An Analysis to Develop a Program for Energy-Integrated Farm Systems

September 1981

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AN ANALYSIS TO DEVELOP A PROGRAM FOR ENERGY-
INTEGRATED FARM SYSTEMS

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CHAPTER 1

PURPOSE OF THE RESEARCH

American agriculture is critically dependent on energy. Lack of fuel during planting and harvest seasons can mean the loss of a crop, hungry people and a weakening of an entire economy. The risks of fuel shortages to agriculture are sufficiently high to warrant a national program of energy-integrated farm systems. The purpose of the research presented here is to: 1) establish the objective of the program, and 2) identify guidelines for program development.

Energy-producing technology has resulted in low-cost gas and oil to the American farmer and has allowed him to produce commodities with less labor. Consumers have benefited from this situation with abundant food at low prices. Farmers now rely on a relatively stable world political economy that assures a constant flow of oil and gas at acceptable prices. Rapid curtailment of oil and gas would cause food prices to soar; food shortages would likely develop in the short term. An energy shortfall of 5% is estimated to result in a 26% increase in the price of farm commodities (Council for Agricultural Science and Technology 1977). However, the U.S. agricultural economy, with its many relatively small producers, who are tied to a complex system of energy suppliers, and responsible for feeding an entire nation and more, is too complex for anyone to determine the precise impact of an energy shortfall. Those intimately familiar with the agriculture industry feel that the current risk of an energy shortfall to agriculture is too high to go unnoticed at the federal level.

Limits on future technological innovations in the oil and gas industry, the precarious nature of the world petroleum economy and the dependence of our food supply on energy necessitate the use of renewable energy resources and possibly a decentralization of energy systems for agriculture. This need requires answers to several questions.

- Do farmers have sufficient energy from the sun, wind, streams that flow through their fields, and residues of their crops to attain a satisfactory degree of independence from petroleum?

- Can the same ingenuity that resulted in the recovery of that oil from above the Arctic Circle, below the ocean and the transport of that oil to the nation's farms be arranged to give farmers a degree of independence from petroleum?
- Can energy-integrated farm systems that apply available technology to the use of renewable energy sources be developed and thereby increase the certainty that our farms can continue to feed the nation? Such requirements warrant a national program to serve as a focal point for facilitating necessary interaction between the public and private sectors to induce conservation of nonrenewable energy resources through technology transfer at competitive market prices (Walden 1978).

A goal must be established to give the program direction and aid in the judicious allocation of federal funds. The program's objective is determined by: 1) an analysis of the technologies that could be utilized to transform renewable farm resources to energy by the year 2000, 2) the quantity of renewable farm resources that are available and 3) current energy-use patterns.

Generation of the first commercial application of a new or improved process or product can originate in facilities that range from small farm machine shops to large sophisticated laboratories. To reach these sources the Department of Energy issued a program opportunity notice soliciting proposals for projects leading to the commercialization of innovative technology (U.S. Department of Energy 1979). The final selection of projects has been made on the individual merits of specific proposals. However, the efficient expenditure of federal funds necessitates the identification of guidelines to assure that individual projects fit together in a comprehensive national program to meet the established objective.

Individual research, development and demonstration projects are fit into a national program of energy-integrated farm systems on the basis of: 1) market need, 2) conversion potential, 3) technological opportunities, and 4) acceptability. Quantification of these factors for the purpose of establishing program guidelines is conducted using the following four

precepts: 1) market need is identified by current use of energy for agricultural production; 2) conversion potential is determined by the availability of renewable resources, and 3) technological opportunities are determined by the state-of-the-art methods, techniques and processes that can convert renewable resources into farm energy.

Each of these factors is analyzed in Chapters 2-4. Chapter 5 draws on the analysis of these factors to establish the objective of the program and identify guidelines for the distribution of program funds. Chapter 6 then discusses the "acceptability of integrated farm systems," which can not be quantified like the other factors.

CHAPTER 2

AN ANALYSIS OF EXISTING ENERGY USE PATTERNS

American agriculture is not equally dependent on energy throughout its different farming regions. Regions currently having farming practices that are more energy-intensive than others are thought to warrant greater concentration of federal effort in promoting energy-integrated farm systems. This position is predicated on the proposition that energy intensity creates need, which is interpreted as a market for alternative energy technology. Commercialization is higher in firms that devote more of their research and development resources to projects that are designed to satisfy a felt market need rather than designed to find specific uses for promising technology (Mansfield et al., 1977). Therefore, the Department of Energy is believed to probably have a greater impact on the inducement of energy-integrated farm systems if it funded a greater share of research, development, and demonstration in areas where the greatest farm use of energy currently occurs.

A literature review shows no analysis of existing data to identify relative regional energy-use intensity. The standard data bases are Energy and U.S. Agriculture: 1974 Data Base, (U.S. Department of Agriculture 1976) and Energy and U.S. Agriculture: 1974 and 1978, (U.S. Department of Agriculture 1980). These data bases are the source of the data presented in this chapter. Friedrich (1978, p. 161-162) presents suggested energy-conservation techniques and analyses and various energy-saving implementation strategies but concludes that differences in geography, climate, politics, economics, and social conditions require policymakers to make appropriate modifications in suggested strategies to maximize social welfare. Dvoskin and Heady (1977) use an interregional linear programming model to determine the response of U.S. agricultural production to various energy supply and price conditions. Lockeretz (1977) analyzes energy use patterns in Northeast farms to determine potential replacement of fossil fuels by energy from renewable resources. He concludes that renewable resources could substitute about 25% of the on-farm energy use.

The purpose of the analysis presented in this chapter is to differentiate the nation into regions based on the recognition of the farm energy market and for agricultural production needs. The nation is first divided into production regions, and total energy consumption patterns for both crop and livestock production are discussed by commodity and function. The energy used for crop production is then detailed by major commodity, region, fuel type, farm function and yield. The energy used for livestock production is then reviewed.

2.1 AGRICULTURAL PRODUCTION REGIONS

The United States has been divided into eight regions to identify regional energy use in agriculture. These regions are pictorially shown in Figure 2.1. The Northeast and Appalachian Regions were combined to form Region 1. The Southeast and Delta Regions of the U.S. Department of Agriculture groupings were combined to form Region 2 so that total regional energy use among regions would be comparable. Arizona was removed from the Mountain States and combined with California because nearly all its agriculture is at low elevations in the warmest climatic zone of the United States and also because Arizona produces crops similar to those grown in Southern California.

2.2 ENERGY CONSUMPTION OF U.S. AGRICULTURE

The purpose of this section is to determine the energy use patterns of U.S. agriculture (livestock and crop production) by farm function or operation, energy form and commodity. The total energy inputs to livestock and crop by farm function/operation are shown in Tables 2.1 and 2.2, respectively. Crop production uses 1,824,843 billion BTU's and livestock production 223,179 billion BTU's. Thus livestock production (excluding feed energy input) accounts for only about 11 percent of the energy used in U.S. agriculture while crop production accounts for about 89 percent. The largest energy consumptive function for crop production is for fertilizer, which accounts for 35.8 percent of the energy used. Accounting for 29.4 percent of the energy use, feed handling is the major energy consuming step in livestock production.

FIGURE 2.1. Agricultural Production Regions

TABLE 2.1. Total Energy Input to U.S. Crop Production
by Farm Function, 1978

<u>Farm Function</u>	<u>BTU Total (Billion)</u>	<u>Percent</u>
Preplant	175537	9.6
Plant	47870	2.6
Cultivate	50031	2.7
Harvest	154755	8.5
Farm Pickup	129559	7.1
Fertilizer Application	12996	0.7
Pesticide Application	16937	0.9
Farm Truck	67732	3.7
Farm Auto-Crops	60767	3.3
Grain Handling (Vehs)	1905	0.1
Grain Handling (Mach)	114	0
Crop Drying (on-Fm)	71364	3.9
Irrigation	254766	14.0
Frost Protection	39824	2.2
Fertilizer	652532	35.8
Pesticides	68130	3.7
Electricity	5783	0.3
Miscellaneous	<u>14232</u>	<u>0.8</u>
Total	1824834	100 (99.9)

Source: U.S. Department of Agriculture 1976.

TABLE 2.2. Total Energy Input to U.S. Livestock Production
by Operation, 1978

<u>Operations-Livestock</u>	<u>BTU Total (Billion)</u>	<u>Percent</u>
Lighting	5914	2.6
Feed Handling	65606	29.4
Waste Disp. (Vehicles)	23756	10.6
Waste Disp. (Machinery)	1639	0.7
Water Supply	7174	3.2
Livestock Handling	2536	1.1
Space Heating	5761	2.6
Ventilation	6892	3.1
Water Heating	9745	4.4
Milking	2708	1.2
Milk Cooling	4438	2.0
Egg Handling	106	0
Brooding	27512	12.3
Farm Vehicles	36278	16.3
Farm Auto-Lvstk	8611	3.9
Other	<u>14505</u>	<u>6.5</u>
Total	223179	100

Source: U.S. Department of Agriculture 1976.

The farm functions and livestock operations have been categorized by energy form as follows: mechanical mobile, mechanical stationary, chemical thermal, electrical and miscellaneous. These categories can then be used to determine how well an energy conversion technology can meet the energy needs of U.S. agriculture. The following groupings of functions and operations were used.

GROUPING OF FUNCTIONS/OPERATIONS BY ENERGY FORM

<u>Energy Form</u>	<u>Farm Function</u>	<u>Livestock Operation</u>
Mechanical Mobile	Preplant	Feed Handling
	Plant	Waste Disp (Vehs)
	Cultivate	Livestock Handling
	Harvest	Farm Vehicles
	Farm Pickup	Farm Auto-Lvstk
	Fertilizer Applic.	
	Pesticide Applic.	
	Farm Truck	
	Farm Auto-Crops	
	Grain Handling (Vehs)	
Mechanical Stationary	Irrigation	Waste Disp. (Mach)
	Grain Handling (Mach)	Water Supply
		Ventilation
		Milking
		Milk Cooling
		Egg Handling
Thermal	Crop Drying	Space Heating
	Frost Protection	Water Heating
		Brooding
Chemical	Fertilizer	
	Pesticides	
Electrical	Electricity	Lighting
Miscellaneous	Miscellaneous	Miscellaneous

The distribution of energy used in U.S. agriculture by energy form is shown graphically in Figure 2.2. For crop production the two biggest energy forms are chemical and mechanical mobile, which accounts for 39.5 and 39.4 percent of the energy used in crop production, respectively. Mechanical mobile energy accounts for 61.3 percent of the energy used in livestock production. Thus, the energy conversion technologies should provide mechanical mobile energy (preferably a liquid fuel) and chemical energy (mostly nitrogen fertilizer) to have a large impact on U.S. agriculture energy.

The energy input by commodity for U.S. agriculture is shown in Table 2.3. Corn production is the highest energy consumer, accounting for 27.9 percent of all the energy used for crop production. Cow and calve operations consume 29.5 percent of the energy used for livestock production with milk cows rating second at 23.2 percent.

2.3 ENERGY CONSUMPTION FOR CROP PRODUCTION

This section examines the energy used for crop production on a regional basis by commodity, fuel type and function.

2.3.1 Regional Energy Consumption By Commodity

The purpose of this section is to determine the intensity of energy use in the production of major energy-using commodities in terms of Btu/ton of product. Production of corn, soybeans, wheat, hay, cotton, and sorghum utilizes 72% of the energy used to produce crops. These six commodities account for 80% of the nation's cultivated acres. Corn and sorghum includes both grain and silage, and hay includes alfalfa and other hay.

The amount of energy required to produce the six commodities is shown in Table 2.4. The table shows that corn is the biggest energy user with hay ranking a clear second, followed closely by wheat. Therefore, a high priority should be put on projects relating to the production of these three commodities. The Midwest (Region 3) is clearly the big energy-using region.

CROP PRODUCTION
1824843 BILLION BTU'S

LIVESTOCK PRODUCTION
223179 BILLION BTU'S

FIGURE 2.2. Distribution of Energy in U.S. Agriculture by Energy Form

**TABLE 2.3. Energy Input to Production Agriculture
by Commodity, 1974**

<u>Crops</u>	<u>Total Btu's (Billion)</u>	<u>Percent</u>
Corn	499256	27.9
Soybeans	126875	7.1
Winter Wheat	158600	8.7
Alfalfa	121474	6.8
Corn Silage	77053	4.3
Cotton	148750	8.3
Grain Sorghum	101399	5.7
Vegetables-Fresh	23109	1.3
Spring Wheat	42868	2.4
Hay-Other	79469	4.4
Potatoes	28578	1.6
Rice	45673	2.6
Sugar Beets	15518	0.9
Oats	32488	1.8
Flue-Cured Tobacco	36680	2.1
Sugar Cane	13248	0.7
Vegetables-Process	26394	1.5
Barley	26757	1.5
Burley Tobacco	7350	0.4
Noncitrus-Other	14874	0.4
Peanuts	128388	0.7
Oranges	40486	2.3
Grapes	7105	0.4
Apples	13461	0.8
Edible Beans-Dried	10966	0.6
Peaches	6465	0.4
Seed Crops	5345	0.3
Sorghum Silage	5253	0.3
Grapefruit	7709	0.4
Flaxseed	2097	0.1
Lemons	2714	0.2
Sweet Potatoes	1369	0.1
Shade Tobacco	311	0
Citrus-Other	3408	0.2
Rye	7323	0.4
Pineapples	345	0
Edible Peas-Dried	295	0
Unspecified Crops	2558	0.1
Unspecified Irrig	33916	1.9
Total Crops	1789930	
<u>Livestock</u>	<u>Total Btu's (Billions)</u>	<u>Percent</u>
Beef-Cows & Calves	66096	29.5
Beef-Feedlot	25585	11.4
Milk Cows	51981	23.2
Hogs	37149	16.6
Chickens-Layers	5639	2.5
Chickens-Pullets	6146	2.7
Broilers	19974	8.9
Turkeys	7174	3.2
Sheep & Lambs	3703	1.7
Misc. Poultry	854	0.4
Total-Livestock	224291	
Total-Agriculture	2014221	

Source: U.S. Department of Agriculture 1976.

TABLE 2.4. Energy Inputs to Produce Eight Commodities in Eight Regions 1974 (Billion Btu's)

<u>Region</u>	<u>Corn</u>	<u>Soybeans</u>	<u>Wheat</u>	<u>Hay</u>	<u>Cotton</u>	<u>Sorghum</u>	<u>Total</u>	<u>Percent</u>
1	53452	15331	8219	34768	5894	789	118453	8.6
2	22489	32975	5326	11120	54429	1850	128189	9.4
3	264273	61173	10207	31878	2949	3037	373517	27.3
4	81208	10189	11604	25830	--	--	128831	9.4
5	111436	5592	60924	37981	--	29965	245898	17.9
6	14622	2596	48602	8815	53733	60054	188422	13.7
7	13138	--	24334	27763	4911	5208	75354	5.5
8	5964	--	23372	23848	26786	32246	112216	8.2
Total	566582	127856	192588	202003	148702	133149	1370880	100

Source: U.S. Department of Agriculture 1976.

One index of energy efficiency is the Btu per ton of output. Energy efficiency calculations for the eight commodities in the eight regions are presented in Table 2.5. This table shows that the most energy-inefficient commodity is cotton in Region 7. The most energy-efficient commodity is sorghum in Region 8. Not much cotton is grown in the Mountain States (Region 7), and the Far West (Region 8) is not particularly noted for sorghum. The yields in tons per acre for these six commodities are shown for each region in Table 2.6.

2.3.2 Geographic Distribution of Fuel Use

Table 2.7 shows the six main types of fuel consumed in producing the eight commodities in the eight regions: gasoline, diesel, LP gas, natural gas, electric power, with fuel oil, and coal, listed as "other" fuel. The total of each type of fuel used for a commodity is also shown. Percent of total used in each region is shown at the bottom of the region column.

Table 2.7 can be used to compare consumption by proposed energy conservation and substitution technologies with current consumption for potential benefit evaluation. Table 2.7 shows that corn and hay are the largest users of gasoline, while corn and soybeans are the largest users of diesel. On a regional basis, Region 1 uses the largest amount of gasoline in the production of corn and hay. Regions 3 and 5 use more diesel in the production of corn than any other region.

2.3.3 Regional Energy Use By Farm Function

As previously discussed, energy powers agriculture to grow a variety of commodities with varying degrees of energy intensity and with several different kinds of fuel. Each fuel must be considered in designing a National Program of Energy Integrated Farm Systems. However, the program's success will rest on the substitution of renewable farm energy for traditional sources through the functional farm use of that energy. The purpose of this section is to prioritize the functional farm energy uses.

TABLE 2.5. Energy Input in Thousand Btu per Ton Yield for Eight Commodities
Produced in Eight Regions for 1974

<u>Region</u>	<u>Corn</u>		<u>Soybeans</u>	<u>Wheat</u>	<u>Hay</u>	<u>Cotton</u>	<u>Sorghum</u>	
	<u>Grain</u>	<u>Silage</u>					<u>Grain</u>	<u>Silage</u>
1	3001	458	4405	3414	1687	51104	2717	470
2	3780	596	6575	5341	1813	50458	4494	671
3	3457	679	3116	2931	1575	44655	3392	547
4	3685	668	3508	1551	1227	-----	-----	---
5	6867	1102	3256	2984	1841	-----	4661	889
6	5539	1527	6847	6847	1086	68757	6212	885
7	4459	618	-----	2809	1681	116837	10742	544
8	3595	582	-----	3219	1665	30430	7027	369

Source: U.S. Department of Agriculture 1976.

TABLE 2.6. Yield in Tons per Acre for Six Commodities Produced in Eight Regions, 1974

<u>Region</u>	<u>Corn</u>		<u>Soybeans</u>	<u>Wheat</u>	<u>Hay</u>	<u>Cotton</u>	<u>Sorghum</u>	
	<u>Grain</u>	<u>Silage</u>					<u>Grain</u>	<u>Silage</u>
1	2.17	13.72	0.65	1.03	2.01	0.16	1.57	11.31
2	1.48	12.06	0.62	0.72	1.94	0.22	1.17	7.72
3	2.15	10.98	0.70	1.02	2.26	0.18	1.44	10.39
4	1.76	9.53	0.59	0.87	2.55	--	--	--
5	1.70	6.28	0.60	0.74	1.41	--	1.05	8.38
6	2.56	13.00	0.75	0.56	2.09	0.13	1.45	12.18
7	2.70	17.78	--	0.83	2.18	0.25	0.97	9.22
8	2.87	18.67	--	1.29	3.69	0.52	2.16	16.10

Source: U.S. Department of Agriculture 1976.

TABLE 2.7. Geographic Distribution of Fuel Use for Eight Major Commodities and Eight Regions in Billions Btu's, 1974

	1	2	3	4	5	6	7	8	Totals	Percent
<u>CORN</u>										
Gasoline	10334	3967	7838	17144	10973	1232	1300	492	53280	7.2
Diesel	11823	5219	26511	11316	26778	1603	2494	1269	87013	11.7
LPG	2205	1134	30528	7307	15255	557	359	21	57362	7.7
Nat. Gas	1072	462	1771	129	18620	6679	2691	233	31657	4.3
Elect.	229	119	1464	491	3115	481	391	1249	8039	1.1
Other	750	375	423	31	2	0	0	0	1581	0.2
Subtotal	26413	11276	68535	36414	74743	10552	7735	3264	238932	32.3
<u>SOYBEANS</u>										
Gasoline	4075	10357	26909	4669	2012	394	--	--	48416	6.5
Diesel	6556	13699	21404	3777	2012	459	--	--	47997	6.5
LPG	269	1084	1630	259	305	69	--	--	3616	0.5
Nat. Gas	15	431	269	38	297	1052	--	--	2102	0.3
Elect.	99	246	604	102	99	75	--	--	1225	0.2
Other	0	0	0	0	0	0	--	--	0	0
Subtotal	11014	25817	50816	8845	4815	2049	--	--	103356	14.0
<u>WHEAT</u>										
Gasoline	1833	717	4646	3103	21940	8612	6970	3195	51021	6.9
Diesel	1750	1071	945	1550	16063	2702	4799	2618	37498	5.1
LPG	77	37	558	283	892	1104	539	182	3692	0.5
Nat. Gas	0	0	1	0	1459	10228	1441	2052	15181	2.0
Elect.	41	20	109	68	549	921	1310	2467	5485	0.7
Other	0	0	0	0	0	0	0	0	0	0
Subtotal	3706	1845	6259	5004	40903	29567	15069	10514	112857	15.2
<u>HAY</u>										
Gasoline	10251	1485	14465	18756	6713	3580	4586	2528	62484	8.4
Diesel	513	7	536	1514	11448	745	4728	789	20230	2.7
LPG	1551	240	2005	2237	2091	673	1097	316	10215	1.4
Nat. Gas	640	152	668	1067	11129	2864	8755	5687	30962	4.2
Elect.	194	58	181	201	1068	242	4722	13136	19802	2.7
Other	0	0	0	0	0	0	0	0	0	0
Subtotal	13149	1942	17855	23775	32449	8109	23888	22556	143723	19.4
<u>COTTON</u>										
Gasoline	926	5357	336	--	--	3758	298	2295	12969	1.7
Diesel	1155	13919	617	--	--	7702	613	4381	28387	3.8
LPG	76	1135	23	--	--	1184	257	0	2675	0.4
Nat. Gas	0	73	0	--	--	13581	2474	5589	21717	2.9
Other	0	0	0	--	--	0	0	0	0	0
Subtotal	2171	20672	982	--	--	27276	3864	17598	72563	9.8
<u>SORGHUM</u>										
Gasoline	166	324	688	--	--	3968	7098	453	12927	1.7
Diesel	313	496	417	--	5297	9327	613	332	15795	2.1
LPG	10	38	194	--	1363	2061	276	25	3987	0.5
Nat. Gas	9	53	38	--	4023	23173	2563	1960	31829	4.3
Elect.	3	7	20	--	334	1713	273	1211	3561	0.5
Other	7	3	3	--	0.3	0	0	0	13	0
Subtotal	508	946	1360	--	14985.00	42372	4183	3758	68112	9.2
TOTALS	56961	55542	156099	74038	167895	119925	54729	57690	742879	100.00
PERCENT	7.7	7.5	21.0	10.0	22.6	16.1	7.4	7.8	100.00	

NOTE: This table does not include energy invested in pesticides or fertilizer.

Source: U.S. Department of Agriculture 1976

The various farming operations common to general crop production were listed in Energy and U.S. Agriculture: 1974 and 1978 (U.S. Department of Agriculture 19). These farm functions are not crop specific and they do not distinguish irrigated from nonirrigated cultural practice. However, the list is considered reasonably representative of all agricultural crop production.

Energy use by farm function appears in Table 2.8. Examination of this table reveals that irrigation and fertilizer are the two largest energy consumers, totaling about 50% of the energy input to total crop production. Fertilizers account for one-third of the energy used in agriculture. On a regional basis, regions 3 and 5 use the most energy, accounting for 23.2 and 15.4 percent of the energy used for crop production. Region 3 uses twice as much energy in the form of fertilizer than any other region. Regions 5 and 1 rank second and third, respectively.

Fertilizer not only requires the largest share of farm energy, it is most likely the most complex because fertilizer use is a function of the estimated yields from alternative levels of use. Based on these estimated yields, the decision to use a given quantity of fertilizer is predicated on the cost of the fertilizer and the expected price of the commodity. Thus, the relative amount of energy embodied in fertilizer among regions could be expected to shift as the relative prices of commodities change.

2.4 ENERGY CONSUMPTION IN LIVESTOCK PRODUCTION

This section describes energy consumption for livestock production. Regional energy patterns are described by operation and livestock type, followed by descriptions of energy use for each major livestock type.

2.4.1 Regional Energy Consumption By Operation and Livestock Type

The distribution of energy use on a regional basis is shown by region in Table 2.9. The leading regions of energy use are regions 1, 2 and 3 respectively, accounting for 17.4, 14.3 and 14.6 percent of the energy used in livestock production. However, the energy consumption by

TABLE 2.8. Energy Input by Farm Function and Region for Crop Production, 1978 (Billion Btu's)

Farm Function	Region								Total	Percent
	1	2	3	4	5	6	7	8		
Preplant	13865	21183	36081	16229	25995	28204	12261	19570	173388	9.5
Plant	4233	5323	13375	6031	6701	6719	2659	2475	47516	2.6
Cultivate	4755	12656	13485	4340	4165	4699	1513	4384	49997	2.8
Harvest	21781	18533	32766	21182	26707	10543	10886	11727	154125	8.5
Farm Pickup	11797	11822	41762	14439	24753	10084	6949	8161	129767	7.1
Fertilizer Applic.	2983	4161	1776	973	979	261	1070	670	12873	0.7
Pesticide Applic.	2881	4469	1713	1613	985	1254	1027	2955	16897	0.9
Farm Truck	10021	5787	16230	8644	12842	4668	5059	4482	67733	3.7
Farm Auto-Crops	8802	4587	13108	7253	11602	4219	4718	6478	60767	3.3
Grain Hndlng (Vehs)	186	59	786	241	456	21	105	49	1903	0.1
Grain Hndlng (Mach)	7	2	46	19	29	2	8	3	116	0
Crop Drying (On-Fm)	21339	6984	29635	7023	5802	346	244	109	71482	3.9
Irrigation	1571	12007	936	1124	51600	85093	41572	57244	252147	13.9
Frost Protection	1825	21182	151	1152	--	2005	125	13389	39829	2.2
Fertilizer	82206	63161	205322	70689	95905	53771	30374	50438	651876	35.9
Pesticides	8025	19665	13171	5631	5107	7826	1750	7027	68202	3.8
Electricity	561	580	1452	640	1228	608	413	320	5802	0.3
Miscellaneous	1835	1697	198	603	5816	1979	560	1454	14142	0.8
Total	198673	214858	422003	167826	280672	222302	121293	190935	1818562	100
Percent	10.9	11.8	23.2	9.2	15.4	12.2	6.7	10.5	100	

Source: U.S. Department of Agriculture 1980.

TABLE 2.9. Energy Input by Livestock Type and Region, 1974
(Billion Btu's)

<u>Livestock</u>	<u>Region</u>								<u>Total</u>
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	
Beef-Cows and Calves	6652	7557	8562	1976	16553	13689	7591	7161	69741
Beef-Feedlot	840	167	2749	2405	3109	2278	1780	3055	16383
Milk Cows	13391	4271	4296	13046	2878	2571	2013	7827	50293
Hogs	3544	2891	11665	4950	1000	672	122	128	24972
Chicken-Layers	1376	1437	425	363	168	241	119	1196	5325
Chicken-Pullets	1516	1653	538	511	229	308	151	853	5759
Broilers	6359	10509	216	203	20	1587	--	958	19852
Turkeys	1020	422	717	2155	159	541	425	1221	6660
Sheep and Lambs	288	19	370	287	457	407	984	513	3325
Misc. Poultry	422	65	125	79	9	32	4	101	837
Total	35418	28991	29663	25975	24582	22326	13189	22998	203142
Percent	17.4	14.3	14.6	12.8	12.1	11.0	6.5	11.3	100

Source: U.S. Department of Agriculture 1976.

region is relatively evenly distributed with region 7 having the lowest consumption at 6.5 percent. The highest energy need is for beef-cows and calves in region 5, accounting for 16,553 billion Btu's. Region 6 also has a high energy use for beef-cows and calves. Regions 1 and 4 have high energy use for dairy farms (milk cows), using 13,391 and 13,046 Btu's respectively. Region 3 has the highest energy use for hog production at 11,665 Btu's. Region 2 has a high energy use for broiler production, which uses 10,509 Btu's.

Regional energy use is shown by operation in Table 2.10. Feed handling in regions 3 (13,642 Btu's) and 5 (19,813 Btu's), brooding in region 2 (10,107 Btu's), and farm vehicles in region 3 (12,933 Btu's) have the highest energy needs.

2.4.2 Energy in Beef Cattle Production

Energy requirements in beef cattle production have been reported by Lipper, Anschultz, and Welker (1976). Their findings are based on a survey of 14 Kansas feedlots over a three-year period. A total of 30 feedlot-years of energy use data was compiled.

Total energy use was broken down to reflect energy requirements for specific operations associated with large-scale cattle feeding. Energies reported in Table 2.11 are in Btu's per 100 lbs of beef produced. Given also are the percentage of total energy required for each operation and the percentages of major energy forms used in each process.

Feed processing energy in the form of natural gas (84%) and electricity (15%) accounts for 57% of the total energy required in beef production. Feed processing includes preparing feed grains, handling roughage feeds (corn and milo stovers), adding mineral supplements, and mixing. Feed grain preparation to improve the digestibility of the grain requires a major portion of the total feed processing energy. Natural gas provides energy for cooking and electricity for rolling or flaking the grain.

2.4.3 Energy in Dairy Production

Energy requirements in dairy production have been reported by Anschultz and Lipper (1975). They estimate that in 1973 Kansas dairies

TABLE 2.10. Energy Input by Operation and Region for Livestock Production, 1978
(Billion Btu's)

Operation	Region								Total
	1	2	3	4	5	6	7	8	
Lighting	1031	889	798	635	664	743	378	691	5829
Feed Handling	6063	3612	13642	3340	19813	6214	6478	5646	64808
Waste Disp. (Vehs)	4512	2195	7172	3237	1080	1334	916	2899	23345
Waste Disp. (Mach)	334	441	153	129	31	147	45	306	1586
Water Supply	781	383	2507	1012	109	98	115	164	5169
Livestock Handling	89	86	50	27	974	741	335	245	2547
Space Heating	324	169	3976	957	62	36	80	153	5747
Ventilation	1579	862	2375	1220	91	167	86	451	6112
Water Heating	2487	793	1303	2403	506	512	384	1349	9737
Milking	686	230	354	647	139	140	111	404	2711
Milk Cooling	1225	333	584	1197	215	191	163	543	3451
Egg Handling	30	20	12	5	1	1	2	33	104
Brooding	7326	10107	1855	2416	240	1864	540	2331	26679
Farm Vehicles	3422	3123	12933	2693	1937	6182	3458	2745	36493
Farm Auto-Lvstk	1912	616	1901	1374	1062	380	576	786	2007
Other	4583	2282	1401	2887	883	361	686	1509	14592
Total	36384	26141	51016	24179	27807	19111	14353	22255	218709
Percent	16.4	11.8	23.1	10.9	12.6	8.6	6.5	10.1	

Source: U.S. Department of Agriculture 1980.

TABLE 2.11. Beef Production Energy Requirements

<u>Operation</u>	<u>% of Total Energy</u>	<u>Energy Required (Btu/100 lb Beef)</u>	<u>Major Energy Forms</u>	
Feed Processing	57%	107,000	Natural Gas	84%
			Electrical	15%
Feed Handling	16%	31,000	Gasoline	67%
			Diesel	29%
Watering	2.5%	4,810	Natural Gas	47%
			Electrical	45%
			Gasoline	8%
Lighting	1.3%	2,510	Electrical	100%
Waste Removal	4%	7,680	Natural Gas	12%
			Gasoline	34%
			Diesel	51%
Administration	5.5%	10,600	Natural Gas	29%
			Gasoline	63%
			Electrical	8%
Branding & Thawing	1%	1,750	Natural Gas	84%
			Electrical	12%
Space Heating	1.5%	3,140	Natural Gas	1.5%
Miscellaneous	11%	20,700	Natural Gas	70%
			Gasoline	14%
			Diesel	16%

Total = 189,190 Btu/100 lb Beef

Source: Lipper, et al, 1976.

used the equivalent of 63.2 million KWh of energy to produce 1,505 million pounds of milk.

A breakdown of total energy use in dairies has been reported by Frank (1977). Table 2.12 gives the percentages of total energy use in Btu's per 100-lbs of milk produced and the typical energy sources for each major operation.

Waste removal makes up 26% of the total energy use in dairy production and typically includes disposal of waste water from milking operations, collection of manure, and field application of the liquid manure slurry.

2.4.4 Energy in Poultry (Broiler) Production

Energy requirements in broiler production have been reported by Baughman and Parkhurst (1976). Summer and winter trials were conducted comparing a conventional curtainwall broiler house with no mechanical ventilation to a fully enclosed, insulated broiler house with mechanical ventilation.

Total energy requirements were broken down to reflect requirements and typical energy sources for major operations in broiler production. Energy data reported in Table 2.13 are the average of the summer and winter trials for the conventional broiler house. Units are Btu's per pound of bird produced.

Feed production and processing accounts for more than 80% of the total energy used in broiler production. Note that the major portion of this energy figure is required in feed production. Feed production energies have not been included in the energy figures reported here for beef, dairy, and swine production.

2.4.5 Energy in Swine Production

Estimated energy requirements in swine production have been reported by Smith, Miranowski, and Vetter (1976) and are given in Table 2.14 in Btu's per 100-lbs of pork produced. The proposed swine operation has a capacity

TABLE 2.12. Dairy Production Energy Requirements

<u>Operation</u>	<u>Percent of Total Energy</u>	<u>Energy Required (Btu/100 lb Milk)</u>	<u>Major Energy Forms</u>
Feed Processing and Handling	8%	1150	Electrical Natural Gas
Water Heating	16%	2300	Electrical Natural Gas
Lighting	3%	430	Electrical
Waste Removal	26%	3730	Natural Gas Gasoline Diesel
Milking	10%	1430	Electrical
Milk Cooling	12%	1720	Electrical
Ventilation and Heating	4%	570	Electrical Natural Gas
Farm Travel & Misc.	21%	3010	Natural Gas Gasoline Diesel

Total = 14340 Btu/100 lb Milk

Source: Frank 1977.

TABLE 2.13. Energy Requirements for Poultry Production

<u>Operation</u>	<u>Percent of Total Energy</u>	<u>Energy Required (Btu/lb of Bird)</u>	<u>Major Energy Forms</u>
Brooding (Space Heating)	16%	2300	LPG (gr) Natural Gas
Lighting	2%	250	Electrical
Feed Production and Processing	82%	12040	LPG Electrical Gasoline Diesel

Total = 14590 Btu/lb of bird^(a)

(a) This total includes feed production energy and should not be compared with other total energy figures reported for beef, dairy, and swine production.

Source: Baughman and Parkhurst, 1976.

TABLE 2.14. Energy Requirements for Swine Production

<u>Operation</u>	<u>Percent of Total Energy</u>	<u>Energy Required (Btu/100 lb of Pork)</u>	<u>Major Energy Forms</u>
Feed Preparation and Handling	2%	2800	Electrical Gasoline Diesel
Space Heating	67%	97000	LPG Natural Gas Electrical
Ventilation	31%	44200	Electrical

Total = 144000 Btu/100 lb of Pork

Source: Smith, et al, 1976.

of 50 sows plus an average of 12.75 pigs per sow per year. Pigs were fed to 220 pounds with high-moisture corn to minimize energy use.

Power requirements for various operations were obtained from equipment suppliers where information was available. Other power requirements were taken from the Structures and Environment Handbook (Midwest Plan Service 1975).

Total energy requirements were broken down to reflect energy requirements of specific operations. Energy requirements were quantified for the areas of space heating, ventilation, and feed processing and handling. No attempt was made to quantify energy requirements for operations such as waste removal, watering, and lighting.

Pigs have a rather limited ability to regulate their body heat through changes in their metabolism. For this reason, maximum gains are achieved in a relatively narrow temperature range (60 to 70°F). As reported here, space heating requires 67% of the total energy requirement.

2.5 CONCLUSION

An analysis of energy intensity by commodity shows that corn and hay production are the biggest energy users. The Midwest (Region 3) and the states that bracket the 100 meridian (Regions 5 and 6) are the regions with the greatest need for an Energy-Integrated Farm System Program.

An analysis of the geographic distributions of fuel use shows that if the Energy-Integrated Farm Systems Program is to contribute to the substitution of renewable farm resources for imported oil, the program should focus on corn in the Northeast quarter of the country: Kansas to Maine (Regions 1, 3, 4, and 5).

An analysis of the functional uses of energy in the farming operation shows that the largest share of energy is mechanical mobile. The Midwest (Region 3) and the states that bracket the 100 meridian (Regions 5 and 6) consume over 70% of the mechanical energy used to power American agriculture. The Midwest (Region 3) uses the most chemical energy of any region.

When the nation is differentiated based on the recognition of the farm-energy market, it is concluded that over 50% of the program should focus on the development of mechanical (both mobile and stationary) energy from farm sources. Forty percent of the program should focus on replacement chemical energy with energy generated from the farm. Over 50% of the program resources should concentrate on technology applicable to the Central United States from Ohio on the east to North Dakota and south to Texas (Region 3, 5 and 6).

CHAPTER 3

AN ANALYSIS OF AVAILABILITY OF RENEWABLE RESOURCES

Energy currently enters through the farm gate in fuel and fertilizer trucks. It enters through power lines, and in the form of other inputs bought in town. Other energy sources are also available: the sun, the wind, stream flow and the earth's heat energy. The purpose of the analysis presented in this chapter is to estimate the availability of renewable resources for farmers to attain a satisfactory degree of independence from their current sources of energy.

Potential resources available for production of alternative energy are site-dependent. Detailed county-by-county and farm-by-farm inventories of these resources are required for a precise estimate of the potential. However, the availability of the renewable energy resource base can be assessed on a broad scale. Time dependent resources are measured during the farming season, which is defined as the period six weeks before to six weeks after the frost-free days. The mean farming season is the average available value for the specific region. This chapter does not attempt to measure the practicality or the economics of renewable resources. Rather, it attempts to assess on a broad basis whether they are available.

3.1 SOLAR INSOLATION

Table 3.1 presents averages of solar energy received at several locations in the U.S. Lincoln, Nebraska, represents a crude average for solar insolation in the 48 contiguous United States. For the six "agricultural" months of April through September, solar energy availability in Lincoln would on the average be approximately $1800 \text{ Btu/ft}^2/\text{day}$, which is equivalent to $78 \times 10^6 \text{ Btu/acre/day}$ or $50.2 \times 10^9 \text{ Btu/mile}^2/\text{day}$.

The 1.0786 billion acres of farms in the U.S. require about 2,480,202 billion Btu's/yr (Tables 2.1 and 2.2) or about 2.3 million Btu/acre/yr. Since in an average day 78 million Btu's fall on a single acre, the solar energy available in about 3% of one day is equivalent to the energy requirements. If the sun shines 180 days a 1,000 acre farm would

TABLE 3.1. Daily Averages of Solar Energy Received on a Horizontal Surface -- Monthly (a)

Location	Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Average
Tucson, AZ	32.5	315 1161	391 1442	540 1991	655 2415	729 2688	699 2577	626 2308	588 2168	570 2102	442 1630	356 1313	305 1124	518.07 1909.92
Charleston, SC	33	250 923	334 1232	451 1664	558 2059	620 2288	587 2166	539 1929	428 1945	409 1509	326 1203	308 1137	313 786	418.58 1570.08
Riverside, CA	34	264 974	312 1151	408 1506	494 1823	544 2007	599 2207	592 2184	545 2011	465 1712	3568 1321	276 1018	212 782	422.00 1558.00
Albuquerque, NM	35	307 1133	367 1345	497 1834	606 2236	676 2494	745 2749	679 2502	624 2299	547 2018	464 1712	348 1284	292 1085	512.67 1890.92
Santa Maria, CA	35.5	290 1070	374 1380	510 1882	610 2251	680 2506	651 2399	659 2428	642 2369	528 1945	432 1594	302 1114	235 867	493.25 1817.08
Oak Ridge, TN	36	174 642	231 852	286 1055	402 1483	570 2103	542 2000	499 1838	463 1708	317 1517	306 1129	204 753	162 598	346.33 1306.50
Lincoln, NB	41	186 686	252 930	338 1247	427 1576	502 1852	557 2052	576 2122	481 1775	409 1509	302 1114	209 771	166 613	367.08 1353.92
Salt Lake City, UT	41	195 592	246 908	386 1424	510 1882	546 2015	595 2192	624 2302	509 2247	442 1631	278 1026	179 661	120 442	385.83 1441.92
State College, PA	41	137 506	174 642	275 1015	387 1428	426 1572	500 1845	513 1889	457 1683	358 1321	248 915	164 605	424 425	338.58 1153.83
New York, NY	42	122 450	191 705	259 956	363 1339	426 1572	439 1646	366 1620	316 1351	243 1166	148 897	148 546	107 395	285.50 1056.08
Blue Hill, MA	42.5	163 601	250 923	324 1196	397 1465	477 1758	518 1911	499 1838	463 1708	364 1343	292 1077	163 601	135 498	337.08 1243.25
St. Cloud, MN	46	170 627	238 878	398 1461	470 1735	561 2070	560 2066	575 2118	462 1667	364 1343	284 1048	175 646	152 561	366.58 1351.67
Glasgow, MT	48	156 576	244 900	392 1446	502 1852	640 2362	767 2494	661 2435	545 2001	378 1395	244 900	174 642	122 450	402.08 1455.25
Spokane, WA	48	120 443	198 731	336 1240	572 2111	483 1782	615 2269	674 2487	581 2144	507 1587	250 923	133 491	78 280	378.92 1374.00

(a) Upper values are in langleys/day ($\text{Cal}/\text{cm}^2\text{day}$); lower values are in $\text{Btu}/\text{ft}^2\text{day}$. To convert from $\text{BTU}/\text{ft}^2\text{day}$ to $\text{cal}/\text{cm}^2\text{day}$, multiply by 0.27125.

Source: Meinel 1977

require less than 2/10 acre to supply the energy. Again, only gross energy availability is considered, not practicality or economics.

Any concern that the farm would be filled-up with collectors appears to be clearly groundless. A question that still might be asked is whether all the regions have enough solar energy to supply farm needs. The regions differ substantially in annual averages as Table 3.1 shows. That part of the energy needs relating to growing crops will, however, have less variation, as Table 3.2 shows.

At $1600 \text{ Btu/ft}^2/\text{day}$ the northeast has a somewhat lower average for the growing season than the mountain west at $2200 \text{ Btu/ft}^2/\text{day}$. However, neither is more than $\pm 15\%$ of the 1900 Btu/day aggregate for the country as a whole. While the growing season in the north is shorter than in the south, the sun does shine in the north during the growing season, -- it warms the soil and the long warm days correlate fairly well with the growing season. The figures in Table 3.2 resulted directly from Table 3.1 using the frost-free data from The National Atlas of the United States of America (1970) to define the number of months averaged. Much solar energy is available during the growing season all over the contiguous 48 states. Local values may vary a great deal from regional values. Specific siting, conversion technology and function or use will determine whether or not even a fraction of this can be achieved. Thus a key conclusion from looking at the amount of energy available in all regions during the growing season (see Table 3.2) is that there is plenty of sunshine available during the growing season most places where the sun shines enough to keep the ground warm enough to grow crops. The peak region varies no more than 15% from the average in Table 3.2.

3.2 WIND POWER AVAILABILITY

The average wind power availability of the United States is shown in Figure 3.1. Average annual wind power availability at 50 m above the ground surface varies from 100 W/m^2 to 500 W/m^2 . Siting, timing, and conversion technology will combine to drastically reduce availability on a practical scale.

TABLE 3.2. An Estimate of the Available Solar Energy During the Mean Farming Season, by Region

<u>Region</u>	<u>Geographic Area</u>	<u>Btu/ft²/Day</u>
1	Northeast	1600
2	Southeast	1900
3	Midwest	1700
4	Northcentral	1800
5	Plains	1900
6	Texas-Oklahoma	2000
7	Mountain	2200
<u>8</u>	Far West	<u>2100</u>
AGGREGATE		1900

FIGURE 3.1. Annual Average Wind Power (W/m^2) at 50 m (Elliott 1977).

Overall wind availability for the farm use can be estimated by assuming:

- Five to ten 2.5 MW machines can be placed on a square mile of land.
- Large machines may give 25% of rated full power averaged over a year.
- Farms require 2.3 million Btu/acre/yr.

When these assumptions and five machines per square mile are used 12.5 MW/mile² of wind energy can be achieved. For 8,760 hours per year at 25% availability 9.343×10^{10} Btu/yr/mile² would be available. At 640 acres to the square mile, 146 million Btu/acre/yr is achieved, or more than 60 times the amount of energy required per year for crops per acre. For a 1,000 acre farm about 17 acres would be needed for wind machines to get the energy needed for a "typical farm"; possibly double use of the land could be achieved, but all uses may not be compatible as many factors exist which might change the outcome.

Several problems need to be considered when applying wind energy to farm needs. One problem is that the growing season is usually the poorest wind season of the year (summer wind power availability is shown in Figure 3.2). Another problem is that farms are frequently not located up on the hilltops where the best winds blow.

In Table 3.3 the expected wind power (W/m^2 of vertical surface) is shown for the various regions for the four seasons. If 400 W/m^2 at 50 m is assumed to be the lower limit for economic application, Regions 1 through 4 and Region 7 would be largely excluded since only in unique locations (hilltops, etc.) does the flux exceed the value of 400 W/m^2 . In the other three regions, the values are high enough to be seriously considered.

In the northwest region and regions 5 and 6 only 10% of the land area has a suitable value (from detailed assessments in progress at PNL) of 400 W/m^2 at 50 m of height, or more. If the 10% rule applies for all the farms then Table 3.4 can be developed.

If the wind blows at 200 W/m^2 in the summer time, an average farm could get all its energy needs (ignoring energy form needed) by using

FIGURE 3.2. Summer - Average Wind Power (W/m^2) Estimated at 50 m Above Exposed Areas (Elliott 1977). Over mountainous regions, the estimates are lower limits expected for exposed mountain tops and ridges.

Table 3.3. Expected Available Wind Power (W/m^2) at Farm Elevations (50 m)

<u>Region</u>	<u>Geographical Area</u>	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Fall</u>
1	Northeast	150 to 400	150 to 400	50 to 200	100 to 250
2	Southeast	150 to 250	150 to 300	50 to 100	50 to 200
3	Midwest	150 to 400	200 to 450	100 to 200	100 to 300
4	Northcentral	200 to 400	200 to 450	100 to 200	100 to 300
5	Plains	300 to 600	350 to 700	150 to 500	250 to 500
6	Texas-Oklahoma	200 to 600	200 to 700	100 to 500	100 to 500
7	Mountain	150 to 800	150 to 600	50 to 300	100 to 500
8	Far West	150 to 600	150 to 600	50 to 700	50 to 400

NOTE: For an estimate of available wind power at 10 m divide these numbers by 2.

Source: Elliott, 1977.

TABLE 3.4. Percent of Farm Energy Available as Wind Energy

<u>Region</u>	<u>Geographical Area</u>	<u>Percent</u>
1	Northeast	--
2	Southeast	--
3	Midwest	--
4	Northcentral	--
5	Plains	10
6	Texas - Oklahoma	10
7	Mountain	--
8	Far West	10

wind, but half of the regions will have few sites with the needed wind flux intensity and of the others only about 10% of the farms will have the needed wind flux intensity. Additional problems with matching the specific energy needs occur, but these will be covered in the following chapter.

One problem, which gives typical values of the wind energy available during the summer and which is not reflected in Table 3.3, is the high degree of variability of local sites for wind applications. Sometimes local variations are dramatic, making some excellent sites only a few hundred feet away from very poor areas. Applications need to be considered carefully to see that individual locations are chosen well.

3.3 ON-FARM STREAM FLOW AVAILABILITY

The aggregate stream flow and head requirements ($Q \times H$) equivalent to the annual energy demand by production agriculture can be described as follows:

$$\begin{aligned}
 \text{Agricultural Energy Demand} &= 2.48 \times 10^{15} \text{ Btu} \\
 \text{The Equivalent Rate over 180 Days} &= 5.7 \times 10^{11} \text{ Btu/hr} \\
 \text{Giving,} &P = 1.67 \times 10^8 \text{ kWe} \\
 Q \times H &= 11.8 P/e \\
 &= 11.8 (1.67 \times 10^8)/.74 \\
 &= 2.66 \times 10^9 \text{ cfs/ft (of head)}
 \end{aligned}$$

At an average vertical fall of 25 ft, generation of low-head hydro energy equivalent to that used to produce the eight primary commodities in the United States would require an instantaneous flow rate of 106 million cfs (at least over the April-September period considered here as being applicable to most of agriculture's needs).

Inventories of low-head hydro sites are being developed by researchers in several states (Lomas et al. 1978 Brow et al. 1978) Further investigations and data compilation are necessary to identify those that may become part of energy-integrated farm systems. Many potential sites, such as irrigation canal wasteways, are already being developed for commercial electricity production. Much detailed investigative work remains to be done

TABLE 3.5. Estimate of the Available On-Farm Stream Flow Energy During the Mean Farming Season, by Region

<u>Region</u>	<u>Geographic Area</u>	<u>Total Low-Head Hydro Billion Btu/yr(a)</u>	<u>% of Low-Head Hydro Located On-Farm</u>	<u>Billion Btu/yr Generated by EIFS</u>
1	Northeast	122,100	20	24,420
2	Southeast	42,000	10	4,200
3	Midwest	40,500	30	12,150
4	Northcentral	24,300	30	7,290
5	Plains	14,400	30	4,320
6	Texas-Oklahoma	15,600	30	4,680
7	Mountain	66,000	10	6,600
8	Far West	162,000	10	16,200

(a) Estimated by PNL from data published in "Inside DOE," October 5, 1979.

TABLE 3.6. Estimate of the Available Geothermal Energy During the Mean Farming Season, by Region (a)

<u>Region</u>	<u>Geographic Area</u>	<u>Wellhead Thermal Energy (Trillion Btu)</u>	<u>% of Farms Available to Energy</u>	<u>Upper Limit of Estimated Contribution to EIFS (Trillion Btu)</u>
1	Northeast	0	--	--
2	Southeast	0	--	--
3	Midwest	0	--	--
4	Northcentral	0	--	--
5	Plains	0	--	--
6	Texas-Oklahoma	0	--	--
7	Mountain	202,000	1-10	11
8	Far West	<u>163,000</u>	1-10	<u>18</u>
	Total	365,000		29

(a) Based on identified high-temperature and intermediate-temperature resources listed in U.S. Geological Survey Circular 790 (Muffler 1979). Low-temperature resources are not included.

before credible estimates of on-farm stream flow, by farm and county, could be made to show potential impacts of the resource toward displacing conventional energy use in production agriculture. However, estimates of low-head hydro availability are shown in Table 3.5.

3.4 GEOHERMAL ENERGY AVAILABILITY

High-temperature ($>150^{\circ}\text{C}$) and intermediate-temperature ($90\text{--}150^{\circ}\text{C}$) geothermal resources in the United States occur predominantly in the Western states. Quantitative estimates of recoverable thermal energy from these resources have been made by the U.S. Geological Survey (USG) (Muffler 1979). The USGS also estimated the electrical potential of each of the identified high-temperature reservoirs. Table 3.6 shows an estimate of the geothermal energy available to the energy integrated farm by region. As shown by this Table regions 7 and 8 have enough geothermal energy on a gross basis to meet about 9 percent of the need.

In addition to the resources discussed above, the USGS has tabulated data on low-temperature (90°C) geothermal resources. The amount of recoverable energy from these resources has not yet been estimated. However, low-temperature geothermal resources are thought to be available throughout the U.S. and to have the potential for significant agriculture uses.

3.6 BIOMASS AVAILABILITY

Biomass available for energy production includes crop residues, livestock manure and crops. Typical agricultural residue yields have been listed in Table 3.7, and the total energy available has been estimated in Table 3.8 from agricultural residues (Miles 1977). Pacific Northwest Laboratory (PNL) has used the 1978 USDA Agricultural Statistics to obtain crop acreages and residue yields from Table 3.7 to estimate the total energy available for each region.

As estimated in Table 3.9, more than 7×10^{15} Btu of energy is available from crop and other renewable residues in the United States. Here again, this is the equivalent of nearly four times the amount of energy

TABLE 3.7. Typical Agricultural Residue Yields

	Residue	
	<u>Tons/Acre</u>	<u>Form</u>
Wheat	2.5	Straw
Corn	2.9	Stalks, Cobs
Cotton	0.4 to 1.0	Gin, Trash
Soybean	1.5	
Sorghum (grain)	4.0	

Source: Miles 1977.

TABLE 3.8. Approximate Total Crop and Other Renewable Residues Developed in the USA

<u>Residues</u>	<u>Quads^(a)</u>
Dry Residues	
Straws, Gin Trash, Nut Shells	2
Damp Residues	
Soy, Sorghum Stalks, Rice Straw	1
Wet Residues	
Corn, Bagasse, Hops	<u>2</u>
Total Crop Residues	5
Manure	2

(a) Quad = 1 quadrillion Btu = 1.0×10^{15} Btu. Energy values given are based on an average lower heat value (LHV) of 6000 Btu/lb.

Source: Miles 1977.

TABLE 3.9. An Estimate of the Biomass Energy Available Annually
by Region

<u>Region</u>	<u>Geographical Area</u>	<u>Trillion Btu</u>		<u>Total</u>
		<u>Crop Residue (a)</u>	<u>Manure (b)</u>	
1	Northeast	370	174	544
2	Southeast	459	191	650
3	Midwest	1,645	290	1,935
4	Northcentral	504	120	624
5	Plains	1,487	321	1,808
6	Texas-Oklahoma	735	320	1,055
7	Mountains	416	182	598
8	Far West	<u>220</u>	<u>152</u>	<u>374</u>
	Totals	5,836	1,750	7,588

(a) Includes corn stalks and cobs, soybean residue, wheat straw, cotton gin, field trash, and sorghum stalks.

(b) This is total manure available and does not necessarily represent that manure is readily convertible to energy.

used in production agriculture (1.78×10^{15} Btu) each year. Biomass in the form of residues thus represents an abundant source of alternative energy available for energy-integrated farm systems in the United States.

The other major biomass resource available for conversion to energy is the crops grown by U.S. agriculture by conversion to ethanol. The total energy available as ethanol produced from major crops is shown in Table 3.10. Conversion of the corn, wheat, sugar beets, potatoes, and grain sorghum to ethanol would produce about 26 billion gallons of ethanol or about 2350 trillion Btu's as liquid fuel as compared to the liquid fuel needs of U.S. Agriculture of about 900 trillion Btu's (U.S. Department of Agriculture 1980).

3.7 CONCLUSION

Table 3.11 shows the availability of EIFS resources and demonstrates that there is more than ample renewable energy available in the various regions to satisfy the entire farm energy needs many times over. Table 3.11 also shows a tabulation of estimated maximum contribution by technology in each region. Obviously in any region the maximum contribution that could be made by any technology cannot exceed the total energy uses on the farms. Thus solar and biomass are shown at the limit of 100% of the energy needs of the farms, although they clearly have many times more resources than shown below. This is reflected in the appropriate columns in Table 3.12, which shows the energy availability by region in percent of that required.

Several conclusions can be inferred from these figures and the research that led to them:

- a) Solar and biomass appear to be far ahead of other renewable resources as defined by the current thrust of energy research projects.
- b) A vast increase in contribution by wind could result from the ability to economically use winds of less than 40 W/m^2 at 50 m height intensity.
- c) Low-head hydro could contribute much more if co-op projects remotely located from the farmstead were included in the EIFS scope.

TABLE 3.10. Energy Availability by Conversion of Major
U.S. Crops to Ethanol

<u>Crop</u>	<u>Total Production (Million Tons)(a)</u>	<u>Ethanol (gals/ton)(b)</u>	<u>Trillion Btu's(c)</u>
Corn	198	93	1,657
Wheat	54	87	423
Sugar Beets	26	20.3	48
Potatoes	18	28.8	47
Grain Sorghum	21	93	<u>175</u>
Total			2,350

(a) Source: U.S. Department of Agriculture 1979.

(b) Source: M. L. David, et. al., 1978.

(c) Calculated using Higher Heating Value of 90,000 Btu/gallon.

TABLE 3.11. Potential Contribution by Various Resources to Energy-Integrated Farms Energy Needs (in trillion Btu's)

<u>Region</u>	<u>Geographic Area</u>	<u>Solar</u> ^(a)	<u>Wind</u>	<u>Low-Head Hydro</u>	<u>Geothermal</u>	<u>Biomass</u>	<u>Regional Needs</u>
1	Northeast	186	--	24	0	186	186
2	Southeast	231	--	4	0	231	231
3	Midwest	397	--	12	0	397	397
4	Northcentral	162	--	7	0	162	162
5	Plains	283	28	4	0	283	283
6	Texas-Oklahoma	232	23	5	0	232	232
7	Mountain	113	--	7	11	113	113
8	Far West	<u>182</u>	<u>18</u>	<u>16</u>	<u>18</u>	<u>182</u>	<u>182</u>
46 Total	1,786	69	79	29	1,786	1,786	

TABLE 3.12. Availability of EIFS Resources in
Percent of Required Energy

<u>Region</u>	<u>Geographic Area</u>	<u>Solar</u>	<u>Wind</u>	<u>Low-Head Hydro</u>	<u>Geothermal</u>	<u>Biomass</u>
1	Northeast	100	0	13	0	100
2	Southeast	100	0	2	0	100
3	Midwest	100	0	3	0	100
4	Northcentral	100	0	4	0	100
5	Plains	100	10	1	0	100
6	Texas-Oklahoma	100	10	2	0	100
7	Mountain	100	10	6	10	100
8	Far West	<u>100</u>	<u>10</u>	<u>9</u>	<u>10</u>	<u>100</u>
Overall Average		100	4	4	2	100

These figures do not show, nor are they limited by, the match of resource to specific energy type, which is covered in the following chapter on the state of the technology. On the basis of these resource figures above, (Tables 3.11 and 3.12) the EIFS program would be proportioned to use 4% of the funds on wind, 4% on low-head hydro, 2% on geothermal and 45% each on solar and biomass.

CHAPTER 4

AN IDENTIFICATION OF TECHNOLOGICAL OPPORTUNITIES

The purpose of this chapter is to identify technological opportunities to integrate renewable energy resources into farm systems and to estimate the contributions that they could make by the year 2000.

Technological opportunities are defined as being created from the application of advances in knowledge found within the industrial and agricultural arts and that could be applied to farm energy production by 2000. The technologies of interest in this chapter are defined as: 1) solar, 2) wind, 3) geothermal, 4) low-head hydro and biomass technologies, 5) gasification, 6) pyrolysis, 7) combustion, 8) anaerobic digestion, 9) fermentation, and 10) liquefaction.

A technology must meet two requirements to qualify as an EIFS program opportunity: 1) the technology must be at the appropriate stage of development to justify government support 2) the technology must have a reasonable probability of being able to produce the kind of energy needed when it is needed. This chapter reviews each of the candidate technologies, discusses the energy conversion efficiencies of the technologies and then concludes with an evaluation of the technological opportunity for the EIFS technologies. The results of this chapter would indicate how much of the energy needed on the farm could be supplied by the various technologies if it were so located that it had good sunshine, plenty of wind, a good source of low-head hydro, a good geothermal source, etc. Obviously these conditions do not really apply but these limitations were addressed in Chapters 2 and 3.

4.1 A REVIEW OF THE TECHNOLOGIES APPLICABLE TO ENERGY INTEGRATED FARM SYSTEMS (EIFS)

Several technologies are considered in the literature to be applicable to collecting, generating, or transforming renewable energy for on-farm use. The following paragraphs generally describe these technologies and include descriptions of agricultural areas to which the technology can be applied. Current research on each application is also described. A subsequent section of this chapter will attempt to categorize the status of examples of these technologies according to their technological readiness.

4.1.1 Solar

Solar energy can be used to produce thermal energy and shaft or electrical energy. Shaft energy and electric energy are not differentiated because the solar technology available to produce one can easily be modified to produce the other.

4.1.1.1 Thermal Energy Production

Solar thermal energy can be collected and utilized by passive or active systems. Passive systems use the building or structure itself as the solar collector and thermal storage medium. Passive systems can be designed in a wide variety of configurations; the effectiveness of the passive design depends on the skill of the designer and the quality of construction. Active systems can be built using a variety of components and combinations of components, but they all require blowers or pumps, a control system, pipes or ducts, collectors, and usually heat exchangers and thermal storage units.

Passive systems are applicable to all kinds of farm buildings. Though most successful when designed into a new building, successful retrofits to passive systems have been accomplished on well-oriented buildings at costs substantially below those of comparable active systems.

Active solar systems include grain drying, crop drying and curing, greenhouse and residential heating, livestock shelter heating, water heating, and animal waste dehydration. In-storage drying of wheat, sorghum, and corn with solar energy will be tested in a prototype model of a chemical dessicant drying system employing solar heat for dessicant regeneration, which will be developed. An economic study and cost analysis of alternative approaches to solar drying will be conducted. Collectors used for solar drying of corn, sorghum, and possibly wheat will include an air-inflated plastic collector; a rigid, flat plate collector; and a combination collector-storage system. In addition, solar energy stored in previous dried corn will be used for heating air at night (Mansfield et al. 1977).

4.1.1.2 Stationary Shaft Horsepower Production

The two methods by which solar energy is used to produce shaft horsepower are thermal conversion using a thermodynamic cycle and direct

photovoltaic conversion. A solar-powered irrigation plant has been built by Sandia Laboratories in Willard, New Mexico. Parabolic trough collectors with a north-south orientation and 622.4 meter^2 area are used to provide heat for operating and storage (Energy Research & Development Administration 1977). The primary heat transfer fluid (Caloria HT43) operates at a peak temperature of 489 K. The secondary fluid (Refrigerant 113) and the vapor turbine operate at a peak temperature of 436 K. The variable speed turbine develops 36,300 rpm, which is reduced through a gearbox to 1760 rpm at the output shaft. The system has a Rankine cycle efficiency of 15% and develops 25 hp. At a rate of 2.5 m^3 per minute water is pumped from a 34 m deep well, irrigating 404.6 m^2 of land.

The first large-scale use of photovoltaic cells to generate electricity for water pumping was put into operation at Meade, Nebraska, in August 1977 (Pytlinski 1978). The electric system has 29 panels arranged in two rows holding a total of 120,000 silicon-type photovoltaic cells. The peak power that each row can develop is about 25 kW. About 6 hr of energy storage is provided by lead acid batteries with a total capacity of 85 kWh. The direct current electricity produced by the cells is converted to alternating current by inverters. The 10 hp pump motor can operate 12 hr a day and deliver 3.8 m^3 per minute of water from a reservoir.

4.1.2 Wind

Wind turbines are larger than most farm windmills and resemble airplane propellers. A typical wind energy conversion schematic is shown in Figure 4.1. The maximum amount of energy that can be taken from the wind is 59.3% of the kinetic energy moving through a disc the size of the rotor. An American farm windmill peaks out at about 31%, while a Dutch windmill achieves about 17% and a modern two-blade turbine will exceed 45%. If the gearing, generator, and transmission are 70% efficient, the best that can be expected is to convert about 32% of the wind energy into electricity. Using the shaft power directly to power a pump or to agitate water for heat will raise the overall system efficiency slightly. A vertical rotor (commonly referred to as the egg-beater style) has a maximum efficiency of about 35%. These efficiencies are estimated for

FIGURE 4.1. Wind Energy Conversion Systems

design wind speeds. The efficiency is lower for higher or lower end speeds. Information about rotor types, efficiencies, blade tip speed ratios, etc., is included in Wealey et al. (1978).

Proper siting of wind energy conversion systems (WECS) is critical. The site needs to be analyzed for turbulence and interference from trees, buildings, and landforms, especially landforms that can accelerate wind flow at a certain height above the ground. For an indepth discussion of WECS siting see Wealey et al. (1978).

Wind energy can be utilized as shaft horsepower or thermal energy. Direct conversion of wind-generated shaft power is possible, but has not come into common use. A submerged pump or agitator will heat a fluid surrounding it and the efficiency of the process is relatively high. The heat has to be generated at or very near the wind power site to avoid the losses associated with transmitting mechanical energy for any distance by shafts, rods, or hydraulic lines.

Heating water or another suitable heat reservoir with wind electricity is an efficient way of storing thermal energy once the electricity has been generated. Battery storage of electricity is 60% to 80% efficient, but heat storage in an insulated water tank can approach 100% efficiency. Machines for generating electricity from wind are commercially available and resistance heaters are also available for use with AC or DC electricity in a wide range of voltages.

No machines are currently being sold for direct conversion of wind to heat, although the heating of water by direct conversion has been demonstrated. Generating high level-heat (250 - 1000°F) by wind-driven friction is in the experimental stage.

Given a suitable site, a properly sized and installed wind machine, and adequate thermal or electrical storage, wind energy would be capable of heating any desired space. A wind/electric/thermal system could also supply electricity for other needs.

As with all wind systems, the better the wind data from the proposed site the more accurately the system output can be calculated. For wind heating, it is important to determine the degree of correlation between wind velocity and heating demand. A wind survey that records length of calm periods will help determine the amount of storage needed or can dictate the need for a backup heating system.

Since batteries typically represent about 35% to 40% of the cost of a wind/electric system, a wind/electric/thermal system will be considerably less expensive than a wind/electric system of the same rated capacity. A typical wind/electric/thermal system of 10 kW rated capacity would cost \$15,000 and could be expected to provide about 30,000 kWh per year when located on a site with an annual mean wind speed of 17 mph. If the cost of the \$15,000 capital is \$1,740 per year and maintenance costs add \$250 per year, the heat received will cost 6.6¢ per kWh.^(a) If someone is presently paying 3.5¢ per kWh, rise at a 9% increase per year, the average cost for the next 20 years will be 8.95¢ per kWh and the cost at the end of the 20 years will be 19.6¢ per kWh. Larger systems will produce heat for up to 25% less per kWh, while smaller systems will produce heat at two to three times as much. Many simplifying assumptions have been made in this example. A complete study of power availability and cost for each specific site is the only way to predict cost and performance with any accuracy.

The traditional American farm windmill is still pumping water for livestock in arid range areas. Such windmills, built by companies that have been building windmills for 40 to 80 years, can still be purchased. Their simplicity, reliability, and the reputations of the manufacturers are excellent selling points, but these windmills also have their drawbacks. First, in a mechanical system the wind machine has to be located at the well, which sometimes is not a good place for wind. Second, their efficiency is not very good, although they do work better than a modern wind turbine if the winds are gentle.

(a) 20-year life, 10% interest.

Other factors that contribute to the benefits of farm windmills to pump water are cost and performance of mechanically-operated versus electric pumps for the depth of the well, the number of animals and/or people to be supplied, and the amount of water storage that can be supplied.

The discussion has centered around use of shaft horsepower to pump water. Undoubtedly, other applications, such as splitting or sawing wood, exist for wind power, but justifying a wind energy conversion system (WECS) for these applications may be difficult. The biggest use of shaft horsepower on a farm is usually in tractors and combines, but running a tractor with a windmill is obviously not a practical solution. Using wind-generated electricity to produce hydrogen fuel by hydrolysis is a possibility but hydrogen technology is still essentially in the laboratory, and diesel fuel prices will have to rise dramatically (a distinct possibility) to make such a scheme financially viable.

The technical requirements for utilizing wind energy for shaft horsepower are: 1) analysis of energy available at the site, 2) analysis of power requirements for the particular application, and 3) analysis of storage required to match supply and demand.

While a simple farm windmill for running a pump can be obtained for a few hundred dollars, a more elaborate system will, of course, cost more. For example, a 2,000 watt generating system will cost approximately \$4,400 without batteries, which is less than most well/pump setup costs. The cost of a water storage tank and/or batteries to store electricity must be added. Batteries should cost about \$2,600 for a 2 kW system. Power cost from this system at a good site would be roughly 17-20¢ per kWh, which still may be much less expensive than running a utility line to the site.

A large system for pumping irrigation water could supply power for as little as 8¢ per kWh, but storage in a reservoir or in batteries would probably add another 2 to 3¢ per kWh unless the crop is hardy enough to be irrigated only when the wind blows, which would eliminate the need for electricity storage.

Before rural electrification, many farms had wind chargers. Some of these are still available, virtually unchanged from the original design, from the original manufacturers. Most of the wind machines on the market now were designed to generate electricity. Traditionally, wind electricity has been low voltage DC. DC electricity has many uses, but also has disadvantages. The motors of many household appliances will not work on DC electricity. Basically three ways of obtaining 60 cycle AC power from the wind are available: 1) control the wind turbine speed within narrow limits and drive an alternator (for very large systems this may be practical, but probably not for a small unit); 2) generate DC and use it to power an inverter (many inverters are on the market and in use); or 3) use a field modulated generator, which will produce fixed-frequency AC at varying speeds.

Electricity is probably the second most versatile energy form. Once it has been generated, the uses are endless; however, some study is necessary to choose the best voltage and whether AC or DC is best for the needed applications. The conversion of mechanical energy to electrical energy requires fairly complicated technology, but integrated systems are on the market. Still, the better wind energy conversion is understood by the buyer, the better chance he has of buying the system that fits his application needs.

As with all wind systems, knowledge of the resource (wind) and the demand will better enable design of a successful system. The factors that influence costs are basically the same as for all wind systems. Knowledge of the average wind speed, preferably on a month-by-month basis, is the most important factor.

4.1.3 Low-Head Hydro

Two trends toward use of stream flow for energy production for farm and farmstead use are prevailing. The first and most technically sound approach is the low-head and very low-head hydroelectric engineering concepts (Gladwell and Warnish 1978). The second is the rejuvenation of past (though perhaps obsolete) technology for individual rural use, as exemplified in such books as The Handbook of Homemade Power (The Mother Earth News 1974). Typical water power methods discussed in the book

include impulse (Pelton) wheels, overshot water wheels, small-scale Francis or propeller (reaction-type) units, and hydraulic ram pumps.

Low-head hydro is usually assumed to pertain to hydroelectric works operating at less than 50 ft of head. Very low-head hydro applies to those situations with 25 or less feet of head. The basic physical relationship between head, rate of stream flow, and generating efficiencies is expressed as:

$$P = \frac{QH}{11.8} e$$

where

P = instantaneous power generated in kW

Q = flow rate through the system in cfs

H = gross head in feet

e = relative conversion efficiency of the installation (technology dependent)

For example, a farm stream dammed with a head of 10 ft, a flow rate of 2,000 cfs and a conversion efficiency of 80% would potentially provide 1,356 kW of power.

Conversion efficiencies for low-head and very low-head hydro installations have been found to vary from 75% to 85%. Conversion efficiencies generally improve toward the higher value as flow rate (discharge) and head both increase (Mercer 1978).

Turbine generators manufactured both in the U.S. and in Europe have gone through several stages of refinement. However, major improvements can yet be made in standardization and mass production of low-head hydro equipment, according to people in the industry. This improvement would significantly lower the unit cost. In addition, low-head hydro equipment is believed to have suffered from a lack of research and development due to neglect of the technology over the past several decades. However, the technology is, for the most part, commercially and readily available.

Capital costs, normally have been estimated to be approximately \$1,000 per kW of installed capacity. A reasonable range might be \$750 to \$2,000 per kW, depending on specific siting and capacity considerations.

FIGURE 4.2. Estimated Low-Head Hydro Capital and Generating Costs as a Function of Plant Capacity

Operating costs typically range from 10 to 70 mills per kWh. Typical cost curves for capital and operating conditions are illustrated in Figure 4.2.

- Impediments to adapting this alternative energy form have included:
- licensing procedures (water rights, siting, environmental impacts, etc.)
- seasonality of stream flows
- capital intensive nature of the projects
- extreme site dependency (season, stream size, energy demands, etc.)
- potential sites may be too large (and too costly) to serve individual farms yet too small to serve rural communities
- high engineering and construction costs of one-of-a-kind installations.

Factors contributing to future adoption of this energy technology include:

- a well-developed technology (but perhaps suffering from R&D neglect) for low-head hydro equipment and design capabilities
- relatively low operating cost for electrical generation once installed.

Many such low-head hydro sites have been abandoned in recent decades in the United States. These sites, many in rural areas, might very well be potential sites for power generation as part of energy-integrated farm systems.

Very low-head and low-head hydroelectric generation is an extremely attractive energy substitution technology for farm energy systems, primarily for irrigation pumping and farmstead electrical energy requirements (lighting, heating, motive power, and farm shop uses such as welding, etc.). The potential is believed available to significantly achieve relative energy independence if pursued as part of an integrated or packaged energy system for American farms.

4.1.4 Geothermal

Applications of geothermal energy to the agricultural industry range from electrical production to animal husbandry to greenhouses. In this section, existing uses of geothermal energy are identified, and existing and

possible applications of these resources to the agricultural industry are listed.

The total potential usable geothermal energy in the U.S. has been estimated by the U.S. Geological Survey (Muffler 1979). Recoverable resources, both discovered and undiscovered, may result in 150,000 MWe of power for 30 years in the United States alone. Most Known Geothermal Resource Areas (KGRAs) are located in the Western United States. Large geopressed resources are found along the Texas-Louisiana coast and radiogenic heat sources can be found along the Eastern Seaboard.

At present, geothermal resources around the world are being utilized for both electrical power production and nonelectric applications. Approximately 1400 MWe are now being produced, in addition to over 7,000 MWt of peak nonelectric use. Electric power available from geothermal heat by 1983 for the United States is estimated to be 1921 MWe (Rex 1978). Non-electric use of geothermal resources in the United States by 1985 is projected to be 0.1 quad/yr or 3,340 MWt (Department of Energy 1977).

The use of geothermal heat in the agricultural industry is not only an efficient use of that resource, but also contributes to the solution of the pressing problem of adequate food supplies. A 26,000 ft² greenhouse in Oregon is currently growing tomatoes and uses geothermal energy to maintain a year-round temperature of 70°F (Head 1970).

4.1.5 Biomass Technologies

4.1.5.1 Gasification

Gasification of combustible solids involves the partial combustion of the solid to generate a combustible gaseous mixture called synthesis gas. Other products of the process can be a condensable liquid (tars) and an ash or carbonaceous residue. The gasifying medium can be oxygen, air, steam, CO₂, or a mixture of these gases.

Possible end products from gasification of wood as a representative renewable resource are illustrated in Figure 4.3. All of these products cannot be generated together; the products listed are options. For example, either 0.7 tons of anhydrous ammonia, or 0.67 tons of methanol can be obtained, not both.

FIGURE 4.3. Possible Products from Agricultural Residues (a)

(a) The residues are also assumed to provide the needed process heat. The yield figures shown here take their requirement into account to obtain the net yields as shown.

The following discussion presents the technical stage of development of the technologies illustrated by Figure 4.3. All of the technologies required to generate the products from the synthesis gas are commercially available. These processes currently use synthesis gas generated from reforming of natural gas. No commercial system for the generation of synthesis gas from wood is available. Technology for generation of synthesis gas is in the demonstration phase, such as the Purox process (Moses et al. 1978); and engineering development phase, such as the Battelle, Garrett Energy Research and Engineering, Wright-Matta processes (Sealock et al. 1978).

A moving bed, also known as a fixed bed, air-stream blown-type of gasifier for generation of a low-Btu gas is the only gasification system that has had significant commercial applications using wood as the solid fuel (Mikesell et al. 1978). The low-Btu gas can be used as a heat source. It can be combusted to raise steam or to dry agricultural crops (Coffman and Hooverman 1978). It can be used as a fuel for an internal combustion engine, or as a reducing gas in the steam-iron process to generate hydrogen for synthesis of nitrogenous fertilizers (Moses et al. 1978).

Production of nitrogenous fertilizers (ammonia) from wood was practiced commercially in India in the 1940s (Rutherford and Ruschin 1949). The process used the low-Btu gas as a reducing gas for the steam-iron process to generate H_2 and was therefore quite inefficient. The scheme illustrated in Figure 4.3 shows the potential for generating one ton of anhydrous ammonia from 2.0 tons of wood, whereas the process used in India required about 5 tons of wood per ton of anhydrous ammonia.

Economics of gasification systems for generation of a low-Btu gas or an intermediate-Btu gas from wastes and biomass are presented in several sources (Skov and Papworth 1975; and Frit et al. 1978). The costs may be optimistically low since they represent the costs of using systems that are being promoted by developers. With zero cost for the solid fuel and a 60% conversion efficiency, a low-Btu gas would cost from 3.12 to 0.783 dollars per million Btu for a 20 ton/day and a 200 ton/day, respectively (Bailee 1976). Medium-Btu gas from the Purox system costs

\$2.55 and \$4.1 per million Btu for the 850 ton/day and 3,400 ton/day capacities, respectively, with a wood fuel cost of \$1.00 per million Btu (Bliss and Blake 1977). At a wood fuel cost of \$2.50 per million Btu, the costs for the respective plant sizes are given as \$4.15 and \$4.68 per million Btu.

Processes now in the engineering development phase should improve the conversion efficiency and the process economics.

4.1.5.2 Pyrolysis

Pyrolysis of combustible solids involves applying heat in the absence of oxygen to destructively distill the solid. Pyrolysis products include a medium-Btu gas, charcoal (carbonaceous residue), and a condensable liquid (tars and pyrolytic acids).

4.1.5.3 Direct Combustion

Combustion (or incineration) of agricultural biomass is the direct means of obtaining thermal energy from this resource. This thermal energy can be used directly or can provide either shaft-horsepower or light as other end uses. Although direct combustion by itself cannot provide liquid fuels, gaseous fuels, fertilizers or chemicals, it could be used as the energy source in the production of these other end-use forms.

The uses of direct combustion as an energy source are shown in Figure 4.4. As shown in the figure, hot flue gases are generated by direct combustion in a furnace (incinerator). The hot flue gases are ideally suited for direct drying of several "nonfood" crops such as feed grains, alfalfa and other hay where slight amounts of ash in the flue gas would not affect the product. Even for certain food crops, the hot flue gases could possibly be used with little or no ash removal. However, potential changes in taste or other harmful results should be considered for each specific use.

The hot flue gases can also be used to produce steam in a boiler. In this application, the furnace and boiler are usually combined in one unit. The steam that is generated can be used to provide shaft-horsepower

FIGURE 4.4. Combustion of Residues for Energy

via either a steam engine or a turbine. The shaft horsepower produced can be used to replace the current uses of shaft horsepower on the farm (i.e., pumping water, conveying, and motive energy). However, shaft-horsepower derived from steam appears to be most applicable to those cases where the energy need is stationary, such as pumping irrigation water, because of the bulkiness of the system. This shaft horsepower can also be used with a generator to provide electricity for home, barn, and greenhouse illumination. The electricity can also be used to supply several small requirements for shaft horsepower where direct use of steam would not be convenient. In addition to providing shaft horsepower, the steam can be used as a thermal energy source for drying and heating applications.

The hot flue gases can be used to heat air in a "gas to air" heat exchanger. The heated air can then be used for crop drying and space heating. This heated air does not contain the ash or the combustion products and can be used for drying food crops for which the direct use of the flue gas would not be applicable, or for space heating where the combustion products might be toxic.

The form of agricultural residue used for direct combustion can vary depending on application. The forms include hammermilled straw, stalks, bales, cubes, and pellets. Thomas R. Miles (1975) describes a bale-burning furnace that can be used on-farm for dehydrating systems. For furnace or furnace/boiler applications where coal or wood are now being used (or could be used), the fuel size depends on the combustion chamber design. For example, fuel particles for a typical grate system for wood are 2 to 3 in., while much smaller particles are used in suspension systems (USDA-Forest Service 1976). For best combustion, the residue should be dry (less than 15% moisture) as recommended by manufacturers of wood-burning furnaces (NASA/ASEE Systems Design Institute 1974). However, fuels with higher moisture content can support combustion and some of the energy from combustion can be used to predry the fuel.

Although the technology for utilizing agricultural residues as an energy substitute via direct combustion is available, it is not currently

being extensively practiced on the farm level. In the not-too-distant past, straw was used to provide energy for threshing grain. The equipment and technologies for the combustion of agricultural residues are very similar to that for hogged fuel and coal. The energy content of most agricultural residues (straw, etc.) is about 8,000 Btu/lb on a dry basis, which compares to wood, also at about 8,000 Btu/lb. The main concern in utilizing these residues is the collection, transportation, storage, and handling problems encountered in delivering the given residue to the energy production site.

4.1.5.4 Anaerobic Digestion

Anaerobic Digestion is the conventional method of processing sewage to minimize water pollution by destroying the principal, oxygen-demanding organic matter. In some cases, the resulting dilute methane gas has been productively used to provide the fuel for steam and electricity for disposal plant operation. Recent emphasis on conservation and improved environmental control has increased interest in wide-scale use of anaerobic digestion for methane fuel production. Such practical applications of the process are currently limited to large-scale tests and demonstrations on feed-lot manure and municipal waste (sewage) and solid waste conversion.

An aqueous slurry containing about 10% by weight of the organic solids suitably prepared (usually by grinding and inoculation by at least two suitable strains of bacteria generally already present in the fermentation feed or residues) is held in large closed tanks at elevated temperatures (above 95°F). Some agitation is desired. Over a retention time of 2 to 3 weeks, about 50% of the organic fraction (principally the carbohydrate fraction) is fermented, resulting in a gas containing about 60% methane and 40% carbon dioxide.

Anaerobic treatment of complex organic materials is normally considered to be a two-stage process. In the first stage the complex organics are changed in form by a group of facultative and anaerobic bacteria commonly termed the "acid formers." Complex materials such as fats, proteins, and carbohydrates are hydrolyzed, fermented, and biologically converted to

simple organic materials. For the most part, the end products of this first-stage conversion are organic fatty acids. Acid-forming bacteria bring about this initial conversion to obtain the small amounts of energy released for growth, and a small portion of the organic waste is converted to cells. Although no waste stabilization occurs during the first stage of treatment, it is required to place the organic matter in a form suitable for the second stage of treatment.

In the second stage of methane fermentation real waste stabilization occurs. During this stage, the organic acids are converted by a special group of bacteria termed the "methane formers" into the gaseous end products, carbon dioxide and methane. The methane-forming bacteria are strictly anaerobic and even small quantities of oxygen are harmful to them. Several different groups of methane formers exist, and each group is characterized by its ability to ferment a relatively limited number of organic compounds. Thus, in the complete methane fermentation of complex materials, several different methane bacteria are required. The methane formers that use materials such as formic acid and methanol grow very rapidly and can thrive at sludge retention times of less than two days. However, the most important methane formers, which live on acetic and propionic acids, grow quite slowly, and retention times of four days or longer are required for their growth. These bacteria carry out the major portion of waste stabilization. Their slow growth and low rate of acid utilization normally represents the limiting step around which the anaerobic treatment process must be designed.

The anaerobic treatment process does have some disadvantages that may limit the use of this process for certain applications. The major disadvantage is that relatively high temperatures are required for optimum operation; temperatures in the range from 85° to 95°F are preferred. Dilute wastes may not produce sufficient methane for waste heating and this may represent a major limitations.

Buswell and Mueller (1952) developed the following equation to predict the quantity of methane from a knowledge of the chemical composition of the waste:

Although livestock wastes and crop residues have a complex mixture of fats, proteins, and carbohydrates, they are composed primarily of carbohydrates that have an empirical formula of $(CH_2O)_n$. These carbohydrates include starch and cellulose, which both have the same chemical formula of $C_6H_{10}O_5$ but differ by the linkages of the groups forming the polysaccharides. For carbohydrates the above digestion equation yields:

Not all of the carbon dioxide is released as a gas but enters into reactions with water and hydrogen ions. Therefore, the gas composition is about 60 percent methane and 40 percent carbon dioxide rather than the 50/50 mixture as would be predicted by the above equation. Theoretical gas generation is about 6.65 ft³ of methane per pound of carbohydrate. For feedstocks that are primarily carbohydrates, the theoretical methane generation is also about 6.65 ft³ per pound of volatile solids (total organic matter). In actual practice, conversion efficiencies are on the order of 80 to 90 percent so that practical methane production is about 5.6 ft³ per pound of volatile solid.

4.1.5.5 Fermentation

In alcohol fermentation (also generally called fermentation) yeasts are employed to convert sugar to ethanol. In addition to crops actually containing sugar, those containing other carbohydrates such as starch and cellulose, which can be converted to sugar, can be used for ethanol production. Conversion of starch crops to sugar utilizes commercial enzymatic hydrolysis processes. The conversion of cellulose to sugar by enzymatic or acid hydrolysis is a more complex process than hydrolysis of starch. Because of this complexity, the use of cellulose to produce ethanol is normally not considered to be commercial.

Cooking is the first step in ethanol production from starch. The starch concentration is adjusted to about 15-20 percent by adding water and

amylase enzymes and the resulting slurry cooked at about 200°F for 2-1/2 hours. This cooking step converts the starch to dextrins (polymeric sugars). The dextrins are then converted to glucose by lowering the temperature to 122°F - 140°F and adding glucoamylase, the enzyme used for saccharification (conversion of dextrins to glucose). The mash is now ready for the fermentation step in which yeasts of the strain *Saccharomyces cerevisiae* convert glucose to ethanol and which is summarized as:

The ethanol solution that is produced is called "the beer" and ranges in concentration from 8 percent to 12 percent ethanol by volume. The ethanol concentration is increased by distillation to a maximum concentration of 96 percent ethanol at the azeotrope. An azeotropic distillation process is conventionally used to produce 100 percent (200 proof) ethanol.

The pH of the initial slurry to be used in cooking should be nearly neutral. The pH can be adjusted by adding dilute sodium hydroxide if the pH is too low or concentrated sulfuric acid or lactic acid if the pH is too high.

The conversion of the starch component of grains to ethanol via fermentation is presently state-of-the-art. The economics are often unfavorable for small-scale operations. For large-scale operations, the economics are heavily dependent on raw material (grain) cost and also on credit for the massive quantities of by-product which result. The conversion of cellulosic materials (stalks, straws and leaves) to ethanol via fermentation is not presently state-of-the-art. Although much research has been done in part, particularly for wood conversion by this process, no economical sustained operation of commercial facilities appears ever to have been maintained in the U.S.

Fermentation processes require energy input in the form of heat to recover the alcohol from the dilute fermentation liquors by distillation. However, these energy inputs can most likely be obtained from combustion of field residues (stalks, straws, etc.). Although fermentation to

produce ethanol is a well-established business (production of premium-valued ethanol for food-based uses), this process is also acknowledged to be generally more costly and in some studies substantially more costly than ethanol produced synthetically by the much larger petrochemical-based industries. However, both biological processes show improved comparative economics as the price of fossil fuel resources (natural gas and petroleum) escalate.

4.1.5.6 Liquefaction

Thermochemical liquefaction is a process whereby almost any carbonaceous material (excluding coal and oil) can be treated with heat and alkali and converted to a liquid product. Since carbonaceous residues of biological origin contain the same four basic ingredients (cellulose, hemicellulose, lignin, and protein), the process can utilize wheat straw, other crop residues, hog and cow manure, sewage, wood waste and paper. When heated to a temperature of 300 to 400°C in a sealed vessel under alkaline conditions (pH about 10) for up to 1 hr, a mixture of water-soluble organic materials, water-insoluble "oil" and gas is formed.

Relatively little is known about the chemistry of this process. It is different from pyrolysis in that the cellulose portion of the biomass is digested to small molecules such as acetone, which then recombine to give the oil product. The lignin and hemicellulose portions have not been studied in detail as the cellulose has, but with similar properties they presumably have similar chemistry. The organic materials in the water-soluble fraction may be intermediates in the degradation and resynthesis pathway, and hence could be recycled. Protein materials in alkali would generate ammonia gas (recoverable), and small molecules similar to intermediates in cellulose degradation (acetaldehyde, etc.), which would then enter the cycle and would also yield oil. Hence, all of the organic materials would be digested.

The yield of oil product achievable from liquefaction ranges from 30% to 50%. The overall product from liquefaction is a viscous oil, with a heating value in the range of 12,000 to 15,000 Btu/lb, compared to a value

of 7,526 Btu/lb for pure cellulose. Thus, although only a half of the initial weight of carbonaceous residue is produced as oil, almost all of the initial energy content is retained. The only major cost in energy is the amount required to perform the conversion.

The initial product itself is a poor liquid fuel. If distilled, it can be separated readily into a light oil useful as a liquid fuel, and a thick black tar, which can either be burned in a special boiler, or be more usefully used as a road paving material (asphalt substitute).

Thermochemical liquefaction, like all of the related processes, is currently in the applied research stage of development. Using current knowledge, it could be built and made to work, but so far none of these systems have been built and installed, and insufficient information is known about possible problems.

On a farm, a central collection area could consist of a haystack (if manure is not to be used as a substrate), or an enclosed tank with a screw transfer system connected directly to the reactor. If sewage and/or animal manure is to be used primarily, the storage tank could be common with storage for an anaerobic digester for methane production. The material entering the reactor tank would have to consist of particles less than 1 in. in diameter for optimum conversion; smaller particles would require a shorter residence time. They would be mixed with twice their volume of water (unpurified water or reaction recycle water), sodium carbonate added and mixed in to bring the pH to about 10, and the slurry heated to 350°F for about 20 min to 1 hr. As an alternative to a continuous reactor, a batch system could also be used. The product gases would consist mainly of carbon dioxide, steam, and small amounts of carbon monoxide, methane, ethane, etc., and would be of little value. They could be flared or passed over a catalytic oxidizer to prevent pollution. The liquid product would be poured off from the bottom of the reactor and would consist of an aqueous layer (lower) and an oil layer (upper), which could be easily separated. Some of the aqueous layer could be recycled, although some would have to be removed from the process at each pass due to the buildup of sodium salts from the alkali added. The rejected portion of the aqueous layer could be added to an

anaerobic fermenter for complete recovery of carbon values and water cleanup. The oil product could be: a) burned directly in a special boiler, b) distilled to a light fuel oil suitable for machinery operation, and c) used as an asphalt fraction that could be either burned or used as a road paving base with aggregate gravel available on the farm. The only residue would be the reject water, which could be purified in conventional systems.

An alternative use for the oil produced would be to subject it to a second hydrogenation step to obtain a high yield of a gasoline substitute. The process is extremely simple in principle and a conservative basis has been used for the material balance, based on PNL experimental results. Literature data (Kaufman and Weiss 1975) on this topic vary widely and are of dubious validity in many cases. Yields of up to 58% have been claimed for thermochemical conversions to oil, while 33% is normal in PNL experiments (the range was 1% to 45% in 130 experiments). Also, PNL has used primarily pure cellulose; lignin would increase the yield somewhat over these results. Hence, PNL has used 33% yield of oil as their basis, with an average heating value of 13,000 Btu/lb, derived from a carbonaceous residue with a heating value of 7,500 Btu/lb (dry). The oil itself can be separated into a net 16% yield of asphalt-like residuum and 17% of light fuel oil directly through distillation at up to 250°C under vacuum. Value of the fuel oil and of the residuum is assumed to be \$100/ton, which corresponds fairly closely to the asphalt price of \$100/ton and the crude oil price of \$15/barrel.

The simplest thermochemical liquefaction variant, therefore, has wide potential applicability to farm use, provided some basic research is done to establish equipment design parameters.

4.2 EFFICIENCIES OF CONVERSION

Efficiencies of converting renewable resources into usable energy forms determine the ultimate practicality and economic motivation for adopting or not adopting a substitution technology for an integrated system of energy production on farms in the United States. Ranges of conversion efficiencies for each general resource and/or technologies

are given in Table 4.1. Biomass conversion technologies offer the widest range of applications among the alternate energy technologies, one process perhaps being more adaptable to a given feedstock than another, depending on the location, climate and nature of the energy demand.

4.3 THE TECHNOLOGICAL OPPORTUNITY FOR CANDIDATE EIFS TECHNOLOGIES

This section attempts, somewhat subjectively to integrate the judgment of the contributors to this report into an assessment of the opportunity for various technologies to contribute to the specific types of needs of the EIFS. This section doesn't try to consider whether resources are available or consider the quantities of energy needed in these various categories. (These were assessed in the previous chapters).

Table 4.2 attempts to evaluate the "conversion technology potential" as a percent of energy that could be supplied if a good resource were available. For example, it is estimated that 40 percent of the electricity needs (not including irrigation) could be supplied by wind energy.

TABLE 4.1. Energy Recovery Efficiency for Substitution Technology

<u>Substitution Technology</u>	<u>Energy Recovery Efficiency</u>
Solar	Up to 80% efficiency for low temperature heating; 12-18% efficient for electrical production via solar cells.
Wind	Available Power = $0.5 DAS^3$ (where D = air density, A = area of rotor disc, S = wind speed) Efficiencies of units vary from 15-40%.
On-Farm	$P = \frac{QH}{11.8e}$ (where P = instantaneous power in kW, Q = flow rate in cfs, H = head in ft, e = conversion efficiency) Efficiencies vary from 75 to 85%.
Geothermal	Thermal range varies widely; efficiency depends on temperature and pressure of source and end-use.
Biomass Conversion Gasification ^(a)	Gas production: 70-80% efficient.
Pyrolysis	Charcoal production: 40% efficient. All other products: 90% efficient.
Biomass Combustion	Hot gas for drying: 85% efficient. Steam generation: 77% efficient.
Anaerobic Digestion	Energy conversion to methane: 60% efficient.
Fermentation	45-50% energy efficiency for conversion to ethanol.
Liquefaction	48% energy efficiency on conversion to liquid fuel.

(a) Feedstock: Agricultural residues with energy content of 6,000-8,000 Btu per pound.

TABLE 4.2. Percent of End Use Energy Form that Could be Supplied by the Substitution Technologies (Reflects Both Stage of Development and Expected Ability to be Feasible) (a)

End Use Energy Form	Solar	Wind	Geothermal	Gasification	Pyrolysis	Biomass Combustion	Anaerobic Digestion	Fermentation	Liquefaction	On- Farm Stream Flow
Electric ^(b)	20	40	100	50	--	30	25	25	--	100
Thermal	60	20	100	25	10	100	25	20	10	50
Chemical (Fertilizer, Pesticide)	5	10	25	100	10	--	10	15	--	25
Mechanical Stationary (Irrigation)	5	40	50	100	--	90	15	100	10	50
Mechanical Mobile (Preharvest Field Care, Harvest, Transport)	--	2	5	100	10	5	5	100	25	10

(a) Assumes availability of good resources.

(b) Not including irrigation.

CHAPTER 5

AN INITIAL DESIGN FOR A NATIONAL PROGRAM OF ENERGY INTEGRATED FARM SYSTEMS

The success of federal involvement in the initiation of a program to induce energy independence in agriculture through energy-integrated farm systems is dependent on the existing use of energy, the availability of renewable energy resources and the state-of-the-art of conversion technology. The preceeding analysis identified 1) the current use of energy for agricultural production, 2) the resource availability, and 3) the conversion potential of renewable resources and technical opportunities. The purpose of this chapter is to establish the objectives of the program in terms of the level of farm energy independence that can be achieved by the year 2000 and to identify program guidelines to reach that objective. The guidelines are developed by integrating energy needs, resource availability and conversion technology potential to arrive at a projection of the energy that could be supplied by the substitution technologies.

The energy input by end use energy form for U.S. agriculture was discussed in Chapter 2 and is reviewed in Table 5.1. This table shows the annual (1978) energy input to both crop and livestock production. As previously discussed in Chapter 2, mechanical mobile energy and chemical energy have the highest energy demands.

An estimation of the energy that could be supplied by the substitution technologies is shown in Table 5.2. The numbers shown were obtained by multiplying the energy need (Table 5.1) by the average resource availability (Table 3.12) times the conversion potential (Table 4.2). Comparing the total energy that could be supplied for each end-use energy form shown in the right hand column of Table 5.2 and the energy needed (Table 5.1) shows that the substitution technologies do have the ability to make U.S. agriculture energy self-sufficient. Projections indicate that the substitution technologies could provide 4,425,920 billion Btu's for U.S. agriculture, compared to an energy demand of 2,027,596 billion Btu's.

TABLE 5.1. Total Energy Input by End Use Energy Form for
U.S. Crop and Livestock Production, 1978 (from
Chapter 2)

<u>End Use Energy Form</u>	<u>Billion Btu's</u>
Mechanical Mobile	854876
Mechanical Stationary	277837
Thermal	154206
Chemical	720662
Electrical	5783
Miscellaneous	14232
Total	2027596

TABLE 5.2. Energy That Could be Supplied by the Substitution
Technology (Billion Btu's)

<u>End Use Energy Form</u>	<u>Solar</u>	<u>Wind</u>	<u>Geothermal</u>	<u>Gasification</u>	<u>Pyrolysis</u>	<u>Combustion</u>	<u>Anaerobic Digestion</u>	<u>Fermentation</u>	<u>Liquefaction</u>	<u>Low- Head Hydro</u>	<u>Total</u>
Mechanical Mobile	-	684	855	854,876	85,488	42,744	42,744	854,876	213,719	3,420	2,099,406
Mechanical Stationary	13,892	4,445	2,778	277,837	--	250,053	41,676	277,837	27,784	5,557	901,859
Thermal	92,524	1,234	3,084	38,552	15,421	154,206	38,552	30,841	15,421	3,084	392,919
Chemical	36,033	2,883	3,603	720,662	72,066	--	72,066	108,099	--	7,207	1,022,619
Electrical	1,157	93	117	2,892	--	1,735	1,446	1,446	--	231	9,117
Total	143,606	9,339	10,437	1,894,819	172,975	448,738	196,484	1,273,099	256,924	19,499	4,425,920
Percent	3.2	0.2	0.2	42.8	3.9	10.1	4.4	28.8	5.8	0.4	

Table 5.2 also provides a guideline as to which substitution technologies should be developed to make U.S. agriculture energy self-sufficient. The bottom row shows the energy that can be provided by each technology as a percentage of the total that all of the substitution technologies can provide. For example, fermentation is expected to be able to provide 28.8 percent of the energy provided by all technologies and would therefore be expected to receive roughly 28.8 percent of the effort of the EIFS program. This analysis applies to each of the technologies and the approximate level of effort they should receive.

A regional analysis of the energy that could be supplied is given in Tables 5.3 through 5.10. Again, a comparison of the available supply shown in these tables with regional energy needs given in Chapter 2, indicates that U.S. agriculture can be energy self-sufficient on a regional basis.

TABLE 5.3. Region 1 - Billion of Btu's that Could be Supplied by the Substitution Technologies (Based on 1974 Energy Needs)

	<u>Solar</u>	<u>Wind</u>	<u>Geothermal</u>	<u>Gasification</u>	<u>Pyrolysis</u>	<u>Biomass Combustion</u>	<u>Anaerobic Digestion</u>	<u>Fermentation</u>	<u>Liquefaction</u>	<u>On- Farm Stream Flow</u>
Electric OVHS	110	--	--	275	--	165	138	138	--	66
Thermal (Frost Protection Crop Drying)	15,726	--	--	6,552	2,621	26,211	6,552	5,242	2,621	1,703
Chemical (Fertilizer, Pesticide)	4,186	--	--	83,729	8,373	--	8,373	12,599	--	2,721
Mechanical Stationary (Irrigation)	76	--	--	1,529	--	1,376	229	1,529	153	99
Mechanical Mobile (Preharvest Field, Care Harvest, Transport)	--	--	--	73,510	7,351	3,676	3,676	73,510	18,377	955
Total	20,098	--	--	165,595	18,345	31,428	18,968	92,978	21,151	5,544

TABLE 5.4. Region 2 - Billions of Btu's that Could be Supplied by the Substitution Technologies (Based on 1974 Energy Needs)

	<u>Solar</u>	<u>Wind</u>	<u>Geothermal</u>	<u>Gasification</u>	<u>Pyrolysis</u>	<u>Biomass Combustion</u>	<u>Anaerobic Digestion</u>	<u>Fermentation</u>	<u>Liquefaction</u>	<u>On- Farm Steam Flow</u>
Electric OVHS	110	--	--	276	--	166	138	138	--	11
Thermal (Frost Protection Crop Drying)	22,504	--	--	9,377	3,751	37,508	9,377	7,501	3,751	375
Chemical (Fertilizer Pesticide)	4,721	--	--	94,426	9,443	--	9,443	14,164	--	472
Mechanical Stationary (Irrigation)	657	--	--	13,142	--	11,828	1,971	13,142	1,314	131
Mechanical Mobile (Preharvest Field Care, Harvest, Transport)	--	--	--	85,199	8,520	4,260	4,260	85,199	21,300	170
Total	27,992	--	--	202,420	21,714	53,762	25,189	120,144	26,365	1,159

TABLE 5.5. Region 3 - Billions of Btu's that Could be Supplied by the Substitution Technologies (Based on 1974 Energy Needs)

	<u>Solar</u>	<u>Wind</u>	<u>Geothermal</u>	<u>Gasification</u>	<u>Pyrolysis</u>	<u>Biomass Combustion</u>	<u>Anaerobic Digestion</u>	<u>Fermentation</u>	<u>Liquefaction</u>	<u>On- Farm Steam Flow</u>
Electric OVHS	287	--	--	718	--	431	359	359	--	43
Thermal (Frost Protection Crop Dying)	19,516	--	--	8,132	3,253	32,528	8,132	6,506	3,253	488
Chemical (Fertilizer, Pesticide)	9,810	--	--	196,201	19,620	--	19,620	29,430	--	1,472
Mechanical Stationary (Irrigation)	48	--	--	958	--	862	144	958	96	14
Mechanical Mobile (Preharvest Field Care, Harvest, Transport)	--	--	--	166,146	16,615	8,308	8,308	166,146	41,537	498
Total	29,661	--	--	436,114	63,959	42,129	36,563	203,399	44,886	2,515

TABLE 5.6. Region 4 - Billions of Btu's that Could be Supplied by the Substitution Technologies (Based on 1974 Energy Needs)

	<u>Solar</u>	<u>Wind</u>	<u>Geothermal</u>	<u>Gasification</u>	<u>Pyrolysis</u>	<u>Biomass Combustion</u>	<u>Anaerobic Digestion</u>	<u>Fermentation</u>	<u>Liquefaction</u>	<u>On- Farm Steam Flow</u>
Electric OVHS	127	--	--	317	--	190	158	158	--	25
Thermal (Frost Protection Crop Dying)	5,408	--	--	2,254	901	9,014	2,254	1,802	901	180
Chemical (Fertilizer, Pesticide)	3,510	--	--	70,199	7,020	--	7,020	10,530	--	702
Mechanical Stationary (Ir- rigation)	53	--	--	1,054	--	949	158	1,054	105	21
Mechanical Mobile (Preharvest Field Care, Harvest, Transport)	--	--	--	80,662	8,066	4,033	4,033	80,622	20,166	333
Total	9,098	--	--	154,486	15,987	14,186	13,623	94,206	21,172	1,251

TABLE 5.7. Region 5 - Billions of Btu's that Could be Supplied by Substitutions Technologies (Based on 1974 Energy Needs)

	<u>Solar</u>	<u>Wind</u>	<u>Geothermal</u>	<u>Gasification</u>	<u>Pyrolysis</u>	<u>Biomass Combustion</u>	<u>Anaerobic Digestion</u>	<u>Fermentation</u>	<u>Liquefaction</u>	<u>On- Farm Steam Flow</u>
Electric OVHS	258	129	--	646	--	387	323	323	--	13
Thermal (Frost Protection Crop Drying)	10,568	353	--	4,403	1,761	17,613	4,403	3,523	1,761	88
Chemical (Fertilizer, Pesticide)	4,897	980	--	97,955	9,796	--	9,796	14,693	--	245
Mechanical Stationary (Irrigation)	2,828	2,828	--	56,544	--	50,899	8,483	56,554	5,655	283
Mechanical Mobile (Preharvest Field Care, Harvest, Transport)	--	23	--	10,990	5,495	5,495	5,495	109,903	27,476	110
Total	18,551	4,313	--	269,461	22,547	74,394	28,500	184,996	34,872	739

TABLE 5.8. Region 6 - Billions of Btu's that Could be Supplied by the Substitution Technologies (Based on 1974 Energy Needs)

	<u>Solar</u>	<u>Wind</u>	<u>Geothermal</u>	<u>Gasification</u>	<u>Pyrolysis</u>	<u>Biomass Combustion</u>	<u>Anaerobic Digestion</u>	<u>Fermentation</u>	<u>Liquefaction</u>	<u>On- Farm Stream Flow</u>
Electric OVHS	119	24	--	297	--	178	148	148	--	11
Thermal (Frost Pro- tection Crop Dry- ing)	2,976	99	--	1,242	497	4,966	1,242	993	497	50
Chemical (Fertilizer, Pesticide)	3,969	794	--	79,372	7,937	--	7,937	11,906	--	397
Mechanical Stationary (Irri- gation)	4,294	4,294	--	85,889	--	77,300	12,883	85,889	8,589	859
Mechanical Mobile (Preharvest Field Care, Harvest, Transport)	--	273	--	61,400	6,140	3,070	3,070	61,400	15,350	123
Total	11,358	5,383	--	228,200	14,574	85,514	25,280	160,336	14,436	1,440

TABLE 5.9. Region 7 - Billions of Btu's that Could be Supplied by the Substitution Technologies (Based on 1974 Energy Needs)

	<u>Solar</u>	<u>Wind</u>	<u>Geothermal</u>	<u>Gasification</u>	<u>Pyrolysis</u>	<u>Biomass Combustion</u>	<u>Anaerobic Digestion</u>	<u>Fermentation</u>	<u>Liquefaction</u>	<u>On- Farm Stream Flow</u>
Electric OVHS	67	13	33	166	--	100	83	83	--	30
Thermal (Frost Pro- tection Crop Dry- ing)	10,684	356	1,781	4,452	1,781	17,807	4,452	3,561	1,781	801
Chemical (Fertilizer Pesticide)	2,945	589	1,472	58,906	5,891	--	5,891	8,836	--	1,325
Mechanical Stationary (Irri- gation)	2,866	2,866	2,866	57,314	--	51,583	8,597	57,314	5,731	2,579
Mechanical Mobile (Preharvest Field Care, Harvest, Transport)	--	95	237	47,340	4,734	2,367	2,367	47,340	11,835	426
Total	16,562	3,919	6,389	168,178	12,406	71,857	21,390	117,134	19,347	5,161

TABLE 5.10. Region 8 - Billions of Btu's that Could be Supplied by the Substitution Technologies (Based on 1974 Energy Needs)

	<u>Solar</u>	<u>Wind</u>	<u>Geothermal</u>	<u>Gasification</u>	<u>Pyrolysis</u>	<u>Biomass Combustion</u>	<u>Anaerobic Digestion</u>	<u>Fermentation</u>	<u>Liquefaction</u>	<u>On- Farm Stream Flow</u>
Electric OVHS	85	--	25	212	--	127	106	106	--	25
Thermal (Frost Protection Crop Dry- ing)	1,615	--	239	598	239	2,392	598	478	239	72
Chemical (Ferti- lizer, Pesticide)	1,680	--	840	33,595	3,359	--	3,350	5,039	--	504
Mechanical Stationary (Irri- gation)	2,092	--	2,092	41,844	--	37,660	6,277	41,844	4,184	1,255
Mechanical Mobile (Preharvest Field Care, Harvest, Transport)	--	--	1,754	35,077	3,508	1,754	1,754	35,077	8,769	210
Total	5,472	--	4,950	111,326	7,106	41,933	12,094	82,544	13,192	2,066

CHAPTER 6

ACCEPTABILITY OF INTEGRATED FARM SYSTEMS TO OWNERS/USERS AND INSTALLATION AND MAINTENANCE PERSONNEL

Every commercial farmer in America works under a capital budget constraint. The impact of an Energy Integrated Farm System Program is predicated on technological acceptability within capital budget constraints. The previous chapters have discussed the development and potential of the EIFS program in technical terms and on an objective basis. This chapter addresses some of the factors affecting the subjective attitudes toward energy-integrated farm systems. The purpose of this chapter is to bring the insights and findings of the preceding chapters into perspective of a "bench mark" farm in each of the eight regions. This analysis is particularly important for those technologies that would be implemented on an individual farm scale.

Two factors affect acceptability: 1) the scale of use, and 2) the attitudes of those who will own/use the equipment and those who will install and maintain the energy-integrated farm systems. The scale of use involves the relative size of the EIFS compared to the normal scale of farm operations. The attitudes of the key players help determine whether anyone will be interested in selling, financing, installing, maintaining or finally using the EIFS.

Accordingly, the first point of this chapter will address indirectly the problem of appropriateness of scale of the technology by looking at typical farms in the various regions. Questions concerning whether a farm needs 50 gal of gas a year or 5,000 gal will be addressed. It makes a great deal of difference to the design, installation, operation and maintenance of the equipment.

In the second part of this chapter some of the viewpoints to be considered in attempting to determine acceptability of concepts for integrated farm systems will be briefly assessed.

6.1 SCALE OF EIFS USE

The scale of energy use on farms is expected to be an important consideration in the acceptability of energy integrated farm systems. This question is examined with the aid of example farms. The process we have used is to characterize average size farms in each of the eight regions (see Tables 6.1 - 6.6 for data about average farms). The farms range in size from 160 acres in the northeast to about 2,500 acres in the mountain west. Next model farms were assembled, each planted entirely with one of the eight major crops. Thus, each region potentially has eight farms. These are included in Appendix B where the energy needs of these farms are shown for gasoline, diesel, liquefied Petroleum Gas (LPG), natural gas, electricity, fertilizer, chemicals, etc.

From these we have carefully selected eight farms, one for each of the regions, that give a reasonable representation of American agriculture. The energy consumption of these eight farms is shown in Table 6.7. To further aid in recognizing what's involved and aid the reader in visualizing the scales involved, they are shown in conventional quantities such as gallons of gasoline, diesel, and LPG; cubic feet of natural gas; and kilowatt hours of electricity in Table 6.8.

Other types of farms exist, including dairies, orchards, and produce farms, etc. These farms have not been characterized although they would account for nearly 20% of agriculture. Dairies are particularly appropriate for consideration because of the unique opportunities for using biomass made available continuously. Therefore, Table 6.9 includes a characterization of an "average" dairy.

In the following section the scale of requirements is reviewed for each energy type for the major crops.

6.1.2 Where Energy Containing Materials are Needed

6.1.2.1 Gasoline

Gasoline use is universal to each farm studied and its use varies from two gal/day (i.e., 600 gal/yr) on a 220-acre farm raising corn in

TABLE 6.1. General Characterization of U.S. Farms

Total number of farms (1978)	2,680,150
Total acres (1978)	1,072,333,000
Irrigated acres (1974)	41,243,000
Average acres per farm	400.1
Total value of farmland and buildings	\$523,952,000,000

Source: U.S. Department of Agriculture 1980.

TABLE 6.2. Average Value of Farmland and Buildings by Region

	<u>\$/Acre</u>	<u>Average Size (Acres)</u>	<u>Average \$/Farm</u>
U.S. Region	488.76	400.1	195,553
1	752.00	159	119,568
2	582.00	244	142,008
3	1,174.00	219	257,106
4	741.00	206	152,646
5	319.00	852	271,788
6	334.00	571	190,714
7	173.00	2,570	446,610
8	430.00	1,907	820,010

Source: U.S. Department of Agriculture 1980.

TABLE 6.3. Average Value of Machinery, Motor Vehicles and Livestock

Value of machinery and motor vehicles	\$ 77,300,000,000
Average value of machinery and motor vehicles per farm	\$ 28,842
Value of livestock	\$ 32,000,000,000
Average value of livestock per farm	\$ 11,940

Source: U.S. Department of Agriculture 1980.

TABLE 6.4. Land Utilization of U.S. Farmland

	<u>% of Total Acreage</u>
Cropland	
Used for crops	34
Idle	2
Used of Pasture	8
Grassland Pasture	56

Source: U.S. Department of Agriculture 1980.

TABLE 6.5. Characterization of U.S. Farm Population (1977)

Total farm population	7,806,000 people
Average population per farm	2.88
Total hired workers	1,295,900
Average hired workers per farm	0.48

Source: U.S. Department of Agriculture 1980.

TABLE 6.6. Livestock by Type on U.S. Farms

	<u>Thousands of Head</u>
Cattle	116,265
Hogs	56,656
All Sheep	12,387
Chickens	386,531
Turkey breeder hens	3,045

Source: U.S. Department of Agriculture 1980.

TABLE 6.7. Energy in Millions of Btu for Various Farm Needs for
Example Farms in Each Region

<u>Crop (Acres)</u>	<u>Region 1</u> <u>Hay (160)</u>	<u>Region 2</u> <u>Soybeans (240)</u>	<u>Region 3</u> <u>Corn</u> <u>Grain (220)</u>	<u>Region 4</u> <u>Corn</u> <u>Silage (200)</u>	<u>Region 5</u> <u>Sorghum (570)</u>	<u>Region 6</u> <u>Cotton (570)</u>	<u>Region 7</u> <u>Wheat (2500)</u>	<u>Region 8</u> <u>Hay (1900)</u>
Gasoline	92	328	76	287	653	275	1920	1322
Diesel	5	435	258	189	872	563	1323	397
LPG	14	34	297	122	225	87	149	158
Natural Gas	6	13	17	2	663	993	396	2859
Electricity	2	8	14	8	55	77	360	6604
Fertilizers	421	113	904	650	1573	750	2230	320
Chemicals	---	<u>63</u>	<u>56</u>	<u>53</u>	<u>129</u>	<u>2359</u>	<u>33</u>	<u>0</u>
Totals	540	995	1622	1311	4170	5104	6411	11660

TABLE 6.8. Quantities of Various Energy Containing Materials Needed
on Example Farms in Each Region

<u>Crop (Acres)</u>	<u>Region 1 Hay (160)</u>	<u>Region 2 Soybeans (240)</u>	<u>Region 3 Corn Gain (220)</u>	<u>Region 4 Corn Silage (200)</u>	<u>Region 5 Sorghum Grain (850)</u>	<u>Region 6 Cotton (570)</u>	<u>Region 7 Wheat (2500)</u>	<u>Region 8 Hay (1900)</u>
Gasoline (gal/yr)	736	2624	608	2296	5225	2200	15360	10576
Diesel (gal/yr)	36	3100	1800	1400	6200	4000	9400	2800
LPG (gal/yr)	150	350	2100	1300	2400	900	1500	1650
Natural Gas (1000 ft ³ /yr)	5	13	16	1	620	920	370	2700
Electricity (kWh/yr)	590	2300	4100	2300	16100	23000	105000	1.93 x 10 ⁶
Fertilizer tons/yr	12.4	3.3	26.6	19.1	46.3	22	65.6	57.8
Pesticides etc., tons/yr		0.27	0.24	0.23	0.56	10.2	0.14	---

TABLE 6.9. Average Energy Used in Milk Production^(a)

	<u>Average Energy in Thousands Btu's per Head (a)</u>	<u>Average Energy per Farm in Millions of Btu's (b)</u>	<u>Units of Energy</u>
Gasoline	2392	185	1480 gal
Diesel	0	0	---
LPG	661	51	534 gal
Natural Gas	0	0	---
Electricity	<u>1530</u>	<u>118</u>	34574 kWh
Total	4583	354	

Source: U.S. Department of Agriculture 1976.

(a) For average herd size, which is 77.3 cows in the U.S. (USDA Agricultural Statistics 1978)

the midwest, or a 160-acre hay farm in the northeast, to about 42 gal/day or 15,000 gal/yr on a 2,500-acre wheat farm in the mountain west. The most striking conclusion is that supplying the gasoline fuels would span more than an order of magnitude in capacity just for the farms included in the eight example farms summarized in Table 6.8.

6.1.2.2 Diesel

Diesel is not universally used on all farms and in particular is used less on small farms and for equipment having light or intermittent duty. In the example farms, diesel usage varied from 1,400 gal/yr for a 200-acre farm growing corn silage to 9,400 gal/yr on a 2,500 acre wheat farm. This usage calculates to be about 4 to 25 gal/day.

6.1.2.3 Liquefied Petroleum Gas (LPG)

Liquefied petroleum gas use varies from 150 gal/yr to 2,400 gal/yr and its use ranges from around 2 gal/day or less to 5 gal/day (see Table 6.8). Again the range varies over more than an order of magnitude. Replacing LPG would require a wide range of ratings for the appropriate energy technologies.

6.1.2.4 Natural Gas

Natural gas use has been very modest on U.S. farms as the example farms reflect, possibly because farmers never had a "national farm gasification administration" to help with the costs of a distributing network covering the farm areas. Natural gas shows up in Regions 6 and 8 where it is extensively used to pump irrigation water and in processing agricultural products.

Replacing the natural gas use (in internal combustion engines) with a biomass gasifier would be more exacting than replacing it in thermal (heating) applications. Using it to replace all the pumping energy on a 2,000-acre hay farm would require about 10 million ft³ and on some other farms somewhat less. Gasifiers would have to span more than an order of magnitude in ratings to cover the market needs. These ratings would cover

a range from about 1 million ft³/day to about 30,000 ft³/day. With this range of gasifiers, the needs of many farms that use only a little natural gas for incidental heating needs would still not be met.

6.1.2.5 Electricity

The use of electricity on farms is almost universal but varies from 590 kWh/yr on a small hay farm in the northeast to about 3 million kWh/yr on a 1,900-acre western hay farm that uses electricity primarily to pump irrigation water. The uses are legion and the applications vary from those absolutely requiring electricity to those that could easily be substituted by other energy forms.

Some of the largest uses, such as irrigation, could be replaced by another motive source. For example, if 3 million kWh would be used in about 3,000 hr/yr, approximately 1,000 hp of prime mover would be needed on a 1,900-acre hay farm.

6.1.2.6 Fertilizers

Fertilizers are almost universally applied in U.S. farming. The use of nitrogenous fertilizers is dramatically less on those farms raising legume crops: beans, peas, soybeans, and alfalfa hay.

The total fertilizer energy is about 10% (on a farm growing legume crops) of what would be required for a farm growing conventional crops, which deplete the nitrogen content of the soil. The fertilizer energy requirements are as low as 113 million Btu/yr for a soybean farm (240 acres) compared to 2,230 million Btu's of fertilizer energy for a 2,500-acre wheat farm. In Table 6.8 this represents a 3 to 65 tons/yr range.

Since crop rotation is practiced on many farms and the rotation system includes legume crops, the fertilizer requirements would be expected to vary dramatically from year to year. These fertilizer energy figures do not include the normal practice of recycling farm wastes and byproducts to the soil. Production of nitrogenous fertilizers on the farm would be more attractive for those farms where heavy fertilization is absolutely required and crop rotation is impractical or

uneconomical, resulting in a stable year to year need. Some farms have been operated with vastly reduced input of imported (i.e., brought onto the farm) fertilizer (Lockeretz, et al. 1975). Lockeretz (1975) compares economic returns and energy consumption for corn belt farms that use inorganic fertilizers and pesticides with corn belt farms that use "organic" fertilizers. The "organic" farms used about one-third of the energy used by conventional farms. The standard of comparison for suggested systems that produce nitrogenous fertilizers on the farm may be the "organic farm."

6.1.2.7 Pesticides

The energy requirements to produce pesticides is quite negligible on many of the example farms. The standout exception is the Region 6 cotton farm, where half of the total farm energy is for chemicals used for herbicides and insecticides. This 570-acre farm used 50 times more energy for pesticides than most of the example farms. Recent developments indicate that this situation may change drastically since most pests are becoming resistant to a broad range of chemical control agents. In any case, chemical production for on-the-farm use appears to be somewhat remote.

6.2 THE ATTITUDES OF THOSE WHO OWN, USE, INSTALL AND MAINTAIN THE EIFS

Attention is often focused on particular aspects of the commercial chain involved in manufacturing, installing, using and finally maintaining various conversion technologies. An overview of the needs of the participants in this process is presented in the following paragraphs and an overall focus pinpointing some potential issues is established. A simplified version of the commercial chain involves manufacturers, financiers, distributors and tradesmen, users/owners, and of course, a number of others (who have been omitted for clarity).

The reactions of some potential market participants to the various candidate EIFS are estimated by PNL staff in Table 6.10. Several key issues are identified:

TABLE 6.10. Estimated Reaction of Market Participants to Candidate EIFS Technologies

	Solar	Wind	Geothermal	Low-Head Hydro	Biomass
Manufacturers	Could make solar packages	Could make wind machines	Architect/engineering firms could design a system	Architect/engineering firms could design a system	Architect/engineering firms could design a system
Financers	Could loan money, but are cautious	Could loan money, but are cautious	Will require other collateral	Will require other collateral	Will require other collateral
Distributors	Could handle, will probably "try a few"	Could handle, will probably "try a few"	Can stock parts if enough systems in	Can stock parts if enough systems in	Can stock parts if enough systems are installed
Tradesmen	Can install won't appreciate "call backs"	Can install won't appreciate "call backs"	Installed by construction crew	Installed by construction crew	Installed by construction crew
Users/Owners	Will initially tolerate tinkering, but will demand reliable trouble-free long term	Will initially tolerate tinkering, but will demand reliable trouble-free long term	Will require continued preventive maintenance	Will require seasonal supervision and maintenance	Will require continuous feeding removal and preventative maintenance

- All of the EIFS systems will have a strong tendency to be unique; getting them reduced to nice packaged products will be difficult. Solar and wind look a little closer to a product line right now.
- Financiers are going to want "a good reputation" or some tangible collateral for EIFS loans in addition to the EIFS itself.
- Distributors will have a very hard time with diversity of designs and concepts. They will "try a few" but won't plunge. Distribution will be a difficult problem and may leave farmers dealing "with the factory."
- The tradesman will have a hard time with diversity of designs and the spread of their territory. As a result, relationships with farmers may be strained.
- Users/owners. A major reason why farmers readily abandoned many old technologies, such as biomass operated threshing machines, was because the machines needed to be continuously fed or tended.
- The economics, of course, also turned toward other approaches - but the newer approaches also supplied convenience and dependability. Convenience and dependability will ultimately spell the difference between those EIFS successful concepts and unsuccessful concepts.

These comments don't represent a basis for discriminating among these concepts at this time, but they should be considered as specific designs are evaluated.

6.3 SUMMARY OF THE TECHNOLOGICAL ACCEPTABILITY OF THE EIFS

The key factor encountered in reviewing the scale of operation required for the various systems is that the needed scale varies by an order of magnitude or more. An industrial product planner will perceive that the concepts have to be suitable for modular use with little loss of efficiency, convenience, or economy--or a family of products sized for each major concept will be required.

The data in the appendices and Tables 6.7, 6.8, and 6.9 will be helpful in evaluating the suitability of various concepts in various

applications. One product class, "chemicals," is seen as being generally unsuitable for on-farm production although they might be suitable for large cooperatives. The scales of use vary over orders of magnitude. On this basis there are likely to be many farms where the scale is eminently suitable for production of portable fuels. For many other uses EIFS technologies appear to have reasonable scale so that they could be applied even in situations where short term economics (i.e., costs) might favor a conventional energy source.

This chapter can be summarized by listing several questions that are raised regarding the energy technologies:

- Will the technology fill a niche between the extremes of being so small in scale that it doesn't displace a valuable commodity or get so large in scale as to jeopardize the other needs of the farm operation (time, capital, etc.)?
- Will the technology provide the energy where it is needed when it is needed?
- Will the technology ultimately meet the needs of the infrastructure of its widescale deployment?

These questions are not independent of Chapters 1, 2, 3, and 4 and may be used as a kind of overview of some of the key issues to be met in getting EIFS off to a good start.

REFERENCES

- Anschutz, J. A., R. I. Lipper. 1975. Electric Use of Dairies in Kansas Paper presented to the Kansas Committee on the relation of Electricity to Agriculture, 1974-75 meeting.
- Baughman, G. R. and C. R. Parkhurst. 1976. Energy Consumption in Broiler Production. Transactions of the ASAE. 20(2):
- Bliss, C., and D. O. Blake. 1977. Silviculture Biomass Farms: Volume V - Conversion Processes and Costs. MTR-7347, Mitre Corporation, McLean, Virginia.
- Brow, R. S., R. Napoli, A. S. Goodman and L. Thatcher. 1978. "Status of Small Hydropower Studies in New York State." In Low-Head Hydro. Idaho Water Resources Research Institute, Moscow, Idaho.
- Buswell, A. M. and H. F. Mueller. 1952. "Mechanics of Methane Fermentation." Industrial and Engineering Chemistry, 44: 550-552.
- Coffman, J. A., and R. H. Hooverman. 1978. "Power from Wastes via Steam Gasification." ACS Symposium Series 76. pp. 252-273.
- Council for Agricultural Science and Technology. 1977. Energy Use in Agriculture: Now and for the Future. CAST Report No. 68, Iowa State University, Ames, Iowa.
- David, M. L., G. S. Hammaker, R. J. Buzenburg and J. P. Wagner, "Gasohol Economic Feasibility Study," Development Planning and Research Associates Inc. P.O. Box 727, Manhattan, Kansas 66502, July 1978.
- Dvoskin, Dan, and Earl O. Heady. 1976. Energy Requirements of Irrigated Crops in the Western United States. Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa.
- Elliott, D. L. "Synthesis of National Wind Energy Assessment" PNL-2220, WIND-5, 1977.
- Energy and U.S. Agriculture: 1974 and 1978. U.S. Department of Agriculture, Washington D.C., 1980.
- Energy and U.S. Agriculture: 1974 Data Base. U.S. Department of Agriculture Washington, D.C., 1976.
- Energy Research and Development Administration. 1977. Solar Energy for Agriculture and Industrial Process Heat, Program Summary. ERDA-77-72, Division of Solar Energy, Washington, D.C.
- Falgenhauser, D. L., 1978, "The W.W.P. View" in Low-Head Hydro-An Examination of an Alternative Energy Source, by J. S. Gladwell, Idaho Water Resources

Research Institute and C. C. Warmick, University of Idaho.

Frank, G. G. 1977. A Guide to Energy Savings for The Dairy Farmer. NTIS No. PR-270 076, Federal Energy Administration, Washington, D.C.

Friedrich, Robert A. 1978. Energy Conservation for American Agriculture. Environmental Law Institute State and Local Energy Conservation Project, Ballinger Publishing Company, Cambridge, Massachusetts.

Fritz, Jack J., et al. 1978. Status Review of Wood Biomass Gasification, Pyrolysis and Pelletization Technologies. MTR-8031 (draft), Mitre Corporation McLean, Virginia.

Goodwin, et al. USGS Circular 647.

Head, J. 1970. "Geothermal Energy for Greenhouse Heating." Ore Bin 32. Vol. 9, pp. 182-183.

"Inside DOE." October 5, 1979.

Kaufman, J. A., and A. H. Weiss. 1975. Solid Waste Conversion: Cellulose Liquefaction. National Environmental Research Center Report #EPA-670/275-031.

Lee, G. K. "Energy Intensiveness of Washington Agriculture and the Effects of Increases in Energy Prices on Washington Agriculture," in Agriculture and Energy, Academic Press, 1977.

Lipper, R. I., J. A. Anschutz, J. C. Welker. 1976. Energy Requirements for Commercial Beef Cattle Feedlots in Kansas. Paper No. MC76-301, American Society of Agricultural Engineers, St. Joseph, Missouri.

Lockertz, W. 1977. Agriculture and Energy. Academic Press, New York, NY.

Lockeretz, W., Klepper, R., Commoner, B., Gertler, M., Fast, S., O'Leary, D. and Blobaum, R. 1975. A Comparison of the Production, Economic Returns, and Energy Intensiveness of Corn Belt Farms that do and do Not Use Inorganic Fertilizers and Pesticides. PB-243 639. July 1975. Prepared for the National Science Foundation by Center for the Biology of Natural Systems, Washington University, St. Louis, Missouri.

Lomas, C. C., and M. J. Robinette. 1978. "Studying the Northwest Low-Head Hydro Potential." In Low-Head Hydro. Idaho Water Resources Research Institute, Moscow, Idaho.

Mansfield, E., J. Rapoport, A. Romeo, E. Villani, S. Wagner and F. Husic. 1977. The Production and Application of New Industrial Technology. W. W. Norton and Company, Inc., New York, New York.

Meinel. 1977. Applied Solar Energy, Reading, Mass, Addison-Wesley Publ. Co., (1976)

Mercer. 1978. "Very-Low-Head Hydroelectric Generation" in Low-Head Hydro-An Examination of an Alternative Energy Source, by J.S. Gladwell, Idaho Water Resources Research Institute and C. C. Warmick, University of Idaho.

Mikesell, R. D., et al. 1978. "A Thermal Process for Energy Recovery from Agricultural Residues." ACS Symposium Series 76, pp. 252-273.

Miles, T. R. 1975. "Consulting Engineers' Synopsis of Our Work" for the Oregon Field Sanitation Committee, December 5, 1976.

Miles, T. R., "Energies From the Field-USA," Presented to Sixth Annual Meeting, The Biomass Energy Institute, Winnipeg, Canada, 1977.

Moses, C. T., et al. 1978. "Co-Disposal of Sludge and Refuse in a Purox Converter." ACS Symposium Series 76, pp. 63-87.

Muffler. 1979. USGS Circular 790.

NASA/ASEE Systems Design Institute. 1974. Energy Recovery from Solid Waste. Vol. 2 Technical Report, NGT 44-005-114, University of Houston.

Program Plan - Non-Electric Applications of Geothermal Heat. 1977. Department of Energy, Division of Geothermal Energy (draft).

Pytlinski, J. T. 1978. "Solar Energy Installations for Pumping Irrigation Water." Solar Energy. 21(4): 260-261.

Rex R., "U.S. Geothermal Industries in 1978", Geo Chemical Energy Vol. 6, No. 7, July 1978.

Sealock, L. J., Jr., et al. 1978. "Catalyzed Gasification of Biomass." Paper presented at the First World Conference on Future Sources of Organic Raw Materials, July 1978, Toronto, Canada.

Skov, Niels A., and M. L. Papworth. 1975. The Pegasus Unit. Pegasus Inc., P.O. Box 121, Olympia, Washington.

Smith, R. J., J. A. Miranowski, R. L. Vetter. 1976. Energy Relationships for a 320-Acre Iowa Farm, An Attempt to Increase Production of Grain and Meat While Rendering the Farm Energy Self-Sufficient by Generating Methane Through Anaerobic Fermentation of Residues. NTIS no. PB-275 274, Agricultural Research Service, Hyattsville, Maryland.

The Handbook of Homemade Power. 1974. The Mother Earth News, Hendersonville, North Carolina.

U.S. Department of Agriculture. Agricultural Statistics 1978. U.S. Government Printing Office, Stock No. 001-000-03775-7.

U.S. Department of Energy. 1979. "Proposals for Energy Integrated Farm Systems, PON No. C501-79CS-40217.

U.S. Department of the Interior Geological Survey. 1970. The National Atlas of the United States of America. Washington, D.C.

USDA-Forest Service. 1976. The Feasibility of Utilizing Forest Residue for Energy and Chemicals. Report to the National Science Foundation and Federal Energy Administration, NSF-RA-7600/3.

Walden, O. 1978. Prepared Testimony before the Senate Energy Committee, Washington, D.C.

Wealey, H. L., M. M. Orgill and R. L. Drake. 1978. A Siting Handbook for Small Wind Energy Conversion Systems. PNL-2521/WC-60. Pacific Northwest Laboratory, Richland, Washington.

APPENDIX A

CONVERSION UNITS USED

APPENDIX A

CONVERSION UNITS USED

Gasoline	1 gal = 125,000 Btu
Diesel	1 gal = 140,000 Btu
LP Gas	1 gal = 95,500 Btu
Natural Gas	1 scf = 1,065 Btu
Electricity	1 kWh = 3,413 Btu
Fuel Oil	1 gal = 140,000 Btu
Coal	1 ton = 25.5×10^6 Btu
Fertilizer	1 ton = 34×10^6 Btu
Pesticides	1 ton = 230×10^6 Btu

APPENDIX B

CHARACTERIZATION OF U.S. AGRICULTURE

TABLE B.1. Average Farm Size (Regional), 159 Acres (Million Btu's/Average Farm)

	Corn		Soybeans	Winter Wheat	Hay	Cotton	Sorghum	
	Grain	Silage					Grain	Silage
Gasoline	250	192	109	124	92	114	125	182
Diesel	286	219	176	118	5	142	236	342
LPG	53	41	7	5	14	9	7	11
Natural Gas	267	20	1	0	6	0	7	10
Electricity	6	4	3	3	2	2	2	3
Fertilizers	468	465	142	308	421	462	275	269
Chemicals (Pesticides)	32	44	18	1	--	572	21	21
Other	<u>18</u>	<u>14</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>5</u>	<u>8</u>
Total ^(a)	1139	999	456	559	540	1301	678	846
Average acres per crop if farm is all in crop	37.7	12.1	34	10.4	54.3	2.2	3.6	4.5
Total these crops			158.8					
Total other crops			0.2					

(a) Each total assumes that entire farm (159 acres) is planted to corn grain or corn silage or soybeans, etc.

TABLE B.2. Average Farm Size (Region 2), 244 Acres (Million Btu's/Average Farm)

	Corn		Soybeans	Winter Wheat	Hay	Cotton	Sorghum	
	Grain	Silage					Grain	Silage
Gasoline	188	255	328	126	148	263	209	229
Diesel	147	335	435	189	1	683	320	351
LPG	54	73	34	7	24	56	37	41
Natural Gas	22	30	14	0	15	4	34	38
Electricity	6	8	8	3	6	9	4	5
Fertilizers	806	1005	113	610	664	757	595	526
Chemicals (Pesticides)	25	25	63	2	--	937	81	73
Other	<u>18</u>	<u>24</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>2</u>	<u>2</u>
Total	1366	1755	995	937	858	2709	1282	1265
Average Acres	20.7	2.4	127.3	11.4	27.2	30.0	2.9	0.8
Total these crops			222.7					
Total other crops			21.3					

TABLE B.3. Average Farm Size (Region 3), 219 Acres (Million Btu's/Average Farm)

	Corn		Soybeans	Winter Wheat	Hay	Cotton	Sorghum	
	Grain	Silage					Grain	Silage
Gasoline	76	77	216	166	233	205	241	280
Diesel	258	261	172	34	9	377	146	170
LPG	297	301	13	20	32	14	68	79
Natural Gas	17	18	2	--	11	0	13	16
Electricity	14	14	5	5	3	4	7	8
Fertilizers	904	901	46	431	493	414	565	663
Chemicals (Pesticides)	56	56	24	--	0	747	28	28
Other	<u>4</u>	<u>4</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>1</u>	<u>1</u>
Total	1626	1632	478	655	781	1761	1069	1245
Average Acres	96	3	75.7	17.2	25.1	0.7	2.5	0.2
Total these crops			220.4					
Total other crops			0					

TABLE B.4. Average Farm Size (Region 4), 206 Acres (Million Btu's/Average Farm)

	<u>Corn</u>		<u>Soybeans</u>	<u>Winter Wheat</u>	<u>Hay</u>	<u>Cotton</u>	<u>Sorghum</u>	
	<u>Grain</u>	<u>Silage</u>					<u>Grain</u>	<u>Silage</u>
Gasoline	253	287	199	128	402	0	0	0
Diesel	167	189	161	64	33	0	0	0
LPG	108	122	11	12	48	0	0	0
Natural Gas	2	2	2	0	23	0	0	0
Electricity	7	8	4	3	4	0	0	0
Fertilizers	747	650	25	304	135	0	0	0
Chemicals (Pesticides)	53	53	23	1	0	0	0	0
Other	<u>--</u>	<u>1</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
Total	1337	1312	425	512	645	0	0	0
Average Acres	61.8	12.5	26.9	6.1	47.7			
Total these crops			155					
Total other crops			51					

TABLE B.5. Average Farm Size (Region 5), 852 Acres (Million Btu's/Average Farm)

	<u>Corn</u>		<u>Soybeans</u>	<u>Winter Wheat</u>	<u>Hay</u>	<u>Cotton</u>	<u>Sorghum</u>	
	<u>Grain</u>	<u>Silage</u>					<u>Grain</u>	<u>Silage</u>
Gasoline	1048	489	608	602	304	0	653	946
Diesel	2556	1195	608	440	518	0	872	1263
LPG	1456	681	119	25	95	0	225	325
Natural Gas	1777	831	89	49	504	0	663	959
Electricity	297	139	30	15	49	0	55	79
Fertilizers	2621	2373	117	694	742	0	1573	2646
Chemicals (Pesticides)	190	190	93	9	0	0	129	129
Other	<u>1</u>	<u>1</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
Total	9946	5899	1664	1825	2212	0	4170	6347
Average Acres	98.1	17.4	25.7	167.8	129.6		61.4	4.4
Total these crops			504.5					
Total other crops			347.6					

TABLE B.6. Average Farm Size (Region 6), 571 Acres (Million Btu's/Average Farm)

	<u>Corn</u>		<u>Soybeans</u>	<u>Winter Wheat</u>	<u>Hay</u>	<u>Cotton</u>	<u>Sorghum</u>	
	<u>Grain</u>	<u>Silage</u>					<u>Grain</u>	<u>Silage</u>
Gasoline	594	977	445	392	572	275	617	670
Diesel	773	1272	519	396	119	563	724	787
LPG	268	442	78	50	107	87	179	195
Natural Gas	3219	5297	1189	465	457	993	2016	2189
Electricity	232	381	85	42	39	77	149	162
Fertilizers	2928	2882	533	843	1	750	1240	1935
Chemicals (Pesticides)	83	83	83	2	0	2359	218	218
Other	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
Total	8097	11334	2932	2190	1295	5104	5143	6156
Average Acres	28.4	2.5	17.7	229.3	65.5	116.8	87.2	2.2
Total these Crops			549.6					
Total other Crops			21.4					

TABLE B.7. Average Farm Size, 2570 Acres (Million Btu's/Average Farm)

	Corn		Soybeans	Winter Wheat	Hay	Cotton	Sorghum	
	Grain	Silage					Grain	Silage
Gasoline	3537	2668	0	1920	1557	4983	2448	547
Diesel	6784	5118	0	1323	1603	10249	3314	740
LPG	976	737	0	149	371	4298	1491	333
Natural Gas	7321	5522	0	396	2973	41366	13852	3097
Electricity	2423	1829	0	360	1603	3713	1477	330
Fertilizers	11624	13750	0	2230	1966	7389	5288	6485
Chemicals (Pesticides)	443	591	0	33	0	8330	759	759
Other	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
Total	33108	30215	0	6411	10073	80328	28629	12291
Average Acres	66.2	39.9		603.5	550.1	9.8	38	2.2
Total these Crops			1309.7					
Total other Crops			1260.3					

TABLE B.8. Average Farm Size (Region 8), 1907 Acres (Million Btu's/Average Farm)

	<u>Corn</u>		<u>Soybeans</u>	<u>Winter Wheat</u>	<u>Hay</u>	<u>Cotton</u>	<u>Sorghum</u>	
	<u>Grain</u>	<u>Silage</u>					<u>Grain</u>	<u>Silage</u>
Gasoline	1650	1384	0	467	1322	2416	1182	667
Diesel	4256	3572	0	383	397	4613	1709	965
LPG	71	59	0	27	158	0	128	72
Natural Gas	782	656	0	299	2859	58856	10084	5694
Electricity	4190	3515	0	360	6604	5616	6230	3518
Fertilizers	11624	13750	0	2230	1966	7389	5288	6485
Chemicals (Pesticides)	236	236	0	31	0	3665	235	235
Other	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>	<u>0</u>
Total	19677	20721	0	7919	11660	30174	28945	11328
Average Acres	30.5	25.1		433	327.2	164.0	19	1.1
Total these Crops			999.9					
Total other Crops			907					

TABLE B.9. Energy in Thousands of Btu's per Milk Cow by Fuel Type

<u>Region</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>
Gasoline	2232	2738	2464	2165	2645	3038	1711	2950
Diesel	0	0	0	0	0	0	0	0
LPG	559	944	701	342	818	1084	633	1068
Natural Gas	0	0	0	0	0	0	0	0
Electrical	<u>1592</u>	<u>1398</u>	<u>1481</u>	<u>1688</u>	<u>1384</u>	<u>1304</u>	<u>870</u>	<u>1517</u>
Total	4383	5080	4646	4195	4847	5426	3214	5535

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