EFFICIENT USE AND CONSERVATION OF ENERGY IN THE AGRICULTURAL SECTOR

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Contents

1. Introduction
2. Energy Usage
3. Energy Efficiency Measures
4. Conservation Agriculture
5. Renewable Sources
5.1. Solar Energy
5.1.1. Photovoltaics
5.1.2. Crop Drying
5.1.3. Greenhouse Heating
5.1.4. Lighting, Space Heating, and Water Heating
5.2. Wind Energy
5.3. Geothermal Energy
6. Biomass: Energy from Agriculture
6.1. Conversion and Use of Biomass Energy
6.2. Perennial Energy Crops
Glossary
Bibliography
Biographical Sketches

Summary

The world relies on agriculture to feed humanity. We simply cannot survive without food, and therefore, without agriculture. Energy is an essential component of agricultural production. It fuels the equipment, irrigates the crops, fertilizes the soil, sustains the livestock, transports the food, and processes the food into its final forms. As the population continues to grow, more agricultural production is required to support the increased food demand.

At the same time, energy and environmental constraints mandate that agricultural production be accomplished effectively with minimal energy consumption. It is necessary to increase agricultural yields per unit area of land, while preserving the soil integrity and environment. Efficient energy management practices will help achieve and maintain this delicate balance. This topic and sub-articles present a wide variety of energy-efficiency opportunities as they relate to sustainable agriculture.

1. Introduction

Agriculture is a core sector of the global economy. As countries mature and grow, it stimulates the establishment of regional manufacturing and service sector spin-offs. The existence of many industries depends on agricultural activity. As technological sophistication in agriculture progresses, this sector will transform into a more autonomous economic entity. It will be able to control terms for the purchase of goods and services. It is likely and even probable that some manufacturing processes will shift to agricultural sites, as on-site quality control solutions are developed.

Agricultural production, however, is increasingly strained by limitations in energy and arable land. This problem is growing due in large part to population growth—more food production is necessary to meet the requirements of a growing population. With the increase in population, more land is required to produce the needed output, or higher yields are necessary per unit area of land. To intensify the challenge, a considerable quantity of arable land is lost each year to erosion, increased salinity, and waterlogging. In fact, roughly one-third of the world's cropland was lost during a 40-year period between the mid-1900s and 1990s. This loss equated to about 1.5 billion hectares of land. To alleviate the increased land requirements, deforestation and increased fertilization practices are continuing, with obvious adverse environmental impacts. Future technological efforts in agriculture should focus on increased yields per unit area of cropland by means that minimize energy usage and promote sustainability.

This topic and the articles contained within it provide descriptions of energy management opportunities in the agricultural sector. Specific attention is given to food production by crop and livestock activities, and food processing energy requirements are also briefly addressed. Section 2 describes agricultural energy usage patterns in various countries of the world, and discusses the primary energy-consuming segments. Section 3 summarizes energy-efficiency opportunities for each of these primary segments. This section also refers the reader to articles containing more detailed descriptions of energy efficiency in the three highest energy-consuming segments: pumping and irrigation systems, agricultural equipment, and fertilizer production and use. Section 4 describes a concept toward sustainable agriculture that is promoted by the United Nations. The approach is termed "conservation agriculture." Section 5 discusses the applicability of various renewable energy sources to agricultural applications. Finally, Section 6 looks at one particular renewable energy source—biomass—in more detail, as it is generated in large part by agriculture.

2. Energy Usage

Energy is required for many aspects of the agriculture industry and the industries that support agriculture. Agriculture can be defined in several ways. In its most general sense, agriculture includes livestock, food crops, energy crops, fibers, ornamental plants, forestry activities, hunting, fishing, mariculture, and aquaculture. Table 1 lists the energy consumption in agriculture for selected countries as a percentage of total energy consumption. These values include forestry and fishing activities in the agricultural sector. The table further compares data from 1987 with data from 1997. Of the countries listed, the agriculture sector of Jamaica has experienced the most significant rise in energy consumption relative to total energy consumption—the percentage rose from 3.1% to 11.9%. For several of the countries listed, including the United States, Australia, Brazil, France, Germany, Japan, Mexico, New Zealand, the United Kingdom, and most notably, Cuba, the percentage of total energy consumption used by agriculture decreased between 1987 and 1997. For developing countries combined, agriculture's share of energy consumption decreased from 3.8% to 2.9%, and the world's share decreased from 3.8% to 2.8%. However, for developed countries as a whole, agriculture's share increased from 2.3% to 2.8%. In summary, agriculture as defined in Table 1 comprises roughly 3% of total energy consumption.

Country	**Energy consumption in agriculture[a] (% of total consumption)**	
	1987	1997
Argentina	5.8	6.7
Australia	2.5	2.3
Brazil	5.9	5.2
Canada	1.8	2.3
Cuba	6.2	3.1
Denmark	4.7	6.5
France	2.2	2.0
Germany	1.2	1.1
Ghana	0.7	1.0
Israel	1.0	1.1
Jamaica	3.1	11.9
Japan	3.5	3.2
Mexico	3.0	2.7
New Zealand	3.1	2.5
Philippines	5.1	8.6
Romania	2.2	3.1
South Africa	2.6	3.4
Turkey	4.9	5.3
United Kingdom	0.9	0.8
United States	1.2	1.1
Developed countries	2.3	2.8
Developing countries	3.8	2.9
World	3.8	2.8

[a] For the data in this table, the agriculture sector encompasses all agricultural, forestry, and fishing activities. It does not include post-processing of agricultural products.

Table 1. Energy consumption in agriculture for selected countries: percentage of total energy consumption. Source: data compiled from the International Energy Agency (IEA) and World Resources Institute, Table ERC.3: Energy consumption by economic sector, <www.wri.org/wri/wr-00-01/pdf/erc3n_2000.pdf.>

In the current treatment, the focus is on energy use in agriculture for food production. Specific attention is placed on crop and livestock production. Therefore this treatment excludes land activities such as hunting, forestry, fiber crops, and ornamental plants, and water activities such as fishing, aquaculture, and mariculture. Though emphasis is placed on food production, support industries that bring the food from the farm to the table are identified. Figure 1 shows a simplified flow diagram of food from agriculture to the table. Support industries and activities include transportation, food processing, the wholesale and retail trade, and final preparation. Transportation can be in the form of food transport between farms, post-processing plants, wholesale and retail locations, and restaurants and homes. Transportation is also required for delivering agricultural inputs, such as fertilizers, livestock, feeds, and seeds, to farms. Food processing requires a large amount of energy and is discussed briefly in a subsequent section. Wholesale and retail activities require energy for refrigeration and general storage. Final preparation entails energy for refrigeration, cooking, dishwashing, and general storage.

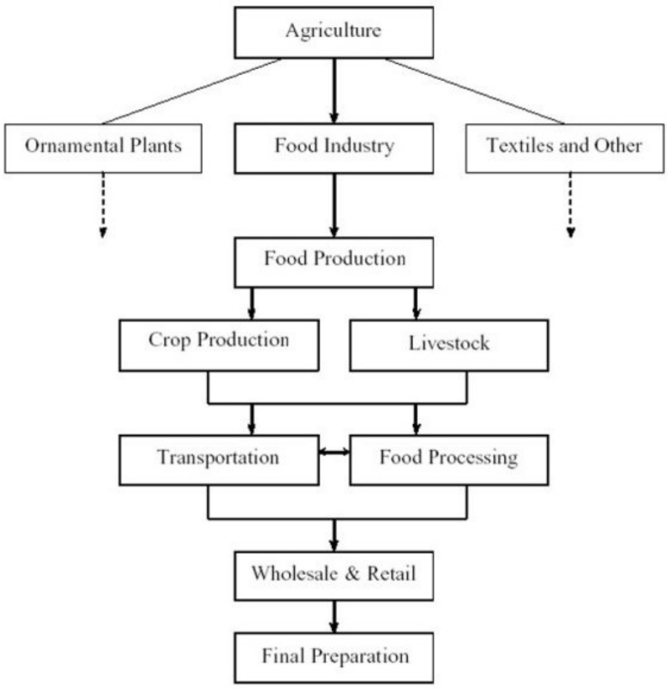

Figure 1. Simplified diagram of the flow of food from agriculture to final preparation

To put energy use in food production into perspective, Table 2 compares the production of meat, cereal crops, and root and tuber crops for selected countries. For the countries listed, the United States produces the most meat, with production at more than 35 million metric tons. Meat production is also notable for Brazil, France, and Germany. The United States is also the largest producer of cereal crops, producing over 340 million metric tons. However, of the countries listed, France, the United Kingdom, Germany, Denmark, Japan, and New Zealand all produce more cereal per hectare than the United States. For the listed countries, root and tuber production is highest for Brazil, followed by the United States. However, New Zealand, the United Kingdom, and Israel have the highest root and tuber yields per hectare. For meat and cereal, worldwide production is divided roughly evenly between developed and developing countries, with production slightly higher for developing countries. For roots and tubers, production is clearly dominated by developing countries. Nevertheless, average yields per hectare are smaller for developing countries when compared to developed countries, due in part to technology gaps.

Country	Meat	Cereal crops		Root and tuber crops	
	Production (1000 metric ton)	**Yield (kg per ha)**	**Production (1000 metric ton)**	**Yield (kg per ha)**	**Production (1000 metric ton)**
Argentina	3643	3260	33 639	22 822	3084
Australia	3335	1995	32 534	31 061	1304
Brazil	12 184	2458	44 725	12 754	26 476
Canada	3320	2737	53 020	27 091	4005
Cuba	210	1973	501	5783	815
Denmark	1904	6130	9351	39 017	1569
France	6533	7109	64 578	37 017	6378
Germany	6069	6366	44 067	39 841	12 446
Ghana	140	1365	1751	11 027	11 109
Israel	323	1776	144	40 704	305
Jamaica	82	1227	3	16 612	327
Japan	3081	6023	12 995	26 265	4937
Mexico	3911	2653	28 839	21 290	1441
New Zealand	1334	5637	930	42 676	480
Philippines	1848	2336	14 563	6728	2767
Romania	1168	2868	17 122	13 157	3372
South Africa	1212	2220	12 104	22 068	1633
Turkey	1206	2196	30 758	24 556	5122
United Kingdom	3658	6880	23 585	41 105	6952
United States	35 085	5352	340 985	37 570	22 392
Developed countries	101 697	3372	875 983	17 436	189 047
Developing countries	112 771	2701	1 198 482	11 688	448 585
World	214 557	2949	2 074 498	12 958	638 438

Note: Meat production includes all meat except for fish. Cereal crops include all dry grains for seed and feed (not hay or harvested green crops). Root and tuber crops include all crops for human consumption.

Table 2. Average food and agricultural production for selected countries, 1996–1998. Source: data compiled from the Food and Agriculture Organization of the United Nations (FAO) and World Resources Institute, Table AF.1: Food and agricultural production, <www.wri.org/wri/wr-00-01/pdf/af1n_2000.pdf.>

There are four main factors that contribute to food production energy consumption. Each factor is an input to the food production process. Figure 2 depicts these energy-consuming inputs: fertilizers and other chemicals, farm equipment, irrigation and pumping, transportation, and other miscellaneous inputs. The three most significant energy consumers are fertilizers, farm equipment, and pumping and irrigation. Each of these categories is treated in a separate article within this topic.

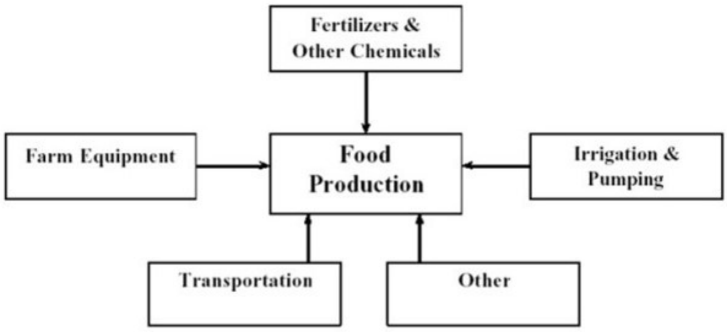

Figure 2. Energy-consuming inputs to food production

Table 3 summarizes data for selected countries that illustrate the significance of the three main categories of energy-consuming agricultural inputs. The table also shows the total cropland for each of the countries, as well as the number of hectares of cropland per 1000 people. The percentage of total cropland that is irrigated depicts the relative importance of irrigation. The annual amount of fertilizer applied per hectare shows how various countries fertilize their cropland. Finally, the number of tractors per 1000 agricultural workers is representative of the level of farm equipment utilized. Of the countries listed, Australia and Canada have the largest amount of cropland per capita; however, the United States has the vast majority of total cropland—over 10% of the world's cropland. Japan and Israel irrigate the largest portion of their cropland of the listed countries. In fact, Japan irrigates over three-fifths of its cropland, and Israel irrigates almost 50%. For the world, the average amount of cropland irrigated is 18%. Japan and Israel also apply the largest amount of fertilizer per hectare of the countries listed. Japan uses more than four times the worldwide average. Canada and the United States employ the largest number of tractors per agricultural workers. Indeed, Canada uses 1.7 tractors per worker and the United States uses 1.5 tractors per worker. In comparison, Ghana and the Philippines use only 1 tractor per 1000 agricultural workers.

As mentioned earlier, industries that support the food industry (for example, processing, transportation, the wholesale and retail trade, and preparation) are also significant energy consumers. Of these, the most significant energy consumer is the processing industry. Food processing takes farm products and modifies them for human consumption. In some cases this includes preserving perishable products. Much of the energy in food processing occurs in industry. However, increasingly as farms consolidate, some level of food processing is being performed on the farm.

Country	Cropland		Irrigated land (% of cropland)	Annual fertilizer use (kg per ha of cropland)	Tractors (# per 1000 agricultural workers)
	Total (1000 ha)	ha per 1000 people			

Argentina	27 200	763	6	28	190
Australia	53 100	2898	5	43	704
Brazil	65 300	399	5	78	58
Canada	45 700	1510	2	67	1678
Cuba	4450	402	20	52	96
Denmark	2373	451	20	167	1133
France	19 468	333	9	262	1256
Germany	12 060	147	4	250	960
Ghana	4550	244	0	4	1
Israel	437	75	46	360	323
Jamaica	274	109	12	85	11
Japan	4295	34	63	440	681
Mexico	27 300	290	24	54	20
New Zealand	3280	872	9	216	437
Philippines	9520	133	16	82	1
Romania	9900	439	31	41	88
South Africa	16 300	421	8	51	60
Turkey	29 162	460	14	66	60
United Kingdom					898
United States	179 000	659	12	151	1515
Developed countries	476 872	369	14	136	NA
Developing countries	853 994	189	24	96	NA
World	1 510 442	259	18	97	NA

Table 3. Agricultural land and inputs for selected countries, 1997. Source: data compiled from the FAO, World Bank Group, Table 3.2: Agricultural inputs, <www.worldbank.org/data/wdi2001/pdfs/tab3_2.pdf,> and World Resources Institute, Table AF.1: Food and agricultural production, <www.wri.org/wri/wr-00-01/pdf/af1n_2000.pdf.>

The North American Industry Classification System (NAICS) is used to classify the various industries in the United States. The system uses NAICS codes, which are numbers consisting of between two and six digits. Two digit numbers identify the particular sector (for example, NAICS 31: Manufacturing). Three digit numbers identify the sub-sector (for example, NAICS 311: Food Manufacturing). Four digit numbers represent the industry group (for example, NAICS 3112: Grain and Oilseed Milling). Five digit numbers refer to the industry (for example, NAICS 31121: Flour Milling and Malt Manufacturing), and six digit numbers refer to the specific US industry (for example, NAICS 311211: Flour Milling). The food manufacturing industrial subsector of the United States includes 9 industry groups, 22 industries, and 39 specific US industries. The nine food manufacturing industries and their NAICS codes are as follows:

- 3111 Animal Food Manufacturing
- 3112 Grain and Oilseed Milling
- 3113 Sugar and Confectionery Product Manufacturing
- 3114 Fruit and Vegetable Preserving and Specialty Food Manufacturing
- 3115 Dairy Product Manufacturing
- 3116 Animal Slaughtering and Processing
- 3117 Seafood Product Preparation and Packaging
- 3118 Bakeries and Tortilla Manufacturing
- 3119 Other Food Manufacturing

Activities in the food manufacturing subsector can also be referred to as food processing activities. The terms "food manufacturing" and "food processing" are used interchangeably in this text.

The basic function of food manufacturing or processing is to convert raw agricultural outputs to food products. Specific activities within the food manufacturing sector include food preservation, packaging, and refrigeration and storage. Each of these main activities requires a significant quantity of energy. In addition, buildings and vehicles, as well as miscellaneous support functions associated with food processing activities, require substantial energy inputs. Figure 3 shows an approximate breakdown of energy use by end-use in the US food manufacturing subsector in 1998. Direct process uses are process heating, process cooling and refrigeration, machine drive, and other miscellaneous process uses, and account for 45% of total fuel consumption. Boiler fuel is an indirect process use, and accounts for 46% of total fuel consumption. Direct nonprocess uses account for 9% of total energy use and include heating, ventilation, and air conditioning (HVAC), lighting, onsite transportation, and other nonprocess uses. Process heat is required for such processes as drying, cooking, pasteurization, and sterilization, and consumes a large share of energy as shown in the figure (17%). Process cooling and refrigeration includes activities such as simple food cooling, freezing, and storage, and utilizes about 6% of total energy. Machine drive systems and other processes each represent about 11% of total energy use. Nonprocess uses, including lighting, HVAC, transportation, and on-site electricity generation, require only about 9% of total energy use.

In 1998, total consumption in the US food manufacturing subsector was 1101×10^{12} kJ (1044×10^{12} Btu). Three of the most significant energy sources for the food manufacturing industry in the United States are natural gas, electricity, and coal. Figure 4 shows the 1998 breakdown of energy use by source for fuel and nonfuel purposes in the food manufacturing industry. Natural gas accounted for more than half of the sector's energy consumption in 1998. Electricity was the next largest energy source, accounting for 20%. Coal contributed about 12% of the energy. Distillate and residual fuel oil are less significant energy sources for the food manufacturing industry; together they supplied about 3% of the energy in 1998.

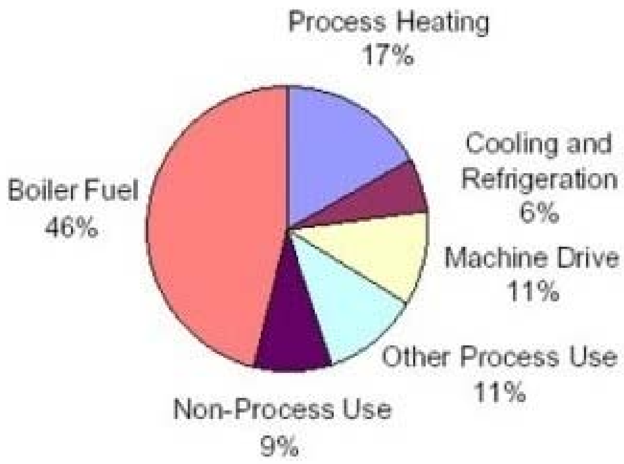

Figure 3. End-use of fuel consumption, 1998 (United States). Food manufacturing industry (NAICS 311). Total energy use = 1101 x 10^{12} kJ (1044 x 10^{12} Btu). Source: data compiled from the Energy Information Administration (EIA). (1998). Manufacturing Energy Consumption Survey (MECS), Table N6.2: End uses of fuel consumption.

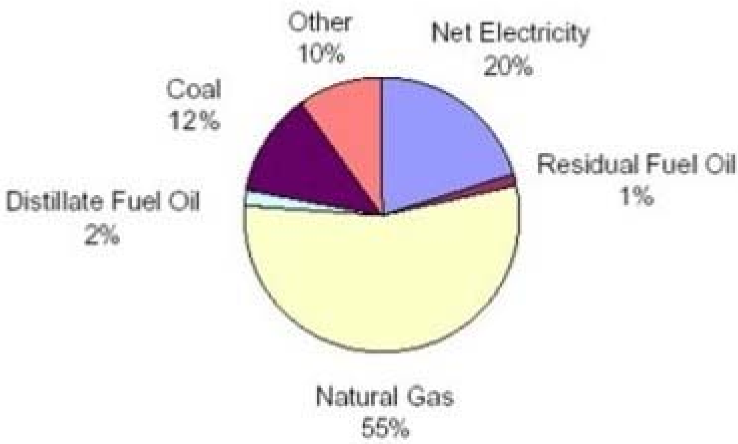

Figure 4. First use of energy for all purposes, 1998 (United States). Food manufacturing industry (NAICS 311). Total energy use = 1101 x 10^{12} kJ (1044 x 10^{12} Btu). Source: data compiled from EIA. (1998). MECS, Table N1.2: First use of energy for all purposes.

Some of the specific US food industries with the highest energy consumption include wet corn milling (NAICS 311221), beet sugar manufacturing (NAICS 311313), soybean processing (NAICS 311222), meat processing (NAICS 311612), fruit and vegetable canning (NAICS 311421), and frozen fruit, juice, and vegetable manufacturing (NAICS 311411).

For canned food, the majority of energy is used in manufacturing the metal cans, but little is required for subsequent storage. The opposite is true for frozen foods, in which the packaging requires little energy compared with that required for frozen storage.

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Biographical Sketches

Clark Gellings' 30-year career in energy spans from hands-on wiring in factories and homes to the design of lighting and energy systems to his invention of "demand-side management" (DSM). Mr. Gellings coined the term DSM and developed the accompanying DSM framework, guidebooks, and models now in use throughout the world. He provides leadership in EPRI, an organization that is second in the world only to the US Department of Energy (in dollars) in the development of energy efficiency technologies. Mr. Gellings has demonstrated a unique ability to understand what energy customers want and need and then implement systems to develop and deliver a set of R&D programs to meet the challenge. Among Mr. Gellings' most significant accomplishments is his success in leading a team with an outstanding track record in forging tailored collaborations—alliances among utilities, industry associations, government agencies, and academia—to leverage R&D dollars for the maximum benefit. Mr. Gellings has published 10 books, more than 400 articles, and has presented papers at numerous conferences. Some of his many honors include seven awards in lighting design and the Bernard Price Memorial Lecture Award of the South African Institute of Electrical Engineers. He has been elected a fellow in the Institute of Electrical and Electronics Engineers and the Illuminating Engineering Society of North America. He won the 1992 DSM Achiever of the Year Award of the Association of Energy Engineers for having invented DSM. He has served as an advisor to the U.S. Congress Office of Technical Assessment panel on energy efficiency, and currently serves as a member of the Board of Directors for the California Institute for Energy Efficiency.

Kelly E. Parmenter, Ph.D. is a mechanical engineer with expertise in thermodynamics, heat transfer, fluid mechanics, and advanced materials. She has 14 years of experience in the energy sector as an engineering consultant. During that time she has conducted energy audits and developed energy management programs for industrial, commercial, and educational facilities in the United States and in England. Recently, Dr. Parmenter has evaluated several new technologies for industrial applications, including methods to control microbial contamination in metalworking fluids, and air pollution control technologies. She also has 12 years of experience in the academic sector conducting experimental research projects in a variety of areas, such as mechanical and thermal properties of novel insulation and ablative materials, thermal contact resistance of pressed metal contacts, and drag reducing effects of dilute polymer solutions in pipe flow. Dr. Parmenter's areas of expertise include: energy efficiency, project management, research and analysis, heat transfer, and mechanical and thermal properties of materials.