysis would show solar electricity costing 30 cents per KWH, about 10 times the cost of alternatives.

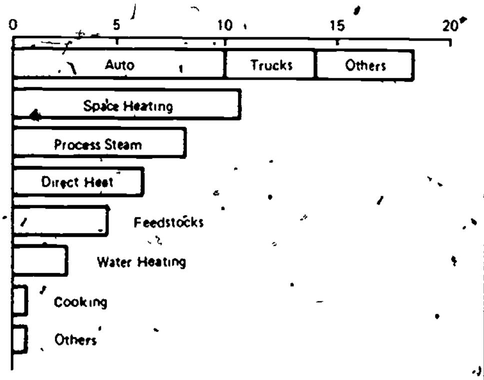
Energy Substitution Economy

- Vigorous Conservation of All Forms of Energy
- Substitute Coal, Nuclear and Solar for Increasingly Scarce Oil and Gas
- Preserve Gas and Oil for Feedstocks, Lubricants, Jet Fuel, Etc

The plain truth is that between now and 2000 we will be forced to overcome the ever increasing shortage of gas and oil by combining vigorous conservation measures *and* increased use of coal, nuclear power and – to a limited extent – solar Simply stated, an Energy Substitution Economy must evolve

Only by bringing this about can we avoid economic disruption while preserving oil and gas for applications they alone can supply such as chemical feedstocks, jet fuel and lubricants.

OIL & GAS USAGE IN THE U.S.
1972
10^{15} BTU



If we are going to find new energy sources to supplant gas and oil, most of the effort will be concentrated in just four uses transportation, space heating, process steam and direct heat These four uses account for 80% of gas and oil consumption.

We believe that by 2000 solar energy will supply space heating and hot water to about 10% of homes.

Coal will be increasingly used for supplying direct heat and process steam in industry In the very largest industries – paper, chemicals and petroleum refining – cogeneration of electricity and process steam will increase significantly.

But in the vast majority of applications, using our coal and nuclear resources will mean substituting electricity for direct combustion of oil and gas in as many applications as are technically and economically feasible.

Let's start with transportation which accounts for 50% of our oil consumption

BATTERY PERFORMANCE CHARACTERISTICS

	Lead Acid	Battery-A
ENERGY DENSITY Watthours/Lb	12	20 25
CHARGING TIME	8 hrs	3 hrs
LIFE	1 yr	5 yrs

World-wide, 20 million dollars a year is being spent on electric battery research, from that will shortly come new batteries with double the performance of the present lead acid battery. They'll recharge in less than half the time and last five times as long

By 1985 we forsee batteries with four-times the performance of lead acid and before the end of the century that figure will be ten.

The Electric vehicles that new battery technology will make possible will find initial application in light vans for urban service in fleet type operations By this I mean mail and parcel delivery, telephone installation, meter reading and taxis

Transportation Sector Electrification

By 2000·

- 70% of Urban Auto Vehicle Miles
- 50% of Urban Bus Vehicle Miles
- 100% of School Bus Vehicle Miles
- 70% of Single Unit Truck Vehicle Miles
- 70% of Rail Traffic
- 100% of Pipelines

With this as a start, by 2000 it would be possible for electric vehicles to provide: 70% of urban auto vehicle miles, 50% of urban bus vehicle miles, 100% of school bus vehicle miles, and 70% of single unit truck vehicle miles.

Also by 2000, 70% of rail traffic can be electrified along with all pipelines.

Next on our list of large oil and gas users is space heating In both the residential and commercial sectors electric resistance space heating is already well known and growing in use. Lesser known is the most efficient form of electrical space heating – the electric heat pump.

This technology had its problems when it was first introduced stemming from poor reliability, misapplication and bad service. But now the major manufacturers have redesigned their heat pumps and are providing products with very acceptable reliability.

Today's heat pump is twice as efficient as electrical resistance heating and four times as efficient as gas and oil at the point of use.

We foresee 65 million homes heated electrically by the year 2000 – 20 million with the heat pump. These homes will use electricity for water heating, cooking and clothes drying, further reducing consumption of gas and oil.

Turning next to process steam, such as is used in making Heinz soup, this use accounts for one sixth of all the energy used in 1972 It has a wide variety of applications with gas and oil fired boilers providing 80% of it and coal fired boilers the rest. Greater use of coal and electric boilers can significantly reduce oil and gas consumption for process steam, but there is something brand new

THE WESTINGHOUSE TEMPLIFIER
Temperature Amplifier

We call it a Templifier – short for Temperature Amplifier It uses the same principle as a residential heat pump, but with a much larger compressor and working at much higher compression ratios and temperatures

FREE HEAT SOURCES FOR INDUSTRIAL PLANTS

IN-PLANT SOURCES

- Overhead Vapors from Distillation Processes
- Warm Water Effluent from Plant Processes
- Refrigeration Equipment Cooling Water
- Air Compressor Cooling Water
- Electric Welder Cooling Water
- Extruder Cooling Water
- Injection Welder Cooling Water
- Cooling Tower/Pond Water
- Flu Gases

OUT-OF-PLANT SOURCES

- Condenser Cooling Water from Power Plants
- Bodies of Water – River • Lake • Ocean
- Air

For a Templifier, better free heat sources than the cold outside air used by the residential heat pump are available A body of water such as a lake, a river, or the ocean can be used Better yet, higher temperature free heat sources are often available from waste heat inside industrial plants

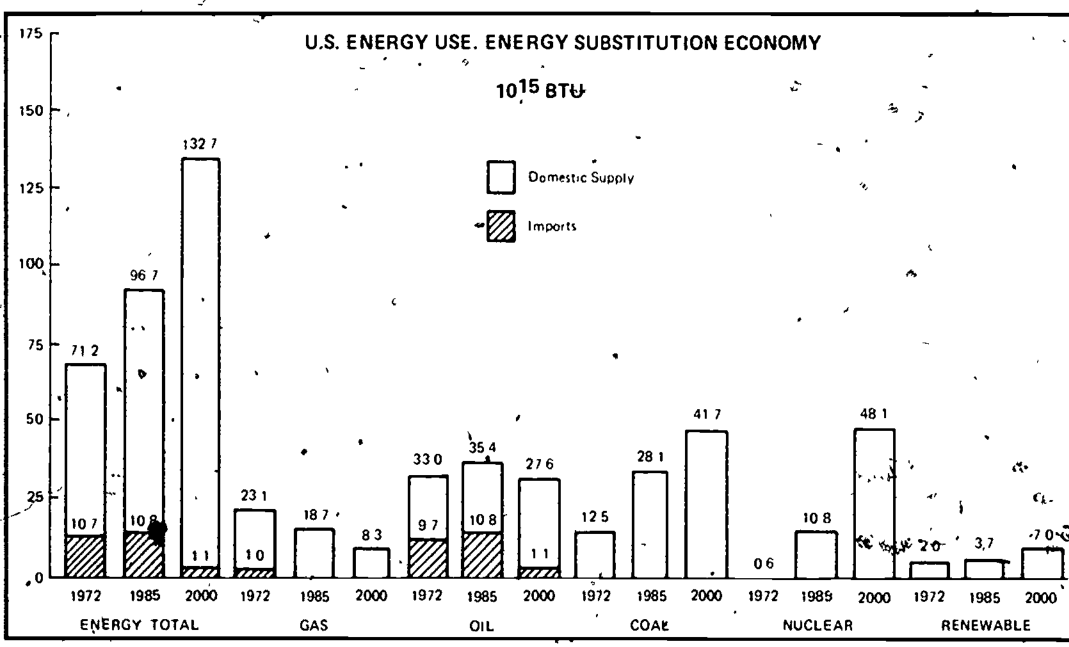
The first Templifier was put into service this Spring in one of our plants and replaced a gas fired boiler It started up just in time to overcome a curtailment in our natural gas supply

Our fourth big user of gas and oil is direct heat Substitution is obviously feasible Industry already uses electric furnaces along with induction heating, dielectric furnaces and electric ovens They are clean and efficient and often yield a higher quality product As supplies of gas and oil dwindle industry is turning increasingly to electricity for direct heat.

An example of what's coming is our own lamp plant in Salina, Kansas Needing more glass melting capacity and with no additional gas available we installed an electric furnace alongside the original gas furnace.

There are a few more energy substitutions, but these are the main ones and are all time will permit me to cover today Let's see what the total effect of these substitutions and aggressive conservation is on the total energy picture.

Now imported energy in 1985 is about the same as our present level of imports. As a percentage of total energy consumption, imported energy drops from 15% in 1972, to 11% in 1985 and to only 1% by 2000. *We have gotten back control of our energy destiny.*

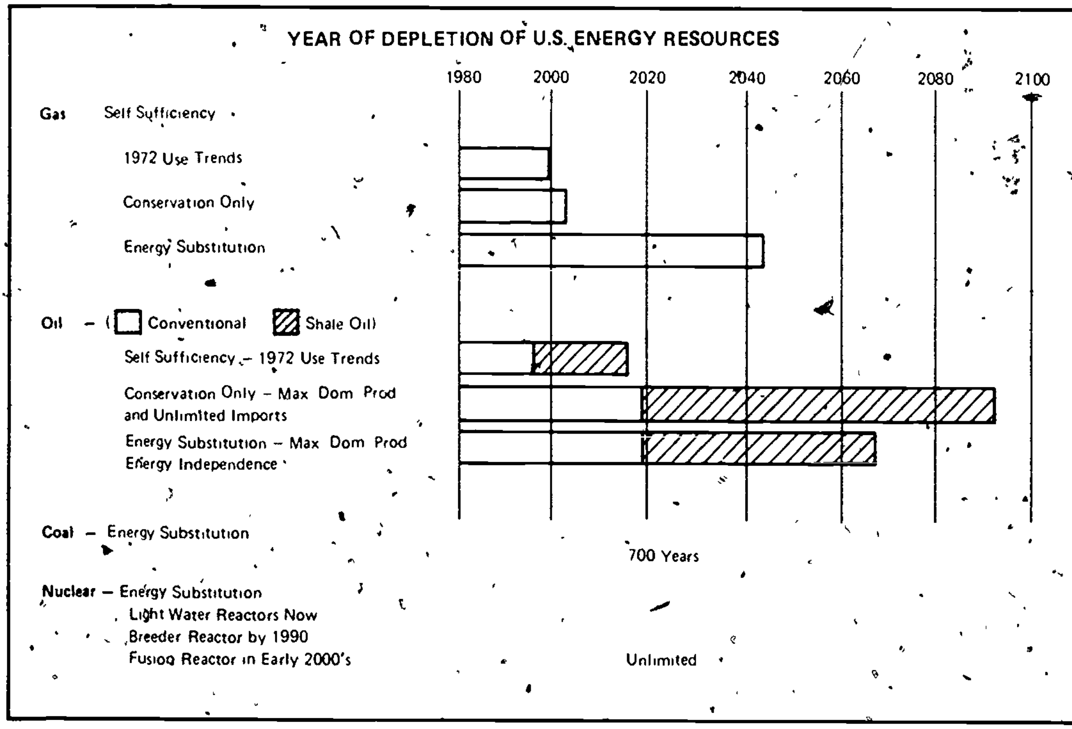


The gas problem has been solved by drastically reducing gas consumption all gas imports have been eliminated by 1985.

The oil problem is now manageable Through 1985, oil imports still increase somewhat over 1972 levels, but then decline rapidly by 2000 Imported oil represents 29% of our 1972 consumption, 31% of our 1985 consumption, and only 4% of our consumption by 2000. Who cares if OPEC decides to impose another boycott!

With the alternative I propose, aggressive conservation combined with energy substitution and achieving energy independence, our supply of conventional oil would still last 43 years because production limitations still apply. Shale oil would only extend the supply another 50 years however I don't see this as a problem because we can start early in the next century to find alternatives for oil in its then remaining applications

Coal and nuclear resources are no problem.

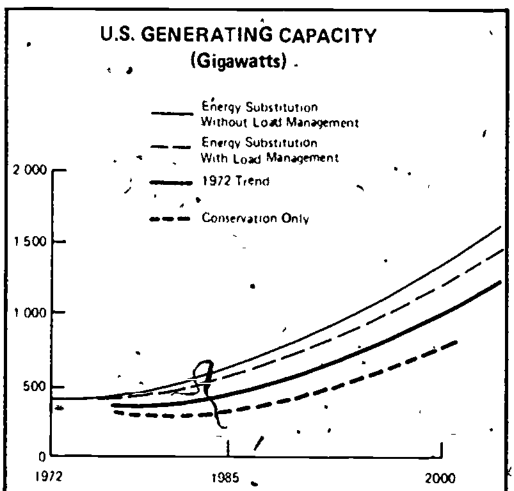


From a depletion standpoint only gas and oil are in imminent danger of depletion.

If we only conserve gas, our supply will be gone in 2005, just 30 years from now. In the meantime the demand for gas in excess of attainable domestic production levels will have to be filled by imports, or by shifts to oil, or just plain suffering If, on the other hand we undertake the Energy Substitution Economy, our supply will last for 70 years, imports can be eliminated, and other energy sources will supply the needed energy

In the case of oil, if we somehow could have supplied all our oil needs from the U.S. from 1972 on, all our oil would be gone in 24 years. Exploiting shale oil would add another 33 years.

If instead we conserve oil, recognize domestic production rate limitations, and would accept the power of the sheiks to stop our economy cold by allowing unlimited imports, our oil would last 43 years. Exploiting shale oil would give us another 75 years supply.



Implicit in the Energy Substitution Economy concept is the increased requirement for electric generation facilities

If 1972 energy use trends had persisted, total generating capacity in 2000 would have been 1410 gigawatts. Conservation alone would reduce that to 1020 gigawatts.

To take care of all the substitutions we have discussed, total capacity in 2000 would rise to 1660 gigawatts. This would be a 63% increase over the Conservation Only case and a 17% increase over the 1972 Trend Case.

But there is an important new development that will lower generating capacity needs. The Federal Energy Administration has begun to enter state utility commission electric rate cases. FEA's objective, in part, is to see that electricity users pay more for using electricity during periods of peak demands on the electric utility system, and less for electricity used in slack demand periods. This strategy should result in shifting electric loads off the peak and reducing the installed electrical generating equipment required.

We estimate that this load management philosophy will reduce the installed generating equipment needed for the Energy Substitution Economy in 2000 from 1660 to 1490 gigawatts, a reduction of 11%

Planning Implications of
The Energy Situation

Conservation:

- Extensive Public Education and Voluntary Agreement Programs
- Increasingly, Mandatory Efficiency Standards for Energy Utilization Devices

From this overview, it should be clear that there are a number of implications for personal and institutional planning in the energy outlook. Let's look into our crystal ball!

On the conservation front we will be seeing a rapid proliferation of public education programs designed to reduce consumption of all forms of energy.

On a parallel track, government agencies will be working with energy intensive industries to reduce consumption per unit of production. Manufacturers of energy utilization equipment of all types will be asked to enter into voluntary agreements to increase efficiency. Such efforts are now underway in the auto and home appliance fields.

As our energy crisis deepens, one can expect to see *mandatory* energy efficiency standards taking over. Likely first candidates are commercial and residential buildings, autos and appliances.

Planning Implications of
The Energy Situation

Gas.

- Shortage is Severe and Will Get Much Worse
- Industry Will Absorb Shortfall to Maintain Supplies for Residential and Commercial Sectors
- Short Term – Industry Will Turn to Oil, Worsening Oil Import Situation
- Mid-Term – Use Control for New Installations
- Long Term – Coercive Measures to Force Switching to Coal, Electricity and Solar

On the natural gas front, the shortage is already severe. It will get much worse and eventually impossible.

In order to maintain service to the residential and commercial sectors, industry will be forced to absorb the shortfall. In the short term industry will turn to oil to replace gas and the oil import situation will worsen. One would expect the worsening import situation to be politically tolerated because the alternative is the loss of thousands of jobs.

In the midterm I expect to see the emergence of energy use controls. That would mean that for applications that could be served by coal or electricity, use of gas or oil would be prohibited. Examples might be hot water supply in the meat packing industry or in industrial metal cleaning and plating processes.

In the larger term there will probably be coercive measures taken to force switching away from gas and oil and to coal, electricity and solar.

Planning Implications of
The Energy Situation

Oil:

- Mid-Term – Oil Imports Will Rise Significantly, Especially if Economy Recovers
- Probably Mandatory Auto MPG Standards
- Coercive Measures to Force Use of Mass Transit
- Heavy Government Investment in Electric Vehicle Technology

On the oil front, oil imports will rise significantly in any event and sharply so if the economy recovers. This event will likely trigger mandatory auto miles per gallon standards among other measures. Coercive measures to force use of mass transit are virtually certain, as well.

Heavy government investment in electric vehicle technology, now in the talking stages, is virtually certain.

Planning Implications of
The Energy Situation

Coal, Nuclear, Solar Electric Generation
- Government Programs to Develop Resources and Ease Financing Problems

Turning to the more plentiful forms of energy, much more governmental involvement in development of coal, nuclear and solar energy resources is certain At present this involvement is concentrated on Research and Development Programs, but pressures will be enormous to extend involvement into brick and mortar in view of the enormous sums of money involved and the inability of the private capital markets to provide it

Planning Implication of
The Energy Situation

Electric Rates.
- Flatten Rate Structure, Probably With "Lifeline" Protection for Low Use Residences
- Long Run Incremental Cost Used for Pricing
- Time of Day Demand Metering/Load Control
- Much Development of Energy Storage Technology

Major restructuring and reform of electric rates is just around the corner and the dimensions are now clear.

Rate structures will be flattened to reduce or eliminate the quantity discounts which now benefit large users. Lifeline rates, intended to provide a cheap but small block of power to low income groups, will become common.

The long run incremental cost concept is likely to achieve acceptance for rate design purposes. Combined with time of day pricing, the net effect will be to increase the cost of electricity used on-peak and reduce the cost of electricity used off-peak.

Time-of-day demand metering will first affect the industrial sector and then be increasingly seen in the commercial sector.

Load control will be increasingly applied to the residential sector The form of load control that will emerge is not clear but is likely to be some combination of time switches controlling electric hot water heaters and some appliances, radio controlled switches accomplishing the same end, or ripple control working through the power lines.

Finally, I expect to see much development work done on energy storage technology. While applicable to all sectors, the first efforts will be in industry so that plants can draw power off-peak, store it as hot water or in batteries, and use the stored energy during utility peak hours.

Setting aside my crystal ball, there may be some ways in which we at Westinghouse can help you cope with the BRAVE NEW ENERGY WORLD.

Ways Westinghouse Can Help
(Partial Listing)

Typical User Energy Problem
- Analysis (Sometimes With Field Data Collection)
- Develop New Technology
- Design, Fabricate and Demonstrate New Device (or System Concept)

The energy problems of most users that we have encountered seem to fall into one of three categories,

The first category is the need to analyze an energy problem, often including collection of field data as well.

The second category is the need to develop new technology to solve a problem

The third category is the need to design, fabricate and demonstrate a new device or system concept.

Ways Westinghouse Can Help
(Partial Listing)

Working Basis
- Existing Product — Related Normal Application Assistance
- New Product/Technology Contract Basis

Ways we can help you are many and varied and obviously depend on what the specific problem is.

At the end of the spectrum, solving a problem may involve nothing more than application assistance for a product we already make. Here, just contacting our product division will be all that is needed.

At the end of the spectrum, solving a problem may take sophisticated analytical techniques, or advanced research and development effort. We would provide this kind of effort on a contract basis.

My own organization, the Advanced System Technology Division, originally existed to perform contract study work on problems of electric utilities. But with the energy crisis there is often a close coupling between energy utilization technology and electric utilities. So today our work goes far beyond just studies for electric utilities.

Here are some ~~of the areas~~ we are currently involved in, either independently, in a project management role, or in cooperation with other Westinghouse organizations

Ways Westinghouse Can Help
(Partial Listing)

Technology and Field Demonstration
- Building Energy Studies
- Process Electrification Technology
- Solar Technology
- Emerging Heat Pump Technology
  - Process Steam and Hot Water
  - Grain Drying
- Electrical Management
  - Energy Storage Technology
  - Demand Metering and Surveys
  - Demand Control Technology
- Impact on Electric Utility Systems

A busy activity is one of our groups which does building energy studies using probably the most powerful computer analytical techniques in existence. Currently their efforts range from studies of energy options for office and commercial buildings for architect engineers and government agencies, to studies of dozens of residences for an EPRI heat pump research project.

Process electrification technology is another active area as gas curtailments escalate. Applying electric arc heater technology to high temperature processes in the chemical industry is an example of one such activity getting a lot of our current attention

On solar technology, Westinghouse activities range from conducting solar demonstration projects in public buildings to work for ERDA on using solar energy to generate electricity in utility-sized quantities.

Heat pump technology is another area of interest. The Templifier, which I discussed earlier, is now being demonstrated as a source of hot water for industrial use We are interested in outside funding for extending the heat pumping principle into the 300°F temperature range as well as into the grain drying field.

Load management technology, both from a user and utility standpoint, is another growing area where we can help. Here our experience includes energy storage technology, and demand metering and control technology.

Ways Westinghouse Can Help
(Partial Listing)

Resources
- R & D Laboratories
- New Product Development Laboratory
- Product Divisions: Products Serve All Sectors
- Advanced System Technology
  - Electric Utility and Program Coordination

As your energy work progresses you may find situations where we can help you We at the Advanced Systems Technology Division of Westinghouse will be happy to put together whatever combination of our resources is needed to support a contract effort to solve your problem.

As I close, let me once again thank you for asking me to join you today. I hope that you have found my presentation to be current, interesting, and maybe even controversial.

I do want to leave you with one thought. The energy crisis is already upon us. If we are going to solve it, now is the time for action, not protracted debate. I think energy action is the theme of your entire program I congratulate you for that and wish you Godspeed.

Thank you.

ENERGY IN AGRICULTURE AND FOOD

Robert H. Brown
Chairman, Division of Agricultural Engineering
University of Georgia

Introduction

If Paul Revere had it to do over again, he would never get to Lexington in time to save the nation. Today in the rush hour of Boston traffic there is no way he can make it By the year 2,000 after Boston builds new transportation surfaces, he would fail because of the lack of fuel for his vehicle. He would fail, that is, unless our modern creative society can rise above traditional politics, traditional philosophies about the Great Society and the new ideological thrusts for saving the total environment. We need a Revolution. A special kind of revolution which could be called the *Energy Revolution.* This can be brought about if America will set aside politics, money goals, and income maintenance programs and instead will concentrate on re-captivating the interest, the attention, the enthusiasm, and the dedication of its most capable citizens. This could become a revolution based upon knowledge, performance, contributions, cooperation and acceptance of responsibility. That is the American way or, more precisely, that is the way the Bicentennial posters proclaim. But so far national energy policy has failed to appear on the main track, U.S.A.

Americans are bewildered by the suddenness with which the energy crisis has impacted on our nation and they are confused about what it means, how long it will last, and what we must do to remedy the situation. There is much disagreement concerning the energy "policy" but all appear to agree that food, population, progress, and energy are related.

The exact relationship, however, has become confused as a result of statements about excessive use of energy by agriculturists. The statements are misleading and the basic data needs to be presented. It is appropriate, therefore, to consider energy in agriculture in terms of energy content of materials, arable land areas, world population, distribution of population and food requirements, production, processing and use. Then the food considerations will be explored in relation to energy budgets in such a manner that the true facts about energy in agriculture and food will come to light.

Land

In the world in 1975 there are approximately 3.6 billion acres of arable land These land areas are shown by regions in Figure 1.

Figure 1
Arable Land Available for Agricultural Production Worldwide, by Geographical Region
(Reference 3, 4)

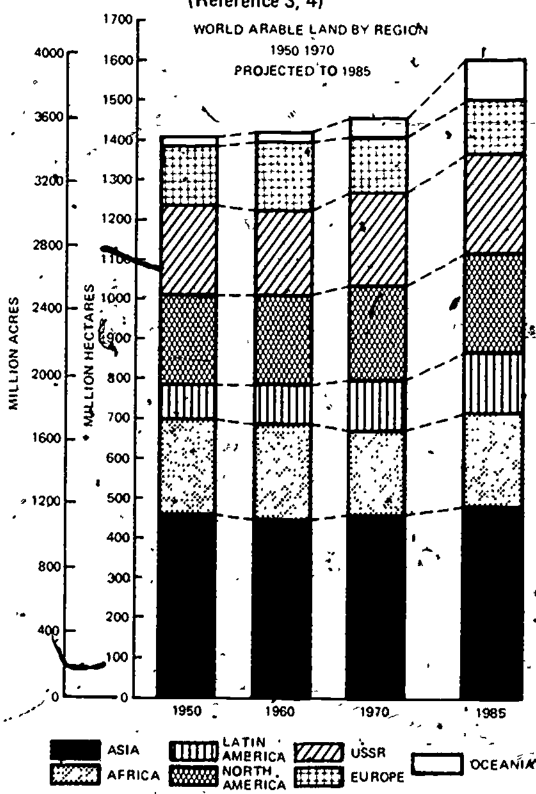


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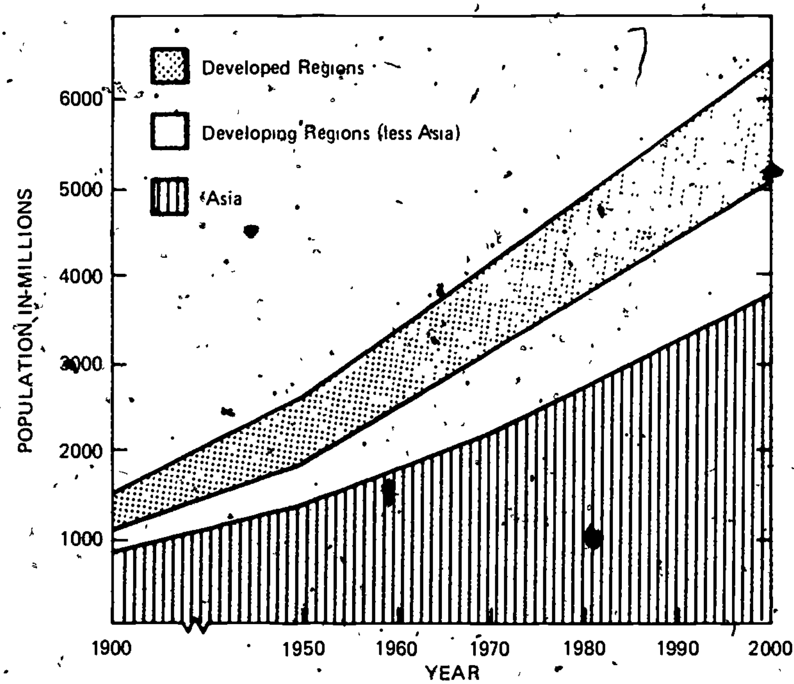
Figure 2

World Population with Projections To Year 2,000

(Reference 3, 4)



People

In the world in 1975 there are approximately 4.0 billion people. The distribution of world population is presented in Figure 2. Note especially the growing population in developing countries and the almost parallel boundary lines for developed regions

$$\text{World Ratio: } \frac{\text{Land}}{\text{People}} = .9$$

Although the average world ratio is about 1 acre per person, the unequal distribution of population causes the 1 acre/person to be somewhat misleading. For example, consider:

For Asia	0.5 acre/person
For U.S.A.	1.5 acre/person

This is quite a major difference when one considers producing food. Do you work with 1.5 acres or 0.5 acres? The daily human requirement for food is the same no matter what the acreage. The peoples of a region must either produce enough food, import it, or accept undernourishment as a part of their life. So long as they permit population to increase without additional land area on which to produce food, or without increased production/ acre, there are obviously problems on hand.

Food

It is estimated that the per capita consumption of food in the world will change very little in the next 25 years. This assumes that food desired will be available. More people will require a greater food total but not per person. The individual food consumption, world average, is:

500 Kg x 2.2 lb/Kg = 1100 lb/year

or

3 lb. of food/day

In terms of Kilocalories, the normal amount required per person per day is 3,000.

1 Kilocalorie = 4 British Thermal Units (Btu)

Daily Btu requirement = 12,000

According to these relationships, a person needs 3 pounds of food having an average Kcal content of 1,000/lb or an average Btu content of 4,000/lb. For the considerations involving energy the latter value is selected for purpose of comparisons.

Required Btu = 12,000/day

Solar

As the single source of all the world's energy, the *Sun* annually sends to the surface of the earth approximately 1,500,000 x 10^{15} Btu Most of this energy is re-radiated into the atmosphere, but it is estimated that maybe one percent is retained If this is the case, the sun supplies annually 15,000 x 10^{15} which turns out to be about 60 times the total energy used in the world Capturing and using more of the sun's energy is challenging and obviously merits much effort

Another challenge, to agriculture especially, is to enhance the efficiency of plants to convert solar energy. It is estimated that plants now use only one to two percent of the available solar energy in their manufacture of plant tissue Ways and means of increasing this percentage is obviously a merited research undertaking

World Usage

The world's energy use in 1970 has been totaled by a University of California Food Task Force (3) as 211 Btu x. 10^{15} Of this amount, the U S.A required 75 x 10^{15} Btu or approximately 35 percent of all energy consumed in the world For 1974 these values are estimated to be

250 x 10^{15} Btu World Use
83 x 10^{15} Btu U.S.A

The projected energy requirements in 1985 are also given in Figure 3 (3, 4). Increases of these magnitudes will seriously deplete energy supplies and much adjustment, reallocation, selection of new types of energy, economy of use, etc. will go up and down the stream between now and 1985 Particularly in agriculture, the concern is about natural gas as a source of nitrogen fertilizer. World petroleum is critical and coal and nuclear sources of energy are sure to come very much into the picture, by 1980-85. Nuclear energy sources will undoubtedly replace about one-fourth of the fossil fuel types by 1985.

Uses of Energy In U.S.A.

As shown graphically in Figure 3, the United States consumes over 1/3 of the total energy used in the world although it has only about six percent of the world's population Ours is an energy oriented living standard and much concern arises when certain energy sources are identified as exhausting and non-renewable. The industrial might, the life style, the food production and transportation and the G N P have all evolved assuming available low cost energy And suddenly, or so it appears, the supply of energy in its present form is very much in doubt

Initially in the U S A the base-energy source was wood, along with animal and man power Then coal became available and our industry quickly moved from wood to coal-burning power units for many applications. Then along came crude oil and its multi-advantages, low cost and abundancy led to the adoption of the fossil-fuel-based economy. Gasoline, diesel, gas-fired turbines, electric devices became the backbone of our energy system It is important to emphasize that in all these instances – wood-coal-oil – the choice to change to the new energy base was *voluntary*. The principal factor in today's energy situation is that the change from one type of energy to another is *not by choice*. There must be a re-distribution of energy types as these are applied to various industries, residences, transportation systems, etc.

Certainly nuclear power, solar energy, and coal will pick up from crude oil much of the present energy burden Nuclear sources may supply over one half of the world's energy of the next generation Oil, coal, solar will share in the load But a restructuring of our energy use and more efficient uses are the order of the day The times of low-cost, abundant energy are gone Accordingly, energy budgets become very much a prime consideration for all future designs and applications

The pie-chart shown in Figure 4 (2), focuses upon the thought that energy use and control involves everyone The residential users of about 20 percent also contribute to the transportation share Commercial and industrial uses require about 56 percent of all U.S A. energy and agriculture is a part of this section.

The pie-chart shown in Figure 5 (2) gets directly to the energy and food issue This chart illustrates the fact that production agriculture uses only 18 percent of all food-related energy. Many times *agriculture*, meaning *production agriculture*, is erroneously charged with all of the energy budget when it is obviously the food processing and food preparation in the home which are the big users of energy The 33 percent for food processing and 30 percent for food-related home-uses are clearly the major energy requirements which presently form the food-chain-complex in America

The total amount of energy required by the food-complex *(Production — Dinner Table)* in America amounts to 13.5 percent of total energy use in this country. Multiplying by the factors in Figure 5, the energy percentages become:

In U.S.A., percent of total energy used for food.

- For Food Production – 18 x 13 5 = 2.4%
- For Food Processing – 33 x 13.5 = 4.5%
- For Transportation & Commercial – 19 x 13.5 = 2.6%
- For Home Preparation – 30 x 13 5 = 4.0%

It is obvious that the two areas, food processing and food preparation in the home, offer opportunities for energy savings. But consideration of the 2.4 percent of all U.S.A. energy now being consumed while producing the food is the principal thrust of this paper. Savings in the production area might spill over into the processing area. But regardless of this eventuality, the concern about energy costs and energy availability for fertilizer (primarily natural gas for nitrogen) and for fuel for trucks and tractors and crop drying are major issues in today's planning and allocations

Figure 3
World Usage and Projected Requirements for Energy — by Geographical Regions

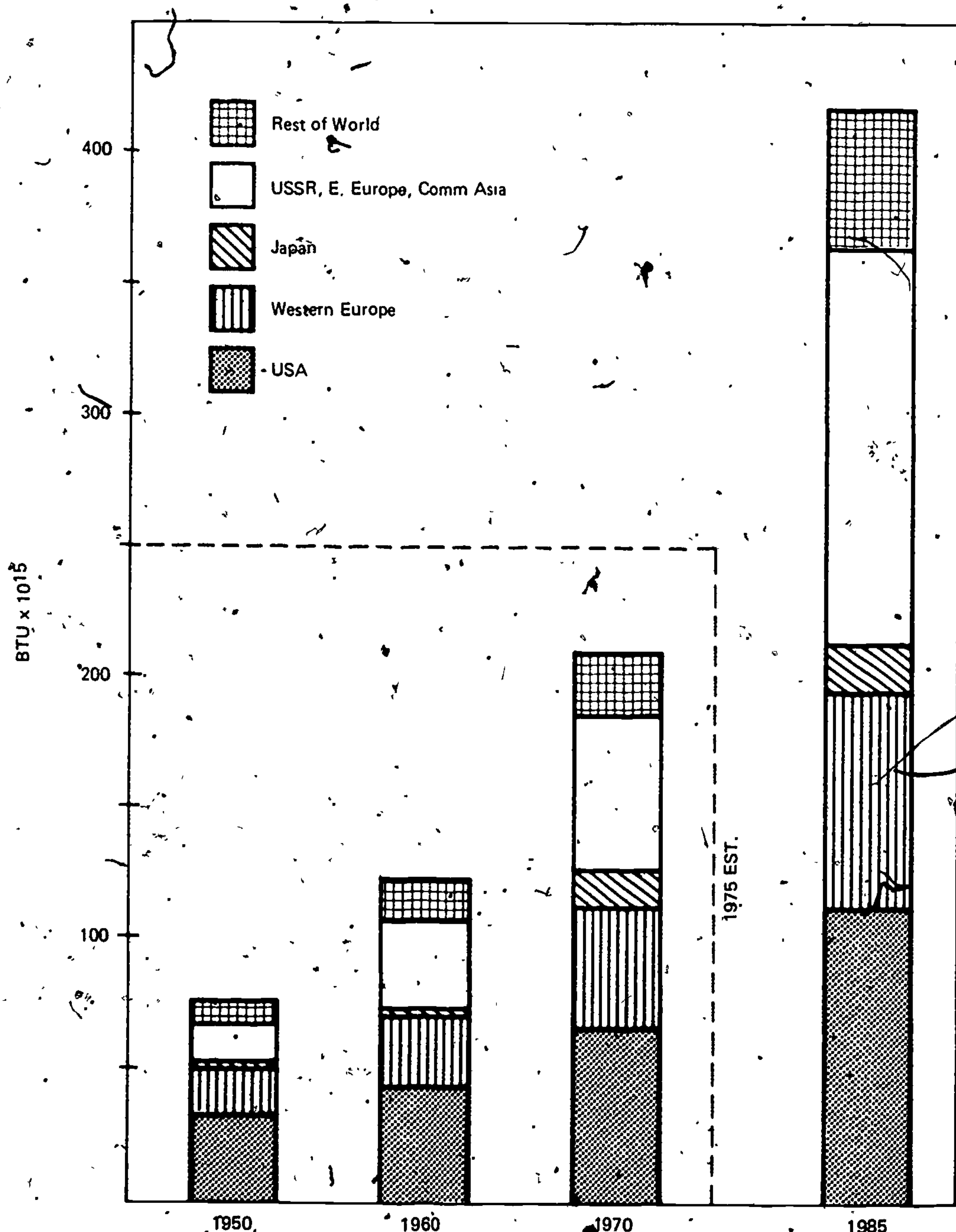


Figure 4

Energy Usage in the United States, 1972

Four Major Categories

(Agriculture is a Part of Industry Section.)

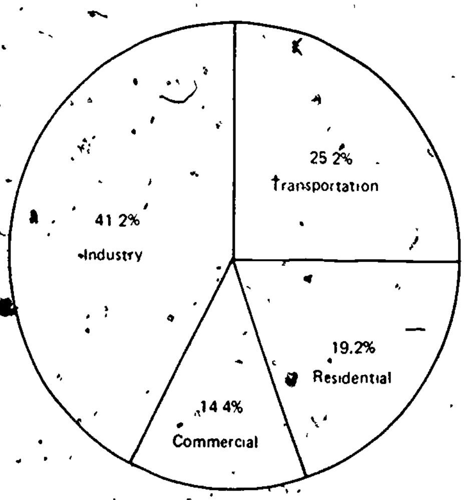
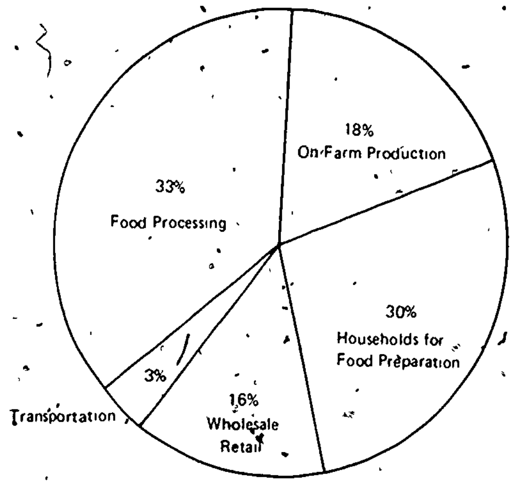


Figure 5

Pie Chart Depicting Energy Usage in the Overall Food System – Production to Dining Table



Energy and Food Production

The plant model of Figure 6 presents the basis for considerations about energy budgets in production agriculture. The plant accepts solar energy, water, and carbon dioxide, converting them through photosynthesis into plant tissue. Thus, green plants are actually converters of solar energy and store it as protein, carbohydrates and oil, thereby providing forms of energy which can be used by humans and animals. Various inputs such as water and fertilizer are applied in efforts to control and enhance the efficiency, the quality and the rate of the conversion. An example with acutal quantities in the instance of the corn plant is shown in Table 1 (13). Note in the "% of Total" column that the largest energy requirements show for fertilizer (36%) and fuel (28%). In this particular example irrigation energy is lower than is the case in the Southeast. The energy for drying is lower than usual because with heated-air this value could easily be as large as that required for gasoline (28%). The values shown are for Ohio conditions.

Calculations for these values and more details on preparing energy budgets are presented in the following sections. The energy values of interest in agricultural production and related activities are furnished in Tables 2, 3, and 4.

It is important to observe that each acre-inch of irrigation water (under center-pivot, South Georgia conditions)

Figure 6

Model for Determining Input-Output Energy Budgets for Field Crops

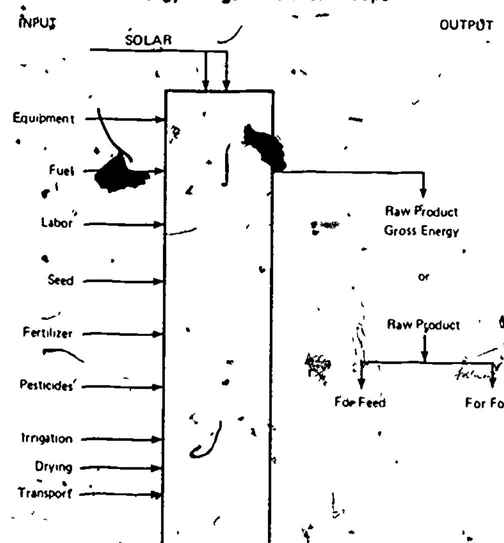


Table 1
Typical Values for Energy Inputs to Field Crops (Corn)
(Base Data from Reference 13)

Item	Thousands Btu Per Acre	% of Total
Equipment	1,667	14.5
Fuel	3,163	27.6
Labor	19	0.2
Seed	250	2.2
Fertilizer	4,190	36.4
Pesticides	87	0.7
Specials		
Drying	1,706	14.8
Transportation	277	2.4
Irrigation	134	1.2
Total Input	11,495	100.0
Harvest (Output)	32,399	81 bu/acre
Ratio $\frac{\text{output}}{\text{input}}$		2.8/1

Table 2
Energy Content of Various Materials In Terms of Fuel Heat Values

Material	Amount	Heating Value In Btu
Coal	lb	13,000
Wood, Pine	lb	9,000
Wood, Hard	lb	12,000
Dry Biomass	lb	6,000
Bagasse	lb	8,260
Fat	lb	17,100
Gasoline	lb	18-20,000
Gasoline	Gal	125,000
Diesel	Gal	135,000
Crude Oil	lb	19,000
Propane	lb	21,680
Propane	Gal	92,000
Nat. Gas	Cu ft	1,000
Methane Pure	Cu ft	1,000
Methane, Avg.	Cu ft	750
Electricity	KWH	3,412
Corn	lb	7,200

requires 500,000 Btu and to note that pesticides require 44,000 Btu/lb. to produce. This is within reason in the budget when 2 lb/acre are used but the values can mount up quickly if pesticides must be reapplied frequently owing to wash-off by heavy rain.

Values of energy required to manufacture a piece of machinery or a tractor can be secured from manufacturers or from Reference 10. The value of energy required to provide all machines in normal row crop operations might be taken as 10 percent of the subtotal, not including the "specials." There are many factors (such as times used, acres, life of machine, energy to manufacture steel, etc.) which make it difficult to specify an accurate value for each item of equipment.

Table 3
Energy Required to Manufacture or Furnish Certain Items Used in Agricultural Production

Material or Item	Amount	Energy Required To Produce or Furnish (Btu)
Labor	Manhour	2,170
Electricity	KWH	10,000
*Irrigation	1 acre-inch	500,000
N	lb	33,600
P	lb	5,200
K	lb	5,200
Herb./Insect	lb	44,000
Seed, Grain	lb	10,000

*Center pivot under typical conditions in Coastal Plain of South Georgia

Table 4
Important Energy Values for Operations in Field Crop Production
(References 10 and 14)

Field Operation (Average Conditions)	Fuel and Labor Energy Required, Thousands Btu/Acre
Moldboard plow and Harrow	400
Moldboard plow	370
Disc Plow	370
Chisel Plow	240
Disc Harrow	125
Planter	45
Cultivator	35
Fertilizer Spreader	30
Sprayex	30

The energy input for any given crop production system is the sum of the individual input energies shown in Figure 6, namely:

$$\text{Energy Input} = E_{equipment} + E_{fuel} + E_{labor} + E_{fertilizer} + E_{seed} + E_{pesticide} + E_{specials}$$

where $E_{specials}$ = Energy for Irrigation $\pm$ Drying + Transportation + Farmer Pickup Truck.

Using this equation and obtaining values from the Tables, a prediction is made for growing one acre of corn under South Georgia conditions. Three inches of irrigation water were included but drying and transportation were not. The

Table 5
Summary of Calculations of Energy Required To Produce One Acre of Corn in Georgia

Energy Item	Amount	Thousands of Btu
Fuel	4 gal	480
Labor		10
Fertilizer	100 lb N	3360
	40 lb P	208
	40 lb K	208
Pesticide	2 lb	88
Seed	10 lb	100
	Subtotal	4454
Equipment	10% of Subtotal	445
Irrigation	3 inches	1500
	Total	6399
Harvest	90 bu x 56 lb/bu x 7200 B/lb	36,288

yield of 90 bushels/acre @ 56 lb/bushel provided data for [illegible] energy yield (output). The results of the computations are given in Table 5. The returns are seen to be 36,288,000 Btu for an input of 6,399,000 Btu and the ratio of output fuel energy to input is 5.67/1.

Almost 6 units are returned for each one unit of heat-energy-equivalent input.

Considering Energy Output/Input

In the corn production data shown in Table 5, drying was not assumed to be a part of the system. This processing step would require 20,000 Btu/bushel to dry corn from 26 to 13 percent moisture under normal conditions. The input total would then become 8199 x 10^3 and the ratio (return/input) becomes 4.42/1.

This type of output/input energy ratio computation is not the measure of agricultural production, quality, value or efficiency. But it is being held up by many as just such a measure. For example, Mr. Clark (5) writing in *Smithsonian* states, "It takes as much energy to run U.S. tractors as is contained in the food produced. Some experts wonder how long we can keep this up." Since when was agriculture to be so evaluated? How about coffee users, would they care to go without coffee because less energy is harvested than was used in the harvest? Coffee has zero energy value so the ratio is zero.

In another example quoted from a 1972 meeting of the *American Association for the Advancement of Science* in Washington, D.C., Rene J. Dubos read this statement. "Paradoxical as this may sound, there are many situations in which the modern farmer spends more industrial calories than the food calories he recovers in the form of food. His caloric expenditure consists chiefly of gasoline for powering his equipment and of electricity for producing chemical fertilizers and pesticides . . ."

Statements such as this create improper and erroneous conclusions. Mr. Dubos has assumed situations to fit his statement. We can establish returns of 26 to 1 for slash pine, of 16 to 1 for alfalfa, of 5 8-10, even 14, to 1 for corn, etc. It is also acknowledged that through certain feeding, slaughtering and processing regimes there are instances where the output energy is less than or equal to the input energy. But it is by design, by intent, not by lack of proper methods, procedures or programs.

There is now and shall remain the "I like it" factor pertaining to food. Energy is added to certain foods in processing or in home preparation because "we like it better" in the new condition. Some plants require much more of this sort of input energy than do others, potatoes, for example. Although energy is inputed in the processing of the potato, none is added to the food value and man is here trading fuel for taste and palatability. In still a third instance, the plant converts energy into a form acceptable and useful to livestock and poultry. For example alfalfa fed to cattle for conversion to milk for use as food. Again the energy budget suffers because man wants milk not alfalfa.

The most logical conclusion offered at this point is that all aims and goals should be considered, not just one superficial situation injected for the sake of dramatizing a condition. Man wants food to be acceptable both in value and in taste. He is willing to trade energy to gain this end.

Another conclusion can now be drawn concerning energy and food. The energy cost and the supply in the United States are sufficiently alarming as to require that a new element be added to decision making when planning agricultural production enterprises, namely:

Calculate the Overall Energy Budget. Determine, at least approximately, the amounts of energy which will be required to produce a desired result. Then make final decisions based upon economics, energy availability and returns, and upon humanity's needs.

Potential Areas for Energy Economy in Agriculture

The next few years can and must bring new energy technology to agriculture. There are many possibilities past the initial step of determining the energy budget which must be done *for awareness*. These possibilities include improved use of solar energy by plants, recylcing of manures [illegible] ments, low-energy irrigation water, solar energy for crop drying, [illegible] duction from wastes, substitution of coal, great savings in space [illegible] water heating energy, solar energy powered cooling systems, improved tillage methods, reduced energy for transportation, new production/harvesting technology resulting in less energy needed for processing and low-energy pest control methods

Table 6
Fuel Energy Required for Crop Production as a Function of Tillage System

Tillage System	Fuel Required Gal/acre	% Saving Over Conventional Tillage
Conventional	4.8	0
Reduced Tillage	3.55	26
Plow Plant	3.30	31
Chisel Plow	3.00	36
No Till	0 85	82

Note Example is for corn production, pesticides were not considered in the energy requirements

Table 6 contains information indicating that the tillage systems selected for various crops should be reconsidered with energy values in mind The data in Table 7 focus upon transportation alternatives and make clear some definite choices in this area

Table 7
Ratios of Output to Input Energy for Selected Crops and Considering Only the Digestible Energy Value in the Output Material
(Data from Reference 10)

Crop	Ratio $\frac{\text{Digestible Output}}{\text{Total Production Energy}}$ As Feed For Cattle	As Food
Alfalfa	10.2	5.9
Corn Kernels	6.9	7.0
Wheat	3.8	3.9
Napia Grass	9.7	

Solar energy adaptations to the agricultural energy field, as well as for homes, merit special attention. At the start of last year there were 138 solar heated structures in the world of which 85 were in the U.S.A., according to W. Shurcliff of Harvard. During 1975 an additional 87 solar heated homes in the U.S.A were started or are now completed. This report is from ERDA. The entire industry is developing, for example, the *Solar Energy Industry Association* lists 50 equipment manufacturers, including Grumman Aerospace, which recently announced a solar water heater selling for $700. Solar home heating equipment is also moving up in sales volume with costs for a 2,000 square foot home decreasing from $5,500 to $4,500 ERDA predicts that the sun will provide 7 percent of United States energy by the year 2,000 and 25 percent by 2020

This percentage is low. A more necessary and attainable goal is 5 percent by 1985 and 10 percent by the year 2,000 Reference to certain energy uses in the home and in agriculture shows a potential for shifting 2.5 percent of the nation's energy to solar. This value is suggested as obtainable if solar energy takes over for water heating (1.0 percent), space heating (1.2 percent) and agriculture (.3 percent) of the nation's energy percentage values. It is recognized that the 3 percent from agriculture means shifting to solar about 13 percent of the energy used in production agriculture. This can be achieved with attention to drying, fertilizers and livestock-poultry environments and to direct solar energy, indirect through methane gas and improved photo synthetic conversion of carbon dioxide to biomass which would then be used for energy.

Some drying should be done with coal as another alternative The use of natural gas because it is clean, etc. must be altered. Gas is needed for fertilizer.

In some locations and instances chemical fertilizers could be replaced at least in part by better management of animal manure The use of sewage sludge or effluent is also a possibility and is being studied.

In the case of nitrogen in particular, an increased use of legumes as a natural source—worked into the crop rotation

Table 8
Conversion Factors for Energy in Agriculture

To Obtain	Multiply	By
Calories	Btu	4
Btu	Kilocalories	4
Lbs	Metric Tons	2200
Acres	Hectares	2.471
Sq. Meters	Hectares	10000
Pounds	Kilograms	2.204
Btu	Joules	1055
Btu/A	MJ/hm2	383

Table 9
Energy Requirements of Transportation for Agricultural Products
(Data from Reference 1)

Transport Mode	Btu/Ton Mile
Pipeline	450
Barge	680
Rail	670
Truck	3,800
Air	42,000

system—must receive renewed consideration. Also, over-applications must cease—better placement and/or timing of application must also receive renewed attention, along with seeking the right combinations of water and fertilizer to increase yields while lower energy inputs.

Although agricultural production energy alone is comparatively small — it should be combined with processing (as a system) with a view toward a sizable decrease in energy requirement. Then a lower level of processing is very much in order for America's future.

References

1 Barnes, K K, "The CAST Report," *Agricultural Engineering*, Vol 55, No 3, No 4 and No 5 ASAE, St Joseph, Michigan. March-May 1975

2. Bickert, W G and F. W Bakker-Arkema, "Energy in Michigan Agriculture," Mimeo Booklet, Agricultural Engineering Department, Michigan State University. March 1974

3 Chancellor, W J et al (University of California Food Task Force), "A Hungry World, Challenge to Agriculture," Davis, California. 1974.

4. Chancellor, W. J. and J R Goss, "Balancing Energy and Food Production 1975-2000," General Session paper presented 68th Annual Meeting ASAE, Davis, California. June 1975

5. Clark, Wilson, "U S. Agriculture is Growing Trouble as well as Crops," *Smithsonian*, Vol. 5, No 10, January 1975.

6 Frith, R. R. and Promersberger, "Estimates of Fuel Consumption for Farming and Ranching Operations under North Dakota Conditions," North Dakota State AES Bulletin 493. 1973.

7 Gaylor, Walter, (Editor), *Technical Survey*, Vol 31, No. 32 Elizabeth, New Jersey. August 23, 1975.

8. Hahn, R R (Editor), *Agricultural Engineer's Yearbook*, St Joseph, Michigan ASAE, May 1974

9. Hoeft, R. G and J. C. Siemens, "Energy Consumption and Return from Adding Nitrogen to Corn," *Illinois Research*, Vol 17, No 1 Urbana, Illinois. 1974.

10. Keener, H M, and W. L. Roller, "Energy Production by Field Crops," ASAE Paper No. 75-3021, Annual Meeting, Davis, California. June 1975.

11 Klass, D L, "A Perpetual Methane Economy – Is It Possible? *Chemtech*, March 1974. pp 161-168.

12 McFate, L. (Editor), "Food and Energy," *Farm Electrification Council*, Columbia, Missouri 1975.

13 Pimentel, David et. al., "Food Production and the Energy Crisis," *Science*, Vol. 182 November 1973.

14 Rice, C. E, Personal Communication, Agricultural Engineering Department, University of Georgia. Athens, Georgia 1975.

15. Wittmus, H, L. Olson, and D. Lane, "Energy Requirements for Conventional Versus Minimum Tillage," *Journal of Soil and Water Conservation*," Vol. 30, No. 2. 1975. pp. 72-75.

AGRICULTURAL POLICY INFLUENCES ON ENERGY USE IN AGRICULTURE

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In this discussion, I am going to review our basic agricultural policies and changes made to fit our current situation, then analyze the influence of these changes on energy use in agriculture and the challenges they present. Hopefully, this perspective will help us determine the highest pay-off in our research development and education programs concerning energy use in agriculture.

Our Agricultural Policy

The long-run goals of American agricultural policy are.

1. To provide ever-increasing quantities of food for our growing population, improve diets, provide food assistance to underdeveloped countries and provide foreign exchange.
2. To provide food at low cost to the American consumer — through continuous improvements in technology and efficiency all along the food chain.
3. To maintain farm incomes at a level comparable to what farmers' resources and talents would pay them in other occupations.
4. To conserve natural resources required for food production — soil, water, natural gas, petroleum, and others.
5. To maintain the commercial family farm in rural America as an institution through which labor, management and capital are applied to the land for efficient low-cost food production.

Institutions and programs in support of these goals include:

- A large, sophisticated system to provide up-to-the-minute information on supply, price, and marketing conditions
- An elaborate road, railroad, water and air transportation system
- A system of cooperative agricultural research supported by federal and state government to unlock the secrets of nature, improve technology and develop management systems for efficient and economical production of food and fiber
- A highly effective cooperative extension education system which provides specialist and county agents to help farmers and agribusiness managers adopt new technology quickly and profitably
- A responsible farm credit system to supply the fluctuating, growing capital needs of agriculture
- A whole system of price and income support, market development and production adjustment programs designed to keep farm incomes at socially acceptable levels and maintain a strong growing productive agricultural plant
- A free choice system in which farmers, input suppliers, processors and distributors can freely enter into new ventures, apply new technology, trade freely and seek new markets for their products with control of monopoly, support of cooperatives

Public interest and support for these goals ebb and flow with changing economic conditions. For example, from the early 1950's until 1973 farm production was increasing faster than demand and farm policy efforts were directed toward solving problems of chronic food surplus, maintaining farm price props, and disposing of surpluses. We retired 60 million acres from agriculture. There was plenty and the relative cost of food was declining steadily. Consumers were concerned with communism, Vietnam, and the environment but not about food.

Public support for research, development, and extension education to increase efficiency in agriculture was hard to maintain.

In 1972-1973 the situation abruptly changed. There was a 7% short fall in world production of food and feed grains in 1972-1973 caused by drought in Russia, India, Australia, South Africa and Asia. Then came the energy crunch, with a shortage of LP gas for crop drying and natural gas for fertilizer and agricultural chemical production. A poor U.S. crop in 1974 and a poor crop in Russia and west Europe in 1975 kept the pressure on food supplies.

With an inelastic demand for food, coupled with double-digit inflation, food prices skyrocketed. They made front page headlines. Food, agriculture, petroleum and fertilizer suddenly joined inflation and the environment as main topics of concern.

With U.S. petroleum reserves dwindling, agricultural exports took on new importance. Efficiency and our competitive advantage in world food production had suddenly become highly significant factors in acquiring foreign currencies with which to buy "liquid gold" petroleum.

These forces have brought major changes in emphasis in agriculture policy. We are now:

- Emphasizing full production and abundance
- Recommiting ourselves to food exports to nations with hard cash
- Providing food for aid in less developed countries (1 5 billion is our 1975 commitment)
- Committing ourselves to assist in rebuilding world food reserves
- Reemphasizing freedom from government restraint

Farmers have brought 30 million acres back into production and we are talking about our capacity to bring still more land into crop production. Private industry has expanded fertilizer production facilities, oil and gas exploration and development. Government funds for research have been expanded in energy and agriculture. The USDA and Agriculture Experiment Stations have shifted research funding to these problems. And the extension service has re-emphasized its commitment to agriculture.

To achieve our current goals, we will have to increase farm output more rapidly than the 2% rate of the past few years. This in turn will take large increases of inputs, specifically fuel, fertilizer and pesticides produced from petroleum and natural gas. Of the total energy used in the U S. the agricultural sector uses 13%. Slightly over 1/2 of this is for direct farm production, the remainder for marketing, processing and distribution.

Table 1
Estimated Energy Consumption in United States Food and Fiber Sector 1980

Fuel	Farm Crops	Production Livestock	Family Living	Food Processing 42 Industries	Marketing and Distribution	Input Manufacturing: Prepared Feeds	Animal Marine Fats & Oils	Fertilizer	Farm Machinery	Pesticides	Petroleum	Total
(Trillion Btu's)												
Gasoline	375.2	125.1	179.6	9.3	86.3	1.2	.3	—	—	—	—	776.
Diesel	301.6	100.2	1.0	—	902 6	—	—	—	—	—	—	1304.
Distilled Fuel Oil	—	—	68.3	68 1	—	3.8	2.9	3.0	1.2	.3	1.3	149.
Residual Fuel Oil	—	—	—	20.1	—	2.6	3.9	1.2	.7	.4	8.7	115.
LP Gas	100.0	33.4	114.5	97.5	—	3.2	.3	—	—	—	—	271.
Natural Gas	—	—	44.5	729.2	—	57.3	28.1	581.5	18.4	6.7	186.8	1652.
Electricity	15.1	45.3	81.4	464.5	—	39.2	.6.8	70.1	4.5	1.0	10.8	738.
Coal	—	—	9.8	153.3	—	.3	.3	1.5	5.4	1.7	1.3	173.
Other	—	—	—	6.2	—	—	—	2.0	1.8	.7	2.5	13.
Total	791.3	304.0	499.2	1548.3	988.9	107.6	42.7	659.4	32.0	10.9	211.4	5195.

Assumptions: 1. Current trends in output and input use to continue
2. Distribution of total Btu by fuel type would be the same as in 1971
3. Same quantity of energy per unit of output in 1980 as in 1970

Source The United States Food and Fiber Sector Energy Use and Outlook prepared by ERS, USDA for United States Senate Committee on Agriculture and Forestry, Committee print, September 20, 1974

Influence on Energy Use

The major influence of all these changes comes to bear on the export sector of agriculture primarily in demand for production of raw products which can be manufactured into food, livestock feed, textiles in importing countries. Influences are also felt in crops using large amounts of petroleum for production. Major crops affected are wheat, rice, cotton, tobacco, soybeans, and corn.

Domestic demand has been growing only slightly faster than the population increase.

In the short run there is no way to get the increased total food production needed without increased energy.

To farm increased acres and increase efficiency, farmers have already purchased much new farm machinery. This will take more diesel fuel, but less gasoline. Increasing intensity and crop yields will require more fertilizer, pesticides, and herbicides. This will require more natural gas. Drying larger quantities of grain will take more LP gas. Increased transport will take more diesel fuel.

In their excellent article on "Energy and the Food System" John and Carol Steinhart estimated that it takes nearly 10 calories of energy subsidy to the food system to obtain one additional calorie of food.[1] This energy subsidy has grown at the rate of about 1 to 1/2 calories per decade

[1] "Energy Use in the US Food System," John S. Steinhart and Carol E. Steinhart, *Science Magazine*, April 1974.

Figure 1
Energy Use in the Food System, 1940 through 1970, Compared to the Caloric Content of Food Consumed

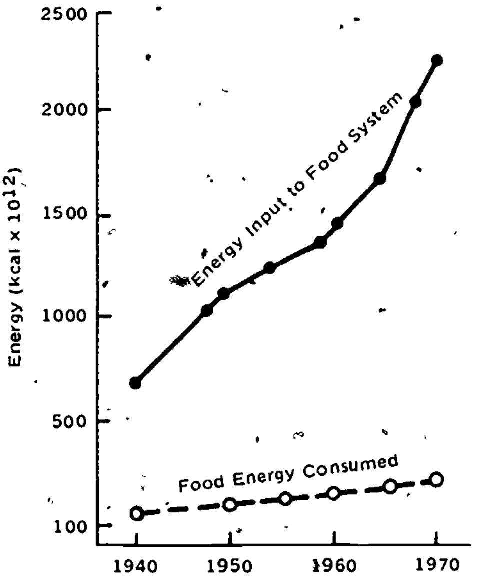


Figure 3
Labor Use on Farms as a Function of Energy Use in the Food System

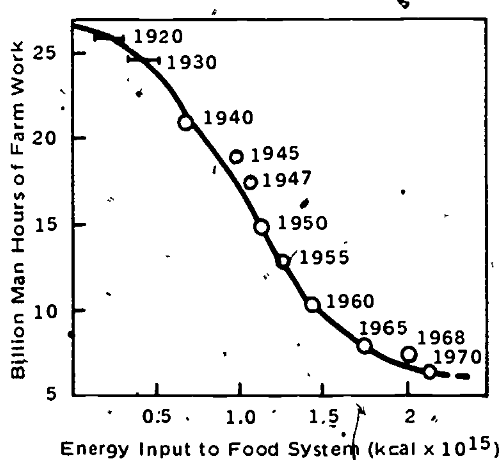


Figure 2
Farm Output as a Function of Energy Input to the U.S. Food System, 1920 through 1970

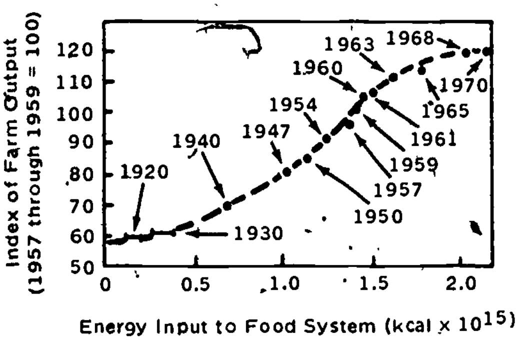
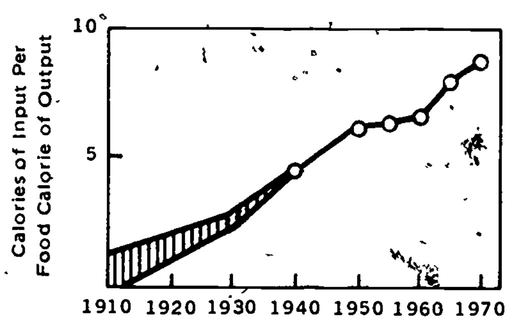


Figure 4
Energy Subsidy to the Food System Needed to Obtain 1 Food Calorie



(Figure 4). Their studies also indicate that each additional unit of farm output in the aggregate requires a greater than proportionate increase in energy input (Figure 2). Figure 1 shows energy input to the food system in relation to food energy consumed in the U.S. As the number of man hours of farm work has decreased (or as the productivity per man hour of work in agriculture has increased) total energy input to the food system has increased dramatically (Figure 3). Their data also show that since about 1960, energy required to replace each additional hour of farm labor has steadily increased.

Our food and fiber system has had about a 4% annual growth rate in energy needs, about the same as for the entire nation. The increase in on-farm energy used from 1950 to 1970 was 73% (Table 2). Grand total of energy used in the food system increased 92% in the same period.

About 25% of the energy used in crop production goes into exports.

Exact increases in quantities of fuel associated with 10% increase in production at the margin for any of our export crops are quite difficult to determine and I do not have good estimates. Clearly, however, these magnitudes ~~will be~~ substantially greater than the average annual increases during the past decade if the increase in production is to come from increased output per acre. It will be significantly greater than the average requirements per unit of production in 1975.

Each additional unit of food production will require more energy than the previous unit. This will remain true until we have either a major breakthrough in technology which provides more output per unit of energy or we are able through research and development to create and apply a large number of small improvements in efficiency of energy use.

Table 2
Energy Use in the United States Food System, Kilocalories

Energy Use	All Values are multiplied by 10^{12} 1950	1970	Percent Change 1950-70
On Farm			
Fuel (direct use)	158.0	232.0	+ 47
Electricity	32.9	63.8	+ 94
Fertilizer	24.0	94.0	+292
Agricultural Steel	2.7	2.0	− 26
Farm Machinery	30.0	80.0	+166
Tractors	30.8	19.3	− 37
Irrigation	25.0	35.0	
Total on Farm	303.4	526.1	+ 73
Processing Industry			
Food Processing Industry	192.0	308.0	+ 60
Food Processing Machinery	5.0	6.0	+ 20
Paper Packaging	17.0	38.0	+123
Glass Containers	26.0	47.0	+ 81
Steel Cans and Aluminum	62.0	122.0	+ 97
Transport (fuel)	102.0	246.9	+141
Trucks and Trailers (manufacture)	49.5	74.0	+ 49
Total Processing Industry	453.5	841.9	+ 86
Commercial & Home			
Commercial Refrigeration and Cooking	150.0	263.0	+ 75
Refrigeration Machinery (home and commercial)	25.0	61.0	+144
Home Refrigeration and Cooking	202.3	480.0	+138
Total Commercial & Home	377.3	804.0	+113
Grand Total	1134.2	2172.0	+ 92

Information was based upon "Energy Use in the U S Food System," John S Steinhart and Carol E Steinhart, *Science Magazine*, April 1974

Challenges We Face

The Search for Energy Efficiency

These new demands to increase food production, coupled with growing scarcities and the certainty of higher prices of crucial petroleum and natural gas present exciting challenges to all of us who produce and deliver scientific information. They may be even more challenging to those who deal in the world of profit and loss.

I see no way to secure the increased food output we must have by replacing today's technology with out-moded production techniques or by giving up the labor efficiencies secured through agricultural mechanization systems. Rather, the increase will have to come from either greater physical inputs or more effective use and management of present inputs and new technology.

We have no choice but to expand our efforts to secure less energy-intensive methods of production to reduce the scarce gasoline, diesel fuel, LP and natural gas per unit of output. And we will have to work on all scientific fronts:

- Biological, for example, to attach nitrogen-getting bacteria to the corn root to reduce nitrogen fertilizer requirements

  This would cut down use of scarce natural gas. This alone could reduce the energy required for growing corn by 30-40% (Table 3).

Table 3
Energy for Corn Production
Thousand K-Cal/ACRE

	1954	1970
Nitrogen	227	941
Drying	60	200
Machinery	300	420
Fuel	340	340
Fertilizer, Chemicals, Seed	92	200
Transportation	45	70
Irrigation	27	34
Labor	9	5
Total Input	1100	2210
Total Output (Parens = bushels/A.)	4133 (41)	8165 (81)
Output/Input	3.7	3.7

Source Gerald Isaacs, Purdue Energy Conference of 1973, Purdue Energy Engineering Center, page 137.

- Physical, for example, solar grain drying
- Chemical, for example, to find improved, lower cost pesticides for use with various crop and tillage systems
- Management, for example, to determine more profitable, lower cost combinations of resources of all kinds (tillage, drying, pest management, machinery, etc.), for the production of crops and livestock

This is especially true for large input items such as fertilizer, tractor and crop drying fuel whose use may be related directly to crop yields.

To do this, we will have to increase the manpower in research, product development and extension programs at more than an annual rate of 2% or 3%. To successfully meet the new demands we will have to double, triple or even quadruple the resources devoted to energy-related problems in producing crops, especially those for export.

Conclusions

In conclusion, our problem of rebuilding food stocks and maintaining exports is clear The seriousness of declining petroleum and natural gas supplies and their higher prices is real. Both are headline news. The public knows about them and is vitally concerned. What the public does not understand is the magnitude of the scientific breakthrough necessary to both increase farm output, and do it with less petroleum and natural gas They understand still less the manpower and cost required to achieve these breakthroughs. With public attention focused on food and agriculture more intensively than any time in the last 25 years, right now is the time for us to redouble our efforts to secure its support for increased scientific research and education.

To do this we will have to pool our best brainpower to:

1. Determine which research offers the biggest potential public payoff
2. Recommend priorities
3. Help the public to understand this problem as well as it understands putting a man on the moon

We will have to articulate these potentials to agricultural leaders, legislators and congressmen so clearly that they can secure the support of the general public for them. And we will have to formulate requests for additional funding support in concrete, clear, concise terms acceptable to legislative finance committees and agricultural support groups.

ENERGY CONSERVING UNITS THAT CONTROL ANIMAL ENVIRONMENT AND IMPACT OF ANIMAL ON ENVIRONMENT

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Energy, environment, and equality are among the most popular terms ever adopted by virtually every individual in our society. Production, population, and pollution represent a similar triplet of commonly used terms for fashionable conversations and also multi-disciplinary research and extension activities. In retrospect, overwhelming attention and emphasis were directed to these areas over a short time frame and much of the glamor has not yet subsided. However, all indications are that at least the technically based topics will represent high priority and fertile work areas for a long time.

Recently, many opportunities for funded research in waste management and energy have catalyzed increased activity, and, thus, technological advances. Initially, major efforts were directed toward characterization work and then state-of-the art investigations which were soon followed by the development of many simple but necessary solutions. Long term commitments to these areas have allowed development of many competent programs integrating expertise from many discipline areas, which has established the framework for innovative ideas currently being developed as a result of continuing efforts in basic work areas. It is this innovative phase that is so highly sought but is most difficult to perceive and expedite.

Although many articles have been recently written on energy conservation in agriculture, very little attention has been directed to energy ramifications of livestock production systems. The information dearth that exists concerning energy relationships of various production systems makes it difficult to secure background information for comparison. Currently, research plans on solar energy utilization for livestock production systems are being invited for a cooperative ARS, USDA, and state agricultural experiment stations program (Reece *et al.*, 1975). Basic objectives are to develop methods and determine the technical and economic feasibility of using solar energy for heating and cooling of livestock facilities, thereby reducing the use of energy derived from petroleum and electricity.

Solar energy systems for heating and cooling buildings are already well developed, and the number of solar heated buildings is expected to increase to several hundred this year. Among the advantages of solar energy is that such energy greatly exceeds our annual rate of consumption, is perpetually available the world over, and most importantly free. Although solar energy has many advantages, there are several disadvantages that have restricted its use to date, which are basically the large collection area needed and storage requirements. Inherent problems are that solar energy is diffuse, thus, large collector surfaces are needed to absorb such energy; and because solar energy is intermittent, efficient storage is mandatory. The cost of overcoming these two major disadvantages has in the past made solar energy more costly than fossil fuels.

Total U. S. oil consumption is 17 million barrels per day. Gross estimates are that 30% of all oil is used for automobiles and 15% for all agriculturally related activities, whereas only 2-4% is used at the farm level. Introductory statements in the *Cooperative Solar Energy Utilization for Livestock Production Research Plan* indicate that the major energy requiring livestock systems are:

(1) poultry, which require 140 to 170 million gallons of liquified petroleum gas (LPG) annually for heating of shelters;
(2) swine, which consume electrical energy requiring about 41 million gallons of oil;
(3) the milking phase of dairy production, which uses electrical energy requiring 243 million gallons of oil.

It is observed that if solar energy could be used to replace 50% of the energy used in livestock production, about 220 million gallons or about 5 million barrels of oil could be saved annually.

Major objectives of this project are:

(1) conduct proof-of-concept studies to determine the feasibility of solar energy utilization in livestock facilities;

(2) develop design parameters for solar collectors for the most economic and efficient use of solar energy in livestock production systems,

(3) explore the use of solar energy to facilitate the handling and drying of livestock waste.

Second generation studies based on initial results will be developed to optimize the use of solar energy in the most promising livestock systems. This optimization process is outlined as,

(1) economic analyses of solar energy as a substitute for conventional energy sources,

(2) development of computer simulation models to permit study of a large number of combinations or conditions,

(3) design of solar energy collection and storage equipment for specific application to livestock shelters and associated waste management systems;

(4) coordination of solar energy use in livestock production with advanced techniques for energy conservation

Ultimately, full scale, solar powered livestock production units will be developed to demonstrate the commercial feasibility of solar energy utilization in the livestock industry

State-Of-The-Art

The U S. Senate Committee on Agricultural and Forestry in January this year requested CAST (The Council for Agricultural Science and Technology) to prepare a report on the potential for energy conservation in agricultural production. This report, Number 40 dated February 6, 1975, precedes earlier report, Number 14 on "Energy in Agriculture," also prepared by CAST The latest report, "Potential for Energy Conservation in Agricultural Production," (CAST, 1975) concluded under the livestock section "In the area of livestock production, studies of the use and potential conservation of energy are generally lacking."

Substantial amounts of the grain produced in the United States are fed to animals Hence, a large portion of the energy used for grain production directly supports livestock production and indirectly human nutrition. Data in the CAST report show that the energy in crop residues of corn, sorghum, and wheat is approximately equal to the energy in the grain. Feed cost-effectiveness and utilization efficiency could be increased by making more extensive use of these feed resources, thus, a number of innovations in forage and hay handling methods as well as refeeding of manure have developed in the last few years.

Environmental control of animal housing for more efficient use of energy has resulted in improved utilization of feed and healthier conditions for livestock. Annually, approximately 3 billion broiler chickens, 115 million turkeys, and 300 million replacement pullets for egg production are reared in the United States which require heat energy for the brooding phase of production. Approximately 140 to 170 million gallons of LPG or the equivalent of about 15×10^{12} Btu are used annually because about 40 to 50 gallons of LPG are required per 1000 birds for brooding.

Approximately 100 million swine are produced annually in the United States, which requires about 3×10^{12} Btu's of energy for the farrowing and brooding phase. This heat energy is currently derived from both electricity and LPG.

About 1.5 x 10^{10} Btu's are used annually in dairy production to cool milk, heat water for cleaning milking equipment, and for space heating of milking facilities Approximately one-half of this energy is in mechanical form, derived from electricity, for cooling milk.

The current *Cooperative Energy Research Program Plan* observes that almost all of the heat energy consumed in poultry and swine production is used at a temperature that can be achieved with relatively low-cost solar collectors. Therefore, if solar energy utilization were coupled with advanced techniques of energy conservation and utilization in poultry and swine production, preliminary calculations referenced in this energy research plan indicate that economically feasible systems could be developed which would produce essentially all U.S. poultry and pork products independent of petroleum energy sources It is further observed that the energy consumed in dairy production is at elevated temperatures that will require advanced solar collector technology However, solar collectors now under development using thin-film, selective surfaces, and concentrator systems make possible the visualization of solar energy systems for dairy production.

Waste management must also be considered in energy utilization and conservation plans for livestock production facilities because waste management has become an integral component of the overall system and waste represents potential energy. Waste management needs are having significant impact on the design of housing units as emphasis is being placed upon environmental control for increased animal performance and waste management schemes necessitating increased energy requirements for ventilation, collection and transport, pretreatment, and terminal management Attention must be placed on waste utilization rather than degradative pretreatment pursuant to disposal because waste represents a valuable resource, whether used simply as fertilizer or inputed into more elaborate schemes as methane generation, refeeding, and reprocessing. Waste management systems emphasizing utilization and, in fact, land recycling also satisfy the no-discharge regulatory criteria; thus, positive impetus for implementation of utilization schemes exists.

The CAST report noted that, "Environmental control of animal housing for more efficient use of animal heat has resulted in improved utilization of feed energy and healthier conditions for livestock. The effort continues to find alternative ways that may give better energy utilization to obtain optimum environmental conditions."

The poultry industry was the first commodity interest to recognize and seek to change the environment in which birds and eggs are produced. Most early efforts in reducing energy consumption in broiler production were directed toward improving the bird and its diet while efforts directed toward housing and associated equipment came later. In the Southeast, the bird and its environment began to receive attention in the late 1950's with the major objective being to reduce broiler and egg production costs. The basic approach was to make the poultry house more comfortable or desirable through the use of adequate insulation and controlled ventilation which also allowed an increase in bird density. Through the years, the major objective remained the same, but various degrees of controlled environment have been investigated and used.

Layers

The electric power consumption and costs for ventilation with layers on the floor were determined in the early 1960's, when this was the prevalent housing scheme (Driggers, 1965). Data for two pole-type construction houses with insulated roof and sidewalls are summarized in Table 1. Houses had roosts over a dropping pit in the outside sections, and birds were allowed access to the floor in the center. With the waterers and feeders positioned on the roost, most of the droppings went directly into the collection pit. Both houses contained about 8,000 birds and total fan capacity was equal. The cost per bird difference shown in Table 1 is primarily due to the number of fans in each house. There were 19 fans in House #1 and 12 fans in House #2. Although the total capacity was about equal, operating costs are different due to the lower efficiency of smaller fans.

Table 1
Layers on Floor
Electric Power Consumption and Cost @ 1.5¢ per KWH for Total Enclosed Houses with Equal Total Ventilation Capacity, 1963

	Power Consumed (KWH)	Total Cost	Cost/bird	KWH/bird
House #1 (19 Fans)	34,515	$517.73	6.47¢	4.31
House #2 (12 Fans)	25,394	$380.91	4.76¢	3.17

Energy consumption and costs in a totally enclosed caged house were investigated in North Carolina as early as 1969 (Driggers, 1971). Power consumption data for the housing of 30,555 birds on September 7, 1969, at 23 weeks of age through their laying period until November 28, 1970, are recorded in Table 2.

Energy costs of 9.8¢ per bird housed (Table 2) were considered reasonable because at that time eggs were 33 to 38¢ per dozen, and it certainly did not take many eggs to pay electric power costs. The major cost was for ventilation, and yet this represented less than the value of two eggs per bird housed. Mechanical ventilation is absolutely necessary in wide houses such as this to obtain the required air flow near the center during summer months. Thus, when a commitment is made to place four birds in a 12" x 18" cage, mechanical ventilation is essential.

Energy costs for commercial layers in three types of houses in North Carolina were later studied to compare both cost and performance of commercial layers grown in different type units (Driggers and Harwood, 1971).

A mechanically ventilated unit (House #1), evaporatively cooled unit (House #2), and a conventional California-type caged laying house (House #3) were evaluated. House #1

Table 2
Caged Layers
Electric Power Consumption and Costs @ 2¢ per KWH for Totally Enclosed, Automated and Mechanically Ventilated House, 1969

Equipment for House #1 (Mechanically Ventilated)	Power Consumption KW-HRS	Cost @ 2¢/KW-HR Total	Cost @ 2¢/KW-HR Per bird housed
Feeders & Egg Gatherers	15,160	$ 303.20	0.9923¢
Fans	68,280	1365.00	4.4693¢
Lights	38,980	779.60	2.5514¢
Pit Cleaners	27,060	541.20	1.7712¢
Total	149,480	$2989.60	9.7842¢

was the one previously studied and reported on in Table 2. House #2 was identical to House #1 in construction and equipment, except that this unit was equipped with evaporative cooling. House #3 was a 10' wide conventional cage laying unit with curtain sidewalls and no mechanical ventilation, automatic feeding, or egg gatherers. House #3 had no insulation, whereas House #1 and #2 were clear span structures with urethane insulation in both the sidewalls and ceiling Both House #1 and House #2 had mechanical pit scrapers for manure removal Houses #2 and #3 were located on the same farm, while House #1 was located in another community

Total costs for the three houses are summarized in Table 3 with energy included in overhead. Data indicates that more eggs were produced per hen with a lower percent undergrade and less feed input in the mechanically ventilated house and, in fact, the total cost per dozen eggs produced was the smallest. Although data for the evaporatively cooled house indicates somewhat better economics than the conventional house, high in-house humidity during the summer period resulted in very uncomfortable conditions. Results of this study were very instrumental in directing efforts in North Carolina toward totally enclosed mechanically ventilated livestock production units as the most cost-effective in spite of the additional energy inputs because of increased production resulting from the controlled in-house environment. Even though there are no comparisons or replications, this background type data shows that high density, totally enclosed mechanically ventilated houses represent an economical production unit. In fact, mechanical ventilation may be more economical in most cases than the so-called conventional house because production generally declines in either extremely cold or hot weather, and thus fluctuating egg production is eliminated

In 1969 work was initiated by Driggers in North Carolina with a commercial producer to modify an existing building for caged brooding of chicks At the time of this study, caged brooding was in its infancy, and thus the major interest was to secure background data A major reason for caged brooding is that birds that will be laying in cages should be brooded in cages, and also a unit of labor can manage more birds in cages than on the floor Ideally, the study unit was not the best, but it was one of the first to be constructed in North Carolina The house was converted from a floor system, and the approximately 3/4" of styrofoam in both the walls and ceilings was not sufficient for a house requiring a brooding temperature around 90°F Additional fans were installed, and the production strategy changed from approximately 15,000 birds on floor to about 25,000 chicks in cages. Additionally, an oil-fired hot water circulating system for heat was installed over the cages. Waste does not have to be removed daily by the pit scraping system because of the limited quantity produced by baby chicks.

Energy costs for this house represent background information for this brooding method (Table 4) Fuel data was not available so fuel costs are not included in the column under heat. Therefore, cost or kilowatt hours indicated

Table 3
Commercial Layers

Performance in Three Types of Caged Houses for About A One Year Laying Period, 1970

	(House 1) Mechanically Ventilated Farm B	(House 2) Evaporatively Cooled Farm A	(House 3) Conventional Farm A
Cost per dozen eggs produced			
Feed	$ 155	$.157	$.164
Labor	.011	.015	.035
Miscellaneous	.004	.009	.013
Hen depreciation	.069	.083	.092
Overhead	.031	.032	.007
Total	$.270	$ 296	$.311
Number hen houses	30,555	30,945	13,305
Percent livability	81.6	77.4	64.5
Eggs per hen housed	190.3	181.0	167.9
Feed per dozen eggs (lbs.)	3.715	3 905	3.951
Undergrade eggs (Percent)	6.7	13.1	11.4

Table 4
Caged Brooding
Electric Energy Consumption and Costs for 25,000 Chicks, 1970

Flock Period	Power Consumption (KWH)					Cost @ 2¢/KWH	
	Fans	Feeders	Lights	Heat	Total	Total	Per 1000 Birds
1/70-3/70	1033	233	2558	979	4803	$ 96 06	$3.84
3/70-5/70	2084	286	1861	638	4869	97.38	3.90
5/70-7/70	2138	191	1820	79	4228	84.56	3.38
7/70-9/70	2944	236	1872	57	5109	102.18	4.09
12/70-1/71	738	198	2173	871	3980	79.60	3.18

under heat is strictly for the energy required to operate the boiler burner and circulate hot water through a piping system over the cages. Birds in this house were brooded for approximately 9 weeks and then removed to a grow-out house before being placed in a laying house at approximately 20 weeks of age.

The fuel costs would certainly have been less in a totally enclosed house with proper insulation. However, the electrical energy costs per 1000 birds was judged to be reasonable, although total energy costs during cold periods would be higher due to fuel requirements which could not be evaluated in this study.

Broilers

Today the use of environmentally modified housing in the broiler industry lags similar advances in laying units by some 5 to 10 years. Tests were run during 1973 and 1974 at NCSU to examine the influence of housing techniques on energy consumption for broiler production (Baughman *et al.*, 1975). Two, 36' x 96' houses were investigated. One unit was a conventional uninsulated house with dropped curtain sides. The other unit was enclosed and insulated resulting in an average roof and sidewalls "R" value of approximately eight and had thermostatically controlled fans. Both houses had identical feeding and brooding equipment. The dirt floors in each house were divided into four equal pens.

To date, three trials with broilers have been completed, and one trial with turkeys is underway. Broiler data for average body weight, feed conversion and mortality are summarized in Tables 5 and 6. This data summary for the three trials indicates that statistically significant differences in average body weight, improved feed conversion and lowered mortality can be expected in environmentally modified houses. The following gains in performance per 1000 broilers would be expected based upon the trials documented in these studies:

1. 140 pounds more live broilers produced per 1000 chicks placed.
2. 130 pounds less feed consumed per 1000 chicks placed.
3. 8 more broilers marketed per 1000 chicks placed.

Table 5
Broilers
Performance Data for Conventional Versus Environmentally Modified Housing
(Density .73 sq. ft./bird)
(4572 birds/house)

	Average Body Weight	Feed Conversion	Mortality
Trial 1—Autumn			
Conventional House	4.34	2.16	3.45%
Environmental House	4.34	1 96	2.79%
Trial 2—Winter			
Conventional House	3.53	2.14	3.50%
Environmental House	3.78	1.99	2.76%
Trial 3—Summer			
Conventional House	4.35	2.02	3.00%
Environmental House	4.54	2.00	2.40%

Table 6
Performance Summary for Conventional Versus Environmentally Modified Housing
Summary of Trials 1, 2 and 3
(Density .73 sq. ft./bird)
(13,716 Birds)

	Average Body Weight	Feed Conversion	Mortality
Conventional House	4.08	2.11	3.31%
Environmentally Modified	4.22	1.98	2.55%

Complete energy records were maintained for Trial 2 which started February 5, 1974, and Trial 3 which ended on August 9, 1974. The birds in both houses were fed identical rations and were at the same densities. Energy consumption and cost projections are shown in Table 7.

Table 7
Energy Costs
As of September 15, 1975

LPG (40¢/gal.)	0.4362¢/1000 Btu	1 7309¢/1000 kcal
Electricity (3¢/kwh)	878¢/1000 Btu	3.4863¢/1000 kcal
Feed (7¢/lb.)	1.176¢/1000 Btu	4 667¢/1000 kcal

Results for the last two trials are shown in Tables 8 and 9. About 4500 chicks were started in each house for Trial 2 during the late winter-early spring, with the winter of 1973-74 being milder than usual. Live weight production was 16,170 lbs. for the conventional house and 17,268 lbs. for the environmental house, resulting in over 1000 pounds more meat on 200 lbs. less feed and 300 gallons less LPG for the environmental house. Although the electric require-

Table 8
Broilers

Energy Consumption
Trial 2

Conventional House (16,170 pounds of bird live weight)

	Amt. Used	Energy Used Btu (Millions)	Energy Used kcal (Millions)	Btu/lb*	kcal/lb*	Cents/lb*	% Total Energy Cost
LPG	700 gal	64	16	3969	1000	1.7316	10.2%
Elect	1430 kwh	5	1	302	76	.2653	1.56%
Feed	34626 lb	206	52	12746	3212	14.9896	88.24%
		275	69	17017	4288	16.9865	100.0%

Environmental House (17,268 pounds of bird live weight)

	Amt Used	Energy Used Btu (Millions)	Energy Used kcal (Millions)	Btu/lb*	kcal/lb*	Cents/lb*	% Total Energy Cost
LPG	400 gal	37	9	2124	535	.9265	6.0%
Elect	2933 kwh	10	3	579	146	.5095	3.3%
Feed	34434 lb	205	52	11869	2991	13.9586	90.7%
		252	64	14572	3672	15.3946	100.0%

*Per pound of bird live weight

Table 9
Broilers

Energy Consumption
Trial 3

Conventional House (19,911 pounds of bird live weight)

	Amt. Used	Energy Used Btu (Millions)	Energy Used kcal (Millions)	Btu/lb*	kcal/lb*	Cents/lb*	% Total Energy Cost
LPG	136 gal	12	3	626	158	.2734	1.87%
Elect	1129 kwh	4	1	194	49	.1708	1.23%
Feed	40290 lb	240	60	12044	3035	14 1643	96.9%
		256	64	12864	3242	14.6085	100.0%

Environmental House (20,753 pounds of bird live weight)

	Amt. Used	Energy Used Btu (Millions)	Energy Used kcal (Millions)	Btu/lb*	kcal/lb*	Cents/lb*	% Total Energy Cost
LPG	89 gal	8	2	393	99	.1715	1.16%
Elect	3983 kwh	14	3	655	165	.5751	3.90%
Feed	41486 lb	247	62	11899	2998	13.9932	94.94%
		269	67	12947	3262	14.7398	100.0%

*Per pound of bird live weight

ments were higher for the environmental house, the total energy used was less for this unit It is noteworthy that feed costs are a full cent per pound of bird produced less in the environmental house Thus, environmental houses show greatest advantages during cold periods due to less LPG consumption and better feed conversion efficiencies.

Data for Trial 3 (Table 9) conducted during the summer showed that the conventional house had a lower energy cost per pound of live bird, but the difference was much less than for the colder period trial. Average energy data for Trials 2 and 3 (Table 10) show that average costs for the environmental house for both warm season and cold season periods are still over a half of a cent per pound less Electrical requirements for the environmental house are over three times greater than the conventional fans An overall net energy savings is achieved with the environmental house with consistently larger conservation of feed and LP gas, along with the opportunity to produce more chickens per housing unit.

It is interesting to note that in both tests and both houses, the main and most expensive source of energy is feed This implies that continued effort should be directed at more efficient feed conversion and using as little feed as possible for heat energy to maintain body temperature

Swine

A revolution in swine production has occurred in the Southeast during the last five years North Carolina has more large swine operations of 100 sows or more than any other state in the nation The Swine Development Center at the Upper Coastal Plain Research Station in Rocky Mount, North Carolina, provides an excellent facility for demonstration of a total swine program emphasizing environmental control This swine center is unique in that it is a cooperative effort of the Division of Research Stations, N C. Department of Agriculture, the N. C Agricultural Experiment Station, and the N C Agricultural Extension Service, and particularly that it is operated as a commercial swine production facility (Driggers *et al*, 1973).

Complete production and financial summaries have been printed (Stanislaw *et al*, 1975), and thus the emphasis in this summary will be on electric energy and fuel heating costs. The totally enclosed 16 crate farrowing house and the totally enclosed breeding barn, which accommodates 18 sows and 9 boars, were equipped in April 1974 to measure the electrical energy consumption in the two buildings The farrowing house is well insulated and mechanically ventilated A fan at one end of this unit is used for underfloor ventilation, while the sidewall fan is used during warmer seasons when additional airflow is required (Driggers, 1974). During the winter, this building is heated to approximately 70°F with a warm air furnace. Supplemental heat lamps are provided in the pig creep areas. During the summer, flexible ducts are attached to the metal branch ducts and a cool stream of conditioned air is directed into the front of each farrowing crate This zone air-conditioning

Table 10
Broilers

Averaged Energy Consumption
for
Trial 2 and Trial 3

Conventional House (36,081 pounds of bird live weight)

	Amt. Used	Energy Used Btu	Energy Used kcal	Btu lb*	kcal lb*	Cents lb*	% Total Energy Cost
		Millions					
LPG	836 gal	77	19	2124	535	9268	5.9%
Elect	2559 kwh	9	2	242	61	.2127	1.4%
Feed	74916 lb	112	28	31[illegible]	784	14 5343	92.7%
		198	49	5480	1380	15.6738	100.0%

Environmental House (38,021 pounds of bird live weight)

	Amt. Used	Energy Used Btu	Energy Used kcal	Btu lb*	kcal lb*	Cents lb*	% Total Energy Cost
		Millions					
LPG	489 gal	45	11	1179	297	.5144	3 4%
Elect	6916 kwh	24	6	620	156	.5457	3 6%
Feed	75920 lb	114	29	2995	755	13 9775	93 0%
		183	46	4794	1208	15.0376	100.0%

*Per pound of bird live weight

system is intended to envelop the sow in a cool stream of air, rather than cool the entire inside of the farrowing house. A 2-1/2 ton air-conditioner is used.

Results for the initial 12-month period represent background data, which must be viewed in light of the fact that this total production facility has returned a continuous profit since being placed into operation. Additionally, cost-effectiveness data derived from this pilot unit has been duplicated both throughout North Carolina and around the nation. (See Table 11.)

Table 11
Swine

Electrical Energy Consumption In An Environmentally Controlled Farrowing House and Breeding Barn

Production Criteria	Energy Consumption Ratio – KWH/Production Criteria	
	Farrowing House Total Energy = 28018 KWH	Breeding Barn Total Energy = 19703 KWH
88 8 Sows	315 KWH/Sow	229 KWH/Sow
202 Sows Farrowed	139 KWH/Sow Farrowed	91 KWH/Sow Bred
1943 Market Hogs	14 4 KWH/Market Hog	10 KWH/Market Hog

Electric energy consumption in the farrowing house for a 12-month period was 28,018 kwh During this period the sow herd averaged 88.8 pigs, farrowed 2.27 litters per sow for a total of 202 sows farrowed and 1943 pigs marketed. Thus, electric energy consumption can be expressed as 315.52 kwh per sow in the herd, 138.7 kwh per sow farrowed, or 14.42 kwh per pig sold. The most meaningful figure is the 14.42 kwh per pig sold. This figure can be used to arrive at the total energy cost per pig sold at the local rate of 3.8¢ per kwh or extrapolated to determine cost at a particular site. This energy requirement is judged to be most reasonable because supplemental heat is generally provided in these type structures; and if insulation is not adequate, larger amounts of heat per pig would be required. The cost for LPG to operate the furnace in this building has dramatically increased during the last year, due to a doubling of costs from $194.88 in 1972 and $152.99 in 1973 to $424.84 in 1974.

The breeding barn was designed on basis of experience with air-conditioning in the farrowing house. Historically, this component has received the least attention, but actually is one of the most important in the total production cycle. When sows are farrowed continuously, it is impossible to circumvent reduced conception during hot weather periods. Improved performance of the breeding herd has resulted in conception rates of 90.4% in 1972, 87.2% in 1973, and 93.3% in 1974. Therefore, for the past three years the conception rate of this herd has averaged 90%. Most commercial producers would be extremely pleased if such a rate could be achieved on a continuous basis. Power consumption in the breeding barn for the previously presented herd statistics, based on the electric consumption of 19,705 kwh, may be expressed at 221.9 kwh per sow in the herd, 90.81 kwh per sow bred, or 10.14 kwh per pig sold.

The energy consumption of approximately 10 kwh per pig sold is not an unreasonable figure if conception rates of over 90% can be maintained. Net farm income can be increased by approximately $7700 for each 10% gain in conception rates based upon a $40 hog market, corn at $3 per bushel, and soybean oil meal at $8 per hundredweight for a 90 sow herd. Therefore, a producer can afford to spend up to $7700 per year to ensure a 10% increase in the conception rate. This expenditure may be annual fixed or operating costs for better breeding facilities, methods, and management required to obtain the increased conception rate (Driggers, 1975; Driggers *et al.*, 1975).

Although the energy consumption figures obtained for the environmental control units at the Swine Development Center may not be typical throughout the industry, they are representative of housing systems rapidly gaining producer acceptance. Additional field studies are needed at commercial enterprises so that meaningful estimates can be made of energy requirements and cost benefits for this type livestock production unit. Data retrieved to date refutes many myths concerning the cost of controlled environmental structures, and thus, Driggers stresses that the question is changing from "Can I afford to control the environment?" to "Can I afford not to control the environment of a livestock production unit?"

Waste Management

Waste treatment and energy conservation have become unanticipated synonyms which are gaining accelerated attention from both the general public and trained professionals. Two forms of energy-rich materials in animal waste are nitrogenous and carbonaceous compounds. Recently the "new technology" of using animal waste as a fertilizer was reintroduced and has since gained wide acceptance. The conversion of waste organics to methane gas for subsequent utilization represents an energy conservation scheme commonly practiced at sewage treatment plants where sewage sludge is anaerobically degraded to methane and carbon dioxide. Manure refeeding represents an exciting potential for direct recovery of waste nutrients. Production of single-cell protein, chemical extraction of nutrient rich materials, and even more exotic processes, such as conversion to oil, gasification, and reforming to building material lure public attention. However, the principles or concepts used in the treatment and utilization of waste are generally well established. Additionally, it is becoming apparent that a higher level or type of technology must be employed to first seek solutions for pollution-related problems, and second to recover appropriate constituents of animal waste for reuse. It is the application of these fundamental principles to this new starting material that is leading to a wide variety of simple and innovative technologies.

Utilization Alternatives

The simplest utilization scheme is to use the waste as it exists or, at some diluted state. Two further alternative processes are separation and conversion, both of which are dependent on constituent concentration for recovery efficiency.

The most practical and cost-effective waste management scheme may be to circumvent pretreatment alternatives by direct land application using either mechanical techniques or animals on pasture. As an example, consider a 100-cow dairy which returns all of its manure and wastewater back to soil-cropping systems. Assumptions include that 50% of the nitrogen and all of the phosphorus and potassium in defecated manure from 100 cows is available as crop fertilizer, and commercial fertilizer costs are about 30¢ per pound of nitrogen, 15¢ per pound of phosphorus, and 10¢ per pound of potash. Additionally, a 100-cow dairy would generate 1,916 tons of fresh manure per year which would contain 22,995 pounds of nitrogen, 5,475 pounds of P_2O_5 and 20,805 pounds of K_2O. Based on these assumptions, fertilizer nitrogen would have a value of $3,450, phosphorus $410, and potash $2290. Thus, the total potential fertilizer value for manure generated by a 100-cow dairy per year would be $6,150. Obviously, the real challenge would be to make optimum utilization of all of these fertilizer constituents.

A recent paper on the utilization of manure from Texas (Sweeten *et al.*, 1974) reported that the demand for feedlot manure in the last 12 months has reached an all-time high as a result of fertilizer shortages. In 1973 when Texas reached its peak feed cattle population of 4.4 million head, most of the 4 million tons of manure produced, plus carryover from previous years, was utilized on cropland by high plains farmers. Today with Texas feedlots operating at only 56% of capacity, it is reported that nearly all manure is being handled on a steady-state basis and some even have a backlog of orders.

Although manure has fertilizer value, and thus represents an energy source, a considerable amount of work is required to collect, stockpile and distribute animal waste. Collection requirements are estimated by Sweeten *et al.*, to be 40,000 Btu per ton based upon observed machine operating times and fuel consumption rates. The amount of energy required to haul and distribute manure ranges from 80,000 Btu per ton for a 5-mile distance to 120,000 Btu per ton for 10 miles. A summary of this data on a state-wide basis indicates that while the per acre energy saving is significant, only 400,000 acres of land could be fertilized with feedlot manure in Texas, which would result in a total savings of 1.8×10^{12} Btu/year. The estimated total energy for production and distribution of all fertilizer used in Texas is about 52×10^{12} Btu/year. Thus, the energy saved by using manure is only about 3.5% of the total fertilizer energy requirement of Texas. Nevertheless, manure can represent a significant energy saver in localized areas and such terminal management minimizes treatment costs while complying with the most rigorous regulatory criteria.

Separation Processes

Waste streams composed of many components may have a higher value if a certain fraction can be separated or removed for further processing. This separation can be conveniently subdivided into physical and diffusional operations depending upon the directive objectives. Physical or mechanical separation has been applied to animal waste slurries using several appropriate unit processes. Basically, the end product is the solids or heavy fraction of the waste input. Selection of the proper separator depends upon the desired product.

Liquid dairy manure solids have been separated and utilized to produce a fibrous building board type material with various degrees of moisture by cooperative efforts between the Biological and Agricultural Engineering and Forestry Department at NCSU. Dairy solids can be used in processes which tolerate moisture contents of 85% or more, such as direct refeeding with ensiled feed or wet process structural board. If these solids were dried, then a wide spectrum of technologies could be investigated that range from particle board to fireplace logs.

Ammonia has been stripped from waste solutions by ion exchange and diffusion. Both processes rely on high ammonia concentration and yield a much more concentrated fertilizer product. Basically, the goal of all separation processes is to selectively remove waste constituents with the highest intrinsic value. Waste organics may be considered more carefully as competition for fossil fuel and natural gas becomes keener.

Conversion Processes

Often it is more advantageous to use chemical or biological conversion processes instead of phase separation for production or removal of utilization constituents. Biological conversion processes are most often used due to the large microbial populations naturally present in animal waste and because many of these reactions proceed without requiring elaborate controls.

Biological conversion processes vary considerably in reactor sophistication and operating requirements. The anaerobic stabilization of organic matter with subsequent production of methane is one of the simplest, naturally occurring processes. Methane gas easily separates from the liquid phase, thus yielding a usable fuel. If this process occurs in a lagoon, the gas produced has been shown to be of good combustion quality because the methane-carbon dioxide ratio is very similar to sludge digestor gas, but production rates are very low.

Gas production at the optimum mesophilic range of about 98°F is about 15 times that for uncontrolled anaerobic lagoons receiving swine waste Heating may be accomplished by solar radiation or by recycling 10 to 20% of the produced gas for fuel Results for a solar still type methane generator at NCSU (Parker *et al.*, 1974) operating in the mesophilic range for the fermentation of swine waste have shown that about 25 cu ft of methane can be produced per day when this 500 gal reactor is loaded on a continuous basis with the waste from ten 100 pound hogs If we assume that the United States, per capita use of natural gas is 60 cu ft per day, this reactor could supply about 40% of the daily individual needs Current problems with the bioconversion of animal waste to methane are the handling and subsequent utilization of this gas

Two fundamental drawbacks which restrict the use of methane is that it has a relatively low energy value of 7500 Btu/gal, and nearly 5000 psi are required for liquification and thus easy storage. For comparison, propane, which has a Btu value of 92,000 Btu/gal., liquifies at around 250 psi Consequently, large storage requirements are necessary for methane utilization At 25% compressor efficiency it would take approximately 1320 Btu to compress 25,300 Btu of methane gas to provide 6,350 Btu of energy value Clearly this sytem is not very efficient because 21% of the resulting work energy is required for compression, while 75% of the available energy is lost as heat.

Methane has been used in tractors and automobiles. Gas bottles carried by such vehicles are often about 5' long by 9" in diameter (1 9 cu ft) charged to 2800 psi, so that about 420 cu ft of methane is carried for the equivalent of about 3-1/2 gallons of gasoline The most efficient use of methane would appear to be in stationary heat engines located near the point of generation, such as compressors or generators. Two major reasons for this approach is that the engine's waste heat can be recirculated in digester coils to augment methane production, and gas can be used directly as it is produced, eliminating the need for storage Correspondingly, the most efficient contemporary use of methane gas is at sewage treatment plants which use it as a fuel for internal combustion engines that provide auxiliary electricity and waste heat is utilized to maintain digesters temperatures at the optimum mesophilic range

Many claims exist concerning energy potential of degrading both animal waste and all organics to methane gas. The publication entitled *Methane Digesters for Fuel Gas and Fertilizer* (Frye, 1973) states. "So speaking generally, methane gas converted from *easily available* organic waste could supply about 150% of the gasoline energy used by all U.S. farm equipment (1965), 7% of the 1970 natural gas energy, and 2% of the total 1970 U.S. energy demands." This publication also indicates that the average per capita daily natural gas requirements of about 60 cu ft could be obtained from 10 pounds of chicken or pig manure per day, which is the equivalent of about 7 pigs and 100 chickens. However, results of NCSU studies indicate that the waste of about 25 hogs would be required to produce this amount of gas. Nevertheless, somewhat corroborating calculations have been presented in a NCSU engineering periodical that if all waste produced in the U S had been gasified, 700 billion cu ft of methane would have been produced. This is equal to over 3 billion gallons of gasoline But to keep things in perspective, this would only be 3% of the U.S. demand of 22 8 trillion cu ft of natural gas

John Shuttleworth, editor publisher of *The Mother Earth News* in a December 1973 news release said, "All we're doing with our digester is speeding that cycle up from a time span of several thousand years to one of only 30 days or so Better yet, we don't have to go exploring to find our pool of energy. We can keep it right in the backyard and tap it any time we want."

Shuttleworth further states in this newsletter that "You can have your own methane generator in operation even before the first commercially manufactured units are marketed Anyone with average mechanical ability should be able to follow these plans and put together his own methane maker from salvaged parts This will cost anywhere from $15.00 for a unit that produces enough gas to cook one meal a day to $3,000 for a system which will generate enough gas to run an entire household . heat, gas, lamps, refrigerator, stove, the works."

Converse (ASAE, 1975) recently stressed the need to look at the net energy retrieved from manure utilization systems rather than only gross energy possibilities Assuming that about 45 cu ft of gas a day could be produced from the waste of a 1000 pound animal, the Btu equivalent would be about 0 23 gallons of gasoline per animal per day and for 100, 1000 pound cows, about 23 gallons of gasoline a day

A 1000 pound dairy cow produces about 86 pounds of manure a day Probably an equal amount of dilution water is needed to attain a slurry that must be heated from 40°F to 95°F which requires about 9000 Btu or 0 08 gallon of gasoline Therefore, gross energy is now down to an equivalent of 0 15 gallon of gasoline per animal, and some additional energy is required to pump the water, mix the reactor contents, and transport wastewater.

A 100 hp tractor needs about 1600 cu ft of gas at atmospheric pressure per operating hour. If methane from manure is compressed to 300 psi and put into an 8 cu ft tank common on most tractors, this tractor would run about one hour. Therefore, a 100 hp tractor running for 10 hours would require the daily gas production from waste of 270 to 675 cows, depending upon net energy retrieved. Certainly, livestock wastes are an energy source and as fossil fuels dwindle, it may be a valuable alternative if the right engineering research is undertaken now.

Refeeding

"Wastelage" derived from the ensiling of ground grass hay and manure has been successfully fed to brood cows, and for several years a whole corn wastelage ration has been fed to finishing slaughter steers at Auburn University Latest reports are that it is an honor to attend the annual recognition banquet featuring the best steaks in the Southeast Researchers with the Virginia and Michigan Agricultural Experiment Stations have been studying the suitability of poultry waste for refeeding One of the nations' large beef cattle feeding companies recently began to include substantial portions of feed derived from cow manure in the normal diet of its herd The U. S. Department of Agriculture estimated that the recovery of only one third of U.S animal waste for use as feed would produce as much protein as is contained in this country's total annual soybean crop

A group of engineers in Texas recently concluded that refeeding offers the maximum potential for energy savings among waste management alternatives presently available in their state (Sweeten *et al*., 1974) The energy saved by refeeding one ton of feedlot manure was judged to be equivalent to the energy required to produce one ton or 1/6 acre of alfalfa in the western high plains area, less the energy required to preprocess the manure. Importantly, freshly collected feedlot manure would not have to be pre-dried to allow refeeding at the 5% level recommended as optimum when using manure as a substitute for roughage rather than grain. Utilizing manure for refeeding would result in more frequent collection and thus reduce odor potential. Feeding manure to range cattle could also provide the vehicle for ultimate disposal on pastures in contrast to the continuing need for terminal disposal with feedlot refeeding programs.

Symbiotic activity of algae and bacteria in controlled reactors allows maximum conservation of waste components because end products of bacterial metabolism are incorporated into algal cell mass by the photosynthetic energy trapping mechanism of green plants In Taiwan, for example, the roofs of animal production units are used for algal propagation with manure-laden wastewater as the culture medium. Effluent water which trickles into the collection gutter is recycled as washwater for this closed loop reactor.

Total Systems Approach

Waste management principles developed over the last ten years at a North Carolina State experimental swine unit have served as the basis for systems which emphasize utilization by terminal land recycling Basic unit processes are a primary lagoon with a floating aerator for odor control by surface agitation and increased pretreatment, a secondary lagoon storage pond, and an irrigation system for wastewater recycling or land application These principles have been implemented at a 300 sow total confinement facility on a 20 acre site adjacent to a new furniture factory and associated development The original 1 1/2 acre lagoon was overflowing when this producer consulted the university Upon finding that only about four acres were available for terminal land disposal, he was advised that much more land was required for a no discharge system However, because additional land was not available and a large investment had already been made in production facilities, a demonstration project was initiated. The total treatment system consists of partially slatted floors which drain to a lagoon, with two, 5 hp floating aerators for odor control by complete surface agitation with overflow to the original 1-1/2 acre lagoon. Additional pretreatment is also obtained by overland flow of wastewater pumped from the second lagoon to a 0.6 acre area which slopes back to this lagoon. A manually operated permanent set irrigation system is used to return lagoon water to the underfloor pits for more positive cleaning and liquid precharge as well as terminal irrigation to the 3 3 acre receiver plot Acceptable no discharge is achieved with this extremely small terminal application acreage because of the approximately 98% nitrogen removal achieved in the aerated unit which is gratifyingly much greater than our fondest expectations. Excavation and equipment costs for this energy intensive system during 1974 were about \$11,000 and current operating costs are about 50¢ per feeder pig sold or about a penny per pound of product (Humenik *et al.*, 1975).

The undercage waterwash and overland flow treatment system for caged layer wastes being investigated at NCSU (Overcash *et al*., 1975) represents an alternative to energy intensive systems for aerobic pretreatment and terminal waste management Wastewater from the undercage washing system is aerated and thus stabilized by natural flow over grass terraces. Effluent from these terraces discharges to a small lagoon which overflows into a large reservoir from which washwater is pumped with a low capacity pump to a storage vessel. Washwater energy is obtained from elevated storage tank discharge, rather than direct pumping which would require a much larger hp motor. Thus, this waterwash-aerobic pretreatment system emphasizes energy conservation by utilization of gravity flow with the exception of a low hp pump for washwater return.

A vibrating screen-solids-separator for the removal of fibrous material from liquid dairy manure represents one of the most exciting utilization processes being studied at NCSU. These separated manure solids are being utilized for bedding and refeeding studies, in addition to reforming into fiber board The three-lagoon system at this site provides complete retention of rainfall runoff and water from the terminal lagoon is recycled for washing. The first lagoon which receives liquid from the solid separator acts more like a swine waste lagoon after this fibrous, non-biodegradeable material is excluded. Irrigation systems are provided to pump waste from the primary lagoon for maximum fertilizer conservation or emptying of subsequent ponds to allow adequate runoff storage capacity.

Many wet and dry waste handling systems now exist for environmentally controlled units and numerous innovations are being introduced Wet systems use water to reduce labor and facilitate transport, but they have the potential disadvantage of increasing the amount of polluted water and energy requirements Dry systems, by contrast, decrease the waste volume to be handled Currently in-house techniques are being developed to provide the best method of waste management or utilization, and also to develop the best environmental condition for the animals. The underfloor ventilation system for houses with manure storage pits provides a totally controlled environment in which air is uniformly exhausted from the manure pit. Moisture is evaporated from the floor, and gases and odors are exhausted from the building before they can enter the animal atmosphere above the slats. As a result of initial work conducted by L B. Driggers and implementation of a total system at the Swine Development Center, over 300 new swine houses with underfloor ventilation have been constructed in North Carolina during the last several years. This is a growing example of the trend toward environmentally controlled growing units currently being recommended as the most important for animal performance and controlling impact of animal on the environment

Economics of EPA Criteria for Waste Management

A stipulation of the 1972 Water Quality Act authorizing EPA to establish affluent guidelines and limitations for feedlot industry was that the economic impact of these regulations would be considered. The most recent and possibly best analysis of the economic impact of water pollution controls on the feedlot industries has been conducted under contract for the National Commission on Water Quality. Very preliminary analyses of these data indicate that feedlots with over 1000 head of cattle capacity, which produce 16.3 million head, can control pollution at a total cost of $130 million, while the smaller feedlots producing 15.3 million head can provide an equal degree of pollution control at the cost of $580 million or 4.5 times the amount for larger feedlots. The cost/head marketed per year/unit abatement can be derived based upon two assumptions (1) waste production as is lineally related to feedlot size and (2) all treatment facilities perform at the same efficiency or percent abatement level regardless of size. Such cost/head marketed/unit abatement ranges from $16 for units over 1000 capacity to $20 for 500 to 1000 capacity, $30 for 100 to 500 capacity, and $100 from 0 to 100 capacity. Thus, national resources are most cost-effective for large feedlots in that more abatement is achieved at a much lower expenditure. Such economic strata could also serve as a basis for determining which feedlot should be permitted or considered as point sources Although this criteria would be quantatively associated as the arbitrary 1000-animal unit cutoff specified in current law, the theoretical generating principle would be cost-effectiveness.

Simple Energy Conservation Techniques

The energy conservation potential of insulating existing poultry houses is remarkable Potential fuel savings can be best illustrated using a typical broiler house 40' wide, 300' long, 7' high sidewalls, a roof slope of 5 and 12. The inside temperature is assumed to be 70°F, and the outside temperature 5°F

- Example 1 For no insulation, Heat loss is 1,490,000 Btu/hour, or is equivalent to approximately 20 gallons of propane per hour
- Example 2 For ceiling insulation with R = 8 material, the heat loss is reduced to 487,000 Btu/hour which is equivalent to about 6.6 gallons of propane per hour
- Example 3: For ceiling insulation with R = 8 material and sidewall insulation with R = 8 material, the heat loss is further reduced to 154,000 Btu/hour or the equivalent of 2.1 gallons of propane per hour.

Thus, insulation can allow a tenfold reduction of heat loss for energy requirements.

Heating energy can be further reduced in an insulated house if double brooding or zone brooding is employed. For double brooding, chicks are confined to the center portion of the house to reduce the heating space until stock indensity requires expansion to the total house. An additional 50% energy reduction over savings for just insulation can be realized if double brooding is practiced.

The second major demand for heat is to warm ventilating air. For each 1000 cfm the heat necessary to raise air temperature from 5°F. to 70°F. is 78,000 Btu/hour or approximately one gallon of gas. Thus, it becomes clear that for a well-insulated house, the energy required to warm ventilating air exceeds heating needs. Therefore, ventilation must be kept to a minimum, and whenever possible, ventilating air should enter from the attic.

The third demand for heat is to evaporate moisture. Gas heaters not ventilated to the outside produce about 6 pounds of water for every gallon of gas burned. Approximately 1000 Btu must be provided for each pint or pound of water evaporated. Therefore, outside venting, adjusted waterers, and absorbent litter are essential to conserve heat required for moisture evaporation.

Conclusion

Environmental control of livestock production units results in overall energy conservation and improved productivity resulting in better long-term profits Implementation of simple insulation recommendations or recycling of waste to land as a fertilizer results in substantial energy savings. Adoption of more advanced environmental control techniques, such as air-conditioning of breeding barns or waste washing systems require added investment, but ultimately result in less cost, especially if energy intensive waste management systems are replaced by the most appropriate utilization scheme because more market animals are produced at lower energy and feed costs, and under better envrionmental conditions. Waste management procedures, which emphasize utilization and terminal land application of residue, have the added benefit of being one of the most economical methods to achieve compliance with the no-discharge criteria. Actually, substantial energy savings can be obtained by implementation of relatively simple techniques while more sophisticated approaches conserve additional energy, allow use of different energy sources, and are most cost-effective in increasing productivity and controlling the impact livestock production has on environmental quality.

References

American Society of Agricultural Engineers, "That Manure Pit Is It a Goldmine?" *Agricultural Engineering*, Vol 56 June 1975 pp 19-20

Baughman, G. R. and C R Parkhurst, "Housing Influence on Energy Consumption," Poultry Housing Seminar, Greensboro, N. C October 1974.

CAST, "Potential for Energy Conservation in Agricultural Production," Department of Agronomy, Iowa State University, Ames, Iowa. Report No. 40 February 1975. 28 pp.

Driggers, L B, "Performance of Ventilation Systems in Similar Modified Environmental Controlled Poultry Houses," ASAE Paper 65-942, Chicago, Ill, December 1965

Driggers, L. B, "Performance of Mechanically Ventilated and Evaporative Cooled Totally Enclosed Commercial Laying Houses," ASAE Paper SE 71-402, Jacksonville, Fla 1971

Driggers, L B, and G B. Harwood, "Environmental Control," *Tar Heel Economist*, North Carolina Agricultural Extension Service, June 1971

Driggers, L. B, C. M Stanislaw, C R. Weathers and J R. Jones, North Carolina Swine Development Center, N. C Agricultural Extension Service, Circular 551 July 1974.

Driggers, L B, "Ventilation of Swine Buildings," North Carolina Agricultural Extension Service, Circular 581 July 1974

Driggers, L B "Heating and Cooling Swine Buildings, North Carolina State University," paper prepared for the proceedings of the National Pork Producers Council Swine Facilities Symposium, Des Moines, Iowa October 15-16, 1975

Driggers, L B., C. M Stanislaw and C R Weathers, "Breeding Facility Design to Eliminate Effects of High Environmental Temperatures," ASAE Paper 73-4511 1975.

Fry, L. J, "Methane Digesters for Fuel Gas and Fertilizer," The New Alchemy Institute Newsletter No. 3, Woods Hole, Mass Spring 1973 47 pp.

Humenik, F J, R. E Sneed, M R. Overcash, J C Barker, G D. Wetherill, "Total Waste Management for a Large Swine Production Facility," Third International Symposium on Livestock Waste Management, Urbana-Champaign, Ill. April 1975.

Overcast, M R, J. W. Gilliam, and F J Humenik, "An Overland Flow-lagoon Recycle System as a Pretreatment of Poultry Wastes," Third International Symposium on Livestock Waste Management, Urbana-Champaign, Ill. April 1975

Parker, R, F J. Humenik, R. Holmes and M. R Overcash, "Methane Production from Swine Waste with a Mesophilic Solar and Thermophilic Reactor," ASAE Paper 74-3033, Stillwater, Okla. June 1974

Reece, F N. and J. P. Mason, "Research Plan on Solar Energy Utilization in Livestock Production Systems," USDA-ARS, Mississippi State, Miss.

Stanislaw, C. M, C R. Weathers and D. G. Spruill, "1974 Production and Financial Summary," Swine Development Center, N. C. Agricultural Extension Service, Miscellaneous Extension Publication No. 108. April 1975.

Sweeten, J. M., D L Reddell and B R. Steward, "Feedlot Manure as an Energy Source," Texas A&M University, paper prepared for presentation at the 1974 Texas Section Meeting ASAE, Abilene, Tex. October 4-5, 1974. 21 pp

ENERGY USAGE IN CROP SYSTEMS

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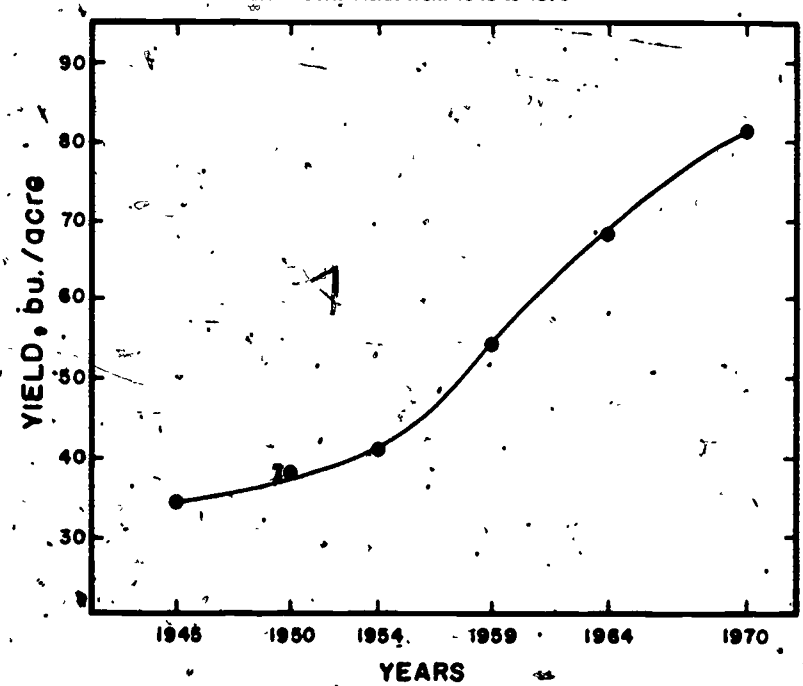
Agriculture, even in its most primitive form, encompasses those activities of man related to the collection and storage of solar energy in a form such that man can use that energy for the sustenance of life processes. To carry out these activities, man must expend energy in terms of human labor, and in the fossil energy used in producing the supplies and operating machinery utilized by agriculture. Fossil energy is in short supply, and many people are concerned about the effect that restricted energy availability will have upon agricultural production. This concern is a valid one.

One measure of agricultural efficiency with respect to fossil energy is the ratio of energy output in agricultural products to the fossil energy input in agricultural activities. This would include the energy associated with tillage, harvesting, storage facilities, machinery manufacture, fertilizer, seed production, pesticides, irrigation and drying.

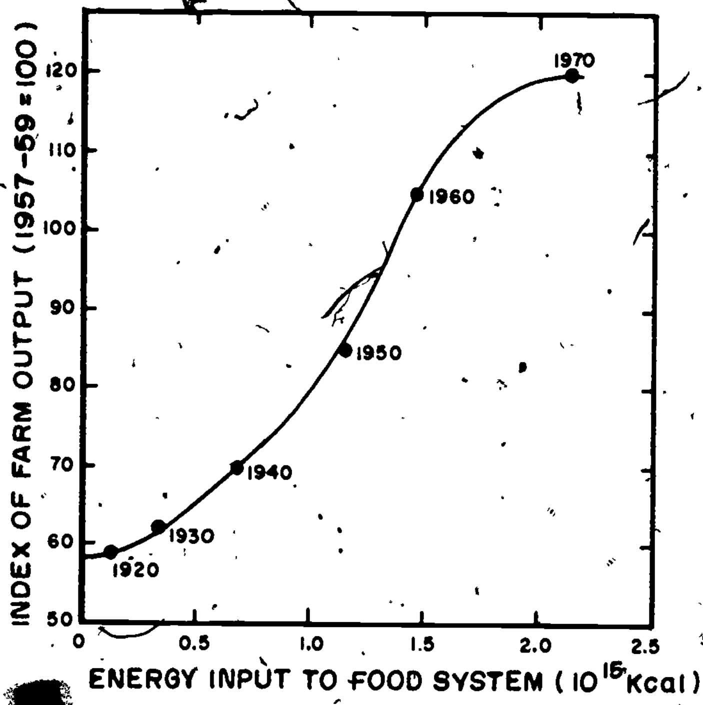
Figure 1
Increase in Corn Yields from 1945 to 1970



Heichel (*1, 2*) refers to these as cultural energy inputs as contrasted to the solar energy input There is also a significant fossil energy input off-the-farm in agricultural processing, transportation and food preparation These latter factors are usually cited as being the largest energy inputs into the total food chain (averaging about 76% of the total), however, they are largely beyond the control of the farmer. The first group of factors are, however, under the farmer's control and as such have a direct relationship to yield and to production efficiency. This was pointed out by Pimentel (*3*) when he reported that corn yield increased from 34 bu/acre in 1949 to 81 bu/acre in 1970 During this same time the labor per acre decreased from 23 man-hours to 9 man-hours This increase in corn production is shown in Figure 1 Similar increases can also be shown for other crops.

The relationship between energy input and increased yield is a real one as illustrated by Steinhart (*4*). (See Figure 2). Certainly no one would argue that a reduction in fertilizer input (a significant component of the energy input into crop systems) would not, in turn, reduce yield. This does not mean that inefficient energy utilization does not exist in agricultural production. It does And, agriculture can economize on its utilization of energy. However, a general reduction or one which restricts a particular practice should be carefully evaluated in terms of its impact on production. This is particularly true in view of the world-wide situation relative to adequacy of food supplies

Figure 2
Farm Output in Relationship to Energy Input Since 1920



Energy Usage Associated with Crop Practices

The fossil energy inputs associated with any crop can be broken down in terms of the energy associated with the different cultural practices and the energy required to manufacture the goods and equipment needed by agriculture By making such an analysis, the effect of alternative practices on the total energy requirement or the percentage of the total associated with any selected practice can easily be evaluated:

Machinery Usage (Tillage, Cultivation, Harvesting)

For most farms one of the major fossil energy inputs is that associated with the operation of agricultural machinery. Information on the gallons of gasoline used per acre in various machinery operations was compiled by White (5). This information in terms of kilo-calories per acre is presented in Tables 1, 2, and 3 in the Appendix. For most operations, values are given for "low," "average," and "high" energy requirements. The difference between the three values is attributable to such factors as weather, depth of tillage, size of equipment, size of fields, topography, etc.

The effect of alternative machine use practices on energy usage can be seen by use of the information presented in the Appendix. Tillage, for instance, is generally considered to be one of the high energy use activities. In fact, it corresponds to one of the peak energy demand periods in agriculture, the other is for harvest and crop drying. Consider three different levels of tillage for corn:

1. Conventional tillage — plowing with a moldboard plow, heavy disking, spring tooth harrowing
2. Reduced tillage — disking of stubble
3. No tillage

Conventional tillage would require approximately 149,000 kilo-calories per acre, reduced tillage 39,800 and no tillage zero. To fully evaluate the energy saved by reduced or no tillage, the total production scheme would need to be considered. For instance, no-tillage corn planting requires the use of a herbicide which represents an energy input and often extra fertilization is recommended. Second, if yields are reduced, the energy input per unit of food would correspondingly be increased. When the energy associated with fertilizer, drying and transportation are included, the difference in tillage method becomes largely insignificant since these three items represent by far the major energy requirement. Conventional tillage methods are usually less than 10% of the total. Nevertheless, potential savings of energy as high as 80% when only the tillage, planting and harvesting energy requirements are considered can be realized through no-tillage production systems. If one assumes the 62 million acres of corn grown for grain in the United States was all planted by no tillage techniques, more than 200 million gallons of fuel could be saved.

Energy in Storage Facilities and Machinery Manufacture

The actual production of facilities for storage, their erection, and their operation also require energy. Similarly, energy is used in the manufacture, distribution, and maintenance of machinery. These energy costs should appropriately be assigned to agriculture. The energy associated with these inputs is not easy to determine. Pimentel suggests that the annual energy input represented by the machinery required for U.S. corn production is 420,000 kilo-calories/acre (3). In a somewhat different approach, Roller suggests an energy value for equipment based upon its dollar cost (6). The value he gives is 10,680 KCal/\$. Using this value and applying it to the farm machinery cost over the years of useful life, a value very similar to that of Pimentel's is obtained. Since the value given by Roller can be used for any type farm operation, its use is recommended. Similarly, Roller gives a value of 3930 KCal/\$ for the energy value in buildings.

Fertilizer

As indicated earlier, the fossil energy used in manufacturing fertilizer represents one of the largest inputs into crop production, at least for grain crops such as corn. Pimentel recommends the following energy figures for fertilizer (3):

Nitrogen	—	8400 KCal/lb
Phosphorus	—	1520 KCal/lb
Potassium	—	1050 KCal/lb.

These energy figures include production and processing, but do not include field placement. Similar figures for nitrogen fertilizer are given by White (7); however, these values are substantially larger than those given by Heichel (1), or by Blevin at this conference. The reason for the differences between the various values is not fully apparent. From the information available, it appears the larger values were based on the overall energy inputs into the fertilizer manufacturing industry and includes some mixing, transportation and auxiliary energy inputs. Since they appeared more inclusive, they were the values selected for use in this paper.

Seed Production

The fossil energy used in seed production is quite variable depending upon the seed type, quality and treatment. An average recommended value for hybrid corn seed is 1800 KCal per pound of seed (3). Converting this value to a volumetric measure, one gets 100,800 KCal per bushel. It is recommended that this value be used for most seed types, however, for extremely small seeds such as that of tobacco and some vegetables, a higher value would be appropriate.

Pesticides and Herbicides

An average energy value for herbicides and pesticides of 11,000 KCal per pound is recommended (11). This value does not include the energy required for application.

Irrigation

The energy associated with the application of water by irrigation is reported as being large. Pimentel (8) considered the energy usage of such magnitude that he recommended that corn production be moved from those regions where irrigation is required to areas where adequate rainfall exists. If, however, other crops were grown in the irrigated areas to maintain high food production and if those crops were irrigated at the same level, the total energy use for agriculture would not be changed. If irrigation is restricted in those regions where rainfall is not adequate for optimum crop production in an effort to conserve energy, a direct reduction in crop yield could be expected.

An estimate of the energy use associated with irrigation is given by Fischback (9). He provides figures for both sprinkler and surface irrigation, as show in Table 4 in the Appendix The tabulated information clearly shows that the use of electric power would be more efficient than using internal-combustion-type powered units by a ratio of approximately 2 5 to 1 It also shows that surface irrigation requires less than 1/2 the energy required by sprinkler irrigation; however, more water may be required when surface irrigating and this may reduce the difference between the two methods Irrigation energy inputs could also be reduced by more effective scheduling of irrigation application The present methods depend heavily on farm operator judgment, and they are not sufficiently influenced by weather variables and probabilistic relationships relative to beneficial return for a specific amount of water application.

Crop Drying

In contemporary corn production, the usual practice is the drying of the harvested grain with heated air. In 1971 it is estimated 67 percent of corn grown in the five states in the corn belt was dried either commercially or on-the-farm with heated air In 1972 it was estimated that 75 percent of the grain was dried with heated air. Drying is primarily done so that the farmer can maintain more control over his farming operation By having drying facilities he can harvest the crop over a much wider range of time and, since he can start harvesting earlier, the danger of significant crop losses due to adverse weather is greatly minimized. It is estimated that 5 to 15 percent of the potential harvest is presently lost in the field (*10*) In one study a heavy storm in early November resulted in the doubling of corn losses during harvesting, increasing the loss from 6 8 to 11.9 percent To keep losses to a minimum, ideally the grain must be removed from the field as quickly as possible when the average grain moisture content is 26% Drying is mandatory with grain harvested at such moisture contents

The energy associated with grain drying is directly related to the initial harvest moisture content since a higher moisture content means that more water has to be removed The energy associated with removal of the various amounts of water can be computed by multiplying the pounds of water to be removed, as seen in Table 5, by the values in Table 6 (*11*) The differences in performance of the various types of dryers are not inlcuded in this calculation, however, for well designed dryers the error made by neglecting "equipment performance" would not be large A more important additional energy input in drying would be the energy associated with the operation of the electric motors for the fans and conveying equipment. For batch in bin or continuous flow dryers this energy use is relatively small, being 10 KCal or less per bushel per each point of moisture to be removed, i e reducing the moisture content of a bushel of grain from 26% to 16% (10 points) with high temperature drying requires about 3000 KCal of energy per bushel. Three percent of the total energy with such drying systems is the electric energy for driving the fans and conveyers. For low-temperature drying or natural air drying, however, the fan energy becomes relatively large In fact, if comparatively moist grain is to be dried with natural air and the recommended air flow per bushel (3 CFM per bushel for grain 10 points of moisture removal) is used, the energy usage for the fan motors will be virtually the same as the energy for electricity and fuel for heated air drying (near 3000 KCal per bushel).

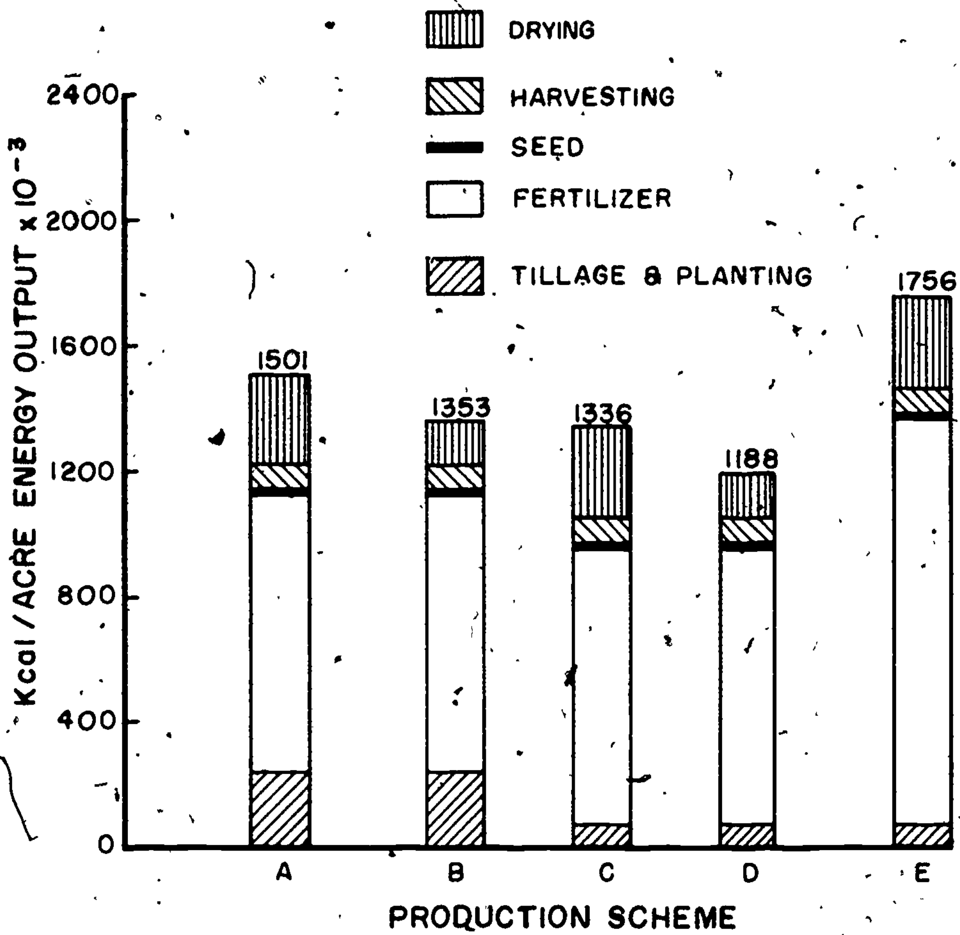
Influence of Cultural Practice on Energy Use

The influence of cultural practice can be dramatic in terms of energy input and yield Heichel (*12*) reports that as little as 200,000 KCal/acre of energy input occurs under subsistence peasant type farming where all energy input is in the form of human energy He reported yields (corn culture in Ghana) of 1,600,000 KCal of food being produced for this expenditure of energy Farming with 1915 horse-pulled equipment along with stationary engines increased the yield to 8,000,000 KCal per acre. When all modern agricultural practices and equipment are used the yield considering both the grain and fodder is increased to 24,000,000 KCal per acre per year, however, at this point 5,000,000 KCal of energy is being expended per acre per year. In terms of energy use efficiency the corn farmer using primitive methods does the best job with about 8 KCal produced per unit of energy input. The modern farmer returns only 4 8 KCal per unit of energy input. Heichel (*12*) further reports that when irrigation is used the return drops dramatically to 2 2 KCal per KCal input. Though this suggests agriculture should return to the energy-efficient procedures of primitive farming, the difficulty is that because yield is so much lower under such technology, adequate supplies of food cannot be produced.

Assuming that in view of world-wide food needs high food output must be maintained, then modern agricultural techniques must be used Under this constraint the options are fewer; however, the opportunity for conservation of energy still exists. This can be illustrated by considering several alternative production schemes. Using corn production as an example and considering all inputs, one can note the energy use for five different cultural techniques shown in Figure 3.

Figure 3

Energy Usage by Various Agricultural Production Schemes



A. Conventional Tillage, drying 10 points
B. Conventional Tillage, drying 5 points
C. No-tillage, drying 10 points
D. No-tillage, drying 5 points
E. No-tillage, heavier fertilization, drying 10 points

The analysis of alternative corn production schemes reveals that different practices have definite impact on energy usage. For the five schemes evaluated, the most energy-efficient system (no-tillage with drying restricted to 5 points moisture reduction) used 32% less energy than the least efficient (no-tillage, increased nitrogen fertilization and drying 10 points).

One of the most significant factors of this analysis is the relatively large energy input associated with fertilization. This input accounts for approximately 60% of the total energy input for conventional culture. No-tillage is frequently regarded as improving energy efficiency when compared with conventional tillage culture (*13*); however, if comparable high yields are desired with no-tillage, approximately 50 lb. more nitrogen fertilization is normally recommended. This is shown in Figure 3 as Scheme E. Though the energy for field machinery operations with no-tillage was less than with conventional tillage, the energy associated with the increased fertilization makes the no-tillage operation the most inefficient from an energy viewpoint.

The next largest energy input is that associated with drying If heated air is used and the moisture content is to be reduced an average of 10 points (say 26% to 16% by drying), then 295,000 KCal of energy is required. Reducing the drying requirement to 5 points (21% to 16%), reduced the energy required for drying to 148,000 KCal In this case the impact on field losses of allowing the corn to remain in the field until it averaged 21 percent as opposed to 26 percent needs to be considered This added field drying could be expected to increase field losses by about 4% (10) Assuming a yield of 100 bushels per acre, the energy in the lost corn would be equal to 403,000 KCal per acre This is 2 7 times greater than the energy saved by delaying harvest

If irrigation had been used (for example, 10 inches by means of sprinklers) an additional 376,000 to 1,463,000 KCal/acre of energy would have been required This could result in a doubling of the total energy input The potential for energy saving should also be apparent For example, with conventional production, if agricultural waste could be used to replace one-half of the fertilizer, a savings of 440,000 KCal/acre of energy might be realized

Similar analyses can be made of other agricultural operations and various alternative production schemes to evaluate the energy requirements for any desired crop of production systems Since the possible combinations are virtually endless, no attempt was made in this paper to evaluate other types of farm operations. It is hoped, however, that the basis for such analyses has been presented To these analyses the effect on production (crop yield) must be evaluated so that the effect on overall production and on the energy required per unit of production can be determined This was clearly demonstrated above in the example relative to increased field losses due to delaying the harvest to allow the moisture content to drop in the field

Summary

An attempt has been made to quantify the on-farm energy inputs in crop production The inputs discussed include machinery operation (tillage, cultivation, and harvesting), energy in storage facilities and machinery manufacture, fertilizer, seed production, pesticides, and herbicides, irrigation, and crop drying Of these inputs, fertilization will often be the largest In an example with conventional corn production, the energy input associated with fertilization represented 60 percent of the total energy input The second largest energy input was that associated with drop drying

When analyses of energy input into crop production are made, it is important to analyze the total operation This includes changes in fertilization required by a change in machinery usage, effect on field losses, changes in yield and changes in product quality A system which has a low fossil fuel requirement (gasoline, fuel oil, etc.) may not have the lowest overall energy requirement, particularly, when yield is considered and the energy usage is computed per unit of food produced

Even with the large energy inputs discussed in this paper, the energy yield in the corn at harvest exceeds by several times the inputs As energy is added in off-farm transport, processing and handling this may cease to be true, but for almost all crop operations the energy at point of harvest or on farm storage exceeds the energy required to produce the crop In this sense agriculture is a producer of energy rather than a user of energy. It is important to remember, however, that agriculture is not practiced to produce energy, rather, it exists to produce food, a basic commodity of man Therefore, any reductions in the energy available to agriculture must be weighed against the acceptability of a potential decrease in food production.

References

1 Cambel, A B, "The Energy-Food Delivery System," Proceedings and Minutes, Twenty-third Annual Meeting of the Agricultural Research Institute October 14-16, 1974 pp 54-68

2 Fischbach, P E, "Energy Uses in Nebraska Agriculture, Energy and Irrigation," Nebraska Extension Service Bulletin CC255. November 1973 pp 15-27

3 Heichel, G H, "Comparative Efficiency of Energy Use in Crop Production," Connecticut Agricultural Experiment Station Bulletin 739. November 1973 20 pp

4 Heichel, G H, "Energy Needs and Food Yields," *Technology Review*. July/August 1974 pp 19 25

5 Heichel, G H and C R Frink, "Anticipating the Energy Needs of American Agriculture," *Journal of Soil and Water Conservation*. January/February 1975 pp 48-53

6 Johnson, H, "Opportunities to Conserve Energy in Dryer Design," Proceeding of Energy for Agriculture Conference, Corn Refiners Association, Purdue University September 18, 19, 1973 pp 111-120

7 Loewer, O J., Jr, G M White, and D G Overhults, "Economics of Drying, Storage, and Feed Processing Part I Operational Considerations," Kentucky Cooperative Extension Service, Department of Agricultural Engineering AEN 34 July 1975

8 Loewer, O J, Jr, G M White, and D G Overhults, "Economics of Drying, Storage, and Feed Processing Part II Drying," Kentucky Cooperative Extension Service, Department of Agricultural Engineering AEN 34 July 1975

9 National Research Council Committee on Agricultural Produc-

tion Efficiency, "Agricultural Production Efficiency," Chapter 6, *Energy and Agricultural Productivity*, National Academy of Sciences 1975 pp 111-131.

10. Nelson, L. F. and W. C. Burrows, "The U S Agricultural Energy Future," *Agricultural Engineering*, Vol. 55, No 9, September 1974. pp. 17-19

11. Pimental, D. "Energy Crisis and Crop Production," Energy and Agriculture: Research Implications Seminar Proceedings Report No. 2, North Central Regional Strategy Committee on National Resource Development October 25, 1973 pp. 41-64

12. Pimentel, D , L. E. Hurd, A C Belloti, M. J Forster, J. N Oka, O D. Sholes, and R. J Whitman, "Food Production and the Energy Crisis," *Science*, Vol. 182. 1973. pp 443-449

13 Roller, W. L., H. F. Keener, and R. D. Kline, "Energy Costs of Intensive Livestock Production," Paper No 75-4042, American Society of Agricultural Engineers. June 22-25, 1975

14 Steinhart, J S and C E. Steinhart, "Energy Use in the U.S. Food System," Energy and Agriculture Research Implications Seminar Proceedings, Report No. 2 North Central Regional Strategy Committee on National Resource Development October 25, 1973. pp. 41-64.

15 White, R. G , "Fuel Requirements for Selected Farming Operations," Ohio Cooperative Extension Service Agricultural Engineering Leaflet No. 10 February 1974.

16 White, W C , "Fertilizer Food-Energy Relationships," Illinois Fertilizer Conference Proceedings, 1974 pp. 37-43

Appendix

Table 1
Estimated Energy Requirements for Selected Farming Operations

Operation	Kilocalories Per Acre*		
	Low	Average	High
Tillage Operations:			
Moldboard Plow	47,100	94,100	188,000
Chisel Plow	29,000	57,900	116,000
Heavy Tandem Disk	19,900	39,800	79,600
Standard Tandem Disk			
Plowed Soil, First Time Over	16,300	32,600	65,200
Plowed Soil, Second Time Over	12,700	25,300	50,700
Corn Stalks, etc	14,500	29,000	57,900
Spring-Tooth Harrow	10,900	21,700	43,400
Spike-Tooth Harrow	7,240	14,500	29,000
Field Cultivator	18,100	36,200	72,400
Planting Operations:			
Row-Crop Planter (with fertilizer, etc.)			
40-Inch Rows	16,300	25,300	38,000
30-Inch Rows	21,700	32,600	48,900
Grain Drill	12,700	18,100	27,100
Potato Planter	32,600	48,900	72,400
Vegetable Planter (Direct)	32,600	48,900	72,400
Transplanter	43,400	65,200	97,700
Crop Cultivation:			
Row Crops, First Cultivation	14,500	21,700	32,600
Row Crops, Second Cultivation	12,700	18,100	27,100
Vegetable Crop Cultivation	19,900	29,000	43,400
Rotary Hoe	5,430	9,050	14,500
Harvesting Operations:			
Cutterbar Mower	14,500	21,700	32,600
Mower-Conditioner (pto)	23,500	36,200	54,300
Mower-Conditioner (self propelled)	34,400	50,700	76,000
Hay Rake	7,240	10,900	16,300

Table 1 – Continued

Operation	Kilocalories Per Acre*		
	Low	Average	High
Harvesting Operations: (Continued)			
Baler, Hay	34,400	50,700	76,000
Baler, Straw	21,700	39,800	59,700
Forage Harvester (flail-type)			
Green Chop	81,400	123,000	185,000
Dry Hay or Straw	41,600	61,500	92,300
Forage Harvester (cylinder or flywheel type)			
Haylage	81,400	123,000	185,000
Dry Hay or Straw	36,200	54,300	81,400
Row Crop			
40-Inch Rows	77,800	116,000	174,000
30-Inch Rows	86,900	130,000	195,000
Combine Harvester			
Small Grain	36,200	54,300	81,400
Pea Beans and Soybeans	39,800	59,700	90,500
Corn, 40-Inch Rows	43,400	65,200	97,700
Corn, 30-Inch Rows	50,700	76,000	114,000
Corn Picker			
40-Inch Rows	30,800	47,100	70,600
30-Inch Rows	34,400	50,700	76,000
Picker-Sheller			
40-Inch Rows	36,200	54,300	81,400
30-Inch Rows	43,400	65,200	97,700
Potato Harvester	52,500	79,600	119,000
Sugar Beet Harvester	50,700	76,000	110,000
Vegetable Harvester	57,900	86,900	130,000
Tree-Fruit Harvester (Shaker)	95,900	145,000	217,000
Miscellaneous Operations:			
Row Crop Sprayer (each operation)	3,620	5,430	9,050
Orchard Sprayer (each operation)	18,100	27,100	41,600
Stalk Shredder	21,700	32,600	48,900
Fertilizer Spreader (bulk, spinner)	5,430	7,240	10,900
Anhydrous Ammonia Applicator	38,000	57,900	86,900
Vine Topper (Beets, Potatoes)	50,700	76,000	114,000
Pea Bean Puller and Windrower	14,500	21,700	32,600
Forage Blower			
Dry Hay or Straw	19,900	29,000	43,400
Haylage or Corn Silage	34,400	50,700	76,000

*To obtain fuel requirements in gallons of gasoline per acre divide by 36,200. For Diesel Fuel requirements, divide by 51,700 and for L-P Gas, divide by 30,200. Figures do not include fuel required for hauling seed, fertilizer, etc. to the field, nor for hauling the harvested crop from the field.

Table 2
Energy Requirements for Farm Tractors

Horsepower Class (Max Observed PTO H P)	Fuel Consumption, Kilocalories/Hour	
	Gasoline*	Diesel Fuel*
20-30 H.P	140,000	103,000
40 59 H.P	217,000	150,000
60-79 H.P.	300,000	207,000
80-99 H P.	393,000*	274,000
100-124 H.P.		341,000
125 149 H.P		408,000
150-174 H.P		476,000
175 200 H.P		543,000

*Based on operating at approximately 75 percent of maximum load.

Table 3
Energy Requirements for Hauling Farm Products from Field to Farmstead

Commodity	Kilocalories Per Acre*	
	First Mile	Each Additional Mile
Corn Silage; Haylage, Potatoes, Sugar Beets, Cherries (in water), et cetera	72,400	27,100
Small Grain, Shelled Corn, Vegetable Crops Apples (in bulk boxes) et cetera	14,500	5,430
Baled Hay, Straw, et cetera	9,050	3,620

*These figures are applicable for short hauls only, such as field-to-farmstead hauling, preferably not in excess of 3 or 4 miles.

Table 4
Energy Required for Sprinkler and Surface Irrigation

Energy	Energy Required/Acre Inch Water, Kcal/Acre	
	Surface	Sprinkler
Electric	16,400	37,600
Diesel	40,300	93,900
L P. Gas	64,000	146,300

Table 5
Pounds of Water to be Removed per Bushel

Percent Moisture Content Wet Grain	Percent Moisture Dry Grain			
	12	14	16	18
18%	3.8	2.6	1.3	0
20	5 1	3.9	2.7	1.4
22	6.4	5.2	4.0	2.7
24	7 6	6 5	5 3	4 2
26	8.9	7 8	6 7	5.5
28	10 2	9 1	8 0	6 8
30	11 5	10 4	9.3	8.2

Table 6
Approximate Number of KCal Required Per Pound of Water Evaporated for Grain Dried at Different Operating Temperatures*

Operating Temperature	Moisture Content KCal lbs. of Water		
	27%	25%	20%
100°- 120°	340	378	403
160°- 180°	441	441	466
180°- 220°	441	466	554

*Based on an ambient air temperature of 60°F

ENERGY REQUIREMENTS FOR THE PRODUCTION AND DISTRIBUTION OF CHEMICAL FERTILIZERS IN THE UNITED STATES

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Introduction

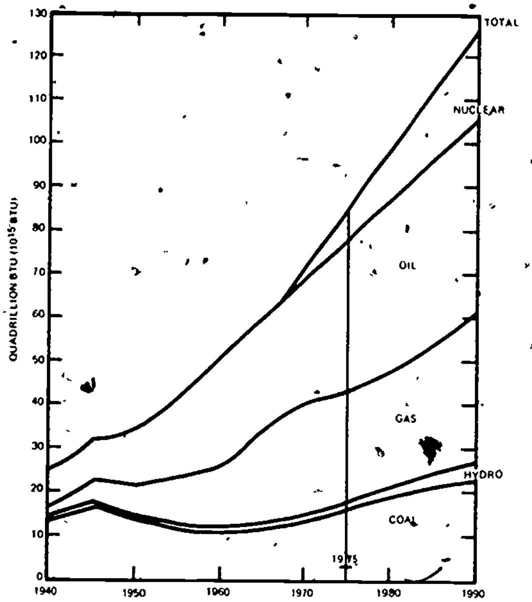
The production of satisfactory quantities of foodstuffs is inexorably bound to the production and distribution of adequate quantities of chemical fertilizers – ammonia, urea, ammonium phosphate, and muriate of potash, to name the predominant fertilizer materials. Just as inexorably, the production and distribution of these chemical fertilizers are dependent upon reliable sources of large quantities of fossil fuel energy—natural gas, nephtha, fuel oils, byproduct hydrocarbons, or, to a minor extent, coal.

Because of the extreme complexity of our current energy crisis, even in a narrow field such as fertilizer production, exact analyses of current and projected energy supplies and requirements are extremely difficult; as a result there are many opinions and estimates and few hard facts. Nevertheless, an attempt will be made to provide energy consumption data for the major fertilizer chemicals on the basis of individual plant processes, as well as on current and short-term projections of total plant nutrient requirements.

One of the ground rules used in this presentation is that the calculated energy consumption for fertilizer production is that which must be imported to an existing battery-limits fertilizer plant. That is, internal energy transformations are not defined individually and only the net consumption (or production) of transferable energy is reported. This includes the energy, in fuel equivalents, of both process feedstocks and fuel; for example, the total energy reported for ammonia production by natural gas reforming comprises about 35% as fuel (burned in reformer) and 65% feedstock ("cracked" in reformer). The "existing" plant approach is specified so as to avoid an assessment of the energy consumed in the construction of the process equipment and plants. Energy consumption in the form of human effort and of plant deterioration is likewise not included.

Before going into details of fertilizer energy consumption and so as to give perspective to fertilizer energy consumption data, some statistics on the total energy forms and consumption in this country may be of interest. A breakdown of past and projected energy consumption patterns is given in Figure 1 (*1*).

Figure 1
Estimated Projected Energy Consumption in the United States



The data indicate that the rate of increase in total energy consumption is about 3% per year. It will be noted – and here is the first of numerous areas of dispute – that the projected *gas* consumption fraction is somewhat higher for the future than at present. These data reflect the supposition that the greatly increased degree of onshore and offshore exploration will result in greatly increased production—a supposition that is thus far generally unsupported by current results. However, proposed importation of liquified natural gas (LNG) and the production of synthetic natural gas (SNG) from coal could account for this projection.

The small bar on the 1975 dateline represents the estimated total agricultural system energy consumption up to, but not including, the food-processing requirements. This amounts to about 3% of the total energy consumed (2, 3). It is little wonder that most of those cognizant of the general energy situation argue that a strict allocation of the total supply of energy—say 1% of the total—could ensure a completely viable agricultural system. Also, most of the industrial sector argue for deregulation of natural gas at the well-head so that increased exploration can be financed and that competition for natural gas as a fuel would be less intensive.

Nitrogen

General

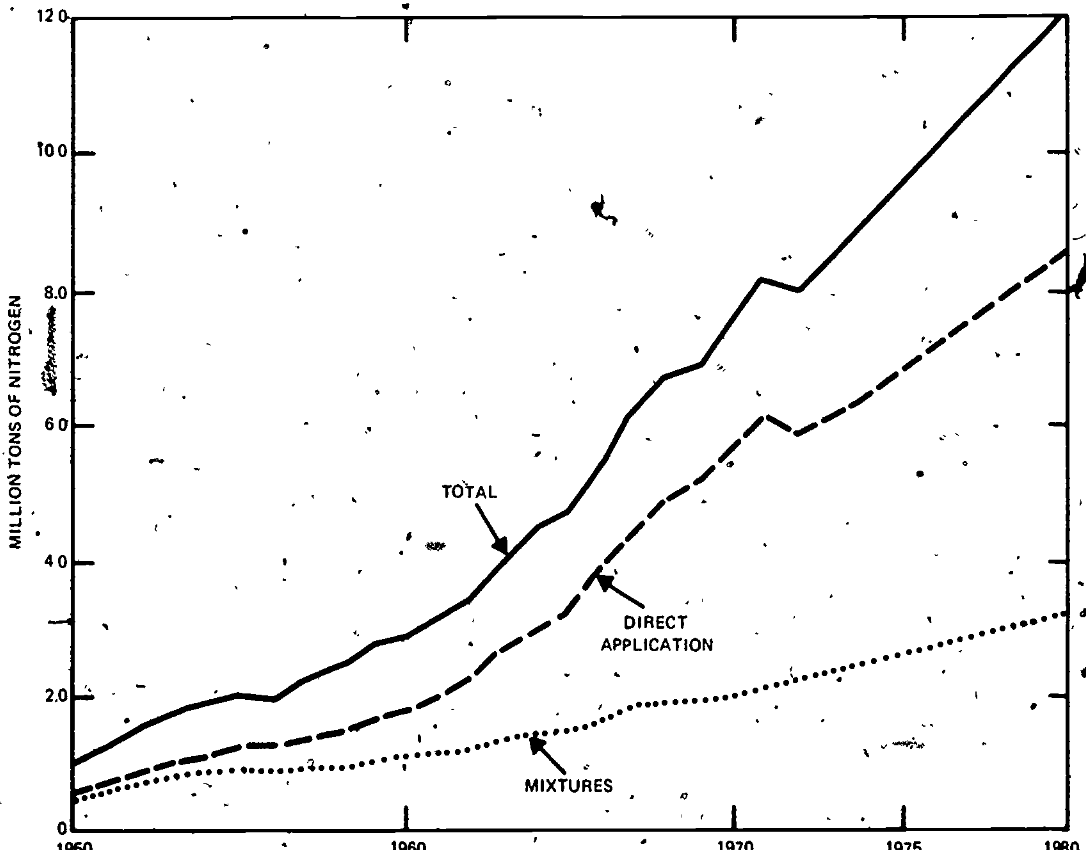
About 95% of all nitrogen fertilizer in the United States is produced from synthetic anhydrous ammonia. Much of the remaining 5% is also in the form of ammonium salts, generally byproduct ammonium sulfate from cooking and caprolactum operations. Past and projected consumption of nitrogen fertilizers is given in Figure 2 (4). These data will be used in a later summary of total energy consumption for agriculture nitrogen production.

Anhydrous Ammonia

Process Description

Anhydrous ammonia is produced commercially by the Haber catalytic reaction of stoichiometric quantities of relatively pure hydrogen (3 volumes) with atmospheric nitrogen (1 volume). In this process, the two gases are mixed and compressed to the range 2500 to 5000 psig pressure where they react on a catalyst to form ammonia. An estimated 16 million tons of ammonia were produced in

Figure 2
Projected Agricultural Nitrogen Consumption in the United States



the United States in 1974-75 but only 11 million tons (70% of total) was consumed in the agro-system. The remainder was consumed by industrial users (explosives, plastics, etc.).

In the commercial versions of the Haber process, the main process variations relate to the manner of hydrogen production. There are basically three processes for hydrogen production, namely: (1) steam reforming of natural gas or naphtha (a light petroleum distillate), shown in Figure 3; (2) partial oxidation of fuel oils or other hydrocarbons, shown in Figure 4; and (3) the gasification of coal, shown in Figure 5.

Figure 3
Steam Reforming of Hydrocarbons for Ammonia Synthesis

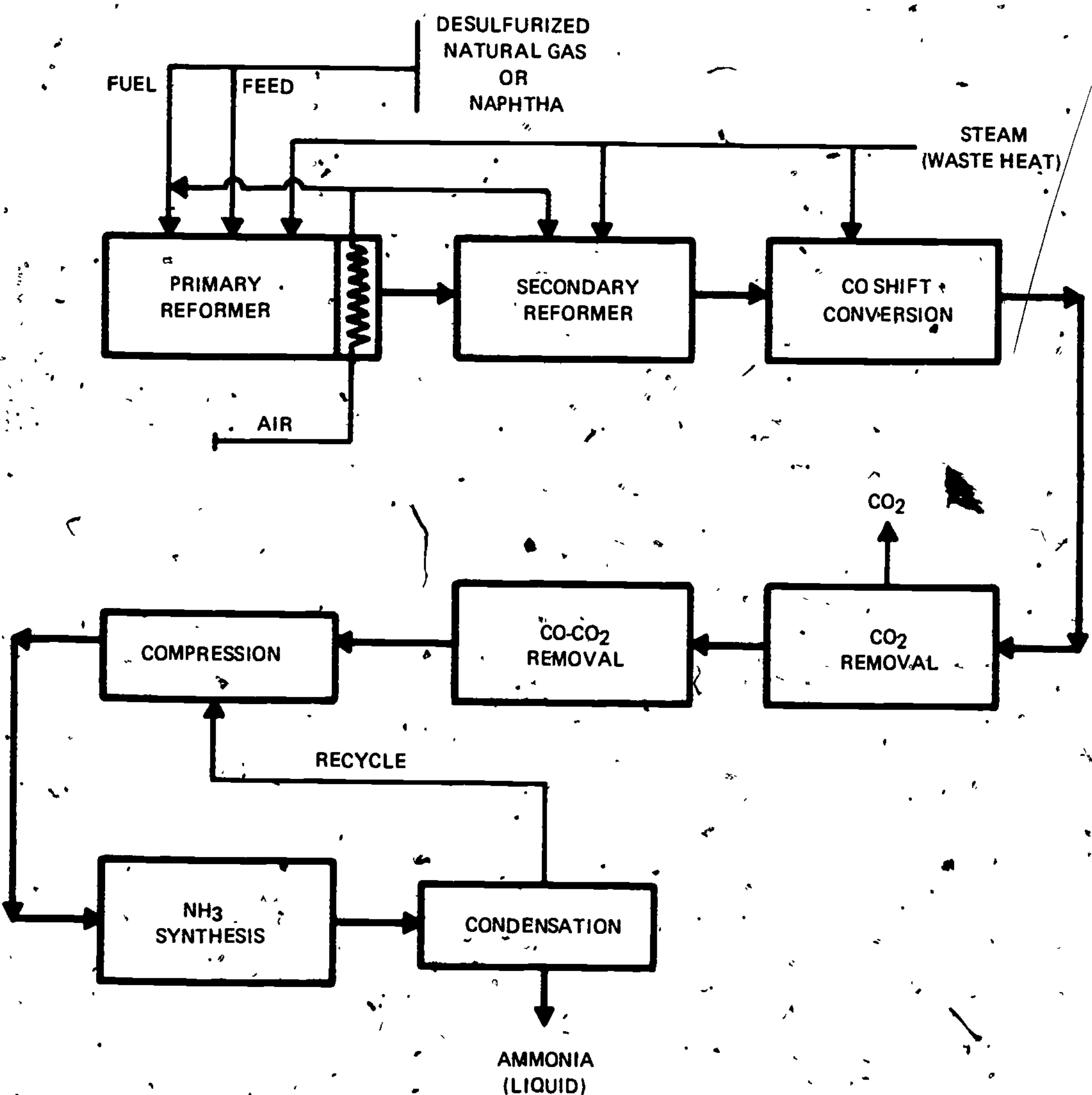


Figure 4
Partial Oxidation of Hydrocarbons for Ammonia Synthesis

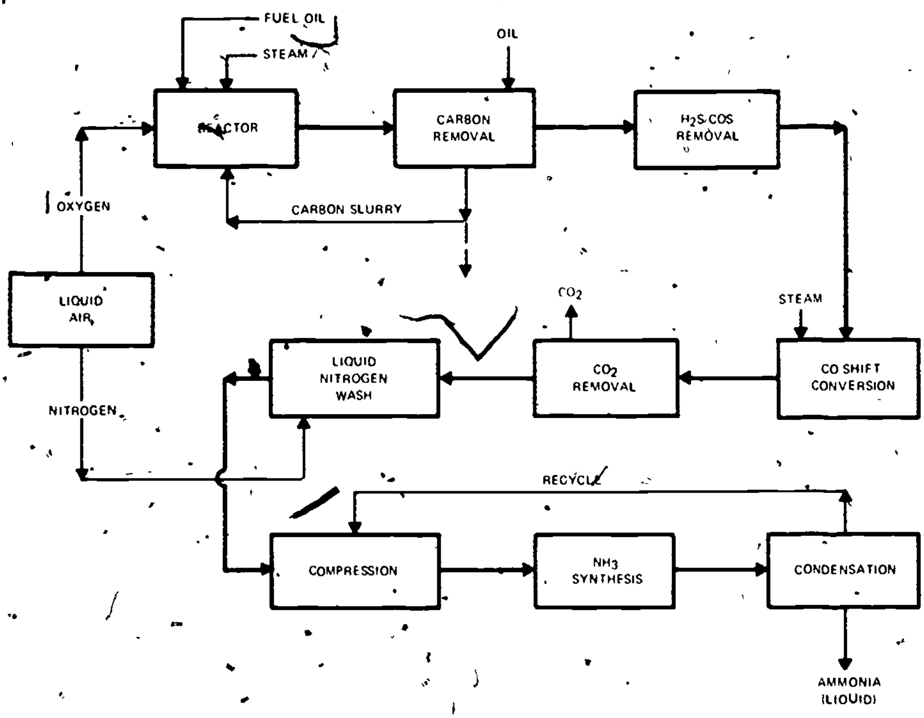
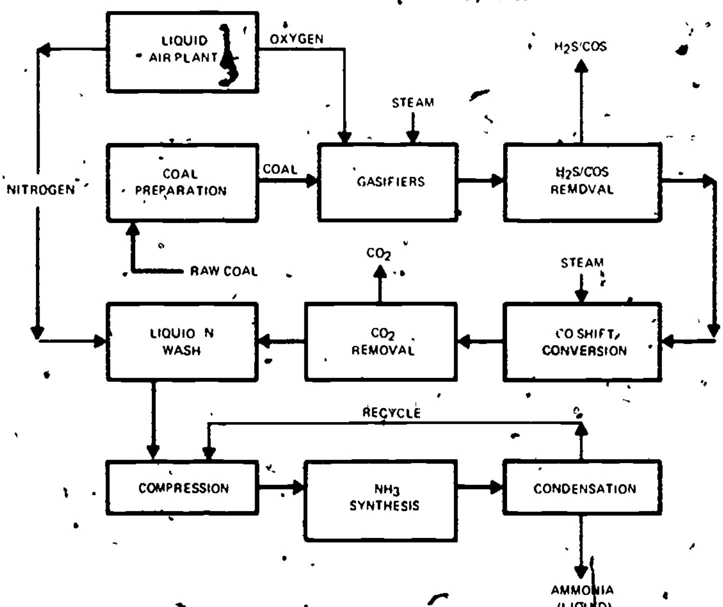


Figure 5
Gasification of Coal for Ammonia Synthesis



The principal desired reactions that occur in the several processes are shown in the following tabulation (*5*).

Tabulation A
Principal Reactions in Hydrogen Production from Gaseous Liquid or Solid Hydrocarbons and in Ammonium Synthesis

Reforming:

A. Natural Gas (Catalytic)

$$CH_4 + H_2O \longrightarrow CO + 3H_2$$

B. Naphtha

$$2C_7H_{15} + 14H_2O \longrightarrow 14CO + 29H_2$$

Partial Oxidation (Noncatalytic):

A. Fuel Oils or Coal

$$C_nH_m + (n + \tfrac{m}{4})O_2 \longrightarrow CO_2 + \tfrac{m}{2}H_2O$$

$$C_nH_m + nCO_2 \longrightarrow 2nCO + \tfrac{m}{2}H_2$$

$$C_nH_m + nH_2O \longrightarrow nCO + (\tfrac{m}{2} + n)H_2$$

Carbon Monoxide Shift Conversion (Catalytic):

$$CO + H_2O \longrightarrow H_2 + CO_2$$

Ammonium Synthesis (Catalytic):

$$3H_2 + N_2 \longrightarrow 2NH_3$$

The objective, of course, is to reduce the hydrogen content of the hydrocarbon feedstock to free hydrogen and to crack the steam feed to free hydrogen by oxidizing the carbon to carbon dioxide. Several states of reactors are required to achieve this overall result, as indicated in the tabulation.

The reforming, partial oxidation and shift conversion reactions usually are carried out at up to 300-400 psig and 1500°F, whereas the ammonia synthesis reaction is at 3500 to 5000 psig and 950°F.

Energy Requirements

The total energy required for the production of anhydrous ammonia — as well as any other fertilizer — consists of the total energy required to produce and transport both the raw materials (feedstocks) and the various energy forms (steam, electricity, fuels) consumed in the process. Some difficulty was encountered in obtaining production energy data for all ammonia feedstocks. In fact, underground coal mining data (*6*) appeared to be the only available data of this nature. Since underground coal mining operation should be more costly, energywise, than production of natural gas, naphtha, or fuel oils, the conservative approach was used in that this maximum raw material production requirement was arbitrarily assigned to the other feedstocks on an equivalent Btu basis.

The data indicated that the electrical energy required was only 19 kilowatt hours, or 190,000 Btu (33% overall generating efficiency) per ton of coal (average, 24×10^6 Btu). Transportation would add about 600 Btu per ton per mile, or 300,000 Btu per ton for a 500-mile haul. The total energy expenditure to deliver 1 ton of subbituminous coal (24×10^6 Btu) is thus about 0.5×10^6 Btu, or about 2% of the energy delivered.

The total estimated energy consumption for the production of anhydrous ammonia via the various feedstocks are given in Table I (*7*). The data indicate that the steam reforming of naphtha and the partial oxidation of fuel oil require about the same energy input as the reforming of natural gas and about 30% less than the gasification of coal. All, however, would be regarded as energy-intensive processes.

It is estimated that the approximately 11 million tons of ammonia consumed by the agro-system in 1974 required 0.378×10^{15} (quadrillion) Btu; this is also shown in Table I.

Table I
Estimated Energy Consumed in the Production of Anhydrous Ammonia

	Normal units/ton NH_3	Energy consumed,[a] Btu	
		Per ton NH_3	Per ton N
Steam Reforming			
Natural gas (900 Btu/SCF)[b]	38 MSCF	34.2×10^6	41.5×10^6
Electricity	20 kWh	0.2×10^6	0.3×10^6
Total		34.4×10^6	41.8×10^6
Total consumption for 1974-75 U.S. production[c]		0.378×10^{15}	
Naphtha Reforming			
Naphtha (19,000 Btu/lb)[b]	0.89 ton	33.8×10^6	41.0×10^6
Electricity	25 kWh	0.3×10^6	0.4×10^6
Total		34.1×10^6	41.4×10^6
Heavy Oil-Partial Oxidation			
Fuel oil (17,500 Btu/lb)[b]	0.98 ton	34.3×10^6	41.6×10^6
Electricity	30 kwH	0.3×10^6	0.4×10^6
Total		34.6×10^6	42.0×10^6
Coal Gasification			
Coal (11,400 Btu/lb)[b]	2.0 ton	45.6×10^6	55.3×10^6
Electricity	235 kWh	2.4×10^6	2.9×10^6
Total		48.0×10^6	58.2×10^6

[a] Including estimated energy required to produce and deliver raw materials.
[b] Low heating value (LHV)
[c] Eleven million tons NH_3 per year, agro-system only

Urea

Urea is rapidly becoming the greatest single source of solid nitrogen fertilizer in the world. In 1967, urea production was about 19% of total nitrogen production, in 1973 it was about 30% of the total (7). Its high analysis and lack of fire and explosive hazards (compared with ammonium nitrate) are largely responsible for its growth. In the United States urea capacity is about equal to ammonium nitrate capacity (nitrogen basis), but somewhat less urea nitrogen is consumed in agriculture. It is expected that by 1978-80, urea capacity (nitrogen basis) will exceed ammonium nitrate capacity (4) Production and distribution cost data show that urea provides lower cost nitrogen to the farmer than does ammonium nitrate, in spite of the latter's production energy consumption advantage (See section on ammonium nitrate.) An estimated 3 million tons of urea (1.4 x 10^6 ton nitrogen) was produced in the United States for agriculture in the 1974-75 season, about one-half of this was in the form of nitrogen solutions.

Process Description

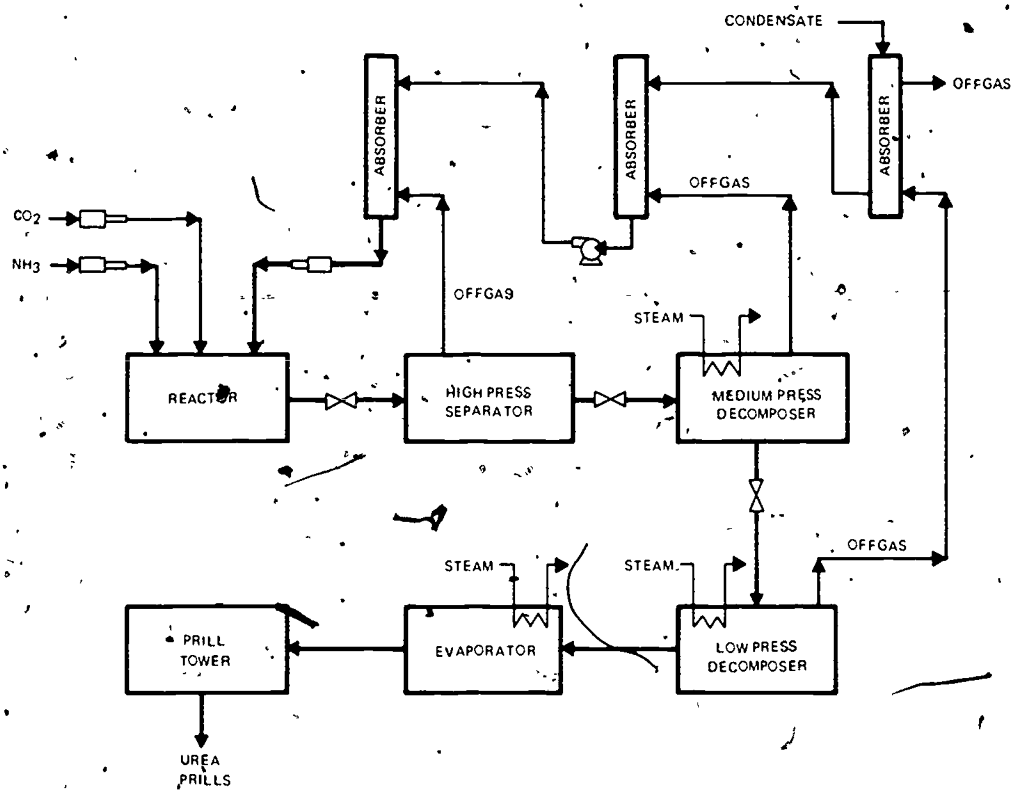
All commercial processes utilize the reaction of liquid anhydrous ammonia and the gaseous byproduct carbon dioxide from the ammonia production unit. As a result, the urea plant is always part of an ammonia complex.

The overall chemical reaction is as follows

$$2NH_3\ (liquid) + CO_2\ (gas) \rightarrow CO(NH_2)_2\ (solid) + H_2O\ (vapor)$$

This is an oversimplification, but is sufficient for this purpose. A simplified schematic flowsheet of a typical total recycle prilled urea plant is shown in Figure 6. The reaction given above is endothermic and requires a significant input of thermal energy as steam to produce the solid prills. The conversion to prills, of course, occurs only after the approximately 75% aqueous solution in the synthesis section is concentrated in the evaporator to a 99+% urea melt at about 275°F. In addition, the indirect input of energy-intensive ammonia significantly increases the energy "content" of prilled urea. The reactor is operated in the range of 2000 to 4000 psig and 375° to 400°F, depending upon the particular process being considered. In practice, a large excess of ammonia is maintained in the internal recycle loop to improve the conversion constant and to reduce corrosion.

Figure 6
Schematic Flowsheet of a Total Solution Recycle Urea Process



The reaction does not go to completion, that is, only 60 to 65% of the carbon dioxide is converted to urea in a single pass (with excess NH_3). As a result unconverted ammonia and carbon dioxide must be stripped from the urea solution in several decomposer stages by heating and successive flashing to lower pressure. After stripping, the reactants are recovered in the absorbers and recycled, partly as aqueous solutions and partly as free ammonia, to the reactor for complete conversion.

Energy Requirements

As was previously indicated, the flowsheet presented here was greatly simplified. There are a number of modifications to the total recycle scheme—too numerous to consider here except as to actual or potential energy requirements. The energy requirements are given in the following tabulation (*7*).

Tabulation B
Energy Requirements for the Production of Prilled Urea

Process	Btu x 10^6/ton prilled urea[a] Equivalent[b] electrical	Steam[c]	Total
Total solution recycle	1.5	2.8	4.3
Stripping	1.2	1.9	3.1
Heat recycle	1.5	1.4	2.9
Hot gas recycle[d]	0.1[e]	0.4	0.5
Average (proven) processes = 7.5 x 10^6 Btu/ton nitrogen			

[a] NH_3 equivalent energy not included; thus, data are incremental for conversion of NH_3 to urea.
[b] At 10,000 Btu/kWh, assuming 33% overall efficiency in steam-electric generation.
[c] Boiler efficiency, 80%.
[d] Unproven but theoretically sound.
[e] Low because there is no cooling water or carbamate solution pumping.

The ammonia energy equivalent (0.6 ton NH_3/ton urea at 34 x 10^6 Btu/ton) was not included in the data, since it would amount to double entry in the final accounting of energy totals. The data indicate that conversion of ammonia to urea is far less energy intensive than the production of ammonia itself.

It is estimated that conversion of ammonia to prilled agricultural urea (1.8 x 10^6 ton) consumed about 0.006 quadrillion (10^{15}) Btu in 1974-75, while the conversion to urea solutions (40% of total, or 1.2 x 10^6 ton) required about 0.003 quadrillion Btu for a total of about 0.009 quadrillion Btu.

Ammonium Nitrate

Ammonium nitrate is still produced in greater quantities in the United States than any single nitrogen fertilizer except the ammonia from which it is made. However, it is becoming less popular in agriculture because of its low grade (33.5% nitrogen) and hazardous nature. When existing ammonium nitrate production facilities reach retirement, there will be a strong tendency to replace them with urea plants (See section on urea.) however, there are some instances where ammonium nitrate is agronomically superior to urea, and ammonium nitrate also fits into the industrial sector (explosives). As a result, ammonium nitrate will probably always command some portion of the total nitrogen market. It is estimated that about 6 million tons of ammonium nitrate (2 x 10^6 ton nitrogen) was consumed in U.S. agriculture in the 1974-75 season

(2.2 x 10^6 ton solution, 3.8 x 10^6 ton prills) (*4*).

The most modern process consists of reacting 55 to 65% of nitric acid with the stoichiometric quantity of ammonia at about 65 psig, under these conditions, almost enough steam is generated in the neutralization reactor to evaporate the water (from the acid) in producing the solid (prilled) product.

Energy Requirements

The energy requirements (incremental in converting ammonia to ammonium nitrate) for modern pressure nitric acid and ammonium nitrate plants are given in the following tabulation (*8, 9*).

Tabulation C
Energy Requirements for the Production of Prilled Ammonium Nitrate in a Modern Plant

Process	Equivalent Btu x 10^6/ton NH_4NO_3 prills
Nitric acid: 0.81 ton 100% HNO_3/ton ammonium nitrate	
Electricity, 0.81 x 5 kWh	0.04
Fuel gas (natural gas),[a] 0.81 x 0.82 x 10^6	0.66
Export steam, 0.81 x 1.7 M lb	−1.20
Subtotal	−0.50
NH_4NO_3 (prills)	
Electricity, 35 kWh	0.35
Steam, 1.25 M lb	1.06
Subtotal	1.41
NET REQUIRED,	
per ton ammonium nitrate	0.91
per ton nitrogen	2.7

[a] Catalytic reduction of nitrogen oxides in tail gas to nitrogen.

The data show that because of the highly exothermic reactions, energy consumption per ton of nitrogen is less than half that consumed in the average urea process (nitrogen basis). However, according to White (*10*), an industry survey indicated an energy requirement of about 13 x 10^6 Btu per ton of nitrogen (about 50% more than urea). These data possibly reflect the maximum energy consumption by older plants having little heat recovery hardware.

It is estimated that in 1974-75 the conversion of ammonia to prilled ammonium nitrate consumed about 0.017 quadrillion (10^{15}) Btu and the conversion to solutions consumed about 0.008 quadrillion (10^{15}) Btu (weighed average of old and new technology) for a total of 0 025 quadrillion Btu.

Nitrogen Summary

Calculations indicate that the agricultural nitrogen industry (ammonia, urea, and ammonium nitrate) consumed about 0.412 quadrillion (10^{15}) Btu or about 0.5% of the total U.S. energy consumption in 1974-75. Agricultural ammonia production consumed about 450 x 10^9 standard cubic feet of natural gas; about 2% of the estimated total natural gas produced in that period.

Phosphate

General

The projected P_2O_5 requirement in the United States through 1980 is given in Figure 7 (*4*). The trend is toward the use of greater proportions of ammonium phosphates and, though not shown here, somewhat greater amounts of concentrated superphosphate; these increases are at the expense of normal superphosphate.

These trends therefore indicate that phosphoric acid, predominantly wet-process acid, will continue to be the most important phosphatic intermediate, and that sulfur, which is used in all economical phosphatic fertilizer processes, will retain its prominence in this area (*11*).

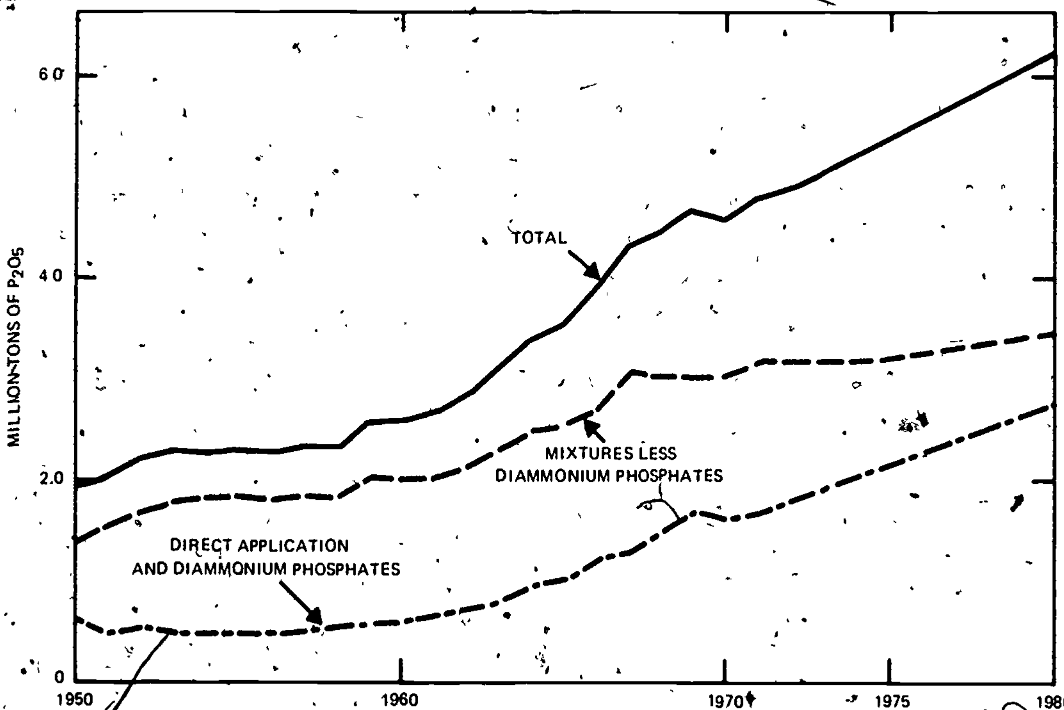
It is estimated that of the 5.2 million tons of P_2O_5 consumed as solids in 1974-75 about 3.2 million was as ammonium phosphates and 1.7 million was as concentrated superphosphate with only 0.3 million tons as ordinary superphosphate (*4*).

Process Description — Raw Materials and Intermediates

Nearly all agricultural phosphate is based on wet-process acid which in turn is based on phosphate rock and sulfur (sulfuric acid). A small quantity of electric-furnace phosphoric acid may be used in agriculture, but it is generally much too expensive (24 million Btu/ton P_2O_5 vs. about 10 million for wet-process acid).

Figure 7

Projected Phosphate Consumption in the United States



Sulfur

The United States produced an estimated 12 million tons of sulfur in 1974, of which about 70% or 8.5 million tons was Frasch mined sulfur, the remainder was predominantly recovered sulfur from sour gas cleanup or sulfide ore-roasting (*11, 12*) Some of the sulfuric acid produced from the sulfide ores finds its way into phosphate manufacture, but its impact is small and therefore is not accounted for *per se* in subsequent calculations.

The Frasch mining process involves the injection of steam or hot brine into a borehole and forcing molten sulfur up through an annular space in the casing Sour gas is cleaned by scrubbing with an amine or a promoted carbonate solution and converting the recovered hydrogen sulfide to sulfur in a Claus unit. The heat energy, generally from natural gas, required for Frasch sulfur varies widely from well to well, but a national average is about 8 x 10^6 Btu per ton sulfur. Recovery from sour gas requires only about 0.3 x 10^6 Btu per ton sulfur (*11*)

It is estimated that desulfurization of oil requires about 27 x 10^6 Btu per ton sulfur, but very little of this sulfur is utilized. The production of sulfur from the roasting of pyrites (a small operation in the U S.) requires about 0.4 x 10^6 Btu per ton of sulfur (*11*)

Sulfuric Acid

Sulfuric acid is produced by burning molten sulfur that has been atomized in burner tips with a sufficient quantity of air to yield a gas mixture containing about 10% sulfur dioxide and 15% oxygen, this is passed over a vanadium oxide catalyst where the sulfur dioxide is oxidized to sulfur trioxide at a temperature of 750° to 950°F. The gas is then cooled (steam generation) and absorbed in water in an absorption tower to yield 98% sulfuric acid. Stronger acid (oleum) may be produced but is not required in fertilizer manufacture.

The overall reaction is highly exothermic so there is an average net yield of energy in the form of moderate pressure steam, this amounts to about 1 9 x 10^6 Btu per ton 100% sulfuric acid after internal electric power generation.

Phosphate Rock

Phosphate rock is the indispensable raw material for all commercial phosphatic fertilizers. There are other sources (guano, bones, etc.), but these are inconsequential. The United States is still the largest single producer of rock, it is estimated that nearly 46 million tons of rock were mined in 1974.

Raw phosphate ore is recovered by strip mining since most of the United States ores are sufficiently close to the surface for this procedure In the distant future, however, shaft mining may have to be practiced Common practice is to slurry the roughly crushed ore in water at the mine and pump it to the beneficiation plant a few miles away. Here the ore is washed through a series of washers equipped with 1 millimeter screens so that plus 1 millimeter and minus 1 millimeter fractions are produced The fractions are further treated in hydroseparators and froth-flotation units to recover, on the average, about 70% of the mined P_2O_5 as salable product. The remainder, in the form of slimes or tailings, is discarded

It is estimated that the average combined mining-beneficiation operation requires about 1 5 x 10^6 Btu per ton of recovered P_2O_5 (*11*)

Phosphoric Acid (Wet-Process)

As indicated previously, wet-process phosphoric acid is now the key intermediate in phosphate fertilizer production and is therefore the key item in determining energy requirements for finished phosphatic fertilizers. There are many variations in processing phosphate rock into phosphoric acid, some of these are the dihydrate process (dominant in the industry), the hemihydrate process, and the anhydrite process. However, all conform in general to the basic reaction below

$$\underset{\text{phosphate rock}}{Ca_{10}F_2(PO_4)_6} + 10H_2SO_4 + 20H_2O \longrightarrow \underset{\substack{\text{calcium sulfate}\\ \text{dihydrate}\\ \text{(gypsum)}}}{10CaSO_4 \cdot 2H_2O} + 2HF + \underset{\text{phosphoric acid}}{6H_3PO_4}$$

The finely ground (−200 mesh) rock is continuously digested for several hours with the sulfuric acid (93%). The resulting calcium sulfate (degree of hydration characterizes the process designation) is filtered off and discarded. About 3 tons of gypsum (dry basis) is produced per ton of phosphoric acid or 4 tons per ton of P_2O_5 A simplified flow diagram is shown in Figure 8. The product acid is generally about 30% P_2O_5, it is normally concentrated to "merchant-grade" 54% P_2O_5, using the byproduct steam from the sulfuric acid plant.

Energy Consumption

The estimated energy consumed in the production of 54% P_2O_5 merchant-grade acid is given in Table II (*11*). Acid produced with Frasch sulfur requires about four times the energy as that produced from recovered sulfur

Granular Phosphate Products

As previously mentioned, the predominant granular phosphates are ammonium phosphate and concentrated superphosphate (CSP or TSP) The future trend will be toward even higher proportions of these products, toward the near exclusion of ordinary superphosphate.

Process Description

Ammonium Phosphate Diammonium phosphate (DAP), having a grade of 18-46-0, is the most popular of the ammonium phosphates. It is generally produced in a TVA continuous rotary drum ammoniator-granulator. The acid (usually 40% P_2O_5) is partially ammoniated in a preneutralizer to increase the degree of water vaporization. The resulting "melt" is distributed over the rolling bed of recycle

Figure 8
Schematic Flow Diagram of Wet-process Phosphoric Acid Process

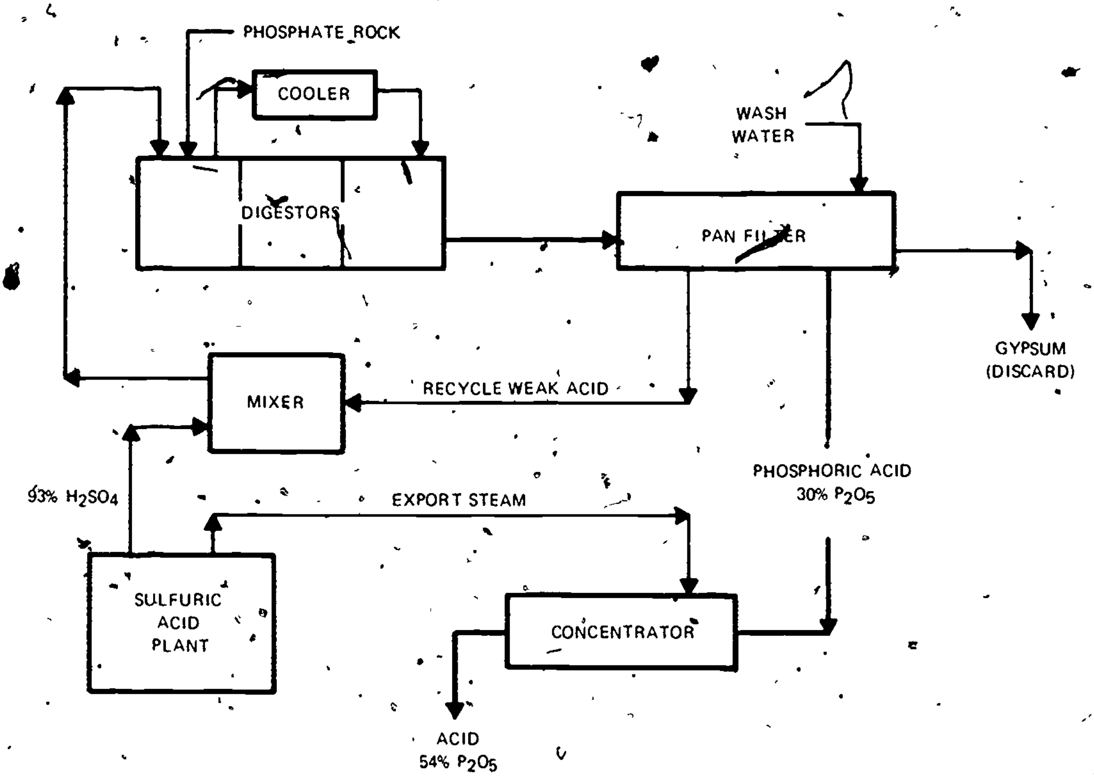


Table II
Estimated Energy Consumption in the Production of Wet-Process Phosphoric Acid
As Affected by Sulfur Source (Frasch or Recovered)

Material	Tons material / Ton acid P_2O_5	Energy requirements, Btu x 10^6			
		Per ton material		Per ton P_2O_5	
		Frasch	Recovered	Frasch	Recovered
Sulfur	0.93	8.0	0.3	7.6	0.3
Sulfuric acid (100%)[a]	2.85	(–)1.9	(–)1.9	(–)5.6	(–)5.6
Phosphate rock (32% P_2O_5)[b]	3.49	0.4	0.4	1.5	1.5
Product acid (30%)[c]	3.50	0.2	0.2	0.7	0.7
Product acid (54%)[d]	1.85	3.0	3.0	5.6	5.6
Net energy required/ton P_2O_5 as 54% acid				9.8	2.5

[a] Byproduct heat energy (–).
[b] Includes mining (25%), beneficiation (12%), drying (63%), but not grinding.
[c] 90% recovery of P_2O_5; includes rock grinding.
[d] Byproduct heat from sulfuric acid plant used to concentrate acid.

fines in the drum and is further ammoniated with excess ammonia to an NH_4 H_3PO_4 of 2 (DAP). The resulting granules are dried, screened, cooled, and stored. A schematic flowsheet in shown in Figure 9.

Granular Triple Superphosphate The most modern TSP process, which is in widespread use, is the continuous direct granulation process. Wet-process phosphoric acid, usually about 40% P_2O_5, is reacted with phosphate rock in a two-stage reactor. The resulting slurry flows to a pug mill (blunger) mixer where it is intimately mixed with cooled undersize and crushed oversize from the product screens. A high recycle ratio (recycle to slurry feed rates) of about 12:1 is required. The granulation occurs in the mixer and the dryer following. The granular material is screened, cooled, and sent to storage.

A schematic flowsheet of the direct granular triple superphosphate process is shown in Figure 10.

Figure 9
Schematic Flowsheet of Diammonium Phosphate Production

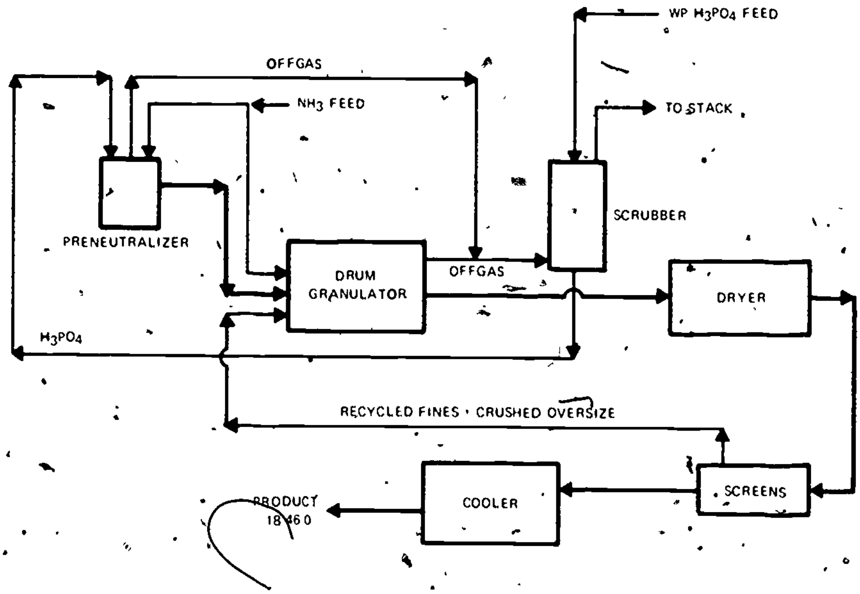
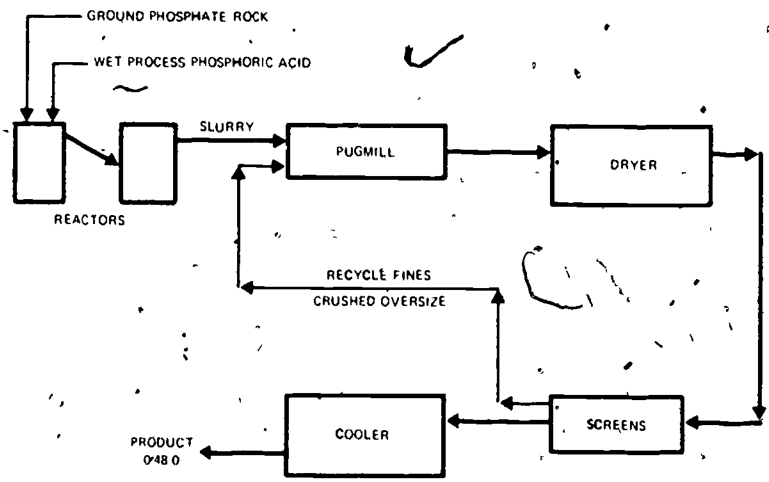


Figure 10
Schematic Flowsheet of the Direct TSP Granulation Process



Energy Requirements (11)

The estimated energy required in the production diammonium phosphate and triple superphosphate is shown in the following tabulations.

Tabulation D
Estimated Energy Consumed in the Production of Diammonium Phosphate

Material or process step	Energy required, Btu x 10^6 per ton product P_2O_5[a] Frasch sulfur	Recovered sulfur
Wet-process phosphoric acid	9.8	2.5
Ammoniation and granulation	0.2	0.2
Product drying	0.8	0.8
Total[a]	10.8	3.5

[a]Not including energy equivalent of nitrogen content.

Tabulation E
Estimated Energy Consumed in the Production of Triple Superphosphate

Material or process step	Energy required, Btu x 10^6 per ton product P_2O_5 Frasch sulfur	Recovered sulfur
Phosphate rock[a]	0.4	0.4
Wet-process phosphoric acid	7.0	1.8
Acidulation and granulation	0.1	0.1
Product drying	0.8	0.8
Total	8.3	3.1

[a]Ground rock, equivalent to 30% of total P_2O_5

Excluding the energy equivalent of its nitrogen content (to avoid double entry in totals), the estimated energy consumption for diammonium phosphate is about 4 to 11 x 10^6 Btu per ton of product P_2O_5 and about 3 to 8 x 10^6 for triple superphosphate depending upon the sulfur source.

Where Frasch sulfur is used in production of diammonium phosphate and triple superphosphate, the data show that triple superphosphate appears to have a significant energy advantage over diammonium phosphate. However, the P_2O_5 contents of both materials are the same, so in shipping 1 ton of P_2O_5 the diammonium phosphate provides a zero shipping energy cost for 18 units of low-cost ammonia-nitrogen, whereas the triple superphosphate "carries" only a calcium diluent, which is of minimal value in most instances.

Liquid Phosphate Fertilizers (11)

Although the production of solution and suspension (slurry) fertilizers is growing rapidly, something less than 10% of the total P_2O_5 utilized in the United States is in the form of liquids. This would amount to perhaps 0.8 x 10^6 tons of P_2O_5 or about 5 million tons of liquids having an average P_2O_5 content of 16%.

At first glance it would appear that the processing of phosphoric acid into liquid N-P grades (base solutions) by ammoniation would be no more energy intensive than diammonium phosphate without the drying step. However, in the United States' liquid market the demand is for the clear wet-process superphosphoric acid rather than black orthophosphoric acid. It is estimated that at energy charges of nearly 3 x 10^6 Btu per ton P_2O_5 for rock calcination (clarity) and 2 x 10^6 Btu per ton P_2O_5 for concentration (superphosphoric acid) the "energy premium" may run to nearly 4 x 10^6 Btu per ton P_2O_5 over dried diammonium phosphate (11).

Phosphate Summary

Calculations indicate that the phosphate fertilizer industry (phosphate rock, phosphoric acid, ammonium phosphates, concentrated superphosphate, etc.) consumed about 0.0628 quadrillion (10^{15}) Btu in 1974-75 or only 0.1% of the total annual energy consumption in this country.

Potash

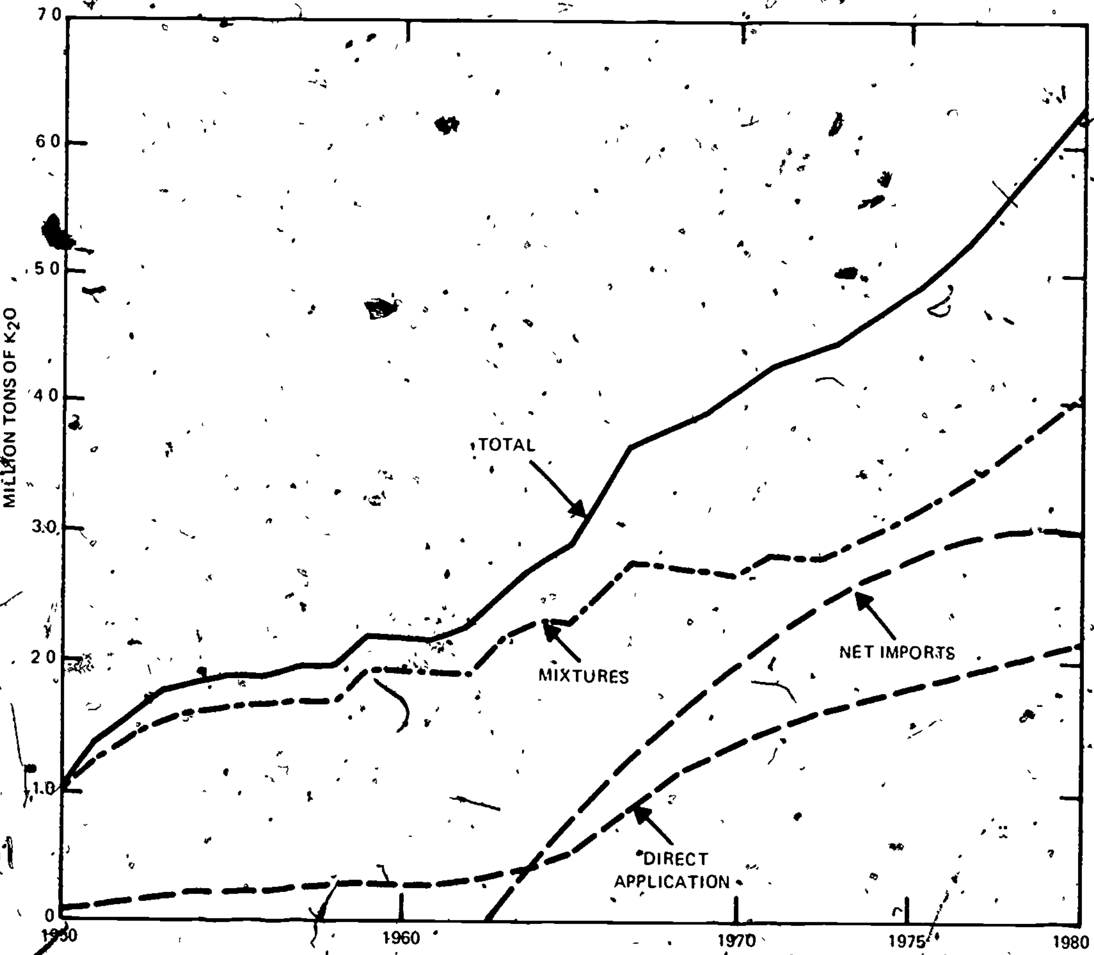
General

Potash, muriate of potash, and potassium chloride are synonyms for the mineral sylvite, which has been deposited underground in eons past. It is thought that reserves of over 50 trillion tons of K_2O (potassium oxide equivalent) exist throughout the world (7). Unfortunately, unlike most phosphate deposits that are accessible by strip mining, potash deposits are nearly all at depths that require underground mining. Also unfortunately, the United States became a net importer of potash in the early 1960's and it is estimated that about 55% of potash consumed in 1974-75 was imported, primarily from Canada.

The potassium chloride (sylvite) makes up about 90% of the agricultural potash used in the United States—which was about 4.5 million tons K_2O (See Figure 11) in 1974-75 (4). The remainder is principally langbeinite, $K_2SO_4 \cdot 2MgSO_4$.

Again, unlike phosphate rock, the potash salts, once beneficiated (separated from impurities in the raw ore), do not require further processing before use. They are applied to the soil in the form in which they are produced.

Figure 11
Projected Consumption of Potash in the United States



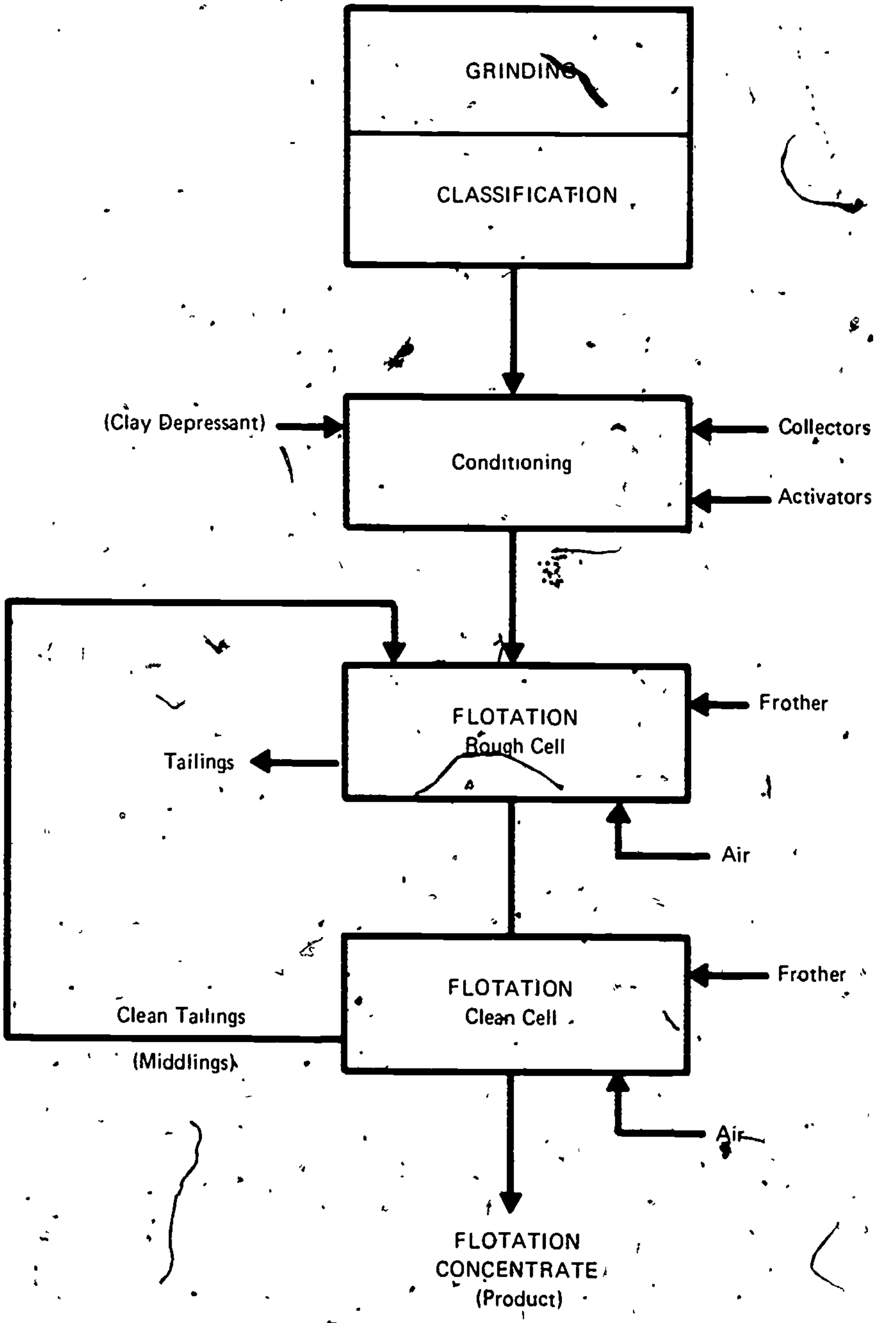
Process Description

The potash ore is recovered from the deep beds in two ways. First is conventional shaft and tunnel mining, which accounts for about 85% of the total potash produced in this country. The other is solution mining—in this approach, in its simplest terms, a hot brine is pumped down one well, through the deposit where it becomes saturated, and up another well to the surface where the potassium chloride is recovered by crystallization.

The deep-mined solid ore is beneficiated by crushing, classification, and flotation. This treatment "unlocks" the sylvite crystals from the principal impurity, halite (common salt), and separates the two compounds. This is a rather complicated chemical treatment and flotation procedure that is so reliable that plants having capacities of up to 6000 tons per day of finished product are not uncommon. A simplified schematic flowsheet of the treatment process is shown in Figure 12.

In the solution mining process, the out-coming saturated brine from the deposit is simply cooled in vacuum evaporative coolers; the potassium chloride preferentially crystallizes, leaving the sodium chloride in solution. This solution is reheated for recycling to the mine.

Figure 12
Principles of Potash Ore Flotation Process



Energy Consumption

The estimated energy consumptions for the two mining procedures are given in the following tabulation (*7*).

Tabulation F
Estimated Energy Consumed in the Production of Potash

	Energy required Btu x 10^6 per ton K_2O	
	Solution mining	Shaft mining
Mining	6 8	2.2
Beneficiation	5.6 (crystallization)	1.0 (flotation)
Total	12 4	3.2

The data indicate that the solution mining is fourfold more energy intensive than shaft mining However, it has been claimed that the original expenditure of energy required to open the mine are so much less for the solution mine that the higher operating energy requirements are offset Data concerning this point are not publicly available.

Potash Summary

Calculations indicate that the approximately 2.5 million tons of K_2O (as KC1) produced in the United States in 1974-75 required about 0 011 quadrillion (10^{15}) Btu, or about 0.01% of the total annual consumption of energy The remainder (2.0 x 10^6 ton K_2O) of the total consumption was imported.

Transport of Raw Materials

Nitrogen Products

About one-half of the anhydrous ammonia capacity in the United States is located on interstate gas pipeline and the other half is located at intrastate gas supply points (*10*). Obviously, all the gas must be collected and transported to the ammonia plants. A rough estimate, is that the average transport distance is about 200 miles. The estimated energy consumed in transporting the 450 x 10^9 SCF per year of natural gas is only about 0.00068 x 10^{15} Btu per year.

Phosphate Products

About 30% of the phosphate capacity is on the Gulf Coast (Texas, Louisiana, Mississippi) near sulfur sources but these plants must import rock from Florida or North Carolina. About 50% of the capacity is in the Florida phosphate fields but these units must import sulfur from Texas or Louisiana. Of the remaining 20% of the plants, 10% must import both rock and sulfur, and 10% must import sulfur only. However, calculations indicate that only 0.00457 x 10^{15} Btu per year is required for this rather complex transport system.

Potash Products

Since potash is invariably used "as is" and is produced (beneficiated) at the mine, no raw material transport energy is required. Product transport energy is covered in another section.

Raw Material Transport Energy Summary

The energy required per year to transport raw materials to the manufacturing plants is summarized in the following tabulation.

Tabulation G
Summary of Annual Energy Requirements for Raw Material Transportation

Products[a]	Annual transport energy required, Btu x 10^{15}
Nitrogen	
Natural gas transmission	0.00068
Phosphates	
Phosphate rock	0.00235
Sulfur	0.00154
Total	0.00457

[a]Potash not involved since all beneficiation is at the mine, only product transport involved.

Chemical Fertilizer Distribution

In preceding sections, the estimated direct energy requirements for the production of the principal nitrogen, phosphate, and potash fertilizers were calculated. In this section, estimated energy requirements for the storage, transportation, and field distribution of the 1974-75 countrywide fertilizer mix is calculated.

The estimated fertilizer mix together with modes of transportation, average transport mileage, and number of transfer points are given in the following tabulations.

Tabulation H
Estimated Fertilizer Mix and Mode of Transportation
and Average Transport Mileage, 1974-75

Material	Annual tonnage x 10^6	Mode of transport, 10^6 tons			
		Rail	Barge	Pipeline	Truck[a]
In-Plant Use					
Anhydrous NH_3	4.7[b]	–	–	–	–
Direct Application					
Anhydrous NH_3	3.8	0.6	2.1	1.1	3.8
N solution	4.7	2.2	2.5	–	4.7
Urea prills	1.1	0.6	0.5	–	1.1
Ammonium nitrate prills	4.2	2.7	1.5	–	4.2
Mixed NPK	25.0	10.0	15.0	–	25.0
Phosphates	3.8	2.3	1.5	–	3.8
Potash	4.5	3.0	1.5	–	4.5
Total tons	47.1	21.4	24.6	1.1	47.1[a]
Estimated transport mileage		500	800	600	105[a]
Estimated energy consumption,[c] Btu/ton mile		670	550	450	2400

[a]All material eventually trucked, average 100 miles from terminal to retail outlet and 5 miles from retailer to farm gate.
[b]This tonnage not added to figures in column below, it was used in production of the products below.
[c]Average of several sources (*2, 11, 13, 14*).

From these data, calculations of through-storage energy requirements at three transfer points, of long- and short-distance freight energy requirements, and of field distribution energy requirements were made. The results are summarized in the following tabulation:

Tabulation I
Summary of Distribution Energy Requirements Per Year

	Quadrillion (10^{15}) Btu/yr.
Storage Energy Requirements	
Anhydrous NH_3–in-plant use	0.0006
Anhydrous NH_3–three transfer points	0.0014
Nitrogen solutions–three transfer points	0.0034
Solids–three transfer points	0.0162
Total–storage	0.0216
Transport Energy Requirements	
Rail	0.0072
Barge	0.0108
Pipeline	0.0003
Truck	0.0119
Total–transport	0.0302
Field Distribution Energy Requirements	
Anhydrous ammonia	0.0025
Nitrogen solutions	0.0009
Solids	0.0053
Total–field distribution	0.0087
Total distribution energy required	0.0605

Summary of Chemical Fertilizer Annual Energy Requirements

The summary of data presented in the previous sections of this report is shown in the following tabulation.

Tabulation J
Summary of Annual Chemical Fertilizer Energy Requirements

Item	Annual energy required, Btu x 10^{15}			
	Nitrogen	Phosphate	Potash	Total
Raw materials preparation and conversion to fertilizers	0.412	0.063	0.011	0.486
Fertilizer distribution[a]	–	–	–	0.061
Raw materials transport	0.0007	0.0038	0	0.005
Total				0.552

[a]Includes field application, complicated fertilizer mix prevents a realistic breakdown between nitrogen, phosphate, and potash.

The total estimated energy consumption of 0.552 x 10^{15} Btu per year by the chemical fertilizer industry amounts to about 0.66% of the total estimated 83 x 10^{15} (quadrillion) Btu. As indicated previously, the total agricultural system utilizes an estimated 3% of the total energy consumed; therefore, chemical fertilizer energy consumption is about 23% of the total agricultural system requirements.

References

1 Clark, J. J "Ammonia Production Must Receive Top Priority," *Farm Chemicals* Vol 137, No 1, January 1974, pp 18 19
2 *Energy in Agriculture*, Task Force, Council for Agricultural Science and Technology, November 26, 1973
3. "Agriculture Depends Heavily on Energy," *Chemical Engineering News* March 11, 1974 pp 23-24
4. Harre, E A "Fertilizer Trends—1973," Tennessee Valley Authority Bulletin Y-77, June 1974, supplement, "North American Production Capacity Data," Tennessee Valley Authority Bulletin Z-57, January 1975
5 *Ammonia 2*, Part I, ed by A V Slack and G R, James, Marcel Dekker, Inc, New York (1973) pp 30-35
6 Information Circular 8632 Bureau of Mines, U S Department of Interior 1974
7 Blouin, G M "Effects of Increased Energy Costs on Fertilizer Production Costs and Technology," Tennessee Valley Authority Bulletin Y-84 November 1974
8 "New Light on Nitric Acid Costs," *Chemical Week* Vol 98, No 27, February 5, 1966
9 Goeller, H E and Mrochek, J E "Generalized Capital and Operating Costs for Power-Intensive and Allied Industries," Oak Ridge National Laboratory Report 4296 December 1969.
10 White, W C "Energy—The Name of the Game," *Fertilizer Progress* Vol 4, No 6 November-December 1973, p 14
11 Davis, C. H "Energy Requirements for Alternative Methods for Processing Phosphate Fertilizers," presented at Technical Conference of International Superphosphate and Compound Manufacturers Association Limited, Prague, Czechoslovakia, September 23-27, 1974
12 Davis, C. H and Corrigan, P A "Energy Requirements for Alternative Methods for Processing Phosphate Fertilizers," presented at American Society of Agronomy Meeting, Las Vegas, Nevada November 12-16, 1973.
13 *Chemical Engineering Progress*, Vol 70, No. 7, July 1974 p 28
14 Breach, I "Freightways of Tomorrow," *New Scientist*, July 12, 1973 p 68

ENERGY RESOURCES FROM ORGANIC MATERIAL

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In accepting the responsibility to lead the discussion on energy resources from organic materials I was given a great deal of flexibility in preparing my remarks. I want to acknowledge the tremendous assistance from members of an undergraduate seminar and a graduate seminar in the Agricultural and Biological Engineering Department during the fall semester of 1975. These young people were invaluable in helping track down various sources of information. We did not discover that many agricultural research organizations have conducted research regarding energy production from agricultural crops. The time may have come in which we need to direct part of our resources in agricultural research, education, and extension, to developing strategies, processes and systems for production of energy from organic material.

As the race between the providers of energy and the consumers of energy continues, it becomes rather clear that we must increase our available sources of energy if our quality of life, and, possibly, the survival of humanity is to continue. Professor Murphy (*1*) states that:

> We are eating away our energy resources not withstanding the advanced technology used for scientific agriculture every calorie of food consumed requires about four calories equivalent of energy sources, out of which one calorie equivalent of fuel for growing and supplying the good to the consumer, and three calories equivalent for cooking that food.

Of course the only reason for utilization of energy in the first place is to sustain and improve life for humanity. With all of the various energy sources presently used by humanity, *fossil fuels, electricity, hydroelectric power, organic material, wind power, etc.*, the primary source of this energy is supplied by "Old Sol," *sunshine.* Our solar energy is nature's way of supplying energy to us by controlled nuclear fusion. We are attempting to develop processes for control of nuclear fusion; however, this may not be on the immediate horizon and may not offer a solution in the long run. As long as the sun continues to shine on planet earth we essentially have a renewable source of energy. When the sun fails, life as we know it to exist on planet earth will cease to exist. Then the question of supplying energy will become a moot point.

Even though we are discussing energy resources from organic material, in reality we are discussing sources of energy from solar radiation. The organic material happens to be a very effective collective and storage device. Since our primary souce of energy from organic material will be solar energy, a quick review of the availability of solar energy is in order. Morse (*2*) states that "Solar energy arrives on the surface of the United States at an average rate of 4000 kcal/m^2-day or about 4.18×10^9 kcal/km^2-day. Over a period of a year a square kilometer would receive an average of 1.53×10^{12} kcal. In 1970 the total energy consumed by the United States for all purposes was about 16.4×10^{15} kcal."

The basic energy conversion in growing plants is the photosynthetic conversion of carbon dioxide to a biomass. Klass (*3*) states that this conversion can be represented by the following equation:

$$CO_2 + H_2O + \text{light} \xrightarrow{\text{Chlorophyll}} (CH_2O)_x + O_2$$

Klass (*3*) states that:

> Carbohydrate is the primary product. For each gram atom of carbon fixed, about 112 kcal are absorbed. Oxygen liberated in the process comes exclusively from the water, according to radioactive labeling experiments. The prerequisites for carbon dioxide fixation and biomass production are carbon dioxide water, light in the visible region of the electromagnetic spectrum, a sensitizing catalyst, and a living plant.

Klass (*3*) states that:

> The first pathway of carbon dioxide fixation is called the Calvin-Benson 3-carbon cycle, after its discoverers, and involves an initial 3-carbon intermediate called phosphoglyceric acid. C_3 (or 3-carbon) plants exhibit lower rates of photosynthesis at low light saturation points, sensitivity to oxygen concentration, photorespiration, and a high carbon dioxide compensation point (about 50 ppm). The carbon dioxide compensation point is the carbon dioxide concentration in the surround-

ing environment below which more carbon dioxide is respired by the plant than is photosynthetically fixed. Typical C_3 plants are peas, sugar beets, and spinach

The second pathway is called the 4-carbon or C_4 pathway because the carbon dioxide is initially fixed as the 4-carbon dicarboxylic acids, malic and aspartic acids In contrast to the C_3 plants, plants classified in the C_4 category have higher rates of photosynthesis, high light saturation points, insensitivity to oxygen concentrations below 21 mole percent, low levels of respiration, low carbon dioxide compensation points, and greater efficiency of water usage. C_4 plants often occur in areas of high insolation, hot daytime temperatures, and seasonal dry periods. Typical C_4 plants include the important crop plants such as corn, sugarcane, and sorghum, and forage species and tropical grasses such as bermuda grass, sudan grass, and even crabgrass Today, at least 100 genera in 10 plant families are known to exhibit the C_4 cycle.

The third mechanism of carbon dioxide fixation is called the Crassulacean Acid Metabolism or CAM cycle, which involves malic acid intermediates. The distinguishing features of CAM plants are a very low gas exchange rate during the day, and the ability to fix carbon dioxide in the dark Plants in this classification are typically adopted to arid environments, have low photosynthesis rates, and have water-usage efficiencies. Examples are cactus plants, and the succulents such as pineapple. Relatively few CAM plants have been exploited commercially.

One would expect that the photosynthetic process is not 100% efficient. Certain energy losses do occur. Schneider (*4*) indicates that

> Energy losses can be divided into three groups (1) losses due to the photochemical and biochemical mechanisms involved directly in photosynthesis, (2) other losses due to the type of plant, the physical environment, agricultural practices, respiration and physiological factors, and (3) losses due to disease, grazing and insects. Some of these losses can be drastically reduced by changes in agricultural practices (improvement of cultivation and harvesting methods, including use of irrigation, fertilizers, etc.) Estimates of the magnitudes of the losses, which are influenced most by agricultural practices, should indicate possible gains in crop yield. All activities which add supplementary energy to the crop, and all agricultural practices which consume energy, must be totaled and subtracted from the energy yield. It is frequently difficult to include all of the energy inputs.

According to Schneider (*4*) the maximum efficiency that is available over the entire solar spectrum is approximately 11% conversion efficiency Coupled with the maximum plant conversion efficiency of 5-6%, he indicates that this will be limiting conversion efficiency in terms of crop growth yield

Even though a conversion efficiency of 5-6% does not sound very large, this is significant when considered that the present conversion efficiency of plants is estimated to be approximately .4% However, agricultural practices can be developed and some are presently available that result in high daily yields Schneider (*4*) indicates that

> Achievement of high daily yields approaching the 5 6 percent conversion efficiency have been reported. Attainment of these yields on an annual basis would result in crop production of 60-100 metric tons/acre each year. The best recorded crop productivities lie in the range of 30-35 metric tons/acre year and are achieved by several tropical grasses. Water hyacinth is expected to be capable of yields of 45-60 metric tons/acre per year when cultivation proceeds under careful management. Sewage grown algae could yield 20-30 metric tons/acre year while some temperate forests exceed 10 metric tons/acre year. (All of these production values are dry organic weight). In the range of 10 metric tons/acre year—20 metric tons/acre year fall many temperate species and it is this range that can be reached with any number of crops including many natural ecosystems as well as agricultural crops.

Dalal (*5*) in his discussion of environment, energy and the need for new technology indicates that photosynthetic fuels offer excellent possibilities. He states that: "It is possible to use highly efficient grass or fast growing crops energy producing biomass "

Wolfe (*6*) in his discussion of potential impacts of solar energy indicates that conversion of sunlight to chemical energy via photosynthesis has excellent potential He indicated that:

> The conversion of sunlight to stored chemical energy via photosynthesis has been utilized by man for approximately 11,000 years through agriculture for the production of his food, of feed for his domesticated animals, and of fuel. Now, these photochemical processes are being reinvestigated for their potential for energy generation. The advantage of the approach is that it results in storable and transportable energy, which can be in the form of gaseous or liquid fuels. The approach generally consists of two states. first, the production of carbohydrates through utilization of photosynthesis, and second, the conversion of these chemical compounds into fuels of higher energy density, such as methane or hydrocarbon oils For

both stages, biological and technological processes are under consideration

The biological processes for the first stage, the reduction of carbon dioxide from the atmosphere to form carbohydrates, would be an extension of present agriculture or forestry methods. These methods generally operate with an annual average efficiency well below 1 per cent. Using improved methods for the cultivation of plant organisms, it is hoped that this efficiency can be raised to approximately 5 per cent. While efficiency *per se* would not be of concern, it becomes important through the limited solar energy flux, and therefore enters into considerations of land use and process economy As a rule of thumb, average delivery of 1000 MWh per day of energy in any form at 10 percent efficiency requires 2 5 km^2 (1 mile^2) of horizontal area in the U S.A As far as cultivation of land plants is concerned it is not known at this time to which degree energy crops might interfere with other land uses

Levitt (*7*) states that

> The fuel that is most easily obtained from plant material is charcoal At least in the case of wood, simple standard methods have long been used Charcoal is an excellent fuel and could be used for the production of electrical energy, in the same way as coal or oil The basic question is whether the amount that could be produced is adequate There are two possible ways of producing this fuel. (1) Farms that produce complete consumed crops (e g hay) would have to find additional land to grow the plant material which would be convertible into charcoal (e g wood) (2) Farms that harvest only a part of the plant material (e g. the fruit or grain) must harvest the remainder for conversion into charcoal. Corn belongs to the second group. According to the calculations of Pimentel et al. (1973), a total of 1 kcal fuel is required for every 2 8 kcal corn produced by modern methods of agriculture. This means that enough of the vegetative part of the corn plant must be harvested as fuel to equal 1/3 of the grain crop

Weinberg (*8*) states that we are producing "155 billion tons per year of cellulose. That's about 150 lbs of cellulose per day for each person on earth." The question then becomes How can we convert this biomass to a form of energy readily stored and converted for use by each consumer? Several possibilities exist I wish to indicate at least three forms that have been proposed These are utilization of the solid material as a direct energy source in thermal conversion That is simply burning the solid material (*2*) gasification and production primarily of methane and (*3*) the production of methanol.

Szego and Kemp (*9*) indicate that

> The technology required for burning energy plantation fuel is already available whereas much technical development still remains to be done before breeder reactors will be as ready for everyday operation For example, wood burning boilers that generate as much as 800,000 lbs/hr of steam at 1250 psig and 950°F are commercially available Such a boiler will support an electric generating capacity of about 80 mega watts.

Szego and Kemp have indicated that conversion of wood and solid cellulose products is the most economical conversion of the solar energy available to us They indicate that the photosynthetic process is estimated to cost $1000/kw whereas the photothermal process is approximately $5,000/kw and the photovoltaic is about $100,000/kw. Their estimations are that approximately 370 square miles of a "energy plantation" is required to support a 1,000 mw base load generating plant. This is essentially equivalent to the amount of land area required for pulpwood production in order to support a 1,000 ton per day pulpmill Assertions by Smith (*10*) that approximately 70% more wood would be required in order to make a pulpmill self sufficient in terms of energy useage Most of us shudder at the thought of supplying an additional 70% more pulpwood in order to produce the paper products required by present day society However, Mr Smith indicates that it is possible that we can capture the "green junk" left on the tree plantations as a part of the pulpwood industry and utilize this material Estimates range as high as 50 to 80 per cent material left on the forest site This material could be used to power a boiler operation and provide the necessary energy for the paper mill Of course an immediate question is What about the energy required to collect and transport this material to the mill? The amount of material needed to transport to the mill would be approximately 1600 tons of wood material per day to produce 10.5 billion Btu's which is necessary to process 1,000 ton of pulp per day Smith indicates that only 1/5 to 1/4 of the total biomass produced each year is utilized as material for the pulp operation He suggests that the remaining biomass could be used to provide the source of energy for the plant operation

The gasification process of nonfossil carbon, which is the material produced by our growing plants can be converted to methane Klass (*3*) states that:

> In the optimum gasification process, the total plant, including water and nutrients, could be accepted as a feed and gasified to produce methane and residual water slurry suitable for total recycling Anaerobic digestion appears to be the closest to the ideal process Water slurries are required for digestion to take place, and it has been demonstrated that the residual liquid-solid slurries from commercial municipal digesters are effective fertilizers

Klass (3) further indicates that the biomass production from 1.3 x 10^6 to 3 26 x 10^6 acres has a potential of producing synthetic natural gas at an estimated cost ranging from S 73 to S1 1 per 10^6 Btu This estimated cost compares to the present cost of natural gas at a cost of S 50 S2 50 per 10^6 Btu This production from the 1 3 x 10^6 (0 3% of U S crop land) acres is estimated to produce 1 billion cubic feet/day of synthetic natural gas.

It has also been suggested that a nonfossil carbon could be an excellent source of methanol production Daley (11) indicates that alcohol can be used as a fuel in internal combustion engines He indicates that a bushel of corn and a bushel of wheat can each produce nearly three gallons of pure grain alcohol Reed, et al (12) indicate that methanol offers a particularly attractive form of solar energy conversion since agricultural and forest waste products can be used as a starting material

A few comments are in order regarding the use of agricultural wastes and by-products as a source of energy. Other speakers have covered this topic in detail but a few comments are in order. Freedman (13) indicates that there are several types of wastes that may be used as energy sources including plant and animal wastes

Knight, et al (14) state that:

> Agricultural wastes represent a potential source of energy, and the utilization of these wastes as energy sources would be of tremendous benefit to the agricultural interests of this country It would change the status of a waste material to that of a resource, and provide much needed fuel from a renewable resource It would eliminate disposal and pollution problems now associated with the wastes The steady flow, low temperature pyrolysis process developed at the Georgia Tech Engineering Experiment Station is a system that is capable of converting the wastes into fuels The process has been developed from bench scale to a pilot plant scale and finally to a large scale demonstration facility capable of feed rates of 50 tons/day of dry feed material The char and pyrolytic organic liquid represents useful solid and liquid fuels that can be transported economically The heating values of the chars are in the range of 10,000 to 13,000 Btu/lb and the heating values of the pyrolytic organic liquid are in the range of 10,000 to 14,000 Btu/lb The char and the pyrolytic organic liquid can be mixed to form a char-oil mix which can be burned directly in existing facilities. Agricultural wastes are very low in sulfur, and therefore the fuels from them are low in sulfur The air emissions from the burning of these fuels would be very low in sulfur dioxide The demonstration of the portability of the EES waste converter system would provide a means for the utilization of large quantities of agricultural wastes that are not now readily available The EES pyrolytic process offers a proven process at the commercial prototype stage for the utilization of agricultural wastes and lignocellulosic materials as energy sources by converting the materials into clean burning fuels

Several researchers have indicated that the production of methane gas from animal waste offers a distinct possibility McDonald (15) indicates that we can expect 14,000 cu. ft./day of gas from a 100-cow dairy After using 6,000 cu. ft. of this to support the digester at 700 Btu's/cu. ft. he indicates that the remainder is more than enough to satisfy the total energy need of 100-cow dairy farm.

Some people even want to recycle a cow burp. Colligan (16) in *Science Digest* indicated that a group of investigators with the Texas Highway Department claim a cow burp has potential. They announced that the nation's cows belch an estimated 50 million tons of hydrocarbon into the air each year They claim that 10 cows burp enough gas in a year to satisfy the annual space heating, water heating and cooking requirements for a small house I offer no suggestions for development of systems and devices for collection and storage of this hydrocarbon fuel, but agricultural processors have long claimed that the only thing not captured in the processing of pork is the "squeal." We may want to capture energy at both ends of the cow.

In summary, we have some exciting opportunities on the horizon concerning energy resources from organic materials, particularly supplied by agricultural production. My purpose was to encourage education, research, and extension organizations to assume their responsibilities including investment of necessary resources to provide alternate energy sources. Agriculture first permitted humanity to develop other talents rather than just be "food collectors." We in agriculture now have an opportunity to help people move into the 21st century with the necessary energy to become truly a whole person.

Appendix A

Undergraduate and graduate students who assisted in locating references

Alicia Carol Anderson	Charles L Gramling	Jeffrey Lynn McCaskill	Curtis G Belford, Jr
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References

1. Murphy, K K, "Population, Power and Pollution," The Ninth World Energy Conference, Detroit, Michigan September 22-27, 1974
2. Morse, F H, "Solar Energy as a National Energy Resource," Section 3, The Ninth World Energy Conference, Detroit, Michigan September 22 27, 1974
3. Klass, D L, "A Perpetual Methane Economy – Is It Possible?" *Chemtech* March 1974 pp 161 168
4. Schneider, T R, "Efficiency of Photosynthesis as a Solar Energy Convertor, *Energy Conversion*, Vol 13, No 3. July 1973
5. Dalal, Vikram, "Environment, Energy and the Need for New Technology,' *Energy Conversion*, Vol 13, No 3, July 1973
6. Wolfe, Martin, "The Potential Impacts of Solar Energy," *Energy Conversion*, Vol 14 August 1974
7. Levitt, J, "Fuel as an Agricultural Crop,' *Energy Conversion*, Vol. 15, No 3/4 July 1975
8. Weinberg, Janet H, "The Green Machine," *Science News*, Vol 107 April 5, 1975,
9. Szego, G C, and C C, Kemp, "Energy Forests and Fuel Plantations," *Chemtech* May 1973
10. Smith, H D,, "Wood as an Energy Source for the Southern Pulp and Paper Industry," North Carolina State University School of Forest Resources, Raleigh, N C
11. Daly, Frank, "Outlook," *Iron Age* February 4, 1974
12. Reed, T B and R M Lerner, "Methanol A Versatile Fuel for Immediate Use," *Science*, Vol 182 December 1973
13. Freedman, S I, "Technical Alternatives for Energy Management," *Energy Conversion*, Vol. 13, No 2 April 1973
14. Knight, J A et al, "Pyrolytic Conversion of Agricultural Wastes to Fuels," A S A E Paper No. 74-5017, American Society of Agriculture Engineers, St Joseph, Michigan June 1974
15. McDonald, Byron, "Cowpower Helps Run His Farm," *Popular Science* May 1975
16. Colligan, Douglas, "How to Recycle a Cow Burp," *Science Digest* October 1974

ENERGY UTILIZATION IN PEST MANAGEMENT

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Introduction

Energy utilization in pest management has received relatively little attention until recently Indeed, utilization in all of agriculture has received much less attention than deserved. Recent adverse developments in availability of fossil fuels from foreign sources have created an awareness of the acute need for information on energy requirements in agriculture It is a well-known fact, recently emphasized by Wittwer (1975), that a major part of the total requirement for energy in agriculture is supplied by illimitable renewable resources – energy from sunlight for photosynthesis and the anaerobic fixation of atmospheric nitrogen in forms available for crop use Nevertheless, a large subsidy of energy from fossil fuels is a major contributor to the success of American agriculture. McColly (1960) has estimated that agriculture uses about 10 percent of the petroleum products marketed in the United States.

Proportionally, energy subsidies from fossil fuels are greater for pest management than in most other agricultural operations. Pest control is still largely dependent upon use of chemical pesticides Much of the energy involved in the acquisition of basic raw materials, construction of manufacturing plants, production of pesticides, transportation to the farm, and application is obtained from fossil fuels.

The amount of energy required for production of food and fiber is increasing more rapidly than in many other segments of world economy. Pimentel et al (1973) estimated that energy inputs in corn production in the United States increased more than three-fold from 1945 to 1970 and now amount to 7.1 million Kcal/ha, the equivalent of about 743 liters of gasoline per hectare. Energy required in pest management increased at an even greater rate during the same period.

The rapid acceleration in use of energy in agriculture is emphasized by the fact that the world population doubled during the last 30 years, but energy consumption doubled during the last 10 years (Pimentel et al 1974). No similar estimates are available for trends in energy utilization in pest management. Because of the trend toward more rational pest control practices, it appears reasonable to believe that energy requirements for pest management may have remained relatively static during the last 5 years. Although energy utilization in pest management may not have increased significantly in recent years, prices have doubled during the last several months.

Procedures For Estimating Energy Utilization in Pest Management

The scanty literature available on expenditure of energy in agriculture has been based on information developed for several crops on yield inputs, and on variable and fixed farming costs. Heichel (1973) and Pimentel et al (1974) have used data of the sort available on selected U.S. crop budgets and in various publications on agricultural statistics as a basis for estimating energy utilization for a number of crops. In general, costs of production were calculated from areas with yields comparable to the national or regional-average. Heichel (1973) used gallons of fuel required per acre, or dollar values of fuel and repairs converted to gallons of gasoline or diesel fuel at 28 cents per gallon, and to energy at 32,000 Kcal per gallon; he used the value of energy as dollars of goods and services at the 1970 rate of about 17.4 Mcal dollar^{-1} in his calculations.

Pimentel et al (1974) used the value of 9570 Kcal per liter of gasoline and 24,200 Kcal per kilogram of pesticide in their estimates of energy utilization. Their procedures were used to estimate energy utilization in pest management systems for cotton and soybean in Louisiana during 1975 Information on average numbers of application, kinds, and amounts of pesticides applied was provided by county agents, production specialists and growers These data were used to calculate averages. Obviously estimates arrived at in this manner are subject to substantial errors However, any errors should apply equally to both crops Estimates of fuel used in application of pesticides were provided by the owner of a large aerial application service [1] His estimate of 3 8 liters of gasoline per hectare for aerial application of pesticides agreed closely with an estimate of the amount per acre for application by ground equipment[2], it was used for all calculations of the energy inputs as fuel

Estimates of the energy utilized for insect control on cotton in Louisiana during 1975 are higher than would have been the case prior to the development in 1974 of a serious problem with high levels of resistance to insecticides in populations of the tobacco budworm The devastating losses to this pest during 1974 were responsible for growers beginning applications at lower injury threshold levels and scheduling applications at closer intervals than in the previous three years The result was an average of about 10 applications per acre during the season One of the most commonly used insecticide mixtures consisted of toxaphene plus methyl parathion plus chlordimeform in a ratio of 2 1 0 2 applied at the rate of 3 41 kg/ha/application It was used as the standard for calculations

An average of 4 applications of herbicide was made at the rate of 0 85 kg/ha/application Two of these applications were made by ground equipment during regular cultivations so charges for fuel were assessed to only two of the herbicide applications

No charges were assessed to use of small quantities of fungicides applied as seed treatments, or in-furrow at planting time, for control of seedling diseases

In contrast to cotton which in areas of heavy boll weevil investation is treated more intensively for insect control than any other major crop in the United States, soybean requires relatively little treatment with insecticides The requirements for weed control are similar. The same procedures described for cotton were used in estimating energy utilization for pest management in soybean.

Discussion of Results

Data in Table 1 show estimates of total energy inputs reported by Pimentel et al (1974) for production of four major crops in the United States, their average yields, and return/input ratios It is unfortunate that 1970 was the year chosen for corn. A severe epidemic of *Helminthosporium* leaf blight occurred throughout most corn-producing areas during 1970 and resulted in substantial losses in yield Thus, the energy ratio of 2.5, obtained in their study probably underestimates substantially the efficiency of corn production in the United States. An energy ratio of about 5.0 reported by Heichel (1973) is probably a more realistic estimate for corn In either case, however, it appears that yields of these four crops in the United States have reached the point that increasing energy subsidies is not likely to result in corresponding increases in yields of digestible energy.

Table 1
Energy Inputs in Crop Production in the United States (Per Hectare)

Crop	Yield kg	Kcal (1,000,000)	Return/Input
Corn (1970)	5,080	7.1	2.52
Potato (1965)	25,600	8.7	2 28
Rice (1963)	5,796	15.4	1,37
Wheat (1962, 1968)	2,554	4.8	1.76

Source: Pimentel et al (1974)

[1]Mr. Ray Thornton, Cane Air, Inc., Donaldsonville, Louisiana
[2]Provided by Dr Carl Thomas, Head, Department of Agricultural Engineering, Louisiana State University

The percentage of total energy inputs required in pest control for each of the four crops was calculated from the data of Pimentel et al (1974), Table 2. Except for potato which required almost 5 percent, energy used in pest control for these four major food crops comprised a relatively small percentage of the total

Table 2
Energy Inputs Allocated to Pest Control

Crop	Kcal/ha for Pest Control	Percent of Total
Corn	54.208	0.76
Potato	406.560	4.64
Rice	271,040	1.77
Wheat	26:620	0.55

Source: Pimentel et al (1974)

Data in Tables 3, 4, and 5 summarize the estimated energy inputs utilized in pest management for cotton and soybean in Louisiana during 1975 There was an almost five-fold difference between the two crops in energy utilization for pest control Less energy was utilized in pest management on 740,000 ha of soybean than on 116,000 ha of cotton One of the most striking features of energy requirements for both systems is the high percentage of the total that is comprised by fuel used in pesticide application — about one third in cotton and more than one-half in soybean.

Table 3
Estimated Energy Inputs Required for Control of Cotton and Soybean Pests in Louisiana, 1975

	Cotton	Soybean
August estimate of acreage for harvest (1,000ha)	116	740
Energy input (1 billion Kcal)	160	128
Energy input expressed as fuel equivalents (1 million liters)	16	13

Table 4
Estimated Energy Inputs by Category for Control of Cotton Pests in Louisiana, 1975
(Per Hectare)

	Kcal	Fuel Equivalents (Liters)
Insecticide, 10 appl @ 3.41 kg/ha	824,978	86.2
Herbicide, 4 appl. @ 0.85 kg/ha	82,522	8.6
Fuel for 12 appl. @ 3.8 1/ha	436,392	45 6
Total	1,343,892	140.4

Table 5
Estimated Energy Inputs for Control of Soybean Pests in Louisiana, 1975
(Per Hectare)

	Kcal	Fuel Equivalents (Liters)
Insecticides, 0.3 appl. @ .57 kg/ha	4,114	0.4
Fungicides, 0.2 appl. @ 0.2 kg/ha	5,566	.6
Herbicides, 4 appl. @ 1.42 kg/ha	137,456	14.4
Fuel, 4.5 appl. @ 3.8 1/ha	163,347	17.1
Total	310,483	32.5

Based on estimates from the data of Strickland and Harwell (1971) on yields, inputs, and variable costs in production of cotton and soybean in the Delta Region of the South Central United States, energy costs of pest management for cotton equals the total variable costs for production of soybean

Energy requirement in pest management for cotton and soybeans was estimated from Strickland and Harwell's (1971) data by use of Heichel's (1973) procedure It amounted to 20 percent of the total variable costs for cotton and 13 percent for soybean – 6,122,190 and 1,276,290 Kcal/ha, respectively These values are about 4 times higher than the values obtained by using the procedures of Pimental et al (1974). Heichel's (1973) estimates of energy requirements for pesticides in corn and rice producing systems in the United States were about 5 and 3 times higher, respectively, than those of Pimentel et al (1974) Much of this difference can be explained by the fact that part of Heichel's (1973) procedure included estimates of fixed as well as variable costs of production Thus, it would appear that the estimates of energy requirements in pest management for cotton and soybean in Louisiana during 1975, Tables 4 and 5, may be reasonable However, it should be emphasized that these estimates would be considerably higher if all costs of production, transportation, etc of pesticides were included [3]

The contribution of energy inputs in pest management to the total energy requirements in major cropping systems of the United States is relatively small However, the source of almost all of this energy is fossil fuel There is a critical need for reducing to a minimum the use of fossil fuels in agriculture. Pest management is an area in which substantial progress can be made toward the objectives of reducing the amount of energy from fossil fuels and of increasing the efficiency of its use

Table 6
Percentage of Energy Allocated to Pesticide Applications for Selected Crops

Crop	Percent of Total	Kcal/ha
Corn grain (Illinois, 1969)	4	513,600
Corn silage (Iowa, 1969)	4	617,550
Rice (Louisiana, 1970)	5	1,492,000
Sorghum (Kansas, 1970)	2	131,150
Soybean (Missouri, 1970)	7	519,050
Oat (Minnesota, 1970)	0.4	23,050
Peanut (North Carolina, 1970)	12	3,471,600
Sugar beet (California, 1970)	6	1,327,350

Source U.S Department of Agriculture, Statistical Bulletin 233 (1958)

Clearly, agriculture is faced with the dilemma of sharply increasing costs of energy and decreasing efficiency in its use as crop yields are pushed higher The situation is made tremendously more difficult by rapid depletion of available fossil fuels coming at a time when a drastic increase in production of food and fiber has become a top priority of human endeavor

[3]Energy utilization in production of pesticidal chemicals is substantial for some compounds. For example, Dr David Humphries of the Ethyl Corporation estimated that 47 gallons of crude oil were required for the manufacture of 1 pound of the organochlorine insecticide *lindane* during 1971.

As the energy crisis grows more critical, some have suggested the need for a return to the practice of less intensive agriculture with substitution of human and animal labor for machinery and chemicals dependent upon fossil fuels However, the solution to the problem of an energy shortage in pest management does not lie in a return to hand picking potato beetles and use of the hoe and mule drawn plow to control weeds If adequate amounts of animal labor rapidly could be made available to replace the energy from fossil fuels that is currently required for agriculture in the United States, about 90 million acres of cropland would have to be diverted from present use to the production of feed for horses and mules, Table 7 Society could not afford to sacrifice production from such a huge area Also, with so many additional horses and mules adding to the current problems of livestock waste disposal, we would soon be up to our elbows in horse manure and the house flies that breed in it The Environmental Protection Agency would undoubtedly view such a development with disfavor

Table 7
Farm Land Required to Produce Feed for Horses and Mules

Year	Hectares, millions	
	On Farms	In Cities
1910	72	16
1920	80	10
1930	63	2
1940	42	1
1950	18	1
1957	7	1

Source U S Department of Agriculture, Statistical Bulletin 233 (1958)

Pimentel et al (1974) pointed out that the savings in energy inputs for weed control by use of mechanical cultivation and hoe or other hand implements instead of herbicides would be about 12 and 94 percent, respectively Before considering such theoretical alternatives to use of herbicidal chemicals their practicality should be examined Mechanical cultivation is impossible in small grain crops, such as rice and wheat It is much less efficient than use of herbicides for control of weeds in the drill of row crops, and it is impossible to use in periods of excessive rainfall Had herbicidal chemicals not been available in Louisiana during 1975, lack of weed control in major crops would have been disastrous As for hand labor, it is not available, and even if it were, the costs involved in controlling weeds by hand in U S agriculture would make profitable farming impossible under current conditions Clearly, it does not make sense to attempt to solve the energy problem in agriculture by reverting to systems of production from which so many are striving so desperately to escape Rather, the most appropriate step to be taken in pest management appears to be development of systems that require minimum amounts of energy derived from fossil fuels used as efficiently as possible Pest management for both cotton objectives can be achieved

Current systems of management of cotton insect pests in areas where the boll weevil is a key pest, are still based on the profligate use of conventional chemical insecticides The system developed when the synthetic organochlorine insecticides became available Prior to this time, very little insecticide was used for control of cotton insects Growers, for the first time, were provided with a highly effective, cheap means of controlling the boll weevil when DDT, benzene, hexachloride, and toxaphene became available The pattern of use rapidly evolved into a system of scheduled applications at weekly intervals from the time of seedling emergence until crop maturity Applications were made on a systematic basis without regard for pest population assessment or economic injury thresholds.

For a relatively short time the system provided highly effective, dependable, and relatively economical pest control Then, the beginning of a disaster syndrome occurred with the appearance of organochlorine insecticide resistant populations of boll weevil during 1955. This was followed by the elevation of minor pests, or species of no previous pest status on cotton, to the position of major pest status, the tobacco budworm and bandedwing whitefly, for example, development of resistance to insecticides in other species, destruction of predators, parasites, and pollinators, massive contamination of the environment generally and of many non target species with persisting residues of toxic chemicals, and finally to the development of resistance in populations of the tobacco budworm in some areas to the extent that it is no longer controlled effectively with any pesticide currently registered for use on cotton Thus, evolution of cotton insect control in the United States during the last quarter-century provides a classic example of the disastrous consequences of overuse of chemical pesticides in pest management systems Not only does such an approach create problems, often more serious than those which it aims to solve, it is extremely wasteful in utilization of energy The details of problems created by unilateral approaches to pest management are too well known to members of this group to require further elaboration

Weed control in cotton provides a number of striking parallels to insect control There are marked differences in the chemicals involved. In general, herbicides are less toxic to non-target organisms, and they are usually less persistent and environmentally hazardous Development of resistance to herbicides has been considerably less rapid in weeds than it has been to insecticides in populations of insects and related arthropods Several cases of resistance have been documented recently and the phenomenon will probably become more common. The most striking parallel between insect control and weed control is the change in dominance of pest species In both, several species of little or no previous importance have been elevated to positions of major pest status as a result of the use of chemical pesticides Surprisingly, weed control specialists have failed to profit from the mistakes that have been made by entomologists They continue to follow the same path that has been disastrous in entomology, *viz* the unilateral approach of reliance upon herbicidal chemicals applied without regard to population assessment and economic thresholds

The situation with insect pest management in soybean contrasts sharply to that in cotton Soybean does not yet have a key insect pest If a rational approach to pest management is followed, none should develop The secondary and occasional pests of soybean are not of sufficient importance to justify an average of one application of insecticide per hectare per year Their status should remain unchanged if a reasonable approach to pest management is followed

The weed problem in soybean is equally or even more important than that in cotton The approach to management of weed pests is the same as that for cotton The potential problems are equally grave.

The challenge to the pest control disciplines is to develop pest management systems that will allow growers to extricate themselves from the "treadmill" of excessive use of insecticides with the attendant waste of energy, for control of cotton pests and to prevent such a situation from ever developing in soybean Neither will be easy but the former is by far the more difficult The situation in management of cotton insect pests and use of energy from fossil fuel in agriculture is similar to that described by the late President Truman for a man riding a tiger He said, "When you are riding a tiger you can't get off, you have to keep riding " An example of the point reached in "riding the tiger" of cotton insect control has been provided recently by a grower in Louisiana In an attempt to control an infestation of highly resistant tobacco budworms in 42 hectares of cotton he made an application on September 27 of a mixture consisting of toxaphene, methyl parathion, and monocrotophos at the rate of 6 91, 3 46, and 1.[illegible] kg/ha, respectively Energy utilized in this single application amounted to 292, 408 Kcal/ha, or the equivalent of about 31 liters of gasoline.

This example is the ultimate in overuse of pesticides and squandering of energy The environmental costs of excessive pollution and adverse effects on nontarget organisms are intolerable, and the tobacco budworm was not controlled. The results of such an approach, if continued to be practiced, will lead to loss of the cotton industry in an area This has already happened in large areas of Mexico It is a major factor in decline of cotton acreage to about 28,000 ha in the Rio Grande Valley of Texas and to 116,000 ha in Louisiana during 1975

Development of Energy-Saving Pest Management Systems

Cotton

The tobacco budworm is an induced pest The species was virtually unknown as a pest of cotton prior to 1950 because it was completely controlled by a large complex of predators and parasites Procedures for successful management of the tobacco budworm in areas where the boll weevil is a key pest have been described (Newsom 1972) For the short term, a pest management system based on the so-called "diapause method" of boll weevil control was recommended. This method is based on application of insecticides during late season and after maturity of the cotton crop The objective is to prevent the development of boll weevils that can overwinter successfully as diapausing adults The system reduces populations of overwintering boll weevils by 80 to 95 percent. This usually delays the development of damaging populations during the following season until late July or August It allows the maximum benefits from predators and parasites, helps to conserve their populations, and relaxes the selective pressure of insecticides on tobacco budworm populations Adoption of this system of pest management would result in a reduction of insecticide by one third to one half thereby resulting in substantial savings in energy Implementation of the system would "buy the time" necessary for the development of long-term pest management systems possessing a high degree of permanence and stability. Ultimately, it would allow growers to "get off the tiger " Such systems would be developed around the following tactics 1) restoration of the effectiveness of predators and parasites for control of tobacco budworm to that of 25 years ago by avoiding early-season applications of insecticides, 2) making maximum use of varietal resistance to insect pests, 3) use of trap crops of early planted, early fruiting, prolific varieties to attract overwintered boll weevils to a very small percentage of the total acreage where they can be controlled with a minimum of pesticides, 4) destruction of crop residues as early as possible, 5) maximum use of microbial pathogens, and 6) use of narrowly selective insecticides whenever possible.

Soybean

Management of soybean pests should have as its prime objective the development of systems that are effective, economical, energy conserving, and stable. Such systems must not be developed along lines of approach that will result in the disasters that have emerged from the systems employed for control of cotton insects Fortunately, a well-coordinated, highly cooperative research program has been organized as a subproject of the NSF EPA Integrated Pest Management Project that has as its major objective development of a pest management system that will avoid the problems that have characterized systems for cotton insect control Some of the progress that has been made in Louisiana was reported by Newsom et al (1975) The system developed in Louisiana is based on the establishment of economic injury thresholds for the pests, regular monitoring of pest populations and application of pesticides based on pest population assessment It makes maximum use of 1) biological control agents, 2) the selectivity principle in use of insecticides, 3) trap plots, and 4) methods for holding costs of monitoring pest populations to a minimum

The major pests of soybean in Louisiana are heavily attacked by a complex of predators, parasites and microbial pathogens The impact of these natural enemies is usually sufficient to regulate populations of most pests at sub-economic levels Applications of pesticides are made only when economic injury thresholds are reached Pesticides are used in the most selective manner possible Recommendations for use of the broad spectrum organochlorine insecticides were discontinued more than a decade ago in favor of the less environmentally hazardous organophosphates and carbamates Additional selectivity of pesticide action has been obtained by reducing to the minimum the rate of applications formerly used for control of most pests and by raising economic thresholds to more accurate levels Acreage requiring treatment for the southern green stink bug and bean leaf beetle has been substantially reduced by using trap crops of small areas planted to early maturing varieties as a means of concentrating overwintered populations so that they can be controlled with minimum use of insecticides and least environmental pollution Costs of monitoring populations of major pests have been substantially reduced by taking advantage of new information on the phenology of the soybean and its pests This information shows that there is no need to start a pest monitoring program before mid July in Louisiana except in areas planted to trap crops The southern green stink bug is of no economic importance on soybean until the beginning of seed development, the soybean looper never reaches economic injury levels before August 1 and then only in areas where cotton and soybean are grown in rotation, the velvet bean caterpillar is of no economic importance prior to August 15, and the corn earworm does not damage the crop before it blossoms and then only in fields in which the foliage canopy has not closed

This system provides effective and economical control of soybean pests with minimum utilization of energy It will be improved as additional information becomes available but its implementation has already brought about reductions of one third to one half the amount of pesticides previously used

There is no reason why insect pest management systems for soybean should ever be plagued by the problems that have been characteristic of cotton insect control It would be a tragedy if they were ever to evolve to the point that application would be required of as much insecticide as has been used for control of cotton insects The increase in energy utilization, costs, and environmental pollution would be intolerable on the huge acreage now planted to soybean There is ample cause for major concern that the amount of pesticide now used on soybean could increase substantially The pesticide industry is viewing the 21,600,000 ha planted to soybean as a potentially huge new market Growers are being subjected to heavy pressure by pesticide salesman to induce them to use more pesticide on soybean An intensive well-coordinated, cooperative educational program on the part of extension and research personnel of the Land Grant Colleges and the U S Department of Agriculture will be required to nullify the effects of these misguided efforts of the pesticide industry Savings in energy alone will more than pay the costs of initiating and implementing such a program I should like to urge that those of you who have administrative responsibility for such programs give top priority to this critical need Agriculture cannot afford to allow pest management systems for soybean to take the same route that has been so disastrous for cotton

References

Heichel G H, "Comparative Efficiency of Energy Use in Crop Production," Connecticut Agriculture Experimental Station Bulletin 739 1973 26 pp

McColly H F, "The Place of Petroleum," in *Power to Produce – Yearbook of Agriculture*, ed by A Stefferud, U S Department of Agriculture, Washington, D C 1960 pp 61-69

Newsom L D, "Theory of Population Management for *Heliothis* Species in Cotton," in *Distribution, Abundance and Control of Heliothis Species in Cotton and Other Host Plants*, Southern Cooperative Series Bulletin 169 pp 80-92

Newsom, L D R L Jensen, D C Herzog and J W Thomas, A Pest Management System for Soybeans, Louisiana Agriculture, Vol 18, No 4, 1975 pp 10 11

Pimentel, D, L E Hurd, A C Bellotti, M J Forster, I N Ika, O D Sholes and R J Whitman, "Food Production and the Energy Crisis," *Science*, Vol 182 pp. 443-449

Pimentel, W R Lynn, W K MacReynolds, M T Hewes and S Rush, "Workshop on Research Methodologies for Studies of Energy, Food, Man, and Environment, Phase 1," Cornell University Center for Environmental Quality Management, Ithaca, New York June 18-20, 1974, 52 pp.

Strickland, P L and R L Harwell, "Selected U.S. Crop Budgets – Yields, Inputs, and Variable Costs," Vol. V, South Central Regional, U S Department of Agriculture, Economic Research Service Publication 461, 1971 184 pp

U.S Department of Agriculture, Changes in Farm Production and Efficiency, U S Department of Agriculture, Economic Research Service Statistical Bulletin 233 1972 31 pp

Wittwer, S H, "Agricultural Productivity and the Energy Crisis," *Phi Kappa Phi Journal*, Vol LV, No 1 1975 pp. 35-38

WASTE ENERGY UTILIZATION AND RESIDUE MANAGEMENT

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In 1898 William Crooks awakened the world by claiming that the world faced ultimate starvation because of the dependence on the nitre beds of Chile The world listened and believed, and research and development, lead to the processes for fixing atmospheric nitrogen Recently we have obtained energy for industrialized society from three fossil fuels — coal, gas and oil Today we are examining alternative energy sources with the conviction that alternatives will be found just as they were found for nitrogen

The present problems created by the geographic location of oil are similar to fuel problems created by the past two World Wars. When availability of essential commodities is threatened or limited, we look for new sources and to the utilization of unused resources

Agriculture, forestry, industry and cities generate wastes in the form of refuse and heat Some wastes are potential sources for fuel and energy for use by agriculture, cities and industry According to the best estimates, 200 million tons of animal waste are produced in the United States annually, 390 million tons of plant debris, and 55 million tons of forest slash, bark and sawdust. Urban dwellers discard 129 million tons of solid wastes and produce 12 million tons of sewage sludge. Industry produces an additional 44 million tons of organic wastes (*2*). The total solid, dry organic wastes produced in the United States in 1971 were 880 million tons of which 136 tons are readily collectible. This is the equivalent of 170 million barrels of oil, 2-3% of our annual use, or 1.36 trillion cubic feet of methane, 2-3% of present use (*8*)

From 7 to 8 x 10^{16} Btu's of energy are used annually in the U S. (*13*) If we assume an average energy efficiency of 50% of all fuel used in the U.S., there is 3.5 to 4 x 10^{16} Btu's of waste heat produced yearly Clearly, there are large quantities of wastes and waste heat which could be used or converted to fuels These wastes could either be burned directly (*7, 14*) or converted to synthetic fuels. There are three major ways to convert wastes to synthetic fuel. They are. hydrogenation (actually reduction), pyrolysis, and bioconversion (*5, 8, 7*)

Hydrogenation

Hydrogenation is really a reduction process in which oxygen is removed from cellulose in the presence of an alkaline catalyst such as sodium carbonate. This material is placed in a reactor vessel with carbon monoxide, steamed at 100-250 atmospheres of pressure, and then heated to 240-380°C for one hour Under best conditions, 99% of the carbon is converted to oil. This yields about two barrels per dry ton; however, because of less than optimum conditions and the heat required for steam, there is a net yield of only 1.25 barrels per ton The oil is a heavy paraffinic oil, low in sulphur (less than .04%) with an energy value of 15,000 Btu's per pound compared with 18,000 Btu's per pound for comparable fossil oil (*8*) A full-scale plant could be operating by 1980 for either animal or wood wastes. This is the most costly conversion technique and could probably be justified if product oil value is greater than $5.00 per barrel. Problems include ways of introducing the solids into the reactor under pressure, the control of sulphur emissions, purification of water used in the process and the separation of the oil from solids.

Pyrolysis

Pyrolysis is the burning or heating of wastes in the absence of oxygen or with reduced oxygen Gas, oil and char are produced. This process is usually carried out at atmospheric pressure so that construction and operating costs of plants should be lower than for hydrogenation

Pyrolysis systems have been built by nearly a dozen groups (*8, 14*) Most units are designed for disposal of municipal garbage with resource recovery Each ton of refuse produces one barrel of oil, 150 pounds of char, and a varying amount of low energy gas (*8*) The oil contains 33% oxygen and has one energy value of only 10,500 Btu's per pound – about 60% of fossil oil. Several cities, with EPA assistance, are constructing such plants The pyrolysis system can be modified to a controlled combustion system which produces a mixture of hydrogen and nitrogen gas that is variously called "producer" or "synthesis" gas that can be used in industrial processes to supply hydrogen now commonly obtained from methane (*3, 5*) Pyrolysis plants will be in operation in cities by 1980. The problems involved with pyrolysis are the expense of plant construction, the disposal of the char, the necessity to separate a portion of the materials present in the waste such as ferrous metals, glass, plastics, etc, the requirement to shred the material and sulphur and other gaseous production, but water pollution is not a major problem. The low Btu gas (500-600 Btu's per pound) could be upgraded to methane, but this is usually too expensive as is transporting the gas by regular gas transmission lines. In some plants the low Btu gas will generate steam to be sold to power companies, however, solid waste incinerators which generate steam have not been highly successful in marketing steam.

Bioconversion

Bioconversion is the production by anaerobic digestion of methane, methanol or ethanol It is one of the simplest and oldest methods of converting wastes to fuel, but little investigation has been done during the past three decades (*2, 5, 7, 8*) Methane production from animal manures was common in Europe during World War II but was abandoned because of economic reasons and the supervision required In recent years there has been increased interest in India and in Pakistan in methane generation with the utilization of simpler, less expensive and probably less efficient equipment The main deterrents to the conversion of animal wastes to methane are the cost of the generating equipment, the cost of collection of the manure and distribution of the gas Methane digestors and other bioconversion techniques produce an undigested residue sludge that is a disposal problem. Superficial examination of this residue reveals a high protein content so it could be used as a raw material for feed production, but even though it appears to have a high protein content, it may not be digestible Bioconversion can produce more than 10,000 cubic feet of methane with an energy content of 1,000 Btu's per cubic foot for each ton of solid waste (10,000 cows could produce enough gas for a 30,000 city). Other gases are produced – mainly ammonia, carbon dioxide and hydrogen sulfide The methane is sufficiently concentrated so that it is practical to upgrade the gas This process has been used for years to reduce and stabilize municipal sewage.

Although bioconversion is theoretically a simpler process than either hydrogenation or pyrolysis, there are unsolved problems. A good way needs to be developed for feeding solids into the digestor, and inexpensive ways of collecting and purifying the methane and recycling the effluents. About 40% of the original material remains as sludge that could be converted to oil or gas with either pyrolysis or hydrogenation, but it would seem more logical to utilize this sludge either as a raw material for animal feed or as a soil amendment. The best estimates are that a full-scale commercial plant for bioconversion of organic waste to methane could be in operation in about 15 years (*8*)

Energy from Wastes

Agricultural wastes obviously have caloric value and can be burned Corn stover, wheat straw and other plant residues have a heat of combustion of approximately 7,500-8,000 Btu's per pound (*7*) This is approximately two thirds the heating value of a pound of coal or one third the heating value of a pound of oil Dry animal manures probably have a similar heating value (*5*). It is estimated that well over half and perhaps as much as 70% of the total annual plant yield of agriculture is left in the field as residue This total residue from corn, wheat, soybeans, oats, grain sorghums, sugarcane, cotton, rice, grass, etc amounts to 427 million tons per year with a Btu equivalent to 270 million tons of coal.

Animal wastes can cause environmental pollution that has forced us to change animal waste management and reexamine the possibility of using the wastes In the Orient, dried cow dung is burned as fuel, and throughout other parts of Asia controlled burning of air dry manure in a suction gas producer in the presence of water has been used to yield a combustible mixture of carbon monoxide and hydrogen with a heat value of 80-85% that of methane (*8*). This process has been suggested to relieve the manure build-up problem in the dairy areas of southern California (*8*).

Anaerobic lagoons are a common method of handling animal waste in the U.S (*5*) These lagoons produce methane in the process of reducing the biological oxygen demand.

Other gases such as ammonia, carbon dioxide and hydrogen sulfide are produced If the methane is sufficiently concentrated, a burnable fuel is available, and it would seem that under some circumstances it might be practical to capture this methane for on farm use One of the critical problems associated with methane production is the difficulty of storage and the low heating value. Recent interest in methane production from organic wastes may result in simple, inexpensive plants such as those used in India and Pakistan The main deterrent to bioconversion of animal wastes to methane has been the cost of collection of manure, its necessary preparation for introduction into equipment, and the distribution of the gas The use of manure as animal feed or fertilizer competes with energy production and environmental quality considerations may preclude methane production because of the waste sludge

Controlled partial combustion of manure can yield "synthesis" gas composed of two parts hydrogen, one part carbon monoxide and one part nitrogen on a volume basis (3) Further reaction with steam produces three parts hydrogen and one part nitrogen which can be catalytically converted to ammonia Each ton of dry manure is reported as capable of yielding 700 pounds of ammonia gas (5) The "synthesis" gas replaces methane as the source of hydrogen, and if it could be adapted to small-scale production it would serve as a ready source of ammonia fertilizer In addition, large scale production of hydrogen gas by this manner would have great importance to the synthesis of plastics by industry Most hydrogen is currently produced from methane Animal manures are visualized as a source of energy for some of the large scale hydrogenation plants.

In Florida most dairy and swine wastes are treated in anaerobic lagoons Because of warm temperatures these lagoons continuously evolve methane and other gases It seems reasonable to investigate low cost methods for trapping the methane gas and using it as a source of farm power for water heating, grain drying, space heating, air conditioning and possibly powering stationary engines for feed mills or milking equipment In most cases the heat content of the gas is rather low, and the equipment used would have to be derated, but there should not be any real engineering problems As a visualization of low cost collection unit envision the possibility of using a floating, clear plastic envelope weighted to rise and fall as the volume of gas contained changed but maintaining a constant pressure Such a device would represent an inexpensive and simple method for capturing methane being produced from animal waste in anaerobic lagoons

In Asia, poultry and swine wastes have been used extensively for methane production. Because of their high value as a feed for cattle (4, 5), it is unlikely that they will be used for methane production in the U S if there are no public health problems from recycling as animal feed.

Energy from plant wastes and residues has been used by General Motors Corporation as a fuel supplement in fossil fuel-fired boilers (7) Most of the work done by the General Motors Corporation has utilized corn stover The sugar refining industry utilizes baggasse as a source of fuel for power boilers Baggasse for cattle feed competes with this usage

During my childhood and many of yours, home heating depended upon wood from farm woodlots The utilization of plant wastes directly for heating and power generation is not new, and various schemes are currently being proposed which would produce agricultural crops for utilization either directly or indirectly as fuel Several innovative techniques have been suggested for utilization of plant wastes Plant wastes comprise about twice the total volume of animal manures and could in many cases be harvested as current harvesting machinery passes through the fields The removal of plant residues will obviously deplete the fertility more rapidly than simply harvesting the grain, so any program to utilize these as energy sources must consider both the loss of nutrients as well as any loss of desirable physical properties of the soil that may result Both hydrogenation and pyrolysis could be used on a commercial scale for the conversion of plant wastes into fuels However, a strong interest has developed in the bioconversion of cellulitic plant materials into fuels The U S Army's laboratory at Natick, Massachusetts Pollution Abatement Division (13) has developed an enzymatic hydrolysis system for converting cellulitic wastes to glucose by utilization of an enzyme produced by a mutant fungi This method has been used to convert wood wastes, garbage and waste paper to glucose The first step is the preparation of a sulfide pulp of milled cellulose which is combined in a reactor with the enzyme to produce a glucose syrup This syrup could then be converted to either food, single-celled protein, fermentation products or alcohol The alcohol would be a direct replacement for gasoline in many cases either as an admixture or as a pure material for internal combustion engines The key to this process is the production of a high quality cellulase enzyme complex which is capable of hydrolyzing insoluble crystalline cellulose to glucose In order to make the process succeed it is necessary to mill the substrate and reduce its crystalinity which is an energy-intensive and costly process Hydropulping has been examined as a substrate pretreatment and, while this process hold some promise, there is a solid waste residue produced that requires disposal.

Waste heat from power generation plants, especially nuclear and large fossil fuel plants, has been used experimentally to enhance the production of agricultural crops (6, 9, 12) While enhancement can be shown by elevation in temperatures, the total amount of waste heat that would be utilized in this method seems to be very limited Much of the interest in waste heat utilization by the power generation companies is simply to find a better method for disposal of their heat which is environmentally acceptable (12) While utilization in high latitudes during the cool season would certainly be beneficial, it is doubtful that the long transmission distances required could be justified Probably the best use that can be made of waste heat would be for direct space heating in areas adjacent to power plant sites (*10*) or possibly in mariculture where elevated temperatures in raceways and ponds might stimulate the growth and production of fish, shellfish and aquatic plants (*1, 12*) Processing plant thermal wastes represents an energy source that can be utilized more efficiently but usually requires plant redesign As an example, the citrus concentrate plants in Florida now utilize a large quantity of their waste heat to dry citrus pulp which is milled into livestock feeds In the process, water from evaporators and wash water is used to scrub the stack effluents and recover fly that would have been an air pollutant as well as condense soluble materials. The water is evaporated, the material recovered and dried with a sizable saving in energy and a reduction in both thermal water pollution and air pollution This system has been adopted by most citrus concentrate plants that produce citrus pulp for animal feed. A more advanced phototype citrus concentrate plant eliminates the boiler, uses the vapor from the evaporated juice directly in the process of heating as well as recovering the waste heat from the cirtus feed mill to further concentrate the juice The plant now in operation offers the possibility of reducing the energy requirements 30% and the production of thermal effluents and air pollution

Utilization of Wastes for Energy on the Farm

According to a recent study done in Florida, agriculture and fisheries use 106 7 million gallons of diesel, 85 5 million gallons of gasoline and 27 3 million gallons of LPG each year While this may not constitute a large percentage of the total energy use in the U S., it represents a purchased input, the cost of which can only increase with time Consequently, it might be well to examine potential methods for increasing the fuel efficiency of farm operations by the utilization of wastes as energy sources Apart from the possible production of methane from animal wastes for on farm use, there are several other ideas that could be explored In Florida as in most of the U S grain is dried after harvesting or during harvest Estimates are that for field corn 4 6 gallons of LP fuel are used for grain drying and 3 3 gallons of gasoline for harvesting Since less than half the fuel burned by the combine is used directly to drive it and the rest is waste heat, why can't this heat be utilized to dry the grain as it's being harvested? Currently this heat is simply lost through the radiator and exhaust Obviously there would have to be some redesign of equipment, but with current cost of grain combines, this additional cost might represent a small percentage increase and could represent a reduction in producer costs

Being even more imaginative, one could visualize grain straw or corn stover as a source of energy to drive an external combustion engine to power the harvesting equipment and fuel the grain drying mechanism On a thermodynamic basis, 3 36 gallons of gasoline and the 4 5 gallons of propane could be replaced by about 115 pounds of corn stover or straw This is an extremely small percentage of total residue Moreover, the equipment for handling or harvesting the stover or straw is already present Probably only that which is rejected as chaff and debris by the combine would be adequate to fuel an external combustion engine External combustion engines such as steam engines or the Sterling engine (*15*) might be used I am not qualified to comment on the engineering feasibility of such an idea I simply offer it for consideration. The old problem of fuel supply such as coal for external combustion engines or water could be alleviated with the Sterling engine since the fuel is drawn in as the harvesting equipment moves through the field Since there is no external fluid in a contained system, no water and boiler would be present In this way we might completely eliminate dependence on fossil fuels for most harvesting and grain drying equipment. While this does not represent complete farm fuel sufficiency it does represent a significant decrease in dependence on fossil fuels by agriculture and opens a challenge to the research community In a similar manner, it is conceivable that it might be possible to generate small scale controlled combustion equipment to produce 'synthesis' gas and ammonia directly on the farm. Wouldn't it be an exciting prospect to harvest grains by power from plant residue, convert a portion of the residue into ammonia so that it would be immediately injected into the soil for a double cropping system so that in addition to harvesting one would be fertilizing a following crop at the same time?

The independent, waste energy farm offers an exciting challenge. The possibility for agricultural science and technology to devise a system of waste energy utilization that makes farms less dependent on fossil fuel will benefit the country and the producer by lowering production costs, reducing adverse environmental pollutants and increasing profits–a benefit to the farmer and to the rest of society as well

Observations

After that rather idyllic scenario, I would like to make a few "philosophical" observations Agricultural faculty pride themselves in being useful, but they may have become too utilitarian and not sufficiently egalitarian Following World

War II the growth in both industrial and agricultural technology was truly amazing The economics of both victor and vanquished flourished for three decades. Big science grew up in the 60s, and agricultural science grew as well. Entomologists controlled insects with insecticides, agronomists grew continuous monocultures with cheap sources of nitrogen and other fertilizers, and animal scientists used hormones, drugs and antibiotics to produce more and less expensive meat, all of which promised to solve many of mankind's problems The scientist became a technologist "fine tuning" the agricultural machine with linear programs, complex statistical designs using high-speed, digital computers which could detect smaller and smaller significant differences, many of which became increasingly less important while many major scientific problems receded or passed by. Agricultural administrators became bureaucrats caught up in the maze of rules and regulations.

When *Silent Spring* was published, there was what I would call shocked resentment among agricultural faculty. When EPA was created and started withdrawing chemicals and enacting rules which dealt with agricultural pollution, even the Secretary of Agriculture said we will have to decide which 20 million people in the U.S. would starve! "Hard Tomatoes, Hard Times" really zeroed in on us in Florida, and we refuted much of the obvious misinformation. The Pound report on agricultural research is still debated and much of it probably misunderstood.

Agriculture has its detractors, but perhaps we became too defensive. If our detractors are wrong, that will pass; if they are right, we have real problems and we had better deal with the real problems. It took *Silent Spring* to awaken us from decades of pesticide use and discover that we were growing too dependent on chemical pesticides and in some cases were making pest problems worse.

We need to be futuristic because scientists working on today's problem will produce solutions to yesterday's problem, tomorrow We need to look over the horizon and work on problems that don't even exist as problems, which the lay person may not understand.

Since this meeting is about energy, what is the philosophical point? I don't know the precise point of Dr. Pimentel's work (*11*) It may not even be very accurate because all the inefficiencies in manufacturing are aggregated into agricultural production. If one considers the total biomass produced by agriculture which natural systems ecologists often do, then the efficiency may be 5 or even 10:1. The main point may be that agriculture and we as scientists have grown too dependent upon thinking about purchased inputs and resources as the main ingredients for a viable agriculture. It has required someone with courage, perception and foresight to challenge us and a political energy crunch to awaken us to a real energy dilemma. Hopefully, this will serve to sharpen our scientific senses and direct our attention to basic problems where we can serve mankind through our professions

Table I
Heat Value of Agricultural Wastes and Fossil Fuels

	Btu dry pound
Manure[1]	
Chicken	5822
Dairy	7100
Beef	6425
Turkey	5800
Horse	6984
Swine	7304
Sheep	7666
Plant	
Corn Stover[2]	7500-8500
Straw	7500-8500
Wood (oak)	8320
Urban Garbage	5000
Fossil Fuel	
Coal[3]	8100-15000
Oil[4]	18,2000

Source. [1]Azevedo and Stout, University of California; [2]Green, GMC, [3]Sutterfield (EPA). [4]Hammond, Metz and Maugh, AAAS.

Table II
Million of Tons of Dry Organic Wastes Produced in the United States in 1971

Source	Wastes Generated	Readily Collected
Agricultural Wastes		
Animal Wastes	200	26.0
Agricultural Crops: Food	390	22.6
Logging and Wood Refuse	55	5.0
Total Agricultural Wastes	645	53.6
Non-Agricultural Wastes		
Urban Refuse	129	71.0
Municipal Sewage (sludge)	12	1.5
Industrial Wastes	44	5.2
Miscellaneous	50	5.0
Total Non-Agricultural Wastes	235	82.7
Grand Total	880	136.3

Source Anderson, Bureau of Mines

183

References

1 Alabaster, J L., "Effects of Heated Discharges on Freshwater Fishes in Britain," in *Biological Aspects of Thermal Pollution,* ed by P A Krenkel and F. L. Parker, Vanderbilt University Press, Nashville, Tenn. 1969 pp 354-370.

2. Anderson, L. L., *Energy Potential from Organic Wastes. A Review of the Quantities and Sources,* U.S Department of Interior, Bureau of Mines Information Circular 8549 1972 16 pp.

3 Anonymous, "From Agricultural Wastes to Feed or Fuel," *Chemical Engineering News,* Vol 50, No. 22 1972 pp 14-15

4 Anthony, W. B, "Cattle Manure Re-Use Through Wastelage Feeding," *Animal Waste Management,* Cornell University Conference on Agriculture Waste Management 1969 pp. 105-113

5 Azevedo, J and P R Stout, *Farm Animal Manures An Overview of Their Role in the Agricultural Environment,* Extension Services Manual 44, California Agricultural Experiment Station, 1974 107 pp.

6 Boersma, L, "Warm Water Utilization," in *Proceedings of the Conference on Beneficial Uses of Thermal Discharges,* ed. by S. P Mathur and R Stewart, New York State Department of Environmental Conservation September 17-18, 1970 pp. 74-107

7 Green, F L, "Energy Potential from Agricultural Field Residues," presented at the Special Non-nuclear Technology Session of the Meeting of American Nuclear Society, New Orleans, La June 9-13 1975 17 pp

8. Hammond, A. L, W. D Metz and T H Maugh II, "Energy and the Future", American Association for the Advancement of Science, Washington, D.C. 1973 184 pp.

9 Jensen, M H, "The Use of Waste in Agriculture," in *Waste Heat Utilization,* ed. by M. M Yarosh. Proceedings of the National Conference, Gatlinburg, Tenn. 1972 pp 21-38

10 Miller, A J, "Urban Use of Thermal Energy from Steam-Electric Plants," in *Waste Heat Utilization,* ed. by M. M Yarosh, Proceedings of the National Conference, Gatlinburg, Tenn. 1972 pp 67-76.

11 Pimentel, D, L E Hurd, A. C. Bellotti, M J Forster, J N Oka, O. D Sholes and R. J Whitman, "Food Production and the Energy Crisis," *Science,* Vol 182, 1973 pp 443-449

12 Rykbost, K A, L. Boersma, H J. Mock and W. E Schimsseur, "Crop Response to Warming Soils Above Their Natural Temperature," Special Report 385, Agricultural Experiment Station, Oregon State University, Corvallis 1974 98 pp

13 Spano, L. A, J Medeires and M Models, "Enzymatic Hydrolysis of Cellulasic Wastes to Glucose", United States Army, Natick Laboratories, Pollution Abatement Division, Food Sciences Laboratory 1975 31 pp

14 Sutterfield, W and F. E Wisley, "Refuse as Supplementary Fuel for Power Plants," Proceedings of symposium on Solid Waste Demonstration Projects, United States Environmental Protection Agency (SW-4p) 1971 pp 129-147

15. Walker, Graham, "The Sterling Engine," *Scientific America,* Vol 229, No 2, 1973 pp 80-87

USING SOLAR ENERGY IN AGRICULTURE

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All plants and animals are dependent either directly or indirectly upon solar energy as the sole source of their energy. Through the process of photosynthesis, water and carbon dioxide are converted into sugar. The radiant energy of sunlight is thus converted to chemically bound energy in the most basic form. Both the most modern and most primitive forms of agriculture are dependent upon the process of photosynthesis to capture and store solar energy.

This, however, is about the only thing which primitive and modern forms of agriculture have in common. Modern agriculture is very energy intensive. With the development of the internal combustion engine, it became possible to replace animal power with mechanical power. This gave the farmer greater capacity to do work, allowing him to complete all operations in the production sequence in shorter time. Plant breeders quickly took advantage of this and developed varieties and hybrids which would utilize the full length of the growing season. With many crops, this required that the agriculture be even more energy intensive. For example, corn utilizing the full growing season in the corn belt does not have favorable weather for drying in the field: As a result, from 2 to 3 times as much fossil fuel energy is required to dry the crop as is required for all operations for producing.[1]

Inexpensive natural gas was used to make ammonia to supply nitrogen to crops, again to increase productivity. Very high productivity is obtained in some arid areas through irrigation. This practice is very energy intensive. Twenty times as much fossil fuel energy may be required to provide irrigation water as is required for all other operations for producing that crop.[1]

Cheap energy, and the developments which it fostered, has allowed one U.S. farm worker to supply food and natural fiber for himself and 50 other people. Although this miracle of U.S. agriculture is very energy intensive, the energy input into producing and delivering our agricultural abundance amounts to only about 2 1/2 percent of our total energy consumption.

As we look to alternate energy sources, it is natural that we, especially in agriculture, look to solar energy. This inexhaustible source of energy supplies the U.S. with about 600 times as much energy as we use annually from all other sources.[2] Not only is this supply inexhaustible, it is also non-polluting. However, there are negative aspects. It is not continuously available, and the relatively low intensity requires large collectors to deliver significant amounts of energy. For applications other than direct thermal, a conversion must be made.

It is estimated that about 1.87 Quads ($Q = 10^{15}$ Btu/year) are currently being used to dry crops such as grain, tobacco, peanuts and forage crops, to heat livestock shelters and facilities, and to heat greenhouses and rural residences.[3,4,5,6,7,8] The major portion of this energy is required for residence heating. All these could use the thermal energy of the sun without any energy conversion.

The energy potentially available is shown for different latitudes in Figure 1. This assumes a horizontal surface and no atmospheric interference. The energy actually received will vary widely, depending upon the season and local weather conditions. Generally speaking, the highest intensity and largest quantity of solar energy available annually in the U.S. occurs in the Southwest with the Southeast following. For example, for Tifton, Georgia the minimum energy recorded during the past year was 183 Btu/sq. ft./day and the maximum was 2881 Btu/sq. ft./day (Table 1). Each year, more than 500,000 Btu are received per square foot: This is equivalent to more than 5 gallons of LP gas. A 40' x 100' storage shed with a flat roof would thus receive the energy equivalent of 20,000 gallons of LP gas annually. By making the roof slope to the south, the energy received would be increased.

For the energy to be useful, however, it must be collected. Solar collectors may be classified broadly as either flat-plate or focusing, with the flat-plate designation including solar ponds, tubes and the like. The flat-plate collectors are generally limited to maximum practical temperatures of less than 250°F, whereas the focusing collectors can produce temperatures of several thousand degrees. Diffuse radiation can be collected by the flat-plate type of collector, but direct radiation is necessary for the focusing

Figure 1
Isolation on a Horizontal Surface at Different Latitudes

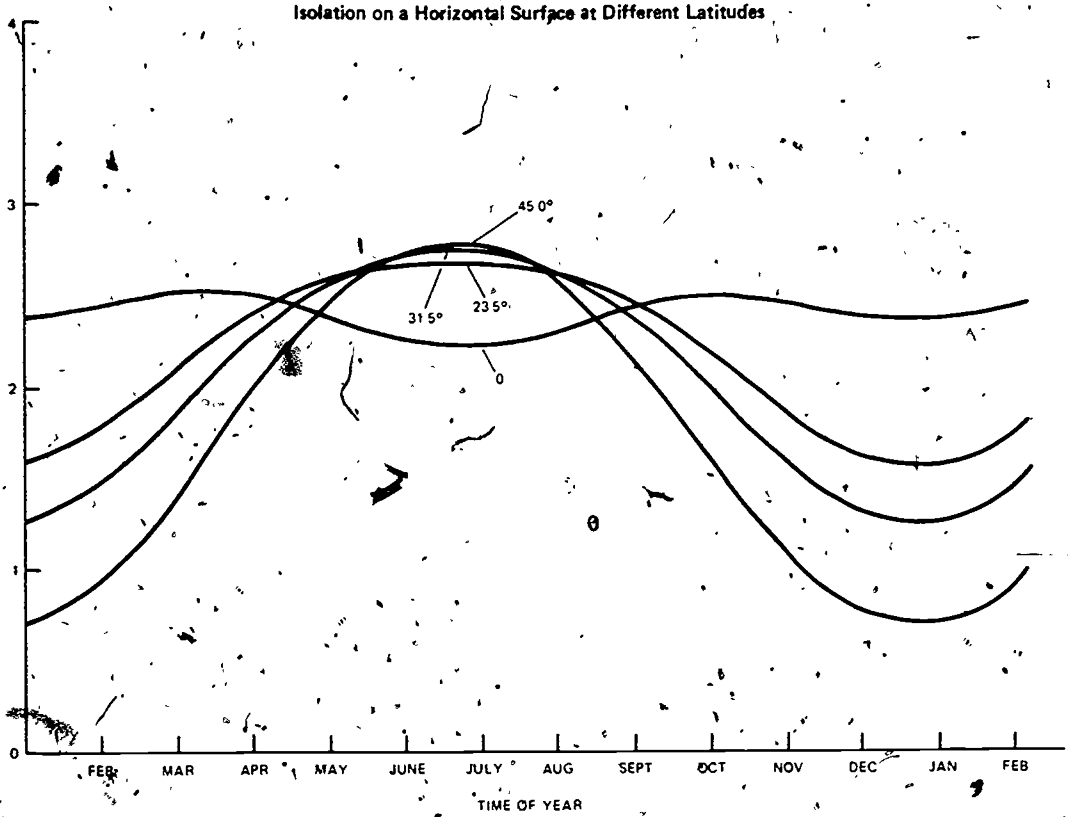

Table 1
Solar Radiation at Tifton, Georgia Since February 1974
(Recorded on horizontal surface)

	Btu/sq ft	Time
Minimum Daily	183	Sept.
Maximum Daily	2881	M[illegible]
Average Minimum	1006	Dec.
Average Maximum	2032	June
Total Per Year	534,000 Btu sq ft	

collector. Most of the agricultural applications require maximum temperatures ranging from less than 100°F upwards, making the flat-plate collector ideally suited.

Although the maximum temperatures may be low, the total energy requirement for a specific application may be great. This coupled with the uncertainty of supply dictates storage for most applications. When air is used as the medium to transfer heat from the collector, rocks are often used as the storage medium. This is a relatively simple procedure and, for some applications, the air may be drawn directly from the collector through the storage media and then to the crop being dried or the facility being heated. During periods of solar radiation, the storage media will absorb heat. When the sun isn't shining, air passing through the media will pick up heat stored previously. Water offers more versatility as a storage media. It does, however, require some sort of heat exchanger. This may range from a simple pipe layout, if the stored energy is used for heating a building or greenhouse, to a more efficient radiator-type heat exchanger when the stored energy is to be used for crop drying.

Even though the solar energy is free and the cost for operating the pump or fan to move it from the collector is very small, the initial cost for the collector and storage system is substantial. Since the collector and storage system cost is fixed, the system should be designed for maximum annual use. Just as it would be unprofitable for an electric power company to provide generating capacity for an irrigation system which would be used twice a year, it would probably be unprofitable for a farmer to put in a solar collector and storage system which would be used for only one or two weeks of the year. Thus, solar energy will probably not be used much unless its cost can be reduced (by using it throughout the year) or unless other sources of energy are no longer available.

The Energy Research and Development Agency (ERDA) believes that solar energy technology offers the potential for supplying as much as 25% of our energy needs by the year 2020 (Table 2) if cost of collecting and utilizing can be reduced substantially.[2]

Table 2
Estimates of the Amount of Energy to be Supplied by Solar Energy

Conversion Technology	Year 1985	2000	2020
Direct Thermal Applications	.2Q*	3Q	20Q
Solar Electric Applications	.07Q	5Q	15Q
Fuels from Biomass	.5Q	3Q	10Q
Total Projected U.S. Demand	100Q	150Q	180Q
Estimated % of the National Demand	0.8	7	25

*Q = Quads = 10^{15} Btu/Year

ERDA has defined eight national energy goals to guide our country's progress toward energy independence. These are

1. Expand the domestic supply of economically recoverable raw materials used for producing energy.
2. Increase the utilization of essentially inexhaustible domestic energy resources.
3. Efficiently transform fuel resources into more desirable forms
4. Increase the efficiency and reliability of the processes used in the energy conversion and delivery systems.
5. Transform consumption patterns to improve energy utilization.
6. Increase end-use efficiency
7. Protect and enhance the general health, safety, welfare and environment related to energy.
8. Perform basic and supporting research and technical services related to energy

Of these eight goals, solar energy can contribute significantly to four of them 2, 3, 5, and 7 Solar energy can be converted into useful forms by 5 basic technologies. These are. thermal, electrical, chemical, biological and mechanical. These may be grouped into three principal categories. direct thermal applications, solar electric applications and fuels from biomass.

The direct thermal applications technology forms one of the four major program units within the National Solar Energy Program. This unit comprises two major subprograms. (1) the solar heating and cooling of buildings and the supply of service hot water, and (2) the use of solar energy to supply heat for agricultural applications and for industrial process heat applications (Table 3).

Table 3
Estimates of Solar Energy for Direct Thermal Applications

	Year 1985	2000	2020
Heating and Cooling	0.15Q	2.0Q	15Q
Agricultural Applications	0.03	0.6	3
Industrial Applications	0.02	0.4	2
Total	0.2Q	3.0Q	20Q

*Q = Quads = 10^{15} Btu/Year

ERDA has made funds available through ARS for research related to the latter subprogram. This is divided into four categories:

- Grain Drying
- Greenhouses and Rural Residences
- Livestock Production Systems
- Peanuts, Tobacco and Forages

Through a principal investigator for each of the four categories, research is contracted with both educational and non-educational research centers. Grain drying research is now into its second year, the greenhouse and rural residence group has almost completed its first year and research related to livestock production systems and drying and curing of peanuts, tobacco and forages was initiated July 1975.

From research programs such as these, it is expected that solar energy applications by the year 2020 will supply a substantial portion of the energy required for the production of our food and comfort.

References

1 Bond, T E, "An Assessment of the Potential of Solar Heating to the Greenhouse Industry," Solar Energy Applications Workshop, University of Maryland June 5-6, 1975
2 Bond, T E, "An Assessment of the Potential of Solar Energy to Rural House Heating Systems," Solar Energy Applications Workshop, University of Maryland June 5-6, 1975
3 J L Butler, "An Assessment of the Potential Application of Solar Energy to the Curing of Peanuts, Tobacco and Forage," Solar Energy Applications Workshop, University of Maryland June 5-6, 1975
4 CAST Report, *Agricultural Engineering*, Vol 55, No 4, April 1974 pp. 37-39
5 Congressional Record, U.S Congress, Senate, Re S. 187, p. S3596 March 11, 1975.
6. Definition Report, Energy Research and Development Agency, ERDA-49 June 1975.
7 Foster, G. H., "An Assessment of the Potential of Solar Energy for Grain Drying," Solar Energy Applications Workshop, University of Maryland. June 5-6, 1975.
8 Reece, F N, "An Assessment of the Potential of Solar Energy in Broiler Housing," Solar Energy Applications Workshop, University of Maryland, June 5 6, 1975.

ENERGY USE AND CONSERVATION IN THE CANNING INDUSTRY

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First let me say that I am not an engineer, I am an analytical food chemist that somehow got into the energy field in a very small way in late 1974 and early 1975 as a result of the energy crisis that hit this country in the winter of 1973-74. That winter, energy was the topic of conversation by nearly everyone from the homeowner to presidents of the nation's largest companies. It soon became apparent that energy conservation was going to be a necessity in order to survive.

Canning Operations that Require Energy

The variety of unit operations that require energy and that are necessary to produce the thousands of thermally processed products each year is almost endless. Also one must remember the seasonality of the canning industry which is probably one of its most outstanding characteristics. Many canned food producers achieve year round operations by varying their produce line and taking advantage of "off season" production opportunities. However, the basic seasonality imposed upon the industry by the harvesting schedule of the products to be canned is a fact. Many plants in the industry are not in significant production during off-season periods but still must maintain heating or cooling of offices and warehouses, etc. which require energy and power. Waste disposal requires continuing energy input even after actual production has ended.

For low acid foods the most significant energy requirement is for the commercial sterilization or thermal processing operation. Processing temperatures for canned products are carefully designed to make certain that all organisms of public health significance are destroyed. These processes must be established by competent authorities qualified by proper training and experienced in this highly specialized field. *Absolutely no attempt at energy conservation should be made by making adjustments in these critical operations.*

For example, retorts or cookers must be properly vented to make certain that all air pockets are removed before the vent is closed and timing of the process is actually started. Air pockets trapped in the loaded retort will impede heat transfer to the canned products and can result in serious understerilization. Proper venting may require that retorts be exhausted through wide open vents for periods up to five minutes or longer; it is conceivable that an uninitiated conservation enthusiast might preceive venting schedules as an obvious opportunity to save stream by reducing venting times. Although there may be opportunities to recover heat from exhausted steam, venting schedules must be established by competent people and must be religiously adhered to. Obviously, the same considerations apply to the heat processing step itself.

Conservation Measures

The organization of a conservation program must first have the commitment of top management to see that the job gets done. The necessity to focus managerial efforts on intensive campaigns to conserve energy resources is relatively new to most companies. Until recently, energy costs in this country were not sufficiently high to repay intensive conservation efforts.

Priorities utilized to deal with the current fuel emergency may be summarized in the following manner but may not be the same in all companies.

Emergency Fuel Allocations

Make whatever fuel allocation decisions that are necessary to stay in production.

Good Housekeeping Utility Conservation Measures Must Be Enforced

We will talk about these a little later.

Engineering Considerations

Money to recover utilities—utilization of waste heat and reuse of water.

Evaluate Opportunities for Alternate Fuel Systems in the Event That This Should Become Necessary

Utility Audits

In order to measure the effectiveness of the utility conservation program it is necessary to have:

(1) An accurate metering of the utility input. This includes electric power, fuel, water — all energy should be converted to common units such as Btu's.

(2) Evaluation of production in terms of energy used per unit output. This could be, for example, Btu's/standard case of food or for that matter — Btu's/1000 lbs. of finished product.

The audit should cover all energy sources utilized by the company such as power plant fuels of all types, vehicle fuels (cars, trucks, forklifts, etc.) electric power and natural gas. Electric power and gas would probably be from metered records and, in addition, accurate records of bottle gas, gasoline, coal and certain other fuel oils would have to be kept separately.

The best place to start a conservation program to eliminate the wasteful use of energy would be housekeeping operations. Many of these housekeeping details are routine and are operations that many people ignored while energy cost was negligible. Therefore, the benefits from such a program will depend on the degree of wastefulness that had been allowed to develop prior to high energy cost.

Conservation in Housekeeping Operations

The following is a greatly abbreviated version of housekeeping hints that may be helpful in eliminating wasteful energy uses.

Lighting

(1) All lighting except for security and safety should be turned off when not in use. Time switches for interior lighting and photo-cell switches for exterior lighting should be considered. Lighting in areas other than work areas can be reduced.

(2) Use fluorescent, mercury or sodium fixtures where feasible rather than incandescent since they deliver more light per kilowatt hour.

(3) Install separate independent lighting circuits and switches where it is practical to provide for localized lighting of work areas.

(4) Replace age-yellowed prismatic panels and louvers. Up to 15% improvement in lighting efficiency may be realized. Consider group instead of singular bulb replacement.

(5) Keep lamps, fixtures and reflecting surfaces clean. Post instructions for operating, cleaning and maintenance of light fixtures.

Heating

(1) Office temperatures should be held to no more than 68°. The use of personal electric heaters is wasteful but could be permitted under extreme or unusual conditions. Keep windows free of obstruction for maximum sunlight and keep windows and doors closed. Time controlled thermostats for lower temperatures after working hours can save a fair amount of energy.

(2) Maintain clean filters in heating and ventilating systems.

(3) Control the make-up air temperatures and quantities in ventilation systems to a minimum.

(4) Warehouses which are not used often should be heated to no more than 40°, while 50° dry bulb temperature may be sufficient for finished product warehousing. Employees working in these areas can wear jackets or sweaters at no reduction in work efficiency.

(5) Particular attention should be paid to keeping warehouse doors closed to the maximum extent possible. Construct entrance ports for large doors leading into plant or offices. Consider the use of carpet to reduce floor heat loss.

(6) Consider night time and weekend shutdown of boilers used for heating only.

Water

(1) The supply of water requires energy for production, transportation, purification, and waste treatment. Consequently, saving water will save energy and dollars.

(2) Stop leaks and use automatic-off faucets or shut off water lines left running for no reason.
(3) Consider reducing the temperature of hot water for personnel use and turning water heating down or off on weekends.
(4) Make a thorough study of the use of processing water with the objective of accomplishing necessary washing and cooling without waste and with the maximum reuse of water.
(5) Consider clean-in-place systems for specific applications.

Electric Power

(1) A systematic review of the entire electric power system should be made. Adequate instruments – voltmeters, RPM indicators, etc. – should be used in this review
(2) Overloaded motors waste power in the form of heat and are obviously undesirable because unnecessary stress will shorten the service life of the motor. Underloaded motors also waste power.
(3) Loose drive belts waste power – check these routinely and also check lubrication of drive equipment.
(4) Do not operate standby equipment when the primary equipment can carry the load. Turn off electric motors during non-production periods.

Steam

(1) Check steam distribution systems from boiler to end of line for losses and remove unused and unnecessary steam piping.
(2) Repair valve seats to prevent steam leakage into empty retorts, steam kettles, etc.
(3) Install and maintain steam traps at the end of steam manifolds at retort installations. It may be worthwhile to pipe the steam exit of the traps to a return line to be used to warm make-up water for boiler operations.
(4) Keep heat transfer surfaces clean and keep insulation in good condition.
(5) Check condensate return system for malfunctioning traps and leaks in the line.
(6) Check for excessive steam vented to atmosphere.
(7) Periodically check steam-using equipment even in blanchers, heat exchangers, exhaust boxes, cookers, retorts and kettles for operation at proper temperature and the absence of leaks.

Boiler & Power Plant Operations

(1) Continued training of boiler operators is essential – particularly in full load operation with alternate fuels
(2) Each boiler installation should include an on-steam gas analyzer to measure directly the volume by percent of oxygen and combustibles in the flue gases. If there is excessive air in the flue gases, the boiler fuel settings should be corrected immediately.
(3) Each installation should have and use a stack gas temperature monitoring device.
(4) Instrumentation and auxiliary equipment must be kept in first-class condition.
(5) Boilers should be frequently checked for cleanliness and condition, including:
dirty burners – inefficient burners should be replaced
cracked or loose refractory, especially around drumheads
loose linkages or stack dampers
lag in boiler control leading to improper oxygen content in flue gas.
all surfaces of drums and tubes
(6) Reduce boilers to low pressure on weekends or during low or non-production shifts, use minimum pressure and number of boilers possible.
(7) Recover heat from waste steam.
If cans are cooled in the retort, suitable piping arrangements can be made to utilize the initial hot water for boiler make-up water.
In water processing of glass containers, the steam-water mixture from the pressure regulating valve overflow could be used for boiler make-up water or for heating boiler make-up water.
If a vent blow-down manifold is used at retort installations, a water line installed in the manifold could utilize heat from the steam for preheating boiler make-up water. Remember that the vent manifold has to be large enough to meet GMP regulations 21 CFR 128b, subtracting the area occupied by the water line.
(8) Make effective use of competent consultants.

Raw Product Handling and Cleaning

Just a few energy saving tips on raw product handling may be worthwhile.

(1) Review product receiving, cold storage, handling and cleaning methods to determine whether engineering changes are feasible for energy or water conservation.
(2) Use gravity flow wherever possible.
(3) Schedule full and continuous production loads whenever possible.
(4) Minimize water use consistent with proper cleaning and investigate dry cleaning possibilities. Re-use water by counterflow where possible.

(5) Determine whether reduction of wash water temperature is practicable.

(6) Do not preheat blanching equipment before it's necessary.

(7) Investigate alternative blanching procedures and avoid unnecessary cooling of blanched product.

(8) Use insulation where needed to minimize heat loss.

Process Equipment

1. Adequate venting of air from retorting equipment and continuous free steam flow from the bleeders is essential for safe processing. *Never attempt steam conservation by decreasing retort venting or closing retort bleeders.*
2. Avoid preheating and venting continuous retorts before the time indicated as necessary by the production schedule.
3. Consider insulation of retorts to prevent loss of radiant heat and minimize employee heat exposure.
4. Check air equipment for leaks to reduce compression time. Compressed air is a costly utility. Inspect and review all plant operations to locate and eliminate unnecessary or wasteful uses.

Equipment Maintenance

Preventive maintenance of all equipment in a canning plant is essential in achieving peak efficiency. While this is no doubt already a major feature of cannery operation it must be doubly emphasized at this time.

Conservation Progress in the Canning Industry

In the winter of 1973-74 it became apparent that energy conservation was going to be a serious business. NCA Research Laboratory personnel organized an ad hoc committee of canning industry engineers to coordinate conservation efforts and pool ideas on specific measures that were undertaken in their respective companies to cut energy use to an absolute minimum. This committee helped produce several mailings to NCA members sharing energy saving ideas. The first format publication to result from [illegible] Staff and Committee efforts was our Bulletin 36L *Energy Conservation in the Canning Industry* issued in April 1974. Much of the information given earlier in this paper actually came from that bulletin.

Later in 1974 then Secretary of Interior, Rogers B. Morton, Chairman of the President's Energy Resources Council and Commerce Secretary Frederick Dent, launched the administration's program to encourage voluntary energy conservation efforts in industry. At a meeting of trade association executives in November, each trade group was challenged to obtain agreement of its members to implement a conservation program with specific long and short term goals along with a regular procedure for reporting results.

In January of this year our ad hoc committee met with DOC officials to discuss organization of a procedure to survey the canning industry and monitor the results of their conservation efforts. Two goals were established by the administration.

(1) reduction of oil imports by 1 million barrels a day by the end of 1975 and (2) an energy conservation of 15% by 1980, using 1972 as the base year for comparison purposes.

We were requested to obtain and compile data on total energy usage and total product output, and to report monthly data at quarterly intervals to the DOC. To facilitate inter-industry comparisons, we were requested to report our data in terms of millions of Btu's per 1000 lbs. (label weights) of finished product. This, of course, includes the packing media.

Our mailing of survey forms reached the canning industry near the end of February of this year, initial results were reported to the DOC in May and were updated in June 1975. The update included results for the first quarter of 1975. We have since reported to DOC results for the second quarter.

Table 1 shows the updated results reported to DOC. Energy use is reported in terms of Btu's/lb. of finished cut of product.

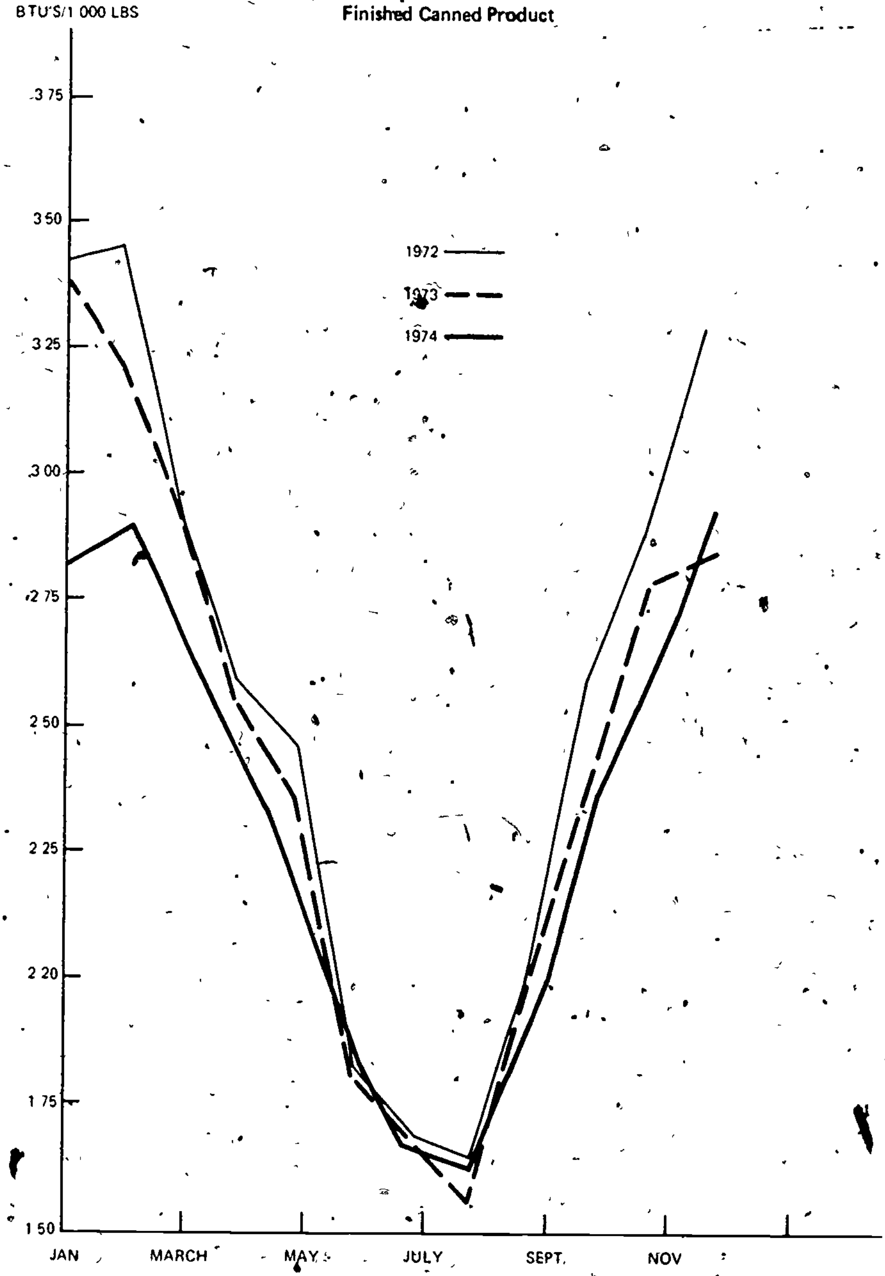
Table 1
Measure of Energy Conservation
Canning Industry

	1972	1973	1974
Production			
(Label Wt. 10^6 lbs.)	20,741	21,762	22,838
Btu (10^9)	47,434	48,096	48,157
Ratio			
(Btu/Label Wt. lb.)	2,287	2,210	2,109
Percent Improvement	Base Year	3.37	7.78

In 1972 production was 20 billion 741 million pounds using 47 trillion 434 billion Btu's – or 2,287 Btu's per pound of finished product – using 1972 as a base, an energy savings of 7.78% was realized in 1974. These data represent an estimated 68% of the total annual production of canned foods in 1973. Estimations were not made for 1972 and 1974.

Figure 1 illustrates energy use per 1000 lbs. of finished product as reported to DOC. Data were presented on a monthly basis.

Figure 1
Energy Utilization per 1,000 Pounds
Finished Canned Product



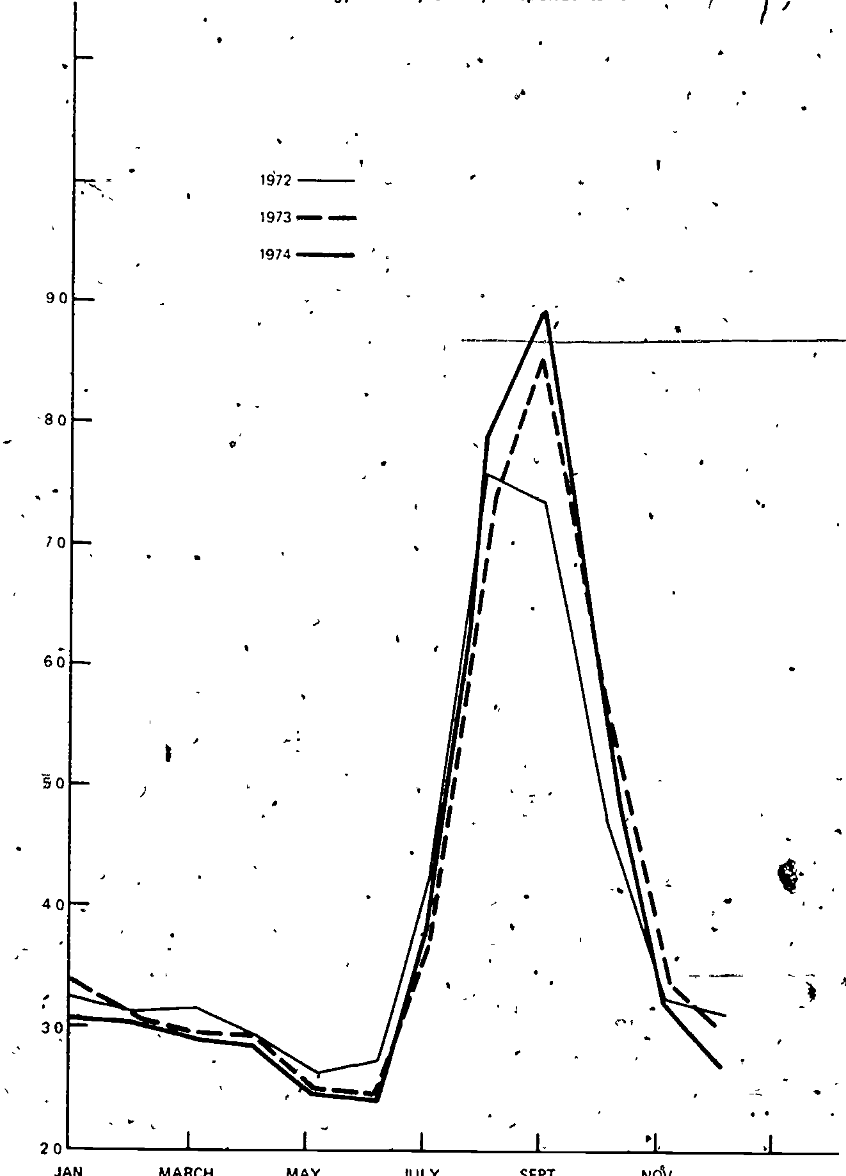
97

The predominating seasonality of the canning industry is immediately apparent. The curves have the expected shape with energy usage on a unit output basis reaching a minimum during the most productive month of August, September, October and June August is the month of highest production followed by September. These months account for substantially more than 50% of the total production of the reporting companies. During the period covered by the report to DOC the month of highest energy input occurred in February 1972 at 3.55 million Btu's per 1000 lbs. finished product.

Figure 2 emphasizes the point that maximum energy usage in the canning industry occurs in the summer months during periods of reduced domestic demand.

The total energy used by all companies responding to the survey is shown on a monthly basis. The number of com-

Figure 2
Seasonality of Energy Use
Total Energy Used by Survey Respondents



panies responding in the three years recorded is approximately, but not exactly, equal. Maximum energy usage occurred in September

Let's now take a look at factors that may complicate conservation efforts The highly seasonal character of the canning industry is well illustrated by the data presented in Figure 2. A substantial majority of the total energy required for the annual production of canned products is used in only about 4 months of the year—the summer months The seasonal character then presents a severe challenge to the industry's energy conservation program Fruit and vegetable canners in particular are at the mercy of the weather and can exercise only limited control over the timing and rates of raw product arrival The nature of the harvest season can dramatically affect the results of the best planned conservation effort For example, in the early part and near the end of each season, it is frequently necessary to fire up the power plant and hold the production line in readiness for receipt of raw product, only to find that unexpected weather conditions have totally interrupted the expected harvest schedule and little or no raw product arrives at the plant These false start ups are difficult to avoid and obviously are costly in wasted energy Intermittent production days in seasons of irregular harvest resulting from unfavorable weather conditions are also costly in terms of energy use per unit of finished production

It should be evident that production volume exercises a dramatic influence on energy utilization efficiency Other factors not entirely within the control of the canner include product mix, or the thermal processing requirements of the canned product in production. Compliance with OSHA, EPA, FDA, USDA and state and local regulatory requirements can totally offset conservation efforts.

In order to illustrate how this can come about I will try and relate to you the expense of one meat canning plant In 1971 the plant had an energy use efficiency of 3.2 million Btu's per 1000 lbs. of production. This plant had installed a hydrostatic cooker which eliminated a number of still retorts and would have expected to bring about a substantial reduction in steam requirements. Further, the plant installed an automated smoking unit which should have resulted in more efficient control of this operation.

Working against these energy conserving steps was the installation of several heated make up air ventilation units and exhausters, added to the plant to satisfy Health Department and USDA requirements. Steam and power required to operate these units amounted to 0 97 million Btu's per 1000 lbs of finished product. A second and extremely important factor operating against conservation efforts was a substantially reduced total volume of finished product output, the 1973 production totaling only 85% of the total label weight of the product produced in 1971. All of these factors added up to an energy use in 1973 of 5.4 billion Btu's per 1000 lbs. That is, it took 2 2 billion Btu's more to produce 1000 lbs. of product in 1973 than in 1971 An interesting observation, however, is that 44% of the increased energy input was accounted for by compliance with government requirements

Let's now look at the future of energy sources to the canning industry The most convenient and certainly the cleanest of our energy sources is "natural gas"

An article in the weekly energy report put the concern for natural gas in perspective by saying "There is a mass of evidence pointing to the fact that United States gas reserves are now being pushed toward exhaustion" As proof of this statement, interstate pipelines curtailed over 650 billion cu ft of gas in the first quarter of 1975, some two and one half times the curtailments in the first quarter of 1974

What does this mean to the food industry? The situation is quite serious in California, all interruptable gas users have been told by their suppliers that they can expect 100% curtailment by 1978. This means that canners, like all others, must be prepared to switch their boilers to an alternate fuel when the curtailment comes. Problems Absolutely no storage capacity for alternate fuels and, in addition, not enough tank trucks to haul the fuel We at NCA and the canning industry are strong advocates of well-head price deregulation which would add large new gas reserves. This would at least give canners time to make the necessary adjustments in switching from gas to an alternate fuel

Fuel oils present another complex situation in which almost anything can happen. There are optimistic predictions that plenty of oil will be made available, but what of the ever-present threat of new Arab-Israeli conflict and another oil embargo which this time would really cripple the world's economy. For the forseeable future, the food industry will continue to obtain all its oil needs under the present allocation priorities However, as more and more gas users convert to oil, there is a good chance of a supply crunch. Every canner should have a reliable oil supplier, and at least 10 days storage capacity.

Some actions that the Federal Government should take to help alleviate the energy problem are

- Postpone strict air quality laws This would allow utilities and other large energy users to convert to coal-fired boilers and take pressure off oil and gas.
- Gradually de-control well head price of new natural gas and old oil which would permit operations of fields now closed in or curtailed due to economics.
- Push development of natural gas lines from Alaska and Canada
- Force regulatory agencies to adopt reform procedures.
- Give natural gas priorities to agriculture, food processors, can making plants, transporters, etc This is urgently needed in order to ensure constant food suppliers.
- Suspend air quality laws to eliminate gas after burners
- Exempt food processing from proposed summer peak load pricing of electricity because of its punitive effect on a seasonal industry.

ENERGY AND THE U.S. FOOD SYSTEM

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For the past two decades, the U S had abundant supply of relatively low cost energy With the availability of this energy, our economic and social activities became energy intensive as indicated by a doubling of energy consumption between 1950 and 1970. The energy was used to obtain a high level of diets and to obtain more and more material comforts for less and less human effort

The U.S. system for producing, processing, marketing and utilization of food and fiber is typical of our energy intensive society. Elements of the system rely heavily on substitution of energy for human effort. In conjunction with other contributing factors such as new crop varieties and animal breeds and improved cultural and management practices, the overwhelming success of the system has been attained principally through the increased utilization of energy. The increased use of energy has resulted in increases in unit productivity on our farms and ranches, a wide spectrum of wholesome and nutritious consumer products, and the release of a major portion of our population from menial, tedious and economically unrewarding tasks.

A review of our energy consumption patterns and the availability of energy resources in the U.S. will help to put the energy consumed in the food system in better perspective. In 1972 the annual energy consumption was approximately 77. x 10^{15} Btu or the equivalent of 36.5 million barrels of crude oil per day (*1*) The major categories of energy consumption are transportation 25%; industry 29%, electric utilities 25%; and residential/commercial 21%

About 95% of the U.S. annual energy budget comes from fossil fuels with 46% being obtained from petroleum, 32% from natural gas and 17% from coal. Hydroelectric generation accounts for about 4% and nuclear energy 1%. Approximately 84% of the annual budget is produced domestically with the remaining imported as crude oil or gas.

Until 1974, domestic energy demand had been increasing between 4-5% annually. The U.S. was self-sufficient in energy through 1950 when dependence on foreign oil began. The situation deteriorated very rapidly and by 1973 imports of foreign oil increased to 35% of domestic petroleum demand Estimates of our depletable energy resources are indicated in Table 1 and the renewable resources are shown in Table 2.

Table 1
Estimates of U.S. Depletable Energy Resources Expressed in Units of Annual Energy Consumption (*2*)

Resource	Recoverable	Total
Coal	125	1300
Petroleum	5	280
Natural Gas	5	110
Oil Shale		2500
Nuclear Fission	117	765
Nuclear Fusion		10^{16}
Geothermal Heat	0.2	>660

Table 2
Estimates of U.S. Renewable Energy Resources Expressed in Units of Annual Energy Consumption (*2*)

Resource	Continuously Available
Solar Radiation	740
Wind Power	5
Sea Thermal Gradients	>6
Hydropower	0.14
Photosynthesis	0 23
Organic Wastes	0.1
Tidal Energy	0.1

Although the embryonic National Energy Policy is directed toward self sufficiency in energy by the mid eighties, there are strong indications that the U.S. will continue to depend upon oil imports to help meet energy needs for all of the eighties The problem in increasing domestic oil production is formidable. Efforts must be devoted to bringing new wells into production and to decreasing the declining output from existing wells. Crude oil production has been declining since 1970 and the most optimistic outlook is to arrest current decline until after the oil from Alaska's North Slope starts flowing around 1978.

Increases in natural gas consumption have exceeded new discoveries since 1968 and the potential for expanded production is limited to price and environmental constraints.

Current research and development on gasification should produce a limited quantity of high-grade fuel

After years of production at the 1940 levels output of coal is now increasing. If the problems associated with environmental concerns, availability of skilled labor and equipment can be solved successfully, production should reach one billion tons a year by 1980. Potentially, coal could yield as much as 45% of the U.S. energy needs.

Generation of electricity with hydropower is not anticipated to increase much above the current level of 67 million kilowatts unless tidal energy can be harnessed. The few remaining suitable hydropower sites would conflict with environmental interests.

Nuclear energy, once believed to be the best chance for a rapid increase in U.S. energy production, has been plagued by technical and regulatory difficulties. Today less than 50 plants are producing about 6% of the nation's electricity. Another 50 are under construction and over 100 plants are in various phases of planning. At least 100 should be in operation in the early eighties with the capacity to provide up to 30% of electrical power requirements.

Current research and development activities should provide practical means of increased utilization of solar energy, wind energy and bio-mass conversion. However, it is not anticipated that these sources will have a major impact on the overall energy demands.

Although our present system of production, processing distribution and consumption of food and fiber has become highly dependent on abundant, low-cost sources of energy, the utilization patterns within each segment are not well-defined. Even the overall magnitude has not been clearly established. Best estimates are that only 12-15% of our annual energy budget is being used by the food and fiber system. A recent report of the U.S. Senate's Subcommittee on Agricultural Credit and Rural Electrification (*3*) indicates the following energy was utilized in the U.S. food and fiber system in 1970.

The data in Table 3 do not include energy requirements of the commercial food fishing industry, commercial forestry, and processing, marketing and retailing of fiber products The total of 4,700 trillion Btu's compares with other studies which have indicated the total food and fiber system uses from 6,100 to 8,600 trillion Btu's.

Table 3
Energy Utilized in U.S. Food System in 1970

Function	BTU (Trillion)	Barrels of Crude Oil (10^3)
Farm Production	1,051	181
Farm Family Living Product	555	96
Food and Kindred Product Processing	1,302	178
Marketing and Distribution	833	144
Selected Input Industries	925	160

Probably the most comprehensive analysis of the total energy utilized in the U.S. food system was made by Hirst (*4*) using 1963 input/output economic data. Another analysis, was made by Steinhart and Steinhart (*5*). Both sets of data for the various segments of the food system are presented in Table 4

Table 4
Energy Utilized in the U.S. Food and Fiber System

Function	Percent of Total	
	Hirst	Steinhart
On-Farm Production	18	24
Processing	33	24
Transportation	3	15
Marketing (Wholesale & Retail)	16	14
Household Preparation	30	23

The current energy consumption for on-farm production is approximately 3% of the total U.S. energy budget. About half of the energy is used directly on farms to operate tractors, trucks, combines, irrigation systems, milking machines, feed-handling devices, brooders, crop drying and conditioning equipment. The remainder is consumed in the direct input and service industries to produce and supply fertilizers, pesticides, petroleum products, machinery, construction material, wire and the many other items required by on-farm production units.

Over 75% of the food and fiber grown on farms is processed before shipment to point of final demand. The degree to which food is processed is related to the distance from the farms to population centers, income sufficient to permit the purchase of processed foods and the value of convenience.

The temporal and spatial characteristics of energy inputs into the production phase of the system have been a factor in the development of a strong and reliable transportation system which is highly dependent upon availability of energy. Many food products are in a highly perishable condition and, therefore, both the quality and quantity available to consumers today are dependent upon the same transportation system.

Food trading consumes almost as much energy as agriculture does in producing the food. Approximately 75% of the energy is used in the retail trade sector with the remainder used by the wholesale sector. Indirect requirements such as construction of retail food stores and the manufacture of food storage equipment are included in the food trading function.

The household preparation function utilizes approximately 26% of the food and fiber energy budget. About 85% of the energy is used in the operation of stoves, refrigerators and freezers for preparing and storing food. The remainder is used in transporting food from stores to homes and in the manufacturing and marketing of household kitchen equipment.

It is essential that more accurate data about the energy utilized in our food production system be determined to provide a basis for measuring improvements in the system, assessing the impact of national policies on the system, determining the effects of conservation and or alternative practices on energy utilization, and establishing research priorities with greatest potential for developing new energy technologies in areas such as under utilized energy sources and the energy potential in food and fiber by products

Agriculture through the ages has been involved in the conversion of the sun's electromagnetic energy into chemical energy through the important biochemical process known as photosynthesis The manipulation of plants and their environment to maximize the conversion process has been and will remain an extremely vital factor in helping agriculture meet the food requirements of the world's population An indication of the degree of the success (*6*) is shown in Table 5

Table 5
Food Production by Photosynthesis

Crop	Organic Matter [(KCAL/m^2) (day)]	Solar Energy Efficiency (%)
Not Subsidized by Fossil Fuels		
Farms in U S, 1880	1 28	0 03
Grain, Africa, 1936	0.72	0 02
Subsidized by Fossil Fuels		
Rice, U.S, 1964	10	0 25
Grain, North America, 1960	5	0 12

The manipulation of animal production practices has also involved extensive use of energy with a resulting increase in productivity. Some of the major returns (*7*) received from the manipulation of our plant and animal production systems through the increased application of energy during the period 1950-1973 are presented in Table 6

Table 6
Agricultural Changes Associated with Increased Energy Utilization 1950-1973

Farm production increased 52%
Hours used for farm work dropped 59%
Production per unit of input increased 53%
Production per hour of labor jumped 274%
Production per acre increased 65%
Land use for crops decreased 6%
Farm population declined 59% while nonfarm population increased 56%

As these data indicate, the application of energy has increased our capacity to produce food and fiber with less drudgery and more efficient use of human and land resources Improved water control, better soil preparation, and more efficient weed and insect control have been key factors in increased productivity Properly applied mechanical techniques of harvesting, handling, drying, storing and processing of products is saving more of the yield and maintaining it at a higher quality Timeliness and precision of production functions have enhanced the maximization of production of each unit of land area and animal production units While these factors can be quantitatively measured, the reduction of the laborious and tedious aspects of farm tasks, improvements in the health and safety of the individual, and the fulfillment of human desires and enhancement of dignity achieved through the increased use of energy are extremely important but are difficult to measure in quantitative terms

In 1973 the estimated amount of petroleum fuels used by farmers was 8 billion gallons, 4 billion of gasoline, 2 5 billion of diesel and 1 5 billion of LP gas (*3*) The consumption of diesel and gasoline fuels was equivalent to 10% of the total U.S consumption and the LP-gas use was about 17% of the total In addition over 40 billion kilowatt hours of electricity were used

The utilization of this energy and the returns obtained have received a great deal of attention Detailed analyses have been made to determine the average energy inputs into a few of our production systems but the relationships among the functional aspects of an operation and the energy inputs are masked To put the so called energy utilization indices in better perspective, it is necessary to examine the tasks performed with the energy If the end objective is to produce food evaluation only on the basis of calories or Btu's, output can be misleading Not only are components other than calories important in determining food value, the availability of energy for human use must be considered

Energy inputs may be classified as those expanding the area cultivated per worker or material handled per worker and those used chiefly to increase output per unit of area or to prevent loss of production or product A lot of the energy input data presented was taken from the comprehensive study (*8*) made by the University of California and the California Department of Food and Agriculture in 1973

Energy utilized in various production operations for selected field crops is presented in Table 7 Data for selected fruit and vegetable crops are shown in Table 8 Energy utilized in livestock activities is indicated in Table 9

A summary of the major energy inputs for the selected field crop is presented in Table 10 Information for the selected fruit and vegetables is shown in Table 11 and the livestock summary is presented in Table 12.

When the ratios of the end product caloric content are compared with the fuel and electrical energy used to obtain that product, a given ratio decreases as the degree of pro-

Table 7
Energy Utilized in Field Crop Operations

Operation	(Kcal x 10^4/ton)				
	Alfalfa[1] Hay	Barley[2]	Corn[2]	Rice[3]	Wheat[3]
Crop Establishment	2.43	12.67	11.00	14.35	12.85
Cultural Practices	0.51	0.03	2.84	–	0.03
Harvest	3.87	6.56	4.03	11.57	6.63
Transport	2.10	3.14	4.02	3.04	9.60
Process	–	2.96	2.96	50.88	4.82
Total (Kcal/ton)	8.91	25.36	24.85	79.84	33.93
(Kcal/acre)	50.79	32.51	66.65	219.48	42.92

[1]Bales [2]Feed [3]Food

Table 8
Energy Utilized in Fruit and Vegetable Production

Operation	(Kcal x 10^4/ton)				
	Green Beans	Lettuce	Potatoes	Apples	Oranges
Crop Establishment	27.16	5.00	3.03	0.62	0.61
Cultural Practices	6.35	2.33	1.43	9.17	2.27
Harvest	32.98	3.41	2.02	1.84	2.43
Transport	2.61	2.75	2.68	1.38	1.38
Process	3.42	3.42	3.42	3.28	3.37
Total (Kcal/ton)	72.52	16.91	12.58	16.29	10.06
(Kcal/acre)	116.03	191.42	203.54	188.64	57.24

Table 9
Energy Utilized in Livestock Operations

Operation	(Kcal x 10^4/ton)				
	Dairy	Beef	Hogs	Broilers	Eggs
Feed Transport	12.78	26.97	1.27	6.21	2.05
Husbandry	17.99	109.65	72.78	139.65	71.66
Market Transport	0.67	7.76	0.39	1.84	11.61
Process	30.81	28.24	24.47	48.41	11.97
Total (Kcal/ton)	62.25	172.62	98.91	196.11	97.29
(Kcal/animal)	388.78	91.83	11.47	411.83[1]	6.08[2]

[1]1,000 Birds [2]1,000 Eggs

Table 10
Major Energy Inputs for Field Crop Production

Crop	Energy Input – 1,000 Kcal/ton			
	Mechanized Operations	Fertilizer	Irrigation	Total
Alfalfa Hay	89	28	183	323
Barley	253	168	–	479
Corn	249	331	388	1,027
Rice	363	323	379	1,185
Wheat	339	170	–	565

Table 11
Major Energy Inputs for Fruit and Vegetable Production

Crop	Energy Input – 1,000 Kcal/ton			
	Mechanized Operations	Fertilizer	Irrigation	Total
Green Beans	725	443	651	2,048
Lettuce	169	125	92	484
Potatoes	126	79	64	325
Apples	163	60	90	401
Oranges	101	123	183	1,089

Table 12
Major Energy Inputs for Livestock Production

Crop	Energy Input — 1,000 Kcal/ton	
	Mechanized Operations	Feed
Dairy	623	2,516
Beef	1,726	41,696
Hogs	99	14,616
Broilers	196	7,522

cessing increases For example the California data indicate .545 for raw green beans and 288 for canned green beans, 1 267 for raw apples and 266 for canned apples, and .246 for raw broccoli and .133 for frozen broccoli

Statements have been made that primitive agriculture systems produce as many as 50 units of energy for each unit of energy input Other statements have indicated that the modern U S. agriculture system is much less efficient than primitive agriculture systems. A comparison of data obtained in a recent study of Korean agriculture with data from the California study will help to put these statements into better perspective.

A total of 4,040 man hours and 10 hours of animal power are used to produce an average of 11,245 kilograms of apples from a cheongbo (2.4506 acres) of land. On barley farms in the middle region 1,315 man hours and 75 animal hours are used per cheongbo, with an average yield of 2, 476 kilograms of unhulled barley In the same region 1,623 man hours and 95 animal hours are used to obtain an average of 4, 662 kilograms of unhulled rice.

The average Korean receives a minimally adequate diet of 2,486 calories per day The human energy input is based upon the equivalent number of 10-hour days required for each crop. Oxen are the only significant source of animal power and the energy input is based upon the work output of an oxen being one horsepower with a feed conversion efficiency of 50% Only the time involved with a specific crop is charged to that crop with the other time assumed to be charged against another activity Therefore, the total man and animal input energy per acre for the three crops is apples 5 6 x 10^3 kcalories, barley 39 4 x 10^3 kcalories, and rice 49 9 x 10^3 kcalories The caloric equivalents of energy required for production are 716 x 10^3 kcalories for the 450 pounds per acre for rice, 712 x 10^3 kcalories for the 405 pounds for barley, and 1,432 x 10^3 kcalories for the 900 pounds used for apple production

Based upon average yields of 5.059 tons of apples per acre, 1.114 tons of barley and 2.097 tons of rice, the respective caloric contents are 2.57 x 10^6, 3.527 x 10^6 and 6.905 x 10^6 kcalories. Therefore the ratios of caloric content to energy input are 1.79 for apples; 4.69 for barley, and 9.01 for rice. Comparison of these ratios with the California data incidates. 1.79 vs 1.27 for apples; 4.69 vs. 6.61 for barley, and 9.01 vs 2.55 for rice.

While many factors are currently acting to produce additional supplies of fossil fuels, to develop new energy technologies and to reduce total demand especially for fossil fuels, the outcome will in all probability have costs not only in terms of money, manpower, materials, equipment, natural resources and environmental effects, but will influence the social and cultural aspects of the United States. Of utmost importance is that Americans must develop a real understanding and concern about the food and fiber system. This concern must go beyond the desire to maintain an adequate food supply at reasonable costs. There is a need to understand that whatever happens in our system influences the world marketplace as well as the availability of a basic food diet for the people of the world.

Our food and fiber system substituted low cost energy, primarily in the forms of fuel and fertilizer, for land and labor If energy shortages and price increases continue, there will be an effort to reverse the above process — substitution of land and labor for fuel and fertilizer. A reduction in fertilizer application rates will require bringing greater acreage under cultivation to make up for the decrease in yields This expanded acreage will place greater demands on hand labor that will be used to reduce fuel consumption. Since much of the labor would be used in rural areas, there would be a movement of the people from population centers back to the areas of expanded agricultural activity.

With the increase in petroleum prices, renewed interest is emerging in the production of wool, cotton and silk to replace synthetic fibers. The shift back to these renewable resources would mean a change in life style as well as increased pressure on population shifts to meet the demands associated with increasing the production of these products.

The utilization of low-cost energy to manufacture commercial fertilizer resulted in a decline in the use of animal manures as fertilizers As fertilizer costs go up more animal manures will be returned to the land. However, going back to the use of horses and mules instead of tractors is neither logical nor possible in the immediate future. It would require eight years just to produce two million head of livestock. The United States had more than 25 million head prior to 1920 when we began to mechanize agriculture on a large scale. We would need even more work animals today to produce food for a much larger population. More importantly over 100 million acres of cropland would be needed to feed the work animals. That would be approximately one-third of the cropland that is currently being used to grow crops. As we look at history, in no area of the world has agriculture, dependent upon muscle power be it animal or human, been able to provide its farm people with much more than a subsistence level of living.

Agriculture in the western United States is heavily dependent upon irrigation for adequate moisture for crop production. The pumping of water from deep wells requires large amounts of energy High cost of energy for irrigation would probably force a shift in production activities to areas of adequate rainfall.

* High cost energy will mean more expensive transportation upon which our current system is so highly dependent In general, as transportation costs decreased, agricultural production moved farther and farther away from our population centers. Increasing transportation costs will favor expanded production nearer population centers and the rail mode of transportation which is less energy intensive than the truck mode The shift in production would be especially true of highly perishable products which require refrigeration during transport to maintain quality

The implications that the production activities will become located closer to population centers will probably result in marginal cropland being brought back into production Again lower yields per unit and the potential for increased soil erosion could result

A demand for high protein diets in the form of milk, eggs and meat was generated with our increasing level of affluence during the past two decades Diets including these items are more energy expensive in terms of food calories than a basic diet of cereals It requires several times as much grain to produce animal products as would be required if the grain was eaten directly. In addition the higher quality diets involve the foods which have the highest fuel energy requirement when all production, processing, marketing and preparation phases are considered. Therefore, scarce and expensive energy could result in an impact on the kind as well as the cost of our diet.

* Highly processed convenience foods have been another result of our low-cost energy and increasing affluence For example, frozen dinners require large amounts of energy to make and continuing energy inputs to store them in their frozen state Plastic film and aluminum, which are desirable packaging materials, require large amounts of energy to manufacture. Consumers will probably decide that the time saved with high priced convenience foods is no longer as important as it once was The degree to which many food products other than convenience items are packaged today may also be questioned by the consumer

United States agriculture has enjoyed a competitive edge in world markets, in the production of major grains Farm exports are vital to our efforts to purchase petroleum from foreign nations Heavy world demand for our farm products coupled with the basic need to meet consumer demand at home will add pressures to increase food prices Rising energy and world inflation factors could drive the cost of food out of reach of our export market. The resulting effect would be to increase the problems of starvation and malnutrition Under these conditions, efficient as well as effective utilization of energy becomes a major concern

In the long run, major changes will probably occur in the United States food and fiber system Shifts in production practices toward energy conservation, the development of new technologies to permit utilization of more abundant forms of energy (generation of electricity with coal and nuclear material, harnessing of solar and wind energy, and the utilization of agricultural products and by products as sources of energies), and less demand for highly processed and packaged food forms will require different types of machinery, equipment, buildings, and management skill

While engineers and scientists will continue to make significant and vital technical contributions to our food and fiber system in the era of energy constraints, participation in the political and social arena is essential. As an example of the challenges in the latter area, we should work to obtain a national policy which encourages the use of fertile land in areas of sufficient water supply for crop production and the use of less productive land for extensive rather than intensive agriculture or urban and industrial purposes to improve the overall energy efficiency of our food and fiber system.

References

1 *Project Independence Report* Federal Energy Administration. Washington, D C November 1974

2 Research News - "Energy Options Challenge for the Future," *Science*, Vol 177 September 1972 p 876

3 The U S Food and Fiber Sector, "Energy Use and Outlook," U S Senate Subcommittee on Agricultural Credit and Rural Electrification September 1972

4, Hirst, Eric, Food Related Energy Requirements, *Science*, Vol 184, No 4133 April 1974 pp 134-138

5 Steinhart, J C and E C Steinhart, "Energy Use in the Food System," *Science*, Vol 184 April 1974.

6 Odum, Howard T, *Environment, Power and Society*, Wiley Interscience 1971

7 "Energy to Keep Agriculture Going," Energy Newsletter, U S Department of Agriculture March 1974.

8 Cervinka, V, W J Chancellor, R J Coffelt, R. G Curley and J B Dobie, *Energy Requirements for Agriculture in California* Joint study by California Department of Food and Agriculture and University of California, Davis, Calif January 1974

DISTRIBUTION IN THE U.S. FOOD AND FIBER SYSTEM: ENERGY USE AND CONSERVATION

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Introduction

The participants in this working conference have had the opportunity to examine the energy dimension of selected segments of the U.S. food and fiber system. The energy required in increasing the *form* utility of a product has been reviewed in terms of input manufacturing, farm production, and processing. These sectors too often are treated as though they exist in a nonspatial economy with few difficulties in transporting goods from one stage to the next.

Energy in Distribution — Scope

Based on the generally accepted major subdivisions of the food and fiber systems, one would anticipate that this current session would dwell upon distribution from the processing stage to the wholesaler in the city where the product ultimately is consumed.

Such a narrow definition deals with from three to four percent of the energy consumed in the food and fiber system. This greatly understates the realities of the total distribution requirements. Placed in a broader context, transportation of goods accounts for about eight percent of total U.S. energy consumption.[1]

Energy expended in moving goods from one location to another indeed is a critical component of this nation's economic fabric. Transportation needs are diffused throughout the system from the mine to the point of consumption. The *place* utility of a good is of equal importance relative to the form utility. For example, unless transportation of farm products from California and Iowa can be facilitated with relative ease, the economic value of these goods to the consumer in New York City approaches zero. Densely populated manufacturing and service centers, often situated far from specialized agricultural regions, would become infeasible.

With these factors in mind, this discussion on energy use and conservation in the food and fiber system is based upon an expanded definition of distribution.

> Distribution is any activity which has the goal of overcoming the friction of distance in moving economic goods from one geographic location to another in order to facilitate the production-consumption processes.

Food and Fiber System — Flows

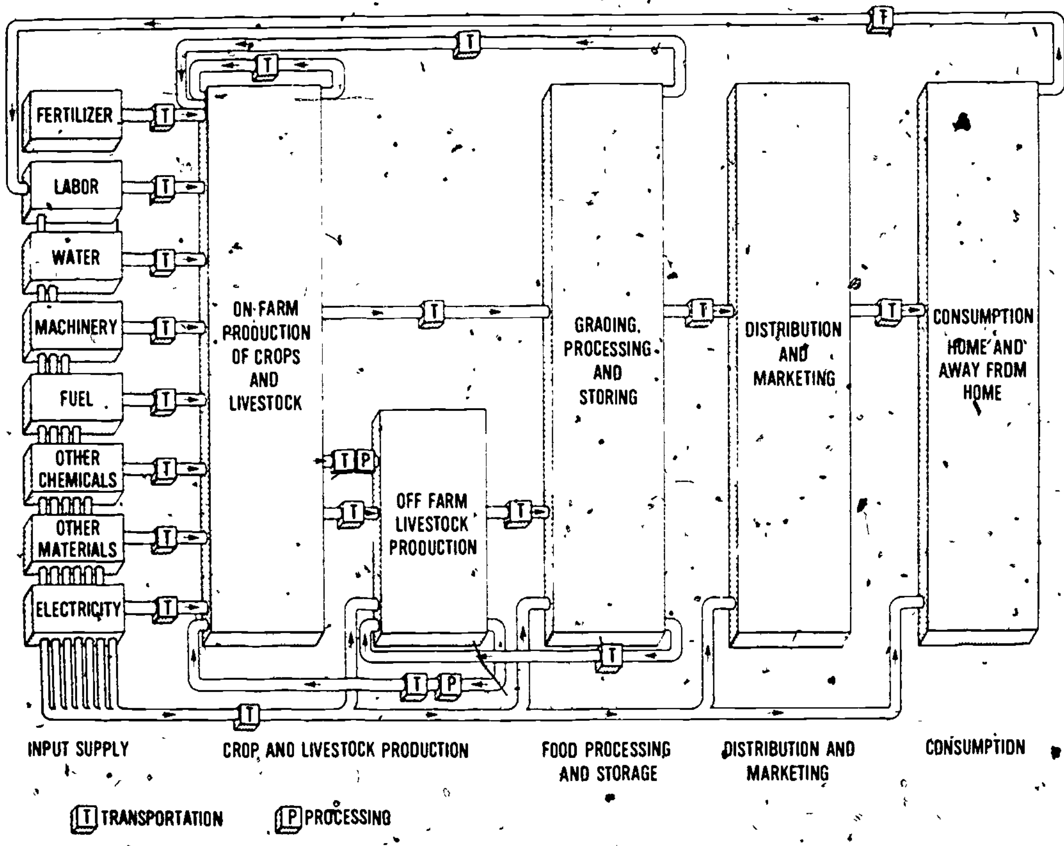
The term "system" has been used frequently in studies of food and fiber economics. When applying the systems concept, one is attempting to proceed beyond analysis of each individual component and to expand the level of comprehension about the *linkages* between the cells. Chart I illustrates the major components of the food and fiber system and portrays the major flows.[2] Observe the transport function (T) associated with each linkage. Transportation enables the system to perform in a spatial environment in which linked activities do not occur at the same location.

[1] Hirst (Reference No. 17) estimated that one-fourth of U.S. energy consumption is required in the transportation of goods and people. The freight component accounts for approximately one-third of this if intracity trucking is included. It is amazing that two-thirds of all transportation energy is used in the movement of people. How much, is involved in consumer purchase trips is yet to be determined. If evaluated on a per ton-mile basis, the human trip is not very efficient.

[2] This chart and much of the remaining discussion are based upon the contents of *The U.S. Food and Fiber Sector Energy Use and Outlook* (Reference No. 13)

Chart I

ENERGY FLOWS IN THE FOOD AND FIBER SECTOR



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A wide variance exists both across and within the distributive flows in terms of:

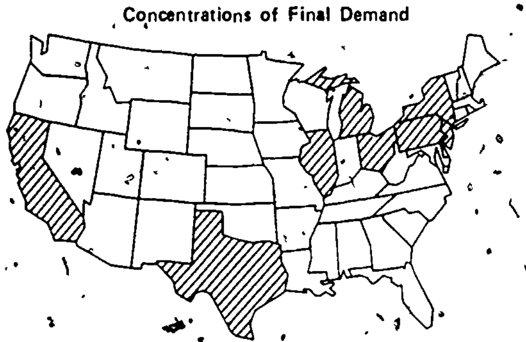
1. Distance and volume moved (ton-miles)
2. Transport modal mix
3. Seasonality (time) of movement
4. Ease of transport
5. Cost of transport
6. Origin-destination patterns
7. Flexibility of alternative

Each flow possesses a transport mechanism whose basic characteristics are dictated by the varying locational patterns evidenced in each stage.

Example Flow — Cotton

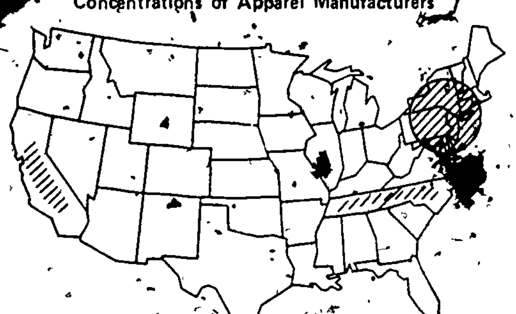
An example which aids in highlighting the importance of transportation is the cotton textile production stream. The standard procedure is to start at the mine and follow through to the consumer. However, since the average individual's level of awareness about the spatial dimension tends to be limited, a reverse approach is adapted in beginning with the most familiar.

Map I
Concentrations of Final Demand



Map I portrays the major concentrations of final demand, as measured by state aggregate personal income. Assume that these states represent the major ultimate destinations of apparel manufactured from cotton textiles. The retail outlets (department stores) are located relatively close to the consumer.[3] However, the clothing manufacturers evidence a highly concentrated locational pattern in the New York-New Jersey complex as shown in Map II. The relative transportation requirements to service the national market are considerable.[4] The textile industry is focused in the Piedmont area (Map III) Most cotton production occurs in the Southwest (Map IV) The resulting long-distance shipments of cotton bales to the textile mills translates into about eight million ton miles. Map V shows the location of farm machinery manufacturers. Again, this involves a significant transportation component Finally, Map VI illustrates the spatial concentration of the three basic fertilizer inputs. In the case of mixed fertilizers the three components must be assembled at one fertilizer plant prior to movement to the farm via the farm supplier.

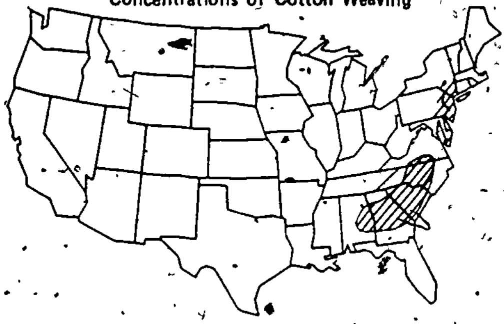
Map II
Concentrations of Apparel Manufacturers



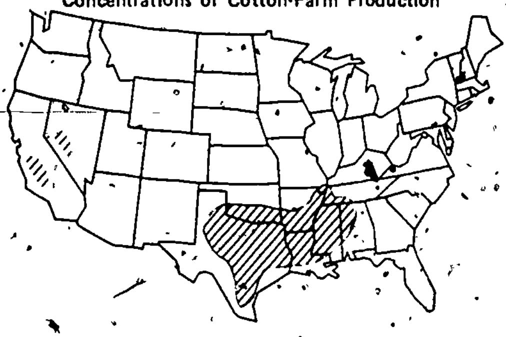
[3]The consumer generates the transportation necessary to make the purchase. This energy component has not been incorporated in the distribution estimates.

[4]The locational pattern of the wholesale sector would be intermediate, occurring in major metropolitan areas.

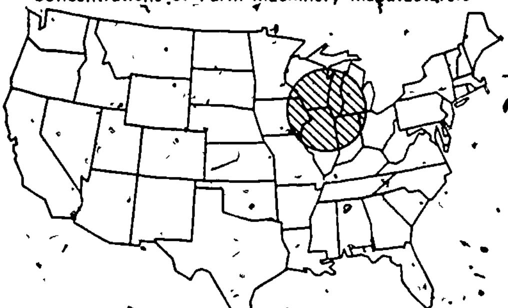
Map III
Concentrations of Cotton Weaving



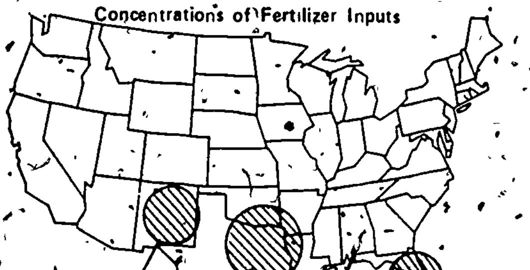
Map IV
Concentrations of Cotton-Farm Production



Map V
Concentrations of Farm Machinery Manufacturers



Map VI
Concentrations of Fertilizer Inputs



Obviously, the locational patterns and flows in this example are simplified greatly in order to highlight the spatial displacements existing within the system. One example of how complex the origin-destination matrix can be even for a basic flow is found in an analysis of cattle and calf movement in the South[5] Marketings of non-slaughter calves and veals are depicted as occurring not only among states within the Southern Region but also as a myriad of external flows to almost every other state in the nation.

Hopefully, the complexity and importance of the distribution segment of the U.S. food and fiber system have been communicated adequately. Although fragmentary data bases and studies do exist, far too little is understood about the distribution phase and its energy requirements. With that in mind, the next section attempts to portray an overview of the transportation energy needs associated with each stage.

Distribution Energy Needs

Best estimates indicate that transportation energy use accounts for about one-fifth of all energy used in the U.S. food and fiber system.[6] This represents only a little more than two percent of all energy consumed in the U.S. There are some who would argue that such a small number warrants only minimal attention in energy conservation efforts. However, the absolute necessity of maintaining a viable food distribution system makes this number far more important than it would first appear[7] Approximately 90 percent of all transport fuel needs in this system are met by diesel, with the remainder met by gasoline. Such a complete dependence upon an energy form of which one-third originates from unstable foreign sources further magnifies the importance of making food and fiber transportation as energy efficient as is practical.[8]

Transportation — Farm Gate to the City

Table I depicts the modal characteristics of agricultural transportation, from the farm gate to the city of final consumption.[9] Observe that farm trucks hauled more tonnage than any other carriers. However, the meaningful value of ton-mileage is dominated heavily by the commercial truck (60 percent). Note also that rail and water transport are five times as energy efficient on the average as are trucks; yet combined they carry only one-fourth of the ton-mileage. The extensive utilization of trucks has evolved for two reasons:

1. Trucks are *available* to service the widely dispersed agricultural community, much of which is accessible only by road.
2. *Timeliness* is essential in moving perishable commodities to the consumer or to the processor.

Table II compares transportation data for selected commodities. Observe that poultry and vegetables undergo average shipments exceeding 1,000 miles. This reflects the remoteness of specialized farm production regions from major population centers. Vegetables, milk, and grains evidence the largest total transportation requirements.

Table I
Agricultural Product Transportation: Estimated Fuel Needs by Mode of Transportation, 1970[a]

Mode of Transportation	Tons (Millions)[b]	Miles[c]	Ton Miles (Millions)	Ton Miles (Percent)	Ton Miles per Gallon[d]
Rail	118.1	497	58,725	23.3	250
All Trucks	559.4	291	162,710	64.7	48
Commercial	266.8	568	151,426	60.2	50
Farm	292.6	39	11,284	4.5	30[e]
Water	34.6	870	30,090	12.0	220
All Modes	712.1	353	251,525	100.0	67

[a] Source: *The U.S. Food and Fiber Sector: Energy Use and Outlook* (Reference No. 13) excludes Alaska and Hawaii.
[b] From USDA Staff Paper, October 2, 1970.
[c] Estimated largely from Ed Heitz, Traffic Manager, Agricultural Marketing Service.
[d] From Lincoln, G.A., "Energy Conservation," *Science*, Vol. 180, April 13, 1973.
[e] Estimated in Economic Research Service, USDA.

[5] L. D. Malphrus, et al (Reference No. 21).
[6] Calculations based on data from *The U.S. Food and Fiber Sector: Energy Use and Outlook* (Reference No. 13). Excludes energy used in intracity transport and for consumer purchase trips.
[7] On a world scale, this energy use actually exceeds the total consumption of some LDC's.
[8] Similar efforts should be made in all economic sectors whether large or small. Only in this manner can successful overall conservation measures be achieved.
[9] Raw agricultural products to the processor or directly to the consumer, plus processed food to the consumer. The data do not include the movement of cotton textiles, etc.

Table II

Agricultural Products Transported by Mode of Transportation, 1970[a]

Commodity	All Modes			Share of Ton-Miles (Percent)		
	Tons (Millions)	Miles	Ton Miles (Millions)	Rail	All Trucks[b]	Water
Livestock	46.1	520	23,950	7.5	92.5	---
Poultry and eggs	14 6	1200	17,520	---	100 0	---
Milk	73 3	500[c]	36,650	---	100 0	---
Feed grains	194 5	159	30,961	28 5	46 5	25 0
Food grains	102.2	312	31,932	46.0	11 0	43.0
Soybeans	97 5	197	19,183	24 0	31.0	45.0
Peanuts	4 5	683	3,075	8 0	92.0	---
Tobacco	4.9	787	3,854	39.5	60.5	---
Fruits	19 2	706	13,552	18 0	81.0	1 0
Vegetables	37 8	1152	43,545	26.5	73.5	---
Hay	24.1	115	2,766	7.0	93.0	---
Sugar	75.3	228	17,154	46.5	53.5	---
Cotton	18.1	408	7,383	66.0	34.0	---
Total	712.1	353	251,525	23.0	65 0	12.0

[a]Source *The U S Food and Fiber Sector Energy Use and Outlook* (Reference No 13) Based on USDA Staff Paper, Projected Agricultural Transportation Requirements, Oct 2, 1970, and USDA staff paper, Projected Agricultural Transportation Requirements—Modal Distribution, Oct. 30, 1970, and estimates on mileage by mode of travel by Ed Heitz, Traffic Manager Agricultural Marketing Service, June 8, 1973, Excludes Alaska and Hawaii

[b]Includes farmer-owned trucking and commercial trucking from Table 53

[c]Includes mileage for trucks returning empty.

Farm trucks are used mainly to carry small grains, hay, and sugar crops to the elevator or processor. Commercial trucks haul a wide variety of goods, including most of the perishables. Trains primarily transport nonperishable items, such as grain crops, sugar, and cotton. In addition, large volume shipments of fruits and vegetables move long distances by rail. Barge traffic is comprised almost exclusively of grain and soybeans.

Regional and commodity patterns quite often diverge from the general trends just described. For example, Casavant and Whittlesey studied potential impacts of rising energy prices upon transportation costs and the resulting influence upon the regional location of agricultural production.[10] By doubling energy costs, the following changes would result in each mode:

	Percent Increase in Total Costs	Absolute Cost Increase Per Ton-Mile
Barge	15%	.068¢
Rail	8%	.056¢
Truck	13%	.170¢

The barge is most sensitive in terms of the impact on total costs. However, on an absolute cost per ton-mile basis, the truck is three times as sensitive as is rail. These cost increases were applied to several commodities and regions, including apples in the Northwest. Twenty years ago 80 percent of the apples moved from Washington eastward by rail. Recently this share has been transferred to trucking, making Washington apple growers increasingly vulnerable to energy price increases. They are apt to lose a significant portion of the eastern market to more favorably located producing areas. The overall conclusion from this analysis is that agricultural producers in the Pacific Northwest are likely to suffer most from energy cost increases, given a heavy reliance on trucking and remoteness from major markets.

[10]Casavent and Whittlesey (Reference No. 7).

Transportation — Farm Inputs

Deficiencies in the data base concerning energy use in the distribution of farm inputs are common. However, partial data can be employed, using ton-mileage as an energy surrogate in assessing the features of input transportation. Although the farm machinery industry was described earlier as concentrated, the location (see Map V) is close to the major farm production regions. About 70 percent of the market is less than 600 miles from the machinery manufacturers. Yet over half of the ton-miles are involved in shipping the remaining 30 percent to more distant markets. Rail accounted for almost half of the ton-mileage (longer hauls).

The agricultural fertilizer industry is more dispersed, resulting in much shorter average hauls. However, the raw materials for fertilizer are highly localized, and the associated transport requirements undoubtedly offset this initial advantage.

Ingredients for the manufacture of feed move an average of 330 miles to the plant, compared to a 60-mile average movement of the product from plant to the farm gate. About 56 percent of the ingredients and almost all of the manufactured feeds move by truck, with most of the remainder traveling by rail Available data indicate a considerable regional variation in modal requirements For example, two-thirds of the feed ingredients in the Appalachian, Southeastern, and Delta states move by rail.

Almost half of the tonnage and two-thirds of the ton-mileage of pesticides travel by rail. This group of commodities is one of the few examples in the food and fiber system where the rail net (more energy efficient) has increased rather than decreased its share of the transport load.

Petroleum products represent a critical input to the farm production mechanism. Use is highly seasonal and is difficult to determine accurately on a monthly basis. On-farm storage facilities usually are limited, often to a two week supply. The wide-flung distribution system necessary in supplying the farmer with 6.5 billion gallons of fuel involves an additional 80 million gallons for transportation (one gallon used to deliver 80 gallons).[11]

In summary, the distribution needs in the U S food and fiber system have been shown to involve the movement of large tonnages over a wide range of distances, requiring one-fifth of all energy used in the system. The least efficient energy user (truck) accounts for about 60 percent of the total ton-mileage

Transportation – Dollar Cost

However, even though energy is important in agriculture, its contribution to the total dollar cost of a product normally is about four to eight percent The transport energy component then represents only about one cent.[12] This number and its variability mean far more to the entrepreneur than energy measures expressed in gallons or Btu's.[13] If energy conserving practices result in increased costs, they are not likely to be adapted This is a critical factor to be kept in mind when discussing potential conservation practices in the ensuing section

Conservation

Even though energy use in food and fiber distribution is such a small part of the total, many possibilities for energy conservation exist How many of the alternatives are economically feasible is yet to be determined.

Truck Capacities

One alternative which represents both energy and economic savings is the expansion of truck capacities.[14] In 1973, freight with a density of 18 to 20 pounds per cubic foot could fill a standard 40 foot semi without exceeding the maximum legal limits (73,280 pounds).[15] The "break even" point for 65-foot, twin trailer combinations is 12 to 13 pounds average density. By employing the larger capacity trailer rigs, over 20 percent fuel savings can be attained for a load averaging 12 pounds per cubic foot due to *fewer vehicle trips.* Combined with greater weight limits (80,000 pounds), the fuel savings for light loads could exceed 30 percent For the high density freight, the increased weight limits could result in fuel savings of about 10 percent.[16] The cumulative effect would not achieve these percentage estimates, since many loads would not be increased. One recent proposal has been to permit doubled 40-foot trailers with a 125,000 pound maximum Many questions must be resolved, such as increased costs of road maintenance, before this would become reality.

Backhauls

An unfortunate circumstance exists in which many trucks throughout the food and fiber system are empty on the return trip Much of this is dictated by traffic imbalances between two shipping points. A much greater volume may be moving in one direction, necessitating some carriers making the return trip without a load.

However, other causes are responsible for an additional number of trucks being "deadheaded" on the return trip. In the regulated trucking industry, backhauls often are prohibited.[17] In a recent loadometer study, it was shown that private tractor-trailer rigs returned empty 62.4 percent of the time.[18] The Interstate Commerce Commission ICC prohibits private carriers from entering either contract or common carrier service on a return trip ICC regulated carriers return empty 38 percent of the time. Part of this is generated by the fact that a contract carrier cannot become a common carrier on the return trip If private carriers could reach even the inefficient ratio achieved by the regulated

[11] Does not include fuel needed to transport petroleum products from the refinery to bulk plants and distributors

[12] Less than a century ago, the importance of land transport costs dominated product costs. For example, a load of lumber could be cut in Sweden and moved 2,000 miles by water to England at a reasonable cost. However, to move that lumber just five miles inland resulted in a doubling of total costs!

[13] An example of the small impact of transport energy costs on product prices is found in a study by Anderson and Budt (Reference No. 2). They calculate that each increase of five cents per gallon of diesel (trucking) adds about one tenth of one cent per pound to the delivered cost of meat.

[14] This issue has been the focus of considerable controversy with respect to the safety element.

[15] American Trucking Associations (Reference No. 1)

[16] Many states permit twin trailers. These rigs have been forced to route around the other states, resulting in inefficiencies of fuel use The 80,000 pound maximum has not been adopted by about 20 states. As a result, many shippers still load to the 73,280 pound limit.

[17] For example, private trucks moving meat from Colorado to New York cannot carry a return load.

[18] Miller (Reference No. 22).

carriers, significant savings would result. Indications are that fuel consumption rates of about five miles per gallon are maintained regardless of whether the truck is full or empty, emphasizing the energy inefficiencies of those backhauls which do not occur solely due to regulatory restriction.

With energy (and labor) costs increasing, firms are exploring backhaul potentials in intracity movement from the wholesaler to the retailer Few possibilities exist at the farm level, since approximately four times as much leaves the farm as is hauled to the farm.

Wasted Space

Many trucks carry less than full loads, and for light density routes this often is unavoidable However, some inefficiencies do exist. For example, a meat truck loaded to legal weight capacity carries two thirds more of the final product than does a livestock truck.[19] Hung carcasses shipped from Iowa to New York represent considerable wasted space over boxed meat.[20]

Rail

The rail system obviously is more energy efficient than trucking. However, this mode is not accessible to many firms and is inefficient for short hauls Although rail service and dependability have improved somewhat, truck service has adjusted much more rapidly in reacting to changing needs. Perhaps reduced regulation of railroads would generate an improved response to the requirements of the food and fiber system, with a resultant shift of some commodities to the more energy efficient rail mode.

Market Realignments

Market realignments could reduce the necessity for dispersed, small volume shipments. The anhydrous ammonia industry contains many instances in which each plant serves several regional markets, on a national scale. More often than not firms are competing in the same markets. Since anhydrous ammonia is a uniform product, it is possible for firms to trade supplies. In this way it is possible for one plant to supply all bulk outlets in Illinois, regardless of company affiliation, while another plant may service all outlets in Georgia. The duplication of routes is minimized.

An analysis of the distribution of bulk dairy feed in the Northeast provides an example of the energy saving potentials of market realignment on a more local scale.[21] Presently the delivery of bulk feed involves a heavy duplication of routes, with relatively small storage capacities on the farm (less than two weeks). If storage capacities could be expanded, thereby increasing the minimum size of shipment, the frequency of delivery would be reduced. This action alone might result in decreases of from 7 to 23 percent in fuel utilization for delivery. If exclusive delivery territories also were adopted, the diesel fuel needs would drop by over one-half![22] Twenty-five million tons of mixed feed are sold per year, and most is bulk delivered. This involves over 100 million miles of route travel and 16 million gallons of diesel fuel If the frequency of delivery could be reduced, from 1.1 to 3 7 million gallons of diesel would be saved annually. If, in addition, exclusive territories evolved, 10.5 million gallons total might be saved. When compared to total diesel use in the United States, this represents less than one day of consumption. However, many conservation alternatives are just as insignificant when considered individually. When measured in the aggregate, the same alternatives assume a much stronger position.

Other

The potential for energy conservation exists in many other elements of food and fiber transportation. Regulated rate structures often lead to indirect routing or perpetuate inefficient locational patterns. By shifting processing stages in which weight loss is significant toward the location of the raw material, unnecessary movement of excess weight is minimized. Multimodal transit (piggyback) combines the advantages each mode has to offer. Waste disposal often involves a duplication of routes. Marketing firms can alter their logistics system for existing market structures in terms of improved routing and storage. The movement of people associated with the agricultural sector has received minimal attention.[23] Little is known about the comparative energy efficiencies of high density versus low density routes.

In conclusion, many other examples could be cited as possible areas of energy conservation. However, it should be evident that one overriding theme can be stated as being responsible for many of the avoidable inefficiencies today—the artificialities created and perpetuated by *regulation*. Change is inhibited by the inflexibilities of existing political and social institutions. Unless regulation can be minimized and that which remains then be made responsive in a timely fashion to economic realities, the aggregate opportunity for energy conservation in transportation is reduced.

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[19] Assumes a 60 percent slaughter yield of beef. Anderson (Reference No. 2)

[20] Under existing weight limitations, little is gained by moving boxed meat instead of carcasses After deducting 30-35,000 pounds for the empty trailer and tractor from the gross allowable 73,000 pounds, 38-43,000 pounds remain for the load. The average full load for hanging beef is 36,500 pounds. Boxed meat is limited by weight rather than space to about 40,000 pounds. By allowing a greater weight maximum, the potential difference would be greater (assuming packaging problems would be solved). However, even under existing conditions more of the product is shipped at a given weight as boxed meat since the byproducts have been removed. (Source: Conversation with James Lauth, Director of Transportation and Warehouse Division, AMS, USDA, Washington).

[21] Davulis, et al (Reference No. 9).

[22] This institutional change would be difficult to implement without stifling competition. One mechanism which could result in spatially contiguous markets would be to require payment of a posted feed price plus the true transport costs by the purchaser, based on his distance from the supplier.

[23] Rupprecht (Reference No. 28).

The Big Picture

The focus throughout this workshop has been on energy efficiency However, it is imperative that energy be placed in perspective relative to other inputs. For example, energy historically has been a substitute for labor. As a proportion of the total cost of a product, energy costs are responsible for 6 to 8 percent, and labor charges are almost 50 percent An 8 percent increase in wage rates impacts the total cost of a product as much as a doubling of energy prices. The entrepreneur may continue to opt for energy if the substitute he faces is labor.

The short run assignment of the food and fiber sector is to eliminate energy inefficiencies which have evolved due to the historic low prices of energy. In the longer run, ways must be found to substitute more plentiful energy sources (such as solar) for the increasingly scarce and costly fossil fuels. The current practice of crisis management must be discarded so that resources may be devoted now to the development of models, logistics systems, and applicable technology in anticipation of *future* needs.

Research, Teaching, and Extension Needs

Professionals dedicated to research, teaching, and extension as related to the food and fiber system face a difficult, yet challenging task in the area of energy conservation. At present the policy maker is forced to make transportation-related decisions based upon minimal data. Too little is understood about the complexities of the distribution system. The researcher can work to alleviate this deficiency by quantifying energy use and efficiencies in assemblying, transporting, and distributing agricultural products. There is a great need to examine these problems at the regional level, since each region is unique in its transportation requirements. Each problem must be analyzed from a total economic as well as an energy standpoint. The teacher is responsible for equipping the student with an increased level of awareness about the spatial dimension of economic activity and for providing the student with the basic tools of background information concerning energy, quantitative techniques, and logic. The extension specialist faces an equally difficult task, since it is his duty to stay abreast of new conservation potentials and make the information available to the agricultural community. Above all, each professional must work at the art of effectively communicating developments in energy use in food and fiber distribution.

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References

1 American Trucking Associations, Inc, *American Trucking and the Energy Crisis*, Washington, D C, 1973.

2 Anderson, Dale G and Wayne W Budt, *A Rate/Cost Analysis of Nebraska Meat Trucking Activities with Livestock Trucking Cost Comparisons*, Research Bulletin No 269, Agricultural Experiment Station, University of Nebraska, Lincoln, March 1975.

3 Anderson, Dale G and D L Helgeson, *Economies of Size, Volume, and Diversification in Retail Grain and Farm Supply Businesses*, Research Bulletin 261, Agricultural Experiment Station, University of Nebraska, Lincoln. April 1974.

4. Bailey, John M., *Potential for Cooperative Distribution of Petroleum Products in the South*, FCS Information Bulletin 91, USDA, Washington, D C, July 1973

5 Baumel, C Phillip et al, *An Economic Analysis of Alternative Grain Systems: A Case Study*, Iowa State University, Ames. November 1973. Prepared for U.S. Department of Transportation, Federal Railroad Administration

6 Brokken, Ray F and Earl O Heady, *Interregional Adjustments in Crop and Livestock Production*, Technical Bulletin No 1396, July 1968.

7 Casavant, Kenneth and Norman K Whittlesey, "Increasing Energy Prices. The Impact on Transportation Costs and the Regional Location of Agriculture Production," presented at the Western Agricultural Economics Association meetings, Moscow, Idaho July 1974

8 Creedy, John A, "Water Carriers and the Energy Crisis," Presented at the Energy for Agriculture Conference, jointly spon-

sored by Purdue University and the Corn Refiners Association. Inc (Washington, D C) September 1973

9 Davulis, J P, R A Andrews, and C E Frick, *The Distribution of Bulk Dairy Feed and the Energy Crisis,* Research Report No 35, New Hampshire Agricultural Experiment Station, University of New Hampshire, Durham (in cooperation with ERS, USDA) April, 1974.

10 Easter, K William and Rolland J Nevins, "Grain Trucking in Minnesota—What It Costs in Region 6E," *Minnesota Agricultural Economist* (Agricultural Extension Service, University of Minnesota), July 1975 pp 1-5

11 Economic Research Service, USDA, *Developments in Marketing Spreads for Agricultural Products in 1974,* AER No 261, Washington, D C , April 1975

12 Economic Research Service, USDA, *Transportation in Rural America,* Part I of an analysis prepared for the Senate Committee on Agriculture and Forestry, USGPO, Washington February 1975.

13 Economic Research Service, USDA, *The U S Food and Fiber Sector Energy Use and Outlook,* Prepared for the Senate Subcommittee on Agricultural Credit and Rural Electrification, USGPO, Washington, D C , September 1974

14 Fedeler, Jerry A , Earl O Heady, and Won W. Koo, *An Interregional Analysis of U.S. Domestic Grain Transportation,* Card Report 54T, Center for Agricultural and Rural Development, Iowa State University, Ames February 1975.

15 "Fuel Savings Through Increased Vehicle Weights," *Research Review,* American Trucking Associations, Inc , March 15, 1974 pp 1-2

16 Hirst, Eric, *Energy Consumption for Transportation in the U S.* Oak Ridge National Laboratory, Oak Ridge, Tennessee. March 1972

17 Hirst, Eric, Energy Intensiveness *of Passenger and Freight Transport Modes 1950-1970,* Oak Ridge National Laboratory, Oak Ridge, Tennessee April 1973

18. Knecht, Ronald L and Clark W. Bullard III, *End Uses of Energy in the U.S Economy, 1967,* Center for Advanced Computation Document No. 145, University of Illinois, Urbana, January 1975.

19. Lauth, James H. (Director, Transportation and Warehouse Division, AMS, USDA), "Transportation and the New Energy Policies," testimony before the Senate Subcommittee on Transportation. February 1974.

20 Lauth, James H. and Rebecca S. Sammartino (Transportation and Warehouse Division, AMS, USDA), "Problems and Issues in Agricultural Transportation," paper presented at the North Central Regional Transportation Committee Seminar, Kansas City, Missouri, May 6, 1975

21. Malphrus, L.D., C Y Liu, and R J. Freund, *Cattle and Calf Movement in the South,* Southern Cooperative Series Bulletin 134 March 1968.

22. Miller, Edward, "Effects of Regulation on Truck Utilization," *Transportation Journal,* Fall 1973. pp 5-14

23 Moser, David E , "Changes in Transportation and Their Implications for the Livestock and Meat Industry," from Thomas Stout, Ed., *Long-Run Adjustments in the Livestock and Meat Industry Implications and Alternatives,* North Central Regional Research Publication 199 March 1970

24. Motor Vehicle Manufacturers Association of the U.S., Inc , *Motor Vehicles and Energy,* Detroit, Michigan, January 1974

25 The National Area Development Institute (Lexington, Kentucky), *Meeting Rural Transportation Needs,* Part II of an analysis prepared for the Senate Committee on Agriculture and Forestry, USGPO, Washington, D C , February 1975

26 National Commission on Productivity and Work Quality, *Backhaul in Food Distribution,* Washington, D.C , 1974

27 *Report on a Field Study of Problems in Agricultural Transportation and Marketing,* compiled for the Senate Subcommittee on Agricultural Production, Marketing, and Stabilization of Prices, USGPO, Washington, D C , October 1974

28 Rupprecht, Erhard O (Economic Research Service, USDA), "Impacts of Higher Gasoline Prices on Rural Households," presented before the American Association of Agricultural Economists, 1975 Summer Meetings, Ohio State University, Columbus. August 1975

29 Sammartino, Rebecca S. (Agricultural Marketing Service, USDA), "National Transportation Policy Issues," presented at the National Research Council, Division of Engineering, Railroad Research Study, Woods Hole, Mass July 1975

30 Sammartino, Rebecca S (AMS, USDA) and Allen G. Smith (ERS, USDA), "Agricultural Transportation Projection," presented at the National Research Council, Division of Engineering, Railroad Research Study, Woods Hole, Mass. July 1, 1975.

31 Seidel, Marquis R , Steven E. Plotkin, and Robert O Reck, *Energy Conservation Strategies,* Section V "The Transportation Sector," U S. Environmental Protection Agency, Washington, D.C , July 1973.

32. Task Force on Railroad Productivity, *Improving Railroad Productivity,* Final Report to the National Commission on Productivity and the Council of Economic Advisors, Washington, D C., November 1973

33. Taylor, Morris H. and Forrest Baker, Jr , *Transportation: Implementing Change in Freight Rate Structure With Emphasis on Utah's Agribusiness,* Utah State University Extension Services, Logan. April 1974

34. Thoman, Richard S and Peter B. Corbin, *The Geography of Economic Activity,* McGraw-Hill Book Co , New York 1974.

35. Transportation Association of America, *Transportation Facts and Trends,* Washington, D C., July 1974

36. U.S Department of Commerce, Bureau of the Census, *1972 Census of Transportation, Commodity Transportation Survey,* USGPO, Washington, D C., 1974

37. U.S. Department of Transportation, *Energy Statistics, A Supplement to the Summary of National Transportation Statistics,* Washington, D C., September 1973.

38. Wyckoff, D Daryl and David H Maister, *The Owner-Operator: Independent Trucker,* Chapter 2. "Components of Owner-Operator Expenses," Lexington Books, Lexington, Mass 1975.

REPORT OF EXTENSION GROUP

Frank J. Humenik, *Chairman*
Ted R. Holmes, *Recorder*

After preliminary discussion, approximately 15 participants in the Extension group agreed that extension programs should be directed toward two major audiences. (1) the general public and (2) agricultural producers. The group then undertook to define messages and to propose delivery systems. The recommendations agreed upon are outlined below:

A. The General Public

I. **The Message**

A. *Energy Consciousness* — Stress the reality of the problem and the need for the public to become involved in decision-making as to priorities.

B. *Cooperative Conservation* — Conservation by agriculture alone will have some, but not much, effect on the total picture. The public must help with conservation and thus the major goal is total cooperation.

C. *Policy* — Provide reliable facts and urge the public to apply its influence toward the making of national policy favorable to a continued supply of adequate food.

D. *Adequate Production* — Promote public awareness of American agriculture's role in supplying adequate high quality food and of the importance of assuring agriculture enough energy to produce this food, while at the same time supporting research and development for new sources and more efficient uses of energy.

II. **Delivery Systems** Develop a nation-wide information program supported by individual state programs.

A. *Provide television and radio spots* for nationwide distribution and seek sponsored or public affairs time on networks, including PBS, to disseminate attention-getting factual information.

B. *Public Press* — Provide information in easily understood form for magazines and other periodicals of general, consumer and homemaker interest.

C. *Wire Service* — Establish accessible and reliable source of information.

D. *Extension Information Channels* — Each state should use normal information channels.

E. *Person-to-Person* — Each state should consider use of energy town hall meetings, homemaker groups, etc.

B. Producers

I. **The Message** (Must be unique to the audience but stress systems approach.)

A. *Energy Consciousness* — Increase producer awareness regarding current and future energy resources and requirements.

B. *Cooperative Conservation* — Give the producer the facts and allow him to make decisions as to alternative enterprises, production practices, use of equipment, etc. Point out that it may become necessary to establish an on-the-farm conservation program in order to obtain fuel.

C. *Audience Uniqueness* — Recognize differing needs of various segments of agriculture with allowance for such inputs by qualified individuals, but stress the total systems approach in all energy considerations.

D. *Total Energy View* — Emphasize the adoption of production practices based on overall energy requirements rather than just limited savings for an individual operation. Such total energy data and recommendations should include support system inputs as well as on-farm production requirements.

E. *Goal* — Emphasize that the farmer is producing food, not energy.

II. **Delivery Systems** It will be a challenge for extension groups at national and state levels to develop effective delivery systems for these programs.

C. Recommendations

The group voted unanimously to ask the Southern Extension Directors Association to request Extension Service USDA to establish a national committee to prepare a public information program for the national delivery system (as suggested under "The General Public" of this report) and that this committee (also as outlined under "Producers" in this report) develop a producer information program that would apply to agriculture in general. It was further recommended that individual states develop inputs for these national efforts and information programs geared to the unique aspects and situations of their producers.

The Extension group unanimously agreed to categorically emphasize the importance of visible administrative support and budgeting for Research, Teaching, and Extension programs to secure sufficient energy for at least continuance of contemporary productivity.

Finally, the group recommends that the entire SREB Energy Conference send a resolution to the National Association of State Departments of Agriculture meeting in West Virginia, October 5, 1975, requesting national support for all programs proposed by the Southern Regional Education Board Conference on *Energy in Agriculture*.

REPORT OF TEACHING GROUP

Cecil E. Howes, *Chairman*
Gerald Zachariah, *Recorder*

Credibility of information sources appears to be a critical factor in disseminating information on energy. Colleges of agriculture have been developed to have credibility with the public, which increases the faculties' responsibilities in providing accurate information on energy subjects. University students are certainly a key group to be provided with current and factual information on energy.

Agriculture should take a lead in disseminating energy information. Too often in the past, when critical situations arose, agriculture let other groups take the lead and we were then placed in a defensive position. One of the problems now confronting us is the lack of adequate information. It was felt that too much of the information coming out at this time is not founded on facts. If we are to teach energy adequately in our courses and retain our credibility as an information source, we must present accurate information. Additional research should be encouraged to generate accurate information on energy used in agriculture which can be used in our teaching programs. Professional societies should take an active role in collecting information on energy and promoting the dissemination of this information.

There was no one recommended course structure which could universally be used in presenting information on energy. The organization of the academic structure within the university, course philosophy and personnel would be important factors in determining how the material was to be incorporated into the educational program. The following are recommendations which evolved from the discussion by the teaching group:

1. Special energy courses, the incorporation of energy topics into existing courses, seminars, campus-wide courses and combinations of these were all considered as viable approaches. The most appropriate would depend on the local situation and as is frequently the case, new courses on energy would likely evolve from some of the less-structured approaches, especially as more accurate information becomes available on energy uses in agriculture.
2. In appropriate existing courses the course philosophy should include concerns for energy. Examples of a few specific points in this regard are listed below. These points reflect a close relationship to specific disciplines.
   a. Develop an understanding about energy requirements and the consumer demands and their interrelationships
   b. Introduce energy as a major design parameter
   c. Continue to teach improvement of production efficiency, with higher energy cost requiring a change in one of the production input items.
3. A better appreciation of the role of energy in agriculture among all faculty and administrators of colleges of agriculture should be developed. This might be accomplished by seminars or other training sessions.

A concern was raised regarding the development of an over-emphasis on energy education. This would suggest that we might try to make an energy expert of everyone which would detract from training in our major disciplines. Energy education should be kept in perspective — remembering that it is a cost factor in producing, processing and marketing food and fiber.

REPORT OF RESEARCH GROUP

A. W. Snell, *Chairman*
F. J. Hassler, *Recorder*

The 34 participants in this group limited their discussion to consideration of two aspects: (1) How to accomplish the needed research or delivery, and (2) researchable topics for Agriculture, Aquaculture and Forestry.

The following recommendations were submitted to the general session and adopted for guidance in the region:

1. Compile and publish a comprehensive bibliography.
2. Emphasize fuel substitution; e.g. utilize solar energy and renewable sources of energy such as methane from biomass for home and farmstead operations in order to conserve liquid fuels for prime movers from field and road locomotions and operations.
3. Employ systems engineering methodology to study inter- and intra-systems relationships (not ready to optimize production systems with least energy requirements as a constraint).
4. Fused energy implications with current on-going research and initiate some high priority targeted energy research.
5. Recognize that energy cost for food and fiber production is still a small part of the consumer's budget, yet we can increase its efficiency.
6. Research is needed to assure the availability of energy as an essential part of a modern agricultural system.
7. Researchable topics
   - A. Production
     1. conservation
     2. utilization
     3. new sources
     4. biomass conversion
     5. solar energy
     6. wind
     7. storage
     8. genetic manipulation (nitrogen fixation)
     9. crop efficiency
     10. product synthesis

     Short Run Adjustments
       - (energy) fuel substitution
       - livestock efficiency

     Fertilizer Efficiency (manufacture and use)
       - pesticide scheduling
       - energy independence
       - water utilization and scheduling
       - low energy production systems

     Policy Concepts of Farm Production
       - new products
       - machinery
       - use of non-agricultural waste
       - fuel efficiency
       - thermodynamic analysis
       - alcohol engine
   - B. Processing
     1. waste utilization
     2. solar energy
     3. fuel substitution
     4. institutional grades and standards
     5. cooking
     6. drying
     7. location
     8. storage
   - C. Distribution
     1. institutional (regulation)
     2. cost analysis
     3. network theory
     4. marketing — grades and standards
     5. mode of transportation substitution
     6. multi-modal transport systems
     7. preservation
     8. storage terming
   - D. Consumer
     1. acceptance
     2. demand analysis