Report No. CSS00-04
December 6, 2000

Center for Sustainable Systems
University of Michigan

Life Cycle-Based Sustainability Indicators for Assessment of the U.S. Food System

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a report of the Center for Sustainable Systems
Report No. CSS00-04

DOCUMENT DESCRIPTION

LIFE CYCLE-BASED SUSTAINABILITY INDICATORS FOR ASSESSMENT OF THE U.S. FOOD SYSTEM
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The Center for Sustainable Systems, Report no. CSS00-04, Ann Arbor, Michigan, December 6, 2000.
59 p., tables, figures, appendices.

This document is available online: http://www.umich.edu/~css

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PREFACE

The impetus for this report came from a workshop organized by the Center for Sustainable Systems entitled "A Life Cycle Approach to Sustainable Agriculture Indicators," held February 26-27, 1999. The workshop brought together 60 participants including organic and conventional farmers, agri-business representatives, state and national level governmental agents, non-governmental organization representatives, and sustainable agriculture and agroecology academics. The objectives of the workshop were:

1. To introduce the concept of life cycle assessment as it applies to agriculture
2. To initiate a dialog among resource professionals, active farmers, government agencies and faculty members in the Great Lakes/ North Central Region to begin to form a comprehensive, interdisciplinary understanding of sustainable agriculture.
3. To develop an initial set of performance indicators to gauge the environmental, economic, and social impacts of all stages of the agricultural life cycle.

The initial set of indicators became a framework for the development of this report. Proceedings of the workshop are also available through the Center for Sustainable Systems (http://www.umich.edu/~nppcpub/resources/compendia/Proceedings.PDF).

Dedicated to my grandfathers, Carl J. Heller and David R. Gordon, each gentlemen who made a good living and raised a family in the oldest (and still challenged) of professions: farming.

\- Martin Heller

Life Cycle-Based Sustainability Indicators for Assessment of the U.S. Food System

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ABSTRACT

The United States food system, from field to table, is at a crossroads for change. Improving the sustainability of this complex system requires a thorough understanding of the relationships between food consumption behaviors, processing and distribution activities, and agricultural production practices. The product life cycle system is a useful framework for studying the links between societal needs, the natural and economic processes involved in meeting these needs, and the associated environmental consequences. The ultimate goal is to guide the development of system-based solutions.

This report presents a broad set of indicators covering the life cycle stages of the food system. Indicators address economic, social, and environmental aspects of each life cycle stage: origin of (genetic) resource, agricultural growing and production, food processing, packaging and distribution, preparation and consumption, and end of life. The report then offers an initial critical review of the condition of the U.S. food system by considering trends in the various indicators.

Multiple threats to the long-term vitality of the U.S. food system demonstrate that the current system is not economically, socially, or environmentally sustainable. Key indicators supporting this conclusion include: rates of agricultural land conversion, income and profitability from farming, degree of food industry consolidation, fraction of edible food wasted, diet related health costs, legal status of farmworkers, age distribution of farmers, genetic diversity, rate of soil loss and groundwater withdrawal, and fossil fuel intensity. We suggest that the most effective opportunities to enhance the sustainability of the food system exist in changing consumption behavior, which will have compounding benefits across agricultural production, distribution and food disposition stages.

INTRODUCTION

Agricultural practices in the United States, as in much of the world, have changed dramatically over the past century. Today, farmers account for less than one percent of the U.S. population yet still manage to adequately feed and clothe America while exporting some $50 billion in agricultural goods, more than six times (in real dollar value) what they did in 1940[1]. The unprecedented yield increases of the Green Revolution era, however, were not gained without cost to environmental health. Similarly, industrial-model consolidation within agriculture and food processing in the U.S. has had a profound affect on the socio-economic face of the nation, especially in rural areas. Numerous indicators show that U.S. agriculture is in a state of major transition: farms continue to grow in size while the number of farm operators decrease; the average age of farmers is on the rise; alternative methods of production, from biotechnology to organic, rally for broader acceptance. Today, agriculture is challenged with a paradigm shift from an emphasis on perpetual gains in productivity to one that embraces the concept of sustainability.

Yet, despite more than a decade of developing and refining in the literature and broad use of the term, a widely accepted, pragmatic definition of "sustainable agriculture" does not exist[2-4]. Hansen (1996) provides a thorough review of approaches to sustainability and proposes that a sustainability concept useful in guiding change in agriculture should be literal, system-oriented, quantitative, predictive, stochastic and diagnostic. Among others contributing to the development of a sustainable agriculture concept, including the U.S. Department of Agriculture (USDA)[5], there tends to be agreement that an appraisal of sustainability should integrate economic, social and environmental dimensions. Given agriculture's unequivocal link with natural resources, however, it is not surprising that initial efforts to develop methodology for assessment and to implement change have focused on ecological or environmental aspects[2, 3].

In general, a sustainable system is one that can be maintained at a certain state or quality on a long-term time horizon. This "quality" of the system can often be evaluated by following trends in certain indicators. When addressing sustainability it is critical to keep in mind the ultimate societal need that is met by the system in question: in agriculture this is to provide necessary food and fiber. The long-term future of agricultural production, therefore, can not be assessed without consideration of the consumption patterns and processes that drive production. In other words, a sustainable food system must simultaneously address production and consumption impacts and demands. A life cycle framework offers a systematic means of linking production and consumption. This report introduces a set of economic, social and environmental indicators that were developed using a life cycle framework through a workshop organized by the Center for Sustainable Systems. The report then provides an initial assessment of the U.S. food system by examining trends with respect to these indicators.

FRAMEWORK AND SCOPE

Life cycle assessment (LCA) is an analytical method used to evaluate the resource consumption and environmental burdens associated with a product, process, or activity[6]. LCA provides a systems-based accounting of material and energy inputs and outputs at all stages of the life cycle: acquisition of raw materials, production, processing, packaging, use, and retirement. This holistic assessment provides an environmental profile of the product system.

Since the standard LCA method has been applied mainly to manufactured products, bottlenecks and methodological challenges arise in application to agricultural products. Many of these challenges have been addressed by researchers[7-9] and the numbers of LCAs evaluating agricultural and food production processes are increasing[10-13].

While our inspiration is derived from an understanding and appreciation of the LCA method, the intention of this report is not to attempt a quantitative LCA of the U.S. food system. Instead, we hope to encourage "life cycle thinking" in approaches to sustainable agriculture and food consumption. A comprehensive LCA of the food system is not possible; yet, a life cycle framework does provide a systematic basis for developing indicators.

Table 1 presents the full matrix of sustainability indicators proposed. The rows represent major stages of the food system: origin of resource (seed production and animal breeding); agricultural growing and production; food processing, packaging, and distribution; preparation and consumption; and finally end of life, or disposal. Indicators for each stage are categorized into the "triad" of sustainability: economic, social, and environmental. Also identified in Table 1 are the primary stakeholders involved or influential in each stage of the food system.

The LCA methodology focuses on the biophysical impacts of a product system: resource depletion, energy consumption, water and air pollution, human health impacts, waste generation. Where appropriate, these types of indicators have been included in the food system assessment. While the standard LCA methodology does not specifically include a cost evaluation of the system, other design-based approaches, such as Life Cycle Design[14], have incorporated economic aspects. Indicators of economic sustainability in the food system are included in this assessment, but as can quickly be seen in Table 1, these economic indicators go beyond cost consideration. In many incidences, the division between economic, social, and environmental indicators is somewhat arbitrary since particular indicators often address more than one aspect of sustainability. The divisions presented in Table 1 are maintained throughout the report primarily for organizational purposes.

Important in any systems-based assessment is a clear definition of the system boundaries observed. In the following assessment, the system boundary considered is the food system of the United States. Thus, while fiber and other biomass production can be a significant part of U.S. agriculture, the focus here is on food production – providing human sustenance. Given the national average level of much of the data used, however, the disaggregation of food from other agricultural production is not completely possible. Similarly, it is extremely difficult to establish rigorous geographic boundaries around the U.S. food system. U.S. agriculture exports a large portion of its production. Agricultural imports are also significant. To be complete, many indicators should be corrected for agricultural trade ratios: this has not been attempted here. Furthermore, national balances on resource inputs such as fossil fuels also factor into an overall assessment of sustainability. The role of U.S. agriculture in international relations and economies should also considered in a rigorous assessment of the food system. Such discussion is beyond the scope of this report. Population and carrying capacity are key parameters in assessing the sustainability of the U.S. food system. Population growth imposes additional stress on the system and there is increasing recognition of the limits in population (carrying capacity) that can be sustained by the biophysical system. The present analysis, however, does not directly explore such population dynamics.

The assessment of the life cycle food system is conducted at a national scale, providing a directional overview of the sustainability of the U.S. food system. Thus, while there can be significant regional and temporal variations in indicators, this assessment offers the general

Table 1: Life Cycle Sustainability Indicators for the Food System

Stakeholders	Life cycle stage	INDICATORS		
		Economic	**Social**	**Environmental**
Farmers Breeders Seed Companies	Origin of (genetic) resource – seed production, animal breeding	-degree of farmer/operator control of seed production/breeding	-diversity in seed purchasing and seed collecting options -degree of cross-species manipulation	-ratio of naturally pollinated plants to genetically modified/ hybrid plants per acre -reproductive ability of plant or animal -% of disease resistant organisms
Farm operators Farm workers Ag. Industry Ag. Schools Government Animals	Agricultural growing and production	-rates of agricultural land conversion -% return on investment -cost of entry to business -farmer savings and insurance plans -flexibility in bank loan requirements to foster environmentally sustainable practices -level of gov't support	-average age of farmers -diversity and structure of industry, size of farms, # farms per capita -hours of labor/ yield and / income -avg. farm wages vs. other professions -# of legal laborers on farms, ratio of migrant workers to local laborers, % workers with health benefits. -# of active agrarian community organizations -% of ag. Schools that offer sustainable ag. programs, encourage sustainable practices -# animals/unit, time animals spend outdoors (animal welfare)	-rate of soil loss vs. regeneration -soil microbial activity, balance of nutrients/acre -quantity of chemical inputs/ unit of production -air pollutants/ unit of production -number of species/acre -water withdrawal vs. recharge rates -# of comtaminated or eutrophic bodies of surface water or groundwater -% waste utilized as a resource -veterinary costs -energy input/ unit of production -ratio of renewable to non-renewable energy -portion of harvest lost due to pests, diseases
Food processors Packaging providers Wholesalers Retailers	Food processing, packaging and distribution	-relative profits received by farmer vs. processor vs. retailer -geographic proximity of grower, processor, packager, retailer	-quality of life and worker satisfaction in food processing industry -nutritional value of food product -food safety	-energy requirement for processing, packaging and transportation -waste produced/ unit of food -% of waste and byproducts utilized in food processing industry -% of food lost due to spoilage/mishandling
Consumers Food service Nutritionists/ Health pro-fessionals	Preparation and consumption	-portion of consumer disposable income spent on food -% of food dollar spent outside the home	-rates of malnutrition -rates of obesity -health costs from diet related disease/conditions -balance of average diet -% of products with consumer labels -degree of consumer literacy regarding food system consequences, product quality vs. appearance, etc. -time for food preparation	-energy use in preparation, storage, refrigeration -packaging waste/ calories consumed -ratio of local vs. non-local and seasonal vs. non-seasonal consumption
Consumers Waste managers Food recovery & gleaning orgs	End of life	-ratio of food wasted to food consumed in the US -$ spent on food disposal	-ratio of (edible) food wasted vs. donated to food gatherers	-amount of food waste composted vs. sent to landfill/incinerator/ waste water treatment

direction in which the country as a whole is progressing. Many of the indicators – for example, soil microbial activity per acre or quantity of chemical inputs per unit of production – are more appropriately evaluated at the regional or farm scale level. Typically, data is not readily available at this level.

INDICATORS FOR EACH LIFE CYCLE STAGE

The remainder of the report is organized as follows: the indicators in Table 1 are considered on a stage-wise basis, further dividing each life cycle stage into economic, social and environmental indicators. Attention is then turned to the food system life cycle as a whole. Food mass flow through the system is demonstrated and discussed. A life cycle energy evaluation compiles the energy use of the entire food system. Consolidation in the food system is then considered as a system-wide life cycle management challenge. Finally, conclusions and recommended future directions are presented.

Origin of Resource

Economic

For most of human history, subsistence activities have relied on hunting and gathering. It wasn't until the dawn of agriculture some 10,000 years ago that humans moved from simply collecting grain to planting it, and from hunting animals to herding them. The development of a vast range of domesticated varieties of plants and animals, suited for local climates and growing practices, has been the result of manipulation and control of the genetics of a select few species of plants and animals by growers. The control of these genetic resources has undergone numerous social and cultural changes over the course of human agricultural history. In recent times, there has been a dramatic shift to legal, patent-like control of plant genetic resources, and increasingly, it is corporations that maintain this control. The United States has three separate intellectual property systems that cover plants. The intention of these proprietary systems is to provide incentive for innovation in plant breeding for the betterment of society. The 1930 Plant Patent Act provides 17-year patent protection to new varieties of asexually reproduced plants (plants produced by budding, grafting and tissue culture). The 1970 Plant Variety Protection Act (PVPA) was established to provide breeders with legal rights over the production, marketing and sale of new, sexually reproduced (i.e. by seed) plant varieties. While PVPA allows farmers to save enough seed from protected varieties for replanting on their own land, recent amendments to the PVPA (1994) have restricted farmers' privileges of exchanging protected seed with other farmers, and breeders' rights to use the genetic material of protected varieties in developing new varieties. In 1985, the U.S. Patent and Trademark Office began issuing utility patents for *all* plant "innovations" that met the standard industrial patenting criteria of novelty, utility and non-obviousness.

The advent of biotechnology in agriculture has greatly increased the plant utility patent application rate as biotechnology companies search for the strongest proprietary protection possible for their transgenic plants. Preparing a U.S. utility patent application costs between \$10,000 to \$20,000, and enforcing such a patent over its lifetime can cost upwards of \$250,000[15], thus limiting application to larger companies that can afford this investment. The claims made are often very broad, covering entire species or even specific traits. The result has been sweeping patent claims of many food and industrial crops: the company DNA Plant

Technology claims ownership of all transgenic pepper plants (genus Capsicum) and transgenic garden pea plants; Calgene Inc. has patented all genetically engineered plants of the Brassica family; Escagenics holds patents on all transgenic coffee plants[15]. Indeed, 79% of the plant utility patents in 1995 were owned by corporations[15]. In the case of utility patents, there are no exemptions made for farmers or plant breeders – all parts of the plant, including its seeds, tissue, and cells are protected, as is the use of a plant's seeds or pollen to create more plants.

Seed costs for U.S. crops have risen steadily in recent years. There was a 20% increase in the seed price index from 1992 – 1997[16]. Seed cost increases add to the input costs of agricultural production and raise questions to the effects on producers of market consolidation occurring in the seed industry, which will be addressed in the next section.

Social

Like numerous other segments of the food system, the seed industry has undergone major restructuring and consolidation in recent years. According to a study conducted by the Rural Advancement Foundation International (RAFI) in 1998, the top ten companies now control 32% of the $23 billion in global commercial seed trade[17]. In certain markets, this consolidation is much higher: 40% of U.S. vegetable seeds come from a single source while the top 5 vegetable seed companies control 75% of the global vegetable seed market; 69% of the North American seed corn market is controlled by 4 companies[17]; a single company, Delta & Pine Land, controls 71% of the North American cotton seed market[18]. The U.S. plant patent protection systems mentioned above, along with the high capital cost of new plant breeding technologies, have contributed to the development of such seed industry oligopolies. While it is difficult to place a clear cut-off for the breakdown of competitive markets due to market concentration, a four-firm market concentration ratio (the market share of the four largest firms) of 40% is often adopted as a rule of thumb for the onset of oligopoly markets[19, 20]. This certainly may be the case in various sectors of the seed industry. Such market concentration places decision-making for new products, adoption of new technologies, and prices in the hands of a few firms. It reduces farmers' access to diverse genetic resource options and often leads to the elimination of seed varieties specialized for local conditions. It also makes entry into the market by new players increasingly difficult, limiting innovation. This barrier to entry is particularly strong with genetically engineered seeds since two or three firms have control over much of the process itself by which genetic manipulation occurs.

The large capital investment required to develop genetically modified seed varieties has led companies to seek additional methods to maintain control of the resource and assure a prompt return on their investment. Most genetically modified products have been granted utility patents, making it illegal for farmers to save seed from their harvest. Monsanto, the principal player in agricultural genetic engineering in the U.S., has made it a point to "vigorously prosecute" farmers that violate the ownership rights given to the company. In addition to paying a $6.50 per 50 pound bag technology fee, farmers have to sign a contract when buying Monsanto's genetically engineered seed which grants access to farmers' fields for collection of tissue samples. Monsanto has hired investigators to search out farmers that are illegally saving patented seed and has created tip lines where farmers can report neighbors that have saved seed. Furthermore, various companies are developing "technology protection systems" or "genetic use restriction technology", genetically engineering plants to produce sterile seed or to require the use of an external chemical trigger to turn on or off a plant's genetic traits. Such techniques create *genetic* control of genetic resources, so that farmers cannot save the harvested seed for replanting but must return each year to obtain seed from the biotechnology companies or, in the case of the use restriction technology, to purchase proprietary chemicals. In 1998, Delta & Pine Land Seed Co. (D&PL) and the USDA patented the original sterile seed technology, now notoriously known as the Terminator. This new technology received immense worldwide attention and disapproval from farmers, governments, and NGOs, including the United Nations Food and Agriculture Organization, forcing Monsanto (who was developing Terminator technology through a planned takeover of D&PL) to publicly pledge "not to commercialize gene protection systems that render seed sterile"[21]. Since this time, however, Monsanto has withdrawn its takeover bid of D&PL, and D&PL, along with the U.S. Department of Agriculture, is continuing with development of Terminator technology[18, 22]. Terminator is targeted primarily for use in markets in developing countries, where legal enforcement of seed intellectual property rights is logistically difficult.

Environmental

In addition to the social and economic consolidation prevalent in the seed industry, modern agricultural systems have also become increasingly genetically uniform. Only 10-20 crops provide 80-90% of the world's calories[23]. In the US, 42% of the soybeans, 43% of the corn, and 38% of the wheat grown in 1980 were dominated by the top 6 varieties[24]. Often, these varieties originate from an even smaller genetic base. For example, the hundreds of corn hybrids grown in the U.S. are largely based on about 12 inbred lines that originated from a few open-pollinated varieties of a single race (although there are some 200 known races of corn)[25]. Repeated warnings have been sounded from the research community about the extreme vulnerability associated with this limited genetic diversity[26, 27]. Lack of biodiversity in crops leads to pest and disease susceptibility[28-30]. A recent large-scale experiment in China demonstrates that mixing varieties of rice within a field significantly reduces the spread of a major fungal disease[31]. Historic examples where insufficient crop biodiversity has led to catastrophe include red rust on wheat in Roman times, ergot-tainted rye during the Middle Ages, the Irish potato famine of the nineteenth century, and the corn leaf blight in southern U.S. in 1970[27]. Recent outbreaks of *Fusarium* head blight in wheat and barley in the Red River Valley of Minnesota and the Dakotas is at least partly due to genetic uniformity[32]. What's more, the forces driving genetic uniformity – the quest for ever-increasing yields, as well as the proprietary systems and industry consolidation mentioned above – also lead to abandonment and loss of landraces, the locally adapted varieties that are the necessary resources to meeting future plant breeding challenges.

Genetic engineering is seen by some as an answer to these problems since it allows individual traits to be added to plant varieties (for example, only the genes for resistance to disease could be added to a potato variety rather than going through extensive breeding routines to incorporate resistance from a landrace into a high-yielding variety). Yet, genetic engineering may actually exacerbate genetic uniformity because the high research and development cost in creating a new genetically engineered organism favors using the same variety over a large area rather than applying the technology to many regionally adapted varieties. In addition, numerous potentially devastating ecological risks associated with genetically engineered plants have been identified. These include transfer of introduced genes to wild populations or unmodified crops (genetic pollution); the development of superweeds, either by the modified crop itself or through transfer of a trait to wild populations; and development of resistant insects due to constant resistance pressure (from plants modified to produce an insecticide such as the *Bt* varieties)[33].

The adoption of genetically engineered crops has been the highest of new technologies by agricultural industry standards[34]. The major genetically engineered crops include soybeans, corn, cotton, rapeseed, and potatoes. Globally, the acreage planted to genetically engineered crops has risen from 6.4 million acres in 1996 to 102.5 million acres in 1999. In the U.S. alone, which leads global acreage of genetically engineered crops with 69.1% of the 1999 total, acreage has grown from 3.6 million acres in 1996 to 70.8 million in 1999[35]. This represents about 22% of U.S. cropland. Despite the rapid growth, early indications suggested that acreage of genetically engineered crops would be down in 2000 from 1999 values, due primarily to market resistance in Europe and elsewhere. Interestingly, a report issued by the European Commission's Directorate-General of Agriculture does not find conclusive evidence of farm-level profitability of genetically engineered crops that would warrant their rapid adoption[35].

Genetic engineering is also creating inroads into the hybridization of crops that, because they are self-pollinating, have eluded commercial hybridization. For example, wheat has remained an open pollinated varietal, despite the fact that it is the most widely cultivated crop on the planet, with 219 million acres harvested in 1995. Now biotechnology is allowing the commercialization of hybrid wheat with aggressive marketing and cash rebates to farmers who try hybrid wheat seed in parts of the U.S.[36]. While hybrid wheat may bring improvements in yield and performance, it also means growers are dependent on buying seed from seed companies every year, as is the case with hybrid corn.

Consolidation and genetic uniformity have also become prevalent trends in livestock breeding. The UN Food and Agriculture Organization concluded that domestic livestock breeds are disappearing worldwide at an annual rate of 5%, or 6 breeds a month[37]. The highly specialized nature of intensive livestock production has created a drive towards genetic uniformity that has been made possible through reproductive technologies such as artificial insemination, embryo transfer, *in vitro* fertilization, and now, cloning. As an example, over 90% of all the commercially produced turkeys in the *world* come from three breeding flocks[38]. Similar conditions exist in hog, chicken, and dairy cattle genetics. But like plants, livestock genetic diversity is crucial in sustaining productivity and animal health in the face of future challenges such as disease and changes in environmental conditions. A genetically uniform system is extremely vulnerable if, for example, a new strain of disease were to evolve for which the animals have no resistance, as occurred with chickens in Hong Kong in 1998.

Agricultural Growing and Production

Economic

Farming involves the careful balance of the three classical factors of agricultural production – land, labor, and capital. Thus, the land available for agriculture is an important indicator of its stability. Land in farms has declined every year since reaching a peak in 1954. In 1997, 931,795,255 acres were reported in farming , 16% below 1964 levels and 5.6% down from 1982[39]. Farmland is taken out of production for various reasons, but of particular concern is the rapid development and urbanization of rural land. A study conducted by the American Farmland Trust demonstrates that development has been occurring disproportionately on high quality farmland. Their study considers 127 'Major Land Resource Areas' (MLRA), covering 76% of the nation's land, but containing 95% of the prime farmland. Within these MLRAs, 22% of the land was classified as prime or unique farmland, but a disproportionate 32% of land developed from 1982 to 1992 was on prime land[40]. It is perhaps not surprising that development is most likely to occur on prime farmland since agriculture was the basis for most permanent inland settlements in the U.S.

The increasing mix of rural and urban land uses creates added social conflict and environmental impact. Farmers are faced with complaints about odor, dust, or noise, and perhaps experience more trespassing. Impermeable surfaces increase, directing rainwater to sewer drains rather than to the soil. New chemicals – from road salt to lawn care pesticides - are introduced into the environment. The total U.S. conversion of prime farmland to urban or built-up land between 1982 and 1992 translates into 45.7 acres every hour over those 10 years. An additional 266,000 acres (3 acres every hour) of unique farmland (soil and climatic conditions suitable for production of specific high-value food and fiber crops) was also lost to development[40]. As prime farmland is being developed, less stable non-prime farmland in arid regions is being added to the base, leading to increased erosion rates and irrigation demands[41].

Industrialization of agriculture has made production extremely capital intensive. Thus, the cost of entry into farming is quite high. Estimates say that it takes $500,000 in assets to support a farm household[42]. This, combined with return on investment considerably lower than can be received in other business ventures, is contributing to declining numbers of young farmers (see *agricultural production – social* section). Rates of return on farm business equity in 1998 were reported at 2.15%, and have averaged –0.3% since 1980 (3.8% since 1990)[43]. Some assistance programs have been initiated to help young farmers gain entry. For example, the Agricultural Credit Improvement Act of 1992 created a beginning farmer down payment farm ownership loan program and required USDA's Farm Service Agency (FSA) to target a percentage of its direct and guaranteed farm operating and farm ownership loans to beginning farmers and ranchers[42].

Providing cheap food for Americans has long been a central tenet in U.S. agricultural policy. Yet, as food processing, handling, and marketing have increased, the farmer has received smaller and smaller portions of the American food bill. USDA estimates that the farmer’s gross return on a consumer’s dollar spent on food in 1998 was 20 cents[44] (in 1975 it was 40 cents[45]). The remaining 80% of the food bill is distributed among marketing labor, packaging, advertising and other categories (see Figure 1). Indeed, the farm-to-retail price spread – the price difference between what consumers pay for food and what farmers receive – has been steadily increasing since the 1950s. The 1997 farm-to-retail price spread for a market basket of foods (the average quantities of food that originate mainly on U.S. farms and are purchased for consumption at home, excluding seafood and nonalcoholic beverages) increased 4.7% over 1996 values. In this same year, farmers received 4.4% less for the food they produced[45].

Table 2 demonstrates the production costs and returns for a few agricultural commodities. Rising costs of production and falling commodity prices in recent years have lead to negative net economic returns in major commodities. Admittedly, agricultural market economics are complicated and commonly subject to annual fluctuations due to weather and growing conditions; thus, a definitive trend cannot be concluded from the numbers in Table 2. Yet, the returns are indicative of the general trends experienced in U.S. agricultural production since the 1996 Freedom to Farm Act effectively withdrew all price stabilization and price support programs.

Nearly half (48%) of all farms reported a negative net cash return (net loss) in 1997. This appears to be an increasing trend: in 1987, 43% of farms had net losses and in 1992 it was 44%. Ninety-two percent of the farms reporting losses in 1997 were relatively small, with sales worth less than $50,000[39]. Still, farm households in the U.S. receive incomes on par with average

Table 2: U.S. Average Production Costs and Returns for Various Agricultural Commodities[46]

	Value of production less operating costs[1]				Value of production less total costs[1,2]			
	1996	1997	1998	1999	1996	1997	1998	1999
Corn ($/planted acre)	212.39	172.56	108.57	77.21	19.40	-28.92	-96.58	-130.60
Soybeans ($/planted acre)	129.56	199.31	143.85	101.67	22.59	32.94	-24.39	-71.02
Wheat ($/planted acre)	56.83	33.17	56.86	43.27	-28.19	-49.45	-50.92	-72.65
Hogs ($/hundredweight gain)	7.03	11.70	8.27	6.15	-12.76	-7.65	-11.10	-12.77

[1] Value of production excludes direct government payments

[2] Total costs include operating costs plus various allocated overhead such as opportunity cost of unpaid labor and land, capital recovery of machinery and equipment, and taxes and insurance.

U.S. households. The 1997 average household income for farm operator households was $52,300. However, 89% of this household income comes from off-farm sources[47]. Indeed, 50% of farm operators in 1996 reported that farming was not their principal occupation[39].

According to the 1997 Census of Agriculture, government payments to farms were $5.1 billion in 1997[39]. However, the Economic Research Service of the USDA reports total direct government payments in 1996 at $7.3 billion and in 1997 at $7.5 billion[47]. Values for 1992 (the next year reported by both the Census and the ERS) were $5.2 billion (Census of Agriculture) and $9.2 billion (ERS). Apparently, part of this difference ($2.2 billion in 1997) represents government payments to landowners that are not considered farm operators by the Census[48], but may also include differences in definition of "government payments". About 35% of the direct government payments in 1997 went to the less than 7% of total farms that have sales greater than $250,000[47]. More than half of the farms specializing in crops were enrolled in Government programs in 1995, accounting for three quarters of all the direct government payments. About 20 percent of farms specializing in livestock received Government payments in 1995[49].

Government payments to farmers have been rising sharply in more recent years. Government payments in 1999 reached $20.6 billion[50] and are forecasted at $23.3 billion for 2000[51], two consecutive years of record high payments. This is a nearly 3-fold increase in assistance payments over the 3 year period from 1996 to 1999. Much of the increased government payments have come in the form of loan deficiency payments, forecast for 2000 at $7.9 billion, up from $1.8 billion in 1998.

Farm business debt totaled $156.2 billion at the end of 1996, increasing from 1995 at a rate slightly higher than the trend in recent years. Table 3 shows the distribution of farm debt holdings. In general, such large debt holdings can limit ingenuity in agricultural production since lenders often require conventional inputs to be included in the cropping system before offering a loan.

Social

The social demographics of U.S. farms have changed significantly over the past 50 years. The general trends have been towards fewer numbers of larger farms (see Table 4). Since 1974, the definition of a "farm" used by the Census of Agriculture has been "Any place from which $1,000 or more of agricultural products were produced or sold, or normally would have been sold, during the census year."[39]

Yet, these average statistics do not reveal the full extent of farm consolidation. When farms are classified by the total value of their gross farm sales, the trend towards very large

Table 3: Farm Debt Holdings, 1985 & 1996[47]

	Real estate debt		Non-real-estate debt		Total	
	Percent holdings					
	1985	1996	1985	1996	1985	1996
Farm Credit System	42.2	31.7	18.1	19.0	31.6	25.5
Banks	10.7	29.5	43.5	52.1	25.0	40.4
Farm Service Agency	9.8	5.2	19.0	5.4	13.8	5.3
Life insurance companies	11.3	11.4			6.4	5.9
Individuals and others	25.8	22.2	19.5	23.5	23.0	22.9

Table 4: Number and Size of Farms in the U.S. by Year

	1998[1]	**1988**[1]	**1974**[2]	**1950**[2]
Number of farms (in 1,000)	2192	2201	2314	5388
Land in farms (in 1000 acres)	953765	994423	1017030	1161420
Average farm size (acres)	435	452	440	216
Farmland per capita (acres/person)	3.5	4.0	4.7	7.7

[1] [47]

[2] [52] To qualify as a farm in the 1950 Census, a place of three acres or more had to produce $150 worth of agricultural products for home use or sale. If less than three acres, $150 worth of agricultural products had to be produced for sale only.

[3] population statistics from [53]

farms becomes more clear. In 1997, 3.6% of the farms had market value of over $500,000 of agricultural products; these large farms averaged 2633 acres, controlled 56.6% of the total market value, and used 19.4% of the total land in farms. On the other hand, 73.6% of farms sold less than $50,000 worth of agricultural products, but constituted only 6.8% of the total 1997 sold product value and 28% of the farmland[39]. To put it another way, 9.5% of the farms and 38% of farmland account for three-quarters of the market value of agricultural products sold[39]. The farms that sold over $500,000 in products averaged $373,730 in net cash return (sales less expenses). Those selling less than $50,000 in products averaged a net loss in cash return of $850[39].

Individuals, families or partnerships own the vast majority of farms – almost 95% - and the remaining are primarily family held corporations. Yet, the average incorporated farm is over 4 times larger (on an acreage basis) than the average family farm. An increasing trend of contractual agreements between producers and both suppliers of inputs and buyers of agricultural outputs presents additional changes in the organizational structure of agricultural production. Nearly one third of the crops and livestock produced by American farmers was grown or sold under contract in 1997[54]. These come either in the form of *marketing contracts* or *production contracts*. Market contracts establish a price for a commodity before the commodity is ready for marketing, but the producer retains management decisions and ownership of both production inputs and output until delivery. Production contracts detail the compensation to the farmer for services rendered, the quality and quantity of commodity, and who is to provide production inputs. Often under production contracts, the farmer does not own the commodity in question and agrees to particular production management conditions. For example, under livestock production contracts, the farmer is paid to house and care for the animals until they are ready for market, but the contractor actually owns the animals. Inputs such as feed and medication are either supplied by the contractor or the farmer is obligated to purchase the inputs from designated providers. Table 5 presents the extent to which certain commodities are produced under contract in the U.S. Two thirds of farms with contracts in 1997 were small family farms (here defined as sales under $250,000), but larger family farms (over $250,00 in sales) were more likely to use contracting – 53% of all larger farms used contracts compared with 8% of small farms[54].

Table 5: Market value of some commodities produced under contract in the U.S. in 1997[54]

	Dollar amount under contract ($ billion)	Percentage of total market value
marketing contracts		
Fruits and vegetables	11	40
Cotton	1.9	33
Corn	1.7	8
Soybeans	1.7	9.4
Sugar beets	0.97	85
Cattle	4.0	10
Dairy products	11.4	60
production contracts		
Poultry and eggs	15.6	70
Hogs	4.5	33
Cattle	5.7	14

Often contractual arrangements are praised as opportunities for farmers to reduce risks of price swings, share production costs, and secure income. Such opportunities must be considered in light of the growing consolidation within the food system, and among the “buyers” who are offering contracts with farmers. As mentioned earlier in the genetic resource section, some analysts question whether current agricultural market concentration allows for a truly competitive market. A quote by Senator Byron Dorgan (democrat, ND) speaks to the marketplace farmers are faced with today:

> When Ronald Reagan became president, the top four beef processors controlled about 36 percent of the market. Today the figure is over 80 percent. A wheat farmer today is dealing with a grain industry in which the top four firms control 62 percent of the business. This means a marketplace with the power to say, "take it or leave it."[55]

This type of non-competitive market control is exacerbated by contractual agreements, which, in many cases, also limit a farmer’s ability to make management choices that benefit the local environmental, social, and economic condition.

Social and economic restructuring in the agriculture and food system has taken its toll on agricultural communities with numerous examples from across the country. McPherson County, Nebraska is by far the poorest county in the country, measured by per capita income. The people of this rural agricultural based county earned an average of $3,961 in 1997. The next poorest country, Keya Paha, also in rural Nebraska, averaged $5,666, while the richest, New York county (Manhattan) had a per capita income of $68,686[56]. In 1920, McPherson County had 1,692 people; today it has fallen to about 540. It once had 20 post offices, 5 towns and 63 school districts; now it has 1 post office, 5 schools, and (with generosity) 2 towns. The average age in the county is in the late 50's[56]. A rural sociologist comments on the degradation of rural agricultural based communities that has resulted from restructuring in the food system: "Increasingly, our agriculturally based communities, like regions with major poultry operations, are looking like mining communities."[38]

Another prominent trend on America's farms is the growing age of farm operators. According to the Census of Agriculture, the average age of farm operators in 1997 was 54.3 years, and 61% of the operators were 55 and over. In 1954, only 37% of farmers were 55 and over. Comparatively, 11.7% of the civilian labor force was age 55 or above in 1997 (18% in 1954)[42]. Twenty percent of farm operators considered themselves retired in 1996, and the farms they operated averaged a negative income[57]. While U.S. agriculture has typically been characterized by older operators, there is a clear trend developing in the age of farmers. This trend is exacerbated by fewer young farmers: the percentage of farmers under 35 years of age dropped from 15% in 1954 to 7.8% in 1997[42]. There is, however, a known biasing in the Census statistics resulting from the surveying methods used. The Census of Agriculture counts only the principal operator for each farm, which, in most multi-generational family operations, will be the eldest member. This shifts average ages higher and undercounts the number of people involved in agriculture. Statistics on agricultural workers from the Bureau of Labor Statistics differ considerably since their survey is concerned with persons in the workforce and would exclude individuals that operate a farm but consider themselves retired. The Census of Agriculture, on the other hand, looks for an operator of any "farm" that produces more than $1000 worth of goods, even if the operator is in retirement. According to the Bureau of Labor Statistics, 38% of self-employed agricultural workers were 55 and over in 1999, and 21.5% of all those employed in agriculture were 55 and over[58].

Farm labor has dropped significantly over the past 50 years, from 9.9 million in 1950 to 2.8 million in 1998[47]. Family workers, whether farm operators, paid, or unpaid workers, accounted for 69% of the farm labor in 1998. The remaining 31% were hired farmworkers. The average wage rate for hired farmworkers was $7.47 in 1998[47]. This can be compared with 1998 average wage rates in other private industries that can also involve hard labor: mining, $16.91; construction, $16.61; manufacturing, $13.49; food and kindred products, $11.80[59]. However, real median weekly earnings (adjusted for inflation) for hired farmworkers increased by 4% between 1990 and 1996, whereas median weekly earnings of all wage and salary workers decreased by 4% over this period. Labor expenses (hired and contract) accounted for 12% of total farm production expenses in 1997; this has changed very little over the past decade[39]. The importance of labor does, however, vary significantly with farm type. Labor accounts for larger proportions of farm expenses on horticultural specialty farms (45 percent), fruit and tree nut farms (40 percent), and vegetable and melon farms (37 percent). At the other extreme, labor comprises only 5 percent of total farm expenses on beef cattle, hog, sheep, poultry, and cash grain farms.

Hired farmworkers (those that do farm work for cash wages or salary) are generally younger and less educated than average U.S. wage and salary workers and are more likely to be male, Hispanic, and never married. About 17% of hired farmworkers were less than 20 years old and over half (52%) were under 35, compared to 6% and 43% of all wage and salary workers, respectively[60]. Fifty seven percent had not completed high school, compared with 14% of all wage and salary workers. While nearly a tenth of all wage and salary workers were Hispanic in 1996, this proportion grows to 36% of hired farmworkers. About three-fourths of Hispanic farmworkers were not U.S. citizens. Overall, 28.4% of hired farmworkers were not U.S. citizens, compared to 7% of all wage and salary workers[60]. Since 1996, the U.S. Department of Agriculture has released quarterly estimates on the percentage of U.S. hired farmworkers that are migrant workers. While these estimates vary with season (higher in July and October than January and April) and have fluctuated somewhat from year to year, migrant workers on average make up about ten percent of hired farmworkers[61].

The current H2A guestworker program allows aliens to enter the U.S. to perform seasonal agricultural labor, given that growers demonstrate to the Department of Labor that American workers are unavailable. Cumbersome paperwork and rigid requirements, however, drive many workers to enter illegally. The most recent National Agricultural Workers Survey conducted by the U.S. Department of Labor estimated that, as of fiscal year 1998, 52% of the agricultural labor force lacked legal authorization to work[62]. Given the tight U.S. labor market and low prices received for agricultural commodities, many U.S. farmers, especially those growing delicate fruits and vegetables that require hand harvesting, are dependent on cheap, illegal migrant labor to harvest their crops.

Farming has one of the highest work-related fatality rates of all occupations, according to the U.S. Department of Labor. While the percentage of fatal injuries suffered by hired farmworkers (as opposed to farm operators and their families) appears to be proportional to their numbers in the farm workforce, hired farmworkers do receive a disproportionately high number of the reported non-fatal injuries (68%)[63]. Farmers face greater public health risks from pesticides than the average population. 2,4-D and other chlorophenoxy herbicides have been implicated in cancer mortalities in wheat producing counties in Minnesota, North Dakota, South Dakota, and Montana[64]. Studies showing that farmers appear to experience an excess of several cancers (lymphatic and hematopoietic system, connective tissue, lip, skin, brain, prostate and stomach) as well as other chronic diseases have become the impetus for a federally funded, cross-agency Agricultural Health Study. The goal of the Agricultural Health Study is to establish a large cohort that can be followed for 10 or more years into the future, to evaluate the role of agricultural and related exposures in the development of cancer, neurologic diseases, reproductive and developmental outcomes, and other chronic diseases[65]. Initiated in 1994, it has already lead to numerous published findings (listed at [66]) as well as criticisms[67].

Publicly supported research in agricultural production methods has been in existence in the U.S. for more than a century. The Morrill Acts of 1862 and 1890 and the Hatch Act of 1887 created the social contract that has maintained a federal-state partnership supporting agricultural research at the country’s 105 Land Grant colleges and universities. As today’s agriculture undergoes a shift in priorities, Land Grant schools are presented with a broad set of research agendas from diverse stakeholders[68]. One of these agendas centers on a heightened concern for sustainable agriculture systems. The development of approaches to sustainability, however, needs to be made with ongoing participation from all parts of society. Increasingly, agricultural research at Land Grants is being conducted in partnership with the private sector. The closeness of this partnership with industry has generated public concern about “corporate driven” research at public institutions[68, 69], and requires carefully monitoring.

Mounting concern for the welfare of farm animals can also be considered a social indicator for the sustainability of agricultural production. A report by the Council for Agricultural Science and Technology (CAST) addresses the absence of appropriate indicators for farm animal welfare and the need for a scientific research agenda[70]. There is a general lack of understanding of how animals respond to the production environment and to stress, what their social behavior and space requirements are, and what the best production practices and systems for improving animal welfare are. Dispute between researchers and regulators over what constitutes distress in animals is ongoing[71].

Environmental

Agriculture is inextricably linked to the environment - soil, water, and sunlight are all necessary inputs for production. Soil biota is essential for carbon and nutrient cycling. Yet, agricultural management and practice focused on short-term yield increases and greater productivity from a limited diversity of crops and animals is jeopardizing the very environment on which agriculture is dependent.

Soil erosion has forever been a challenge in agriculture, to the point that Wes Jackson, revolutionary agriculturist, calls it not a problem *in* agriculture, but the problem *of* agriculture[72]. Indeed, tillage for the purpose of agriculture has led to unfathomable losses of topsoil through countless civilizations, regions, and timeperiods. The National Resources Inventory of the USDA reports that 1.9 billion tons of soil eroded from U.S. land in 1997, 0.84 billion from wind and 1.06 billion from sheet and rill (caused by water)[73]. The magnitude of this number is nearly impossible to grasp: if one were to load the 1.9 billion tons of soil into freight cars at their rated loading capacity, the resulting train would encircle the *planet* about 7 times. Remember that this is for the United States alone in one year. And the situation has improved considerably – the number reported for 1982 is 3.07 billion tons[73]. 112 million acres (30% of cropland) were determined to be excessively eroding in 1997 (erosion rates greater than an erosion tolerance rate), totaling to 1.3 billion tons of eroded soil per year[73]. Average estimated erosion rates from 1982 to 1997 are shown in Table 6. Eleven states had estimated wind erosion rates higher than the national average in 1997, and 19 states had higher sheet and rill erosion rates. Wind erosion rates on cultivated cropland in Nevada in 1997 were reported at 27 tons per acre per year, while Tennessee had the highest sheet and rill rate on cultivated cropland at 7.7 tons per acre[73].

If the 1.9 billion ton of topsoil lost in 1997 were evenly distributed over all of the U.S. cropland, the average rate of erosion would be 4.4 tons per acre per year (which approximates the sum of the reported average rates for wind and sheet & rill). This translates into an inch of topsoil lost from all U.S. cropland every 34 years. At the extreme rate of erosion reported for Nevada, an inch of topsoil is lost every 5 ½ years. While under ideal situations where soil is supplemented with large amounts of fertile organic matter, an inch of soil can be rejuvenated in perhaps 30 years[72], it has been estimated that under normal agricultural conditions, it takes between 200 and 1000 years to form an inch of soil[74]. It can be quickly recognized that this practice is not sustainable.

Table 6. Average Estimated Erosion Rates for nonfederal rural land in the U.S. by Year and Land Use Type[73]

Year	Cropland			CRP* land	pastureland
	cultivated	**non-cultivated**	**Total**		
Wind erosion (tons per acre per year)					
1982	3.6	0.4	3.3	--	0.1
1987	3.5	0.4	3.2	6.8	0.1
1992	2.7	0.2	2.4	0.6	0.1
1997	2.5	0.2	2.2	0.3	0.1
Sheet and rill erosion (tons per acre per year)					
1982	4.4	0.7	4.0	--	1.1
1987	4.0	0.7	3.7	2.0	1.0
1992	3.5	0.6	3.1	0.6	1.0
1997	3.1	0.7	2.8	0.4	0.9

*Conservation Reserve Program

To address this erosion problem, various soil conservation policies have been implemented in the U.S. over the past 60 years. Early policy focused on keeping the soil on the land to increase net farm income, but in the 1980s, policy goals began to shift towards reducing the off-site impacts of erosion, such as water quality impairment[75]. Under the Food Security Act of 1985, the voluntary Conservation Reserve Program (CRP) was established. The CRP allows the USDA to enter into 10-15 year agreements with owners and operators in order to remove highly erodible and other environmentally sensitive cropland from production. The contracts provide annual rental payments and cost-share assistance in implementing various environmental practices such as filter strips, riparian buffers, grass waterways, shelter belts and windbreaks, and wetland restoration. Approximately 2.5 million acres will be enrolled into CRP in the year 2000, bringing the total CRP enrollment to about 33.5 million acres as of October 2000[76]. The data presented in Table 6 demonstrate that conservation programs, combined with changes in agricultural practice, have reduced erosion rates somewhat. Still, soil erosion presents a substantial social cost, estimated at $29.7 billion in 1997[75].

Agricultural practices remove nutrients from the soil in the form of harvested plant matter: these nutrients must be replenished to sustain the practice. Historically, animal manure and other farm refuse were used as nutrient sources, but today commercially manufactured chemical fertilizers are by far the major source of applied plant nutrients in the United States. Commercial fertilizer accounted for 6.4% of total farm production expenses in 1997, and was applied to 25% of the total farmland (total farmland includes pastureland, rangeland, etc., which typically receives little to no fertilizer)[39]. Commercial fertilizer use for particular crops, such as corn, is very high: 98% of the acreage in the top 10 corn producing states received commercial fertilizer[77]. Animal manure is still a major potential source of soil nutrients, but consolidation of confined livestock farms into large specialized production facilities with little associated cropland has made use of this source less economically feasible. The result has been not only underutilized manure nutrient resources in high-density livestock areas, but also major problems with soil and water pollution and stench. The *economically available* nutrients from manure are estimated to be 10% of total available nitrogen, 24% of phosphate, and 22% of potash[77]. These values are much less than what is physically available (economic availability is limited primarily by transportation costs from areas of high manure nutrient densities to croplands), and greater than what is actually applied. A recent study identified counties in the U.S. where manure nutrient availability exceeds the *potential* plant uptake and removal from all agricultural land in the county, including pastureland application. Using Agricultural Census data for 1992, the study treated each U.S. county as a single large farm (boundries were placed at the county level) and assumed that all surveyed cropland and pastureland in the county could be used for manure disposal. Crop nutrient uptake was estimated by the nitrogen and phosphorus content of harvested biomass plus a nitrogen utilization efficiency factor to account for nitrogen consumption during plant growth; manure application on pastureland was at a rate appropriate for plant growth assuming the land was being grazed. Ignoring current applications of commercial fertilizers, the study found that 35 counties still had manure-based nitrogen levels that exceeded potential plant uptake and 112 counties showed excess levels of phosphorous[78]. These reflect areas of the country with high livestock densities but insufficient cropland for manure disposal. There has been a clear increasing trend in these numbers with time: statistics from 1954 show only about 6 counties with excess nitrogen and 38 with excess phosphorous; in 1982 there were 17 counties exceeding uptake of nitrogen and 80 exceeding phosphorous. The mounting impacts of manure build-up from large confined livestock operations became nationally apparent when Hurricane Floyd flooded manure lagoons in North Carolina and contaminated public water sources. Areas where manure nutrient availability exceeds plant uptake can also contribute to ground and surface water contamination through leaching and run-off.

Soil erosion and nutrient leaching are among the primary sources of water pollution from agricultural production. The National Summary of Water Quality Conditions reported that agriculture is the leading source of pollution in the nation’s rivers, lakes, and wetlands[79]. Siltation and nutrients are among the top three pollutants/stressors in each of the water body categories (rivers, lakes, wetlands). Pesticides were also indicated as a pollutant of rivers and wetlands. Siltation alters aquatic habitat, can suffocate fish eggs and bottom-dwelling organisms, and in extreme cases, can interfere with drinking water treatment processes and recreational use of water. Agricultural runoff of nutrients contributes to accelerated eutrophication, disrupting ecosystems and interfering with the health and diversity of native fish, plant, and animal populations. The Mississippi River is a critical example of the effects of agricultural nitrate runoff on aquatic ecosystems. States in the Upper Mississippi River Basin (Illinois, Indiana, Iowa, Ohio and Minnesota) have the highest percentage of total land in agriculture, the highest use of nitrogen fertilizers, and the greatest amount of artificially drained soil (contributing to nutrient leaching to surface water) in the country. As a result of these intensive agricultural practices, total nitrogen output to the Gulf of Mexico has increased 3 to 7-fold compared to pre-settlement outputs. The Gulf of Mexico is now the third largest hypoxia zone (oxygen deficient “dead zone” due to nitrogen input) in the world, with the area uninhabitable by most aquatic organisms varying between 12,000 to 18,000 square kilometers in mid-summer[80].

The use of chemical pesticides has made significant contributions to the level and method of agricultural production in the U.S. Estimates claim that each dollar invested in pesticide control returns approximately $4 in crops saved[81]. According to the Census of Agriculture, $7.6 billion were spent on agricultural chemicals in 1997, up from $4.7 billion in 1987[39]. Average application rates appear to have decreased somewhat, however, from a two decade high of 1.8 pounds per acre in 1987 to 1.15 pounds per acre in 1996[82]. Interestingly, while pesticide use is generally seen as profitable in terms of direct crop returns, it has not necessarily led to decreases in crop loss. Even with a tenfold increase in insecticide use from 1945 to 1989, total crop losses from insect damage have nearly doubled from 7% to 13%[83]. This rise in crop losses is partly caused by changes in agricultural practices such as abandoning crop rotations and increased crop homogeneity. Pimentel *et al*. estimated the environmental and economic costs of pesticide use. They considered human health impacts, animal poisonings and contamination of animal products, loss of natural pest enemies, the costs of pesticide resistance, honeybee and pollination losses, crop losses, fishery and bird losses, groundwater contamination, and the cost of government regulations to prevent damage. Based on available data, they estimated the cost of pesticide use at $8 billion per year, $5 billion of which society pays in environmental and public health costs[81].

Researchers have recently demonstrated that combinations of agricultural chemicals (pesticides and nitrate) are capable of altering immune, endocrine, and nervous system parameters in mice at concentrations of the same order of magnitude as current groundwater maximum concentration levels[84]. These same researchers suggest that current testing protocols for pesticide approval are deficient in six identified testing arenas and do not adequately address the potential for biological effects under real world exposure scenarios (such as mixed and pulse dosages). They further raise the question of whether pesticides and/or other environmental chemicals might be associated with developmental concerns such as the surge in learning disabilities, attention deficit disorders, and orthopedic problems exhibited by children in the United States.

One response from consumers to this societal cost of pesticide use has been the rapidly growing organic market in the U.S. Annual growth of organic food sales is expected to continue at a rate of 20-24% over the next decade[85]. The acreage of certified organic cropland more than doubled from 1992 to 1997, but still only represented 0.2% of total cropland in the U.S.[86]. While the U.S. ranked third in total land area under organic management (behind Australia and Canada) in a recent world wide survey, numerous European countries have higher percentages of agricultural land in organics including Austria at 8.4%, Denmark at 6%, Italy at 5.3%, Germany at 2.4% and Britain at 1.8%[87].

Agriculture also greatly affects the quantity of water consumed in the U.S., primarily through irrigation of crops and through livestock production. In 1995, 134 billion gallons per day of freshwater were withdrawn for irrigation purposes (39% of total freshwater withdrawal), 49 billion gallons per day of this from ground-water sources. Water consumption for livestock totaled 5.49 billion gallons per day in 1995, 41% of which was from ground water[88]. The concern is that, in certain regions of the country, withdrawal from groundwater sources is exceeding the natural recharge rate of aquifers. An excellent case-in-point is the Ogallala aquifer in the High Plains states. Home of the Dust Bowl in the 1930s, the High Plains region receives less than 12 inches of rain a year (compared to 30 in the midwestern Corn Belt). Yet, mechanized irrigation from the vast underground water of the Ogallala aquifer has turned this dry land into the “breadbasket of the world”. Today, it is widely recognized that this practice is not sustainable. The Ogallala is largely a nonrenewable resource since its sources were geologically cut off thousands of years ago. It is more than 3 billion acre-feet (an acre-foot equals 325,851 gallons) of essentially fossil water that has been mined at rates that greatly exceed recharge. Pumping from the aquifer is measured in feet per year while replacement, trickling in from the surface, occurs at less than an inch a year[89]. More than a half-billion acre-feet of Ogallala water were consumed by irrigation farmers between 1960 and 1990. As water levels in the aquifer drop, pumping becomes more costly. Irrigation rates have decreased slowly over recent years, but it is clear that current irrigation practices will lead to a day when Ogallala water will no longer be accessible to High Plains farmers. As historian John Opie puts it, "At worst, if Ogallala water becomes inaccessible over the next ten to thirty years, the region will become unmanageable and revert to a deserted wasteland. At best, rethinking the Ogallala and reworking High Plains agriculture could provide America with a model for sustainable development."[89]

Air pollutants from agricultural production are shown in Table 7. Agriculture makes a notable contribution to most criteria air pollutants. Of particular significance is ammonia emissions, the majority of which (90%) is from livestock production. Also considerable is the atmospheric deposition of pesticides (not shown in table). For example, approximately 30% of the atrazine load entering Lake Michigan (amounting to nearly 3000 kg yr^{-1}) is associated with precipitation[90, 91]; farther north in Lake Superior, atmospheric inputs account for 95% of the atrazine inputs[92].

Table 7: Agricultural Production contribution to criteria air pollutants (thousand short tons)

	1980		1997	
Pollutant	Emission from ag. production	percent of U.S. total	emission from ag. production	Percent of U.S. total
VOC	575	2.2	640	3.3
Nitrogen oxide	1296	5.2	1144	4.9
Carbon monoxide	1550	1.3	847	1.0
Ammonia	Na	Na	2089	65.7
PM-10	300*	4.1*	4791	14.3
PM-5	na	Na	1000	12.0

Values compiled from [93]; includes emissions from agricultural chemical manufacturing.
* data from a significantly contributing category not available

Agricultural activities were responsible for 7.7 percent of total U.S. greenhouse gas emission in 1997[94]. The sources of these emissions are detailed in Table 8. Methane is produced through enteric fermentation as part of the normal digestive processes in animals. Ruminant livestock are major producers of methane in the U.S.: 19% of the total annual methane emitted in the U.S. comes from livestock. Nitrous oxide emissions from agricultural soils, accelerated by management practices, are also a significant contributor to greenhouse gas emissions. Potentially significant greenhouse gas contributions not included in these data are agriculture's portion of electricity consumption and perhaps natural gas consumption in irrigation pumps.

Increasingly, research is recognizing the important role biodiversity plays in agroecosystems[27]. Biodiversity, referring to all species of plants, animals and micro-organisms existing and interacting within an ecosystem, is responsible for various ecological services essential to agriculture, including recycling of nutrients, regulation of microclimate and local

Table 8: Greenhouse gas emissions from Agricultural production (MMTCE)[94]

Emission and source	1990	1997
Methane	**50.3**	**54.1**
Enteric fermentation	32.7	34.1
Manure management	14.9	17.0
Rice cultivation	2.5	2.7
Agricultural residue burning	0.2	0.2
Nitrous oxide	**68.2**	**77.3**
Manure management	2.6	3.0
Agricultural soil management	65.3	74.1
Agricultural residue burning	0.1	0.1
Farm equipment	0.1	0.1
Carbon dioxide	**7.7**	**8.9**
Agricultural machinery, gasoline	1.2	2.2
Agricultural machinery, diesel	6.5	6.7
Total	**126.2**	**140.4**

hydrological processes, suppression of undesirable organisms, and detoxification of noxious chemicals[95]. Modern agriculture has created an ecologically simplified system that is highly dependent on inputs. Biodiversity has suffered in the wake of monoculture cropping of annuals and heavy pesticide application. As mentioned in the genetic resources section, modern agriculture relies on a very narrow genetic base for the world's major crops. Diversity in the species as well as varieties of plants and animals that we use for food can aid in buffering from disastrous effects from pest and disease outbreaks, floods, droughts, etc. Polycultures (mixing dominant plant species in a plot) often demonstrate lower populations of insect pests[96]. Vegetation adjacent to crop fields and certain weed populations can aid in insect pest management by harboring and supporting natural enemies[95]. Soil biodiversity is extremely important for soil fertility and plant health. A square meter of healthy temperate agricultural soil may contain 1000 species of organisms. Disruption of this diverse web through tillage, nutrient spikes, lack of organic matter, and pesticide applications can hinder the role of soil biodiversity in nutrient cycling, suppressing soil-borne pathogens, supporting plant growth, and altering soil structure. Researchers investigating soil quality indicators suggest that biological indicators – the diversity and population of insects, for example – might prove to be a preferred measure of soil quality. Insect communities respond relatively slowly to rapid changes in soil chemistry (such as nitrogen content) but respond rapidly to the slower changes in physical characteristics of the soil (such as carbon levels associated with organic matter)[97].

There has been recent interest in Government "agri-environmental" payment programs which would compensate producers for maintaining beneficial agricultural practices or mitigating adverse environmental impacts[98]. The effectiveness of such programs in providing a net benefit will be greater if policymakers consider the full environmental impacts of modern food systems. The indicators suggested here may provide guidance in designing programs.

Food processing, packaging, and distribution

Economic

Marketing of domestically grown and consumed food, including charges for transportation, processing and distribution, cost an estimated $466 billion in 1998[44]. That represents 80% of the $585 billion that consumers spent on foods originating on U.S. farms. Marketing costs rose 54% from 1988 to 1998. Nearly 88% of the $186 billion increase in consumer expenditures for domestically grown food resulted from increases in the marketing costs[47]. The cost of labor composed nearly half of the 1998 marketing bill. The remainder of the marketing cost is balanced between packaging, transportation, energy, advertising, business taxes, net interest, depreciation, rent, and repairs (see Figure 1). The relative cost of marketing different food items is reflected partly in the farm value as a percentage of retail price seen in Table 9. As mentioned earlier, the farm-to-retail price spread has increased every year for the past 30 years. While retail food prices rose 2.4% from 1996 to 1997, farmers received 4.4% less for the food they produced[57]. In 1997, food manufacturers (including the tobacco industry) received an after-tax profit return on stockholder equity of 19.8% (5.6% as a percentage of sales), a culmination of 5 years of increasing profits. Food retailers averaged a 17.3% return on stockholder equity in 1997 (1.6% of sales)[45].

Figure 1: What a dollar spent for food paid for in 1998

Source: USDA's Economic Research Service.

Consolidation and concentration in the processing, packaging and distribution stage of the food system has been extensive over the past 3 decades. William Heffernan, Professor of Rural Sociology at the University of Missouri, likens the effects of this market concentration on the food system to "an hour glass with thousands of farmers producing farm products which had to pass through a relatively few processing firms before becoming available to the millions of consumers in this and other countries" [99]. These processing firms may be able to exert non-competitive influence on the market, influencing quantity, type, and quality of the product,

Table 9: Farm value as a percentage of retail price for domestically produced foods[47]

Items	1988	1998
Livestock products:		
Meats	45	30
Dairy	40	36
Poultry	49	43
Eggs	53	42
Crop products:		
Cereal and bakery	9	6
Fresh fruits	25	17
Fresh vegetables	28	20
Processed fruits and vegetables	28	18
Fats and oils	24	22

location of production, and price of the product at the production stage and throughout the entire food system (see *consolidation* section). Food retailing has, until the past few years, maintained competition between firms of equal economic power. Major mergers in 1998 changed this: the largest ten firms now control half of the retail trade[99], with the four largest firms controlling almost 29% (up from 16% in 1992)[100].

Supermarkets represented 24% of the food retail store types in 1998, but accounted for 77% of retail food sales[101]. Even the nature of supermarkets have been changing under the influence of consolidation. In 1980, 85% of supermarkets (73% share of sales) were categorized as “conventional” (full-line self-service grocery store with annual sales of $2.5 million or more). By 1997, conventional stores decreased to 44% (19% of sales), and “superstores” (supermarket with at least 30,000 square feet, doing $12 million of business or more annually, and offering expanded selection of non-food items) rose to 31% of stores (43% of sales)[101]. The structure of food retailing is strongly aligned with the structure of the food distribution industry. Large corporate chain stores are typically organized around regional or national food distribution, with warehouses occupying the central position in the flow of goods. Retail stores are either a direct subsidiary of the distribution corporation or operate under a contractual relationship with a distributor. Warehouses often charge food processors a slotting fee for delivery and stocking services, a relationship which creates a clear advantage for large food processors. Product quality in a distribution-centered system is defined by shelf-life, packaging, and appearance. While it may be argued that “superstores” make shopping more convenient and reduce trips to multiple stores, they also displace local neighborhood groceries that would be accessible to more people by foot, bicycle, or public transportation. It is likely that a distribution-centered system also adds delivery and personnel efficiency. Yet, the sheer scale limits market access for smaller food processors, and tends to concentrate capital as it moves up the ownership hierarchy, removing it from the communities that generated that capital. Because of the sheer volume of sales handled, distribution-centered superstores are less likely to buy direct from local producers, instead relying on large concentrated processors and distributors.

On the other end of the retail food spectrum, the number of farmers’ markets, which provide consumers direct access to locally grown produce, has grown substantially over the last several decades. State reported farmers markets numbered 1,755 in 1993, and more than 2,746 in 1998, though some analysts claim that the total number, including those not reported, is more than double that figure[47]. Still, only 0.3% of the market value of agricultural products were sold directly to individuals for human consumption in 1997[39].

Social

As mentioned earlier, labor is the dominant cost of food "marketing." The total number of food marketing workers in 1998 (which includes labor used by assemblers, manufacturers, wholesalers, retailers, *and* eating places) was about 13.8 million[47]. This is an increase of about 17% from a decade earlier, and 4.9 times more than the number of farm workers in 1998. About 73% of the growth in food marketing employment over the 1988-1998 decade has occurred in away-from-home eating places[47]. In 1997, eating and drinking places employed 56% of food marketing employment, while about 25% worked for foodstores, 12% for food manufacturers, and 7% for wholesalers[45].

Today's consumer is presented with an overwhelming variety of food products. The average supermarket maintains over 400 fresh produce items, compared to 250 in the early 1980s and 150 in the mid-1970s. The assortment of processed foods has increased equally, if not more dramatically, with an emphasis on convenience foods – snack foods, pre-cooked, and already prepared meals. Prepared and convenience foods accounted for 12.5% of at-home food expenditures in 1995[102] Often, processing of food removes important nutrients contained in the whole food products. For example, more than 98% of the 150 pounds of wheat flour consumed per capita in 1997 was refined flour, which loses most nutrients, including fiber, vitamins, minerals, and phytochemicals, during processing[47]. Five nutrients (iron, niacin, thiamine, riboflavin, and folate) are replaced by manufacturers in enriched flour from chemically synthesized sources, but many others are not. Consumer preference is the main reason for this processing: whole grain flour requires less processing, avoids the loss of nutrients and does not require that the nutrients be supplemented from other sources. It should be noted that much of the nutrient value in byproducts of food processing such as refined flour is not "lost" from the food system but is typically fed to animals (see, for example, the mill byproduct flow in Figure 3).

Interestingly, food manufacturers spend enormous amounts of money in advertising the processed and convenience foods they market. Food manufacturers spent over $7 billion in advertising in 1997, nearly 10% of the total mass media advertising market. Twenty two percent of this was spent on prepared and convenience foods, another 15.5% on confectionery and snacks, and an additional 10% on soft drinks and bottled water[102]. The connection between advertising and the food we eat will be further considered in the "consumption" section of this report.

Though the U.S. food supply has been widely recognized as being very safe, government officials, public health agencies, industry trade associations, and consumers are giving increasing attention to food safety. The latest data from the Center for Disease Control and Prevention estimates that 76 million people are sickened, 325,000 are hospitalized, and 5,000 die annually from food poisonings in the U.S.[103]. While the years leading up to 1997's national interagency Food Safety Initiative saw rises in foodborne illnesses[104, 105], monitoring by the Foodborne Diseases Active Surveillance Network (FoodNet) has found a 19% overall decline in the incidence of bacterial foodborne infections[106]. Good estimates of how many foodborne illnesses originate in the food processing, packaging and distribution stages are not available (other points of contamination could be at the farm itself or during preparation, either in restaurants or in the home). However, much of Government's effort to improve food safety have focused on new regulations for the processing industry. For example, in 1996 the Food Safety and Inspection Service of the USDA initiated its Hazard Analysis and Critical Control Point (HACCP) Systems for reducing pathogen contamination associated with meat and poultry products[107]. A recent review of the changing patterns of infectious disease both in developed and developing countries points to food-borne disease as a high priority in the coming century[108]. Changes in technological and industrial practices throughout the food system are highlighted as contributing to contemporary concerns with food-borne disease. These include the feeding of antimicrobial agents to livestock as growth promoters, the feeding of rendered materials to food animals, increased emphasis on longer food shelf-life and preservation by refrigeration only, and the growing consolidation within the food industry[108].

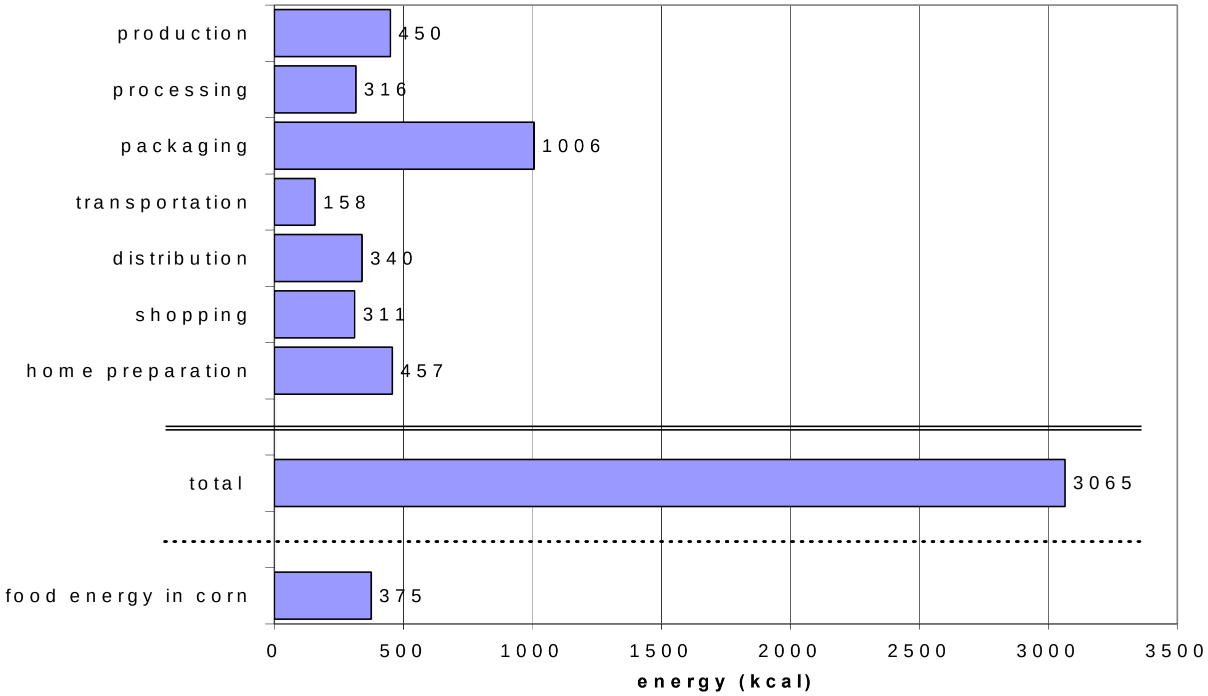
Environmental

The continuous supply of the diverse selection of foods that consumers have come to expect in the United States and in other developed countries relies heavily on processing and packaging to preserve food as well as transportation of fresh foods from production areas to those areas with limited growing seasons. An immediate indicator of the impact of this practice on the environment is the energy consumed. The energy required for processing foods is included in the Life Cycle Energy analysis in a later section. The energy consumed by the food and kindred products manufacturing sector accounted for 4.7% of the total energy consumption in the U.S. in 1991[77]. In general, this energy is much greater than the food energy provided by the product. As an example, the energy inputs for producing a can of corn are shown in Figure 2. The energy requirement for processing and packaging alone is much greater than the food energy contained in the corn. Breakfast cereals, which contain about 3600 kcal of food energy per kilogram, require on average 15,675 kcal/kg to process and prepare. A 12-ounce can of diet soda requires a total of 2200 kcal to produce (over 70% of which goes toward the aluminum can) and may provide only 1 kcal in food energy[109].

More than half of the energy consumption in food retail is used in refrigeration. While food retail only accounts for 2.6% of the total commercial building energy consumption, it is very energy intensive: food retail uses 214 BTU/sq. foot whereas the average commercial building uses 90.5 BTU/sq. foot[101].

Packaging is second only to the cost of labor in the food marketing bill: 8.5% of the food dollar goes into packaging. Thirty three percent of the total packaging expense is due to cardboard boxes, used extensively for shipping processed foods (i.e., packaging that does not go home with the consumer)[45]. While recycling efforts across the country have greatly increased in the past decade, food packaging is still a major contributor to municipal solid waste. About 10.3% (22.3 million tons) of the total municipal solid waste generated in 1997 can be directly attributable to food and beverage packaging; 30% of this was recovered[110]. This number is an underestimate, however, because some of the packaging categories that could not be specifically attributed to food and beverages but likely contained food packaging materials (such as plastic wraps and corrugated boxes) were omitted. A 1993 study found that the food retail industry generated 25.4 million tons of grocery packaging, and in that year, grocery packaging was more than one third of the total containers and packaging found in the municipal solid waste stream[101]. Recovery of grocery packaging, however, has also increased: in 1970, only 860 thousand tons of grocery packaging waste was recovered whereas by 1993 it had increased to 8.4 million tons[101].

Figure 2: Energy inputs for a 455g can of sweet corn
Recreated from [109]



Food waste, or food discards, can also be substantial in the food processing and distribution stage. A study by the USDA Economic Research Service estimated food losses throughout the food system. They reported that 5,449 million pounds of edible food, or 2% of the total edible food supply, were lost at the retail stage in 1995[111]. Nearly half of the retail losses came from perishable items such as fluid milk and other dairy products and fresh fruits and vegetables. The report mentions potential losses during processing and wholesaling due to frequent handling and spoilage, but these farm-to-retail losses were not measured. As mentioned earlier, however, the food processing industry does a reasonable job at finding value in byproduct streams, most often as animal feeds, so it is expected that true "losses" in food processing will be relatively small.

Preparation and Consumption

Economic

The system described up until this point has a single primary function: to provide necessary nutrition to our society. Agricultural policy in the U.S. has rested on providing an abundance of food cheaply to U.S. citizens. To this extent, U.S. agriculture has been very successful. In 1996, the average U.S. consumer spent only 10.7% of their disposable personal income on food[57]. Forty days of earnings is sufficient for the average American to pay for his or her family's food bill for the entire year. This can be compared with the 130 days of earnings necessary to pay off federal taxes[112]. And the cost of food to Americans has been decreasing:

11.6% of disposable income was spent on food in 1990; in 1970 it was 13.8%, and in 1930 it was 25%[57]. Indeed, food in the U.S. is more affordable than in many other countries, as can be seen in Table 10.

Table 10: Portion of Total Personal Consumption Expenditures Spent on Food and Alcoholic Beverages Consumed at Home, by Selected Countries, 1994[113]

country	Food [1/] (%)	Alcoholic beverages (%)
United States	7.4	1.0
United Kingdom	11.2	6.1
Sweden	14.6	2.7
France	14.8	1.9
Australia	14.9	4.4
Germany	17.3 [2/]	[2/]
Japan	17.6 [3/]	[2/]
Israel	20.5	0.9
Switzerland	24.4 [3/]	[2/]
Mexico	24.5	2.5
South Africa	27.5	6.5
Greece	31.7	2.9
Venezuela	38.2 [2/]	[2/]
India	51.3	0.5

[1/] food includes non-alcoholic beverages
[2/] alcoholic beverages included in food
[3/] food includes alcoholic beverages and tobacco

There has also been a clear increasing trend in away-from-home food. Away-from-home meals and snacks accounted for 46% of the U.S. food bill in 1997, up from 38% in 1977[57]. A combination of increased discretionary income and lack of time and skill to prepare foods at home is likely responsible for this trend. While increases in away-from-home meals have fed a thriving restaurant industry that provides 7.6 million jobs[45], eating away from home makes it more difficult to monitor personal nutritional intake. Food consumed away from home typically has a higher content of fat, saturated fats, and cholesterol.

Social

Relatively cheap food in the United States is of social benefit because it makes food more accessible to poorer members of society. In addition, federal nutrition assistance programs, aimed at improving access to food for children and needy families, appropriated a total of $35 billion in fiscal year 2000, reaching one out of every six Americans[47]. As a result of affordable food and food assistance, more than 90% of U.S. households were food secure, meaning they had assured access at all times to enough food for an active healthy life. Still, 9.7% of U.S. households – about 10 million – were food insecure over the 1996-1998 period. In other words, these households did not always have access to enough food to meet basic needs. Included in these were the 3.5% of households in which one or more household members were hungry at least some time during the year due to inadequate resources for food[114].

A sustainable food system must be founded on a sustainable diet. In the most general sense, this would be a diet that matched energy intake with energy expenditure while supplying necessary nutrients for a healthy lifestyle. However, consumers make dietary decisions based also on economical, physiological, psychological, sociological, and even spiritual considerations[115]. Eating becomes more than just a biological necessity, often being a focus of social, business, and family events or a simple act of pleasure. Nutritional problems of a century ago that resulted in deficiency diseases such as scurvy and rickets have been replaced with problems of nutritional overindulgence: obesity, heart disease, stroke, diabetes, hypertension. A recent report, entitled "America's Eating Habits: Changes and Consequences," compiled by the Economic Research Service of the U.S. Department of Agriculture[116] provides a good starting point for understanding the complications of dietary choices. Certainly, a life cycle evaluation of a sustainable food system must also include the effects and impacts of the dietary choices that drive that system.

Data from the National Health and Nutrition Examination Surveys of 1977-80 and 1988-1994 demonstrate that the prevalence of obesity is on the rise throughout the American population. The 85th percentile of body mass index (BMI, is the body weight in kilograms divided by the square of the height in meters – kg/m^2) has previously been set as the definition for overweight. The number of overweight individuals rose over the time between surveys from 25.4% to 34.9% among American adults, from 7.6% to 13.7% among children ages 6-11 years, and from 5.7% to 11.5% among adolescents[117]. Under an updated definition presented in the 2000 Dietary Guidelines, a BMI greater than 25 is considered overweight and a BMI over 30 is obese[118]. By these standards, 60% of males and 46% of females 20 years and over were overweight in 1994-1996[119]. Increasingly, scientific studies confirm that America's diet of high fat intakes and low intakes of whole, fiber-containing foods such as whole grains, vegetables, and fruits has a significant impact on our health, quality of life, and longevity. Diet is a significant factor in the risk of coronary heart disease, certain types of cancer, and stroke – the three leading causes of death in the United States. Estimates of diet-related medical costs, loss of productivity, and value of premature deaths reach $71 billion annually[120]. Estimates of the direct health care costs of obesity alone range from $39 billion[121] to $52 billion[122] annually. The prevalence of overweight and obese Americans was highlighted as a major agenda issue at the National Nutrition Summit in May of 2000[123].

Multiple sources suggest that there has been a slight increase in food energy consumption by Americans over the past 20 years. The food energy available for consumption, based mainly on national disappearance of food, increased by about 15% from the 1978 value to 3800 kcal per capita per day in 1994[124]. However, this value includes food that is wasted at the retail and consumer level and the increase in per capita food available could partly reflect increases in food wastes. The Agricultural Research Service of the USDA also conducts the Continuing Survey of Food Intakes by Individuals (CSFII) to gain insight into what Americans are eating. The surveyed caloric intake rose from 1854 to 2002 kilocalories between the 1977-1978 and 1994-1996 surveys [119], an increase of only 8%. Survey-based data on food intake are typically plagued with underreporting by participants, and some of the increase in dietary intake may be due to improvements in the ways that data is collected[119]. Increases in food energy intake alone do not easily account for the considerable change in the number of overweight Americans. The population also appears to be engaging in less physical activity: there has been a shift by a large portion of the workforce from manual labor to white-collar jobs that "require nothing more active than pushing keys on a keyboard"[117]. Establishing trends in physical activity and energy expenditure in a population is very difficult, however, due to lack of a reliable means of measuring such things. Methods of surveying personal energy expenditure demand increased attention since this provides this missing element needed in designing a sustainable food system approach where food production matches necessary intake.

Marked changes have occurred in U.S. food consumption patterns over the past 25 years. While some of these changes reflect dietary recommendations presented by professional science and health groups, others appear to arise from changes in lifestyle: faster paced life, more women in the workforce and single parent households, increased discretionary income. Consistent with health recommendations, Americans now consume two-fifths more grain products and a fifth more fruits and vegetables per capita than they did in 1970. They also eat leaner meat and drink lower fat milk. But while red meat consumption decreased by 15% between 1970 and 1997, poultry increased by 90%. Total annual meat consumption (red meat, poultry, fish) in 1999 reached a near record high197 pounds (boneless, trimmed-weight equivalent) per person, 20 pounds above 1970 levels[47]. While the health implications of such high meat consumption can be debated, the environmental and resource burdens of a meat-based diet greatly exceed those of a plant-based diet (this will be further addressed under environmental indicators of consumption). Average annual use of added fats and oils remains near record-high levels. Per capita consumption of cheese increased 2 ½ times between 1970 and 1998.

Per capita consumption of caloric sweeteners – mainly sucrose and corn sweeteners – continues to increase. Each American consumed a record average 154 pounds of caloric sweeteners in 1998 – 53 teaspoons per person per day. Of course, some of this is wasted in the food system or at home, but even if an assumed 40% is lost, the remaining 32 teaspoons still greatly exceeds the recommended maximum intake of 18 teaspoons for a person consuming a 2800 kilocalorie diet (6 teaspoons for a 1600 kilocalorie diet)[47]. Corn sweeteners (especially high fructose corn sweeteners) continue to replace sucrose (made from cane and beets), increasing from 16% of total caloric sweeteners in 1970 to 57% in 1998. Sugar has become America's number one food additive, accounting for 16% of total caloric intake. Carbonated non-diet soft drinks, for which per capita consumption rose 51% between 1986 and 1998, account for more than a fifth of the refined and processed sugars in the American diet[47].

As mentioned earlier, large sums of money are spent on advertising of food in the United States. Food manufacturers spent $7 billion on advertising in 1997, whereas the U.S. Department of Agriculture spent only $333.3 million on nutrition education, evaluation and demonstrations[102]. Foods that are intensely advertised tend to be the ones that are overconsumed relative to dietary recommendations. Confectionery and snacks, prepared and convenience foods, and soft drinks are all heavily advertised (relative to their share of the food-at-home budget). On the other hand, fruits and vegetables, for which Americans consume lower than recommended amounts, receive very little advertising.

There is ongoing debate as to how best inform consumers of the health effects of their dietary choices. Policy changes in the mid-1980s allowed manufacturers to explicitly link diet to disease in advertising and labeling. It is unclear whether this has lead to market-driven improvements in consumers' dietary knowledge and choices, or has added to confusion[125]. Measuring consumer awareness of both nutritional knowledge and knowledge of the consequences of food production is a complex and difficult task. General observation, however, suggests that Americans are not well informed of the health and environmental effects of the food that they buy. Inconsistent information presented by diverse stakeholders (food producers, food manufacturers, government, special interest groups) certainly can hinder understanding by creating confusion.

Perhaps even more deeply polarized is the debate around product labeling to provide consumers with information regarding such things as the geographic origin of food, means of production, or genetically engineered content. Although some food manufacturers and retailers volunteer the place of origin of their products, this is rare. Rarer still is sufficient information to allow consumers to make educated choices on the environmental and social impacts of the origin of their food. While the organic foods market continues to grow in the U.S., a consistent definition for this claim on production methods still has not been developed. The national organic food standards proposed by the USDA in 1998 received record numbers of public comments identifying problems in the standards. Numerous interests throughout the food system must be considered in establishing such national standards. Still, the lack of a clear understanding of the organic claim, complicated by related claims such as 'natural', 'chemical free', 'free farmed', or 'Amish grown', creates confusion for the consumer trying to understand the impact of production methods. A number of polls have indicated that a majority of American consumers support labeling of foods containing genetically engineered ingredients, as is presently required in Europe[126, 127]. Bills on both the house (HR.3377.IH) and senate (S.2080.IS) floor would require such labeling. But proponents of genetically engineered food (including biotechnology companies, food manufacturers and retailers, and farmers' organizations protecting the interests of the farmers planting genetically engineered crops) feel that labeling would be equivalent to placing a "skull and crossbones" on genetically engineered foods. They argue that government regulatory bodies have agreed with claims that approved genetically engineered food is "substantially equivalent" to non-engineered food[128].

Environmental

Consumer choices have major influences on the environmental impact of the food system. A recent study by researchers at the Union of Concerned Scientists named food as one of the most environmentally harmful consumer activities, second only to transportation by cars and light trucks. According to this study, the second most effective environmental choice that a consumer can make is to eat less meat and poultry (second to driving less and/or driving an energy efficient car). Following this, the authors list buying organic produce as a very effective environmental choice[129]. The authors suggest that such food choices make a greater environmental impact than household operations such as installing efficient lighting and appliances, and certainly more impact than rather benign choices like 'paper versus plastic' or the occasional disposable cup. Indeed, when one considers the fossil energy inputs alone required to sustain a meat-based versus a vegetarian diet, the differences are surprising. Pimentel calculates that providing a 3600 kcal diet with 1000 kcal from animal products requires about 35,000 kcal of fossil energy whereas a 3600 kcal vegetarian diet (with more than sufficient levels of protein) takes about 18,000 kcal of fossil energy – almost half that of the non-vegetarian diet. A lacto-ovo vegetarian diet (including milk and eggs) requires around 25,000 kcal of fossil energy[130]. If we return to our can of sweet corn (Figure 2) which took 3065 kcal of energy to produce, providing the same 375 kcal of food energy with beef would require 13,497 kcal of fossil energy– most of which (96%) goes into producing the beef as opposed to processing, packaging, etc[109]. From an energy efficiency standpoint alone, choosing a vegetarian diet, or at least one greatly reduced in animal products, significantly reduces the environmental impact of our food system. Replacing poultry and red meat with nutritional equivalents of grains and pulses would also significantly cut food-related land use and common water pollution.

Containers and packaging generated in the U.S. municipal waste stream in 1997 totaled 71.8 million tons, or 33% of the total generated waste stream. As mentioned in the previous section, about 16.9 million tons of this can be directly attributed to food and beverage packaging[110]. However, there are many categories in the municipal solid waste characterization (such as paper or plastic bags and sacks or plastic wraps) that are used extensively for food packaging that may also be used for packaging other goods and have therefore not been included. Containers and packaging have maintained a relatively steady fraction of the total municipal solid waste stream since 1970, but recovery of packaging has greatly increased. In 1970, a reported 7.7% of total containers and packaging was recovered while in 1997, this had increased to 39.4%[110].

A large portion of food loss occurs at the food service and consumer level of the food chain. The Economic Research Service of the USDA attributed 94% (by weight) of 1995 food loss to the food service and consumer stage. At 90.8 billion pounds, this amounts to 26% of the edible food available for human consumption in the U.S. Fresh fruits and vegetables accounted for 19% of these losses, and an additional 18% was fluid milk[111]. This is roughly enough milk to serve everyone in the U.S. one-third of an 8-ounce glass *every day.* Examinations of household garbage by researchers at the University of Arizona concluded that large quantities of single food items – entire heads of lettuce, half-eaten boxes of crackers – accounted for a larger share of household food loss than did plate scraps. They also found that specialty products such as sour cream, hot dog buns, or impulse items had a higher frequency in household garbage than did frequently purchased staples like bread, milk and cereal[111].

End of Life

Economic

According to a report issued by the Economic Research Service of the USDA, retail, food service, and consumer food losses in 1995 totaled 96,266 million pounds, or 27% of the total edible food supply[111]. This does not include pre-harvest, on-the-farm, and farm-to-retail losses. In its annual report of the U.S. municipal solid waste stream, the EPA found that 10% - 44,260 million pounds – of the solid waste stream was food wastes in 1998[131]. The discrepancy in these two studies is mostly attributable to differences in scope and definition: the EPA report only accounts for food that becomes part of municipal solid waste. For example, the USDA report included loss of 17 billion pounds of fluid milk that, in most cases, would not be included in municipal solid waste. While the absolute amount of food waste in the municipal solid waste stream has nearly doubled since 1960, the proportion of food in the total waste stream has remained relatively constant[131].

Disposal of food waste generally occurs either through additions to landfill, incineration, or by garbage disposals connected to sewer systems. All have associated costs. Nationwide, the weight-averaged tipping fee for landfill disposal was $32 a ton in 1996[132]. If all of the 21,550 thousand tons of food waste discarded in 1998 were landfilled at this rate, the cost to Americans would be $690 million annually. However, about 10% of municipal solid waste is incinerated, with an average tipping fee of $63 a ton[132]. This brings the estimated cost of discarding food waste nationwide to $756 million. This only accounts for the food that is disposed of through municipal solid waste channels. Large amounts of food are fed to garbage disposals and treated along with municipal sewage. Food in sewage contributes to biological oxygen demand, adding to the burden of wastewater treatment.

Social

The USDA Food Loss report did not estimate the share of food loss that was recoverable for human consumption (unrecoverable food loss would include diseased or otherwise unsafe produce and meat, spoiled perishables and plate waste from foodservice establishments)[111]. However, if a mere 5% of the 96 billion pounds of food loss were recovered, this would be enough food to feed 4 million Americans every day. Recovering 10% of the edible food loss would feed the entire population of New York City! While not yet at these levels, significant food recovery efforts are made in the U.S. Second Harvest, the nation's largest domestic hunger relief charity, provides more than 1 billion pounds of food and grocery products annually through 45,000 local charitable agencies. Another national recovery network called Foodchain collects surplus prepared and perishable food from restaurants, corporate cafeterias, caterers, grocery stores, and other foodservice establishments. In 1997, Foodchain distributed more than 150 million pounds of food. The Society of St. Andrew, the nation's leading field gleaning organization, rescues over 20 million pounds of fresh fruits and vegetables yearly that would normally be discarded at packing and grading sheds or directly from farmer's fields. Mickey Weiss' Charitable Distribution Facility distributes more than 2 million pounds of fresh produce *a month* from the wholesale produce industry to emergency feeding programs throughout Southern California. The project is being emulated nationwide through a program called From Wholesaler to the Hungry[133].

Environmental

Food losses can also be recovered through composting. A 1997 nationwide survey found 214 commercial composting sites for food wastes, 3.7 times the number found in 1995. The sixty-eight projects reporting tonnage data in this survey totaled to 360,000 tons of food residuals processed annually[134]. The EPA reports 580,000 tons of recovered food waste in 1998, though this number includes recovery of paper for composting[131]. Model programs highlighted by the EPA demonstrate the enormous potential for waste reduction through food discard recovery[135]. For example, the New York State Correctional Facilities recovered 6,200 tons of food discards and other organics (90% of the food discard waste stream) in 1997 through on- and off-site composting. Fletcher Allen Health Care in Vermont recovered 90% of their pre-consumer food discards, amounting to 90 tons in 1997[135]. Still, food wastes are characterized by low levels of recovery: in 1998 less than 2.6% (by weight) of food wastes were recovered, making food wastes the second largest single source of discards (waste remaining after recovery) in the municipal solid waste stream[131].

INDICATORS FOR THE TOTAL FOOD SYSTEM

Life Cycle Materials: Food System Mass Flow

Material and energy flow analyses provide a means to assess overall system efficiencies and the distribution of consumption across life cycle stages, and to identify areas for improvement. The flow diagram in Figure 3 gives an overview of the material flow throughout food production and consumption in 1995. The mass flow analysis here concentrates on feed,

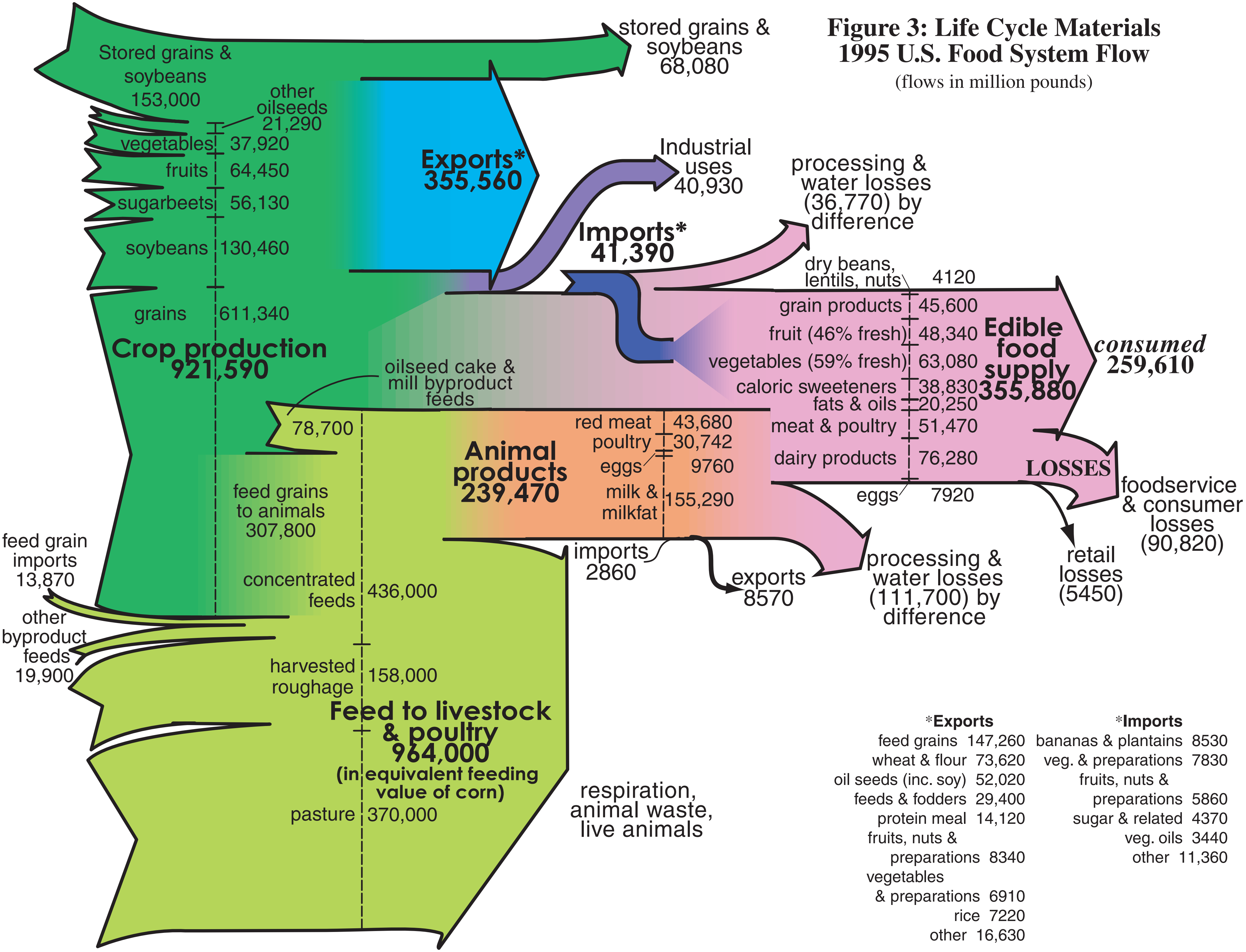


Figure 3: Life Cycle Materials 1995 U.S. Food System Flow

(flows in million pounds)

*Exports	
feed grains	147,260
wheat & flour	73,620
oil seeds (inc. soy)	52,020
feeds & fodders	29,400
protein meal	14,120
fruits, nuts & preparations	8340
vegetables & preparations	6910
rice	7220
other	16,630

*Imports	
bananas & plantains	8530
veg. & preparations	7830
fruits, nuts & preparations	5860
sugar & related	4370
veg. oils	3440
other	11,360

food and food products and does not include other inputs into the food system such as chemicals, fertilizers, mass of fuel consumed, or packaging materials. The left side of Figure 3 represents the plant-based production in 1995. A large fraction of this is used to feed animals (light green section) and is thus converted to animal products (orange section). After exports (light blue section, including both raw and processed exports) and food-crop based industrial products (purple section) are removed, the remaining portion of the plant based production (by difference), along with the addition of food imports (dark blue), makes up the food consumed in the U.S (pink section). The following paragraphs detail this food mass flow model.

Over half of the grains (corn, sorghum, barley, oats, wheat, rye and rice) grown in the U.S. get fed to farm animals in this country. A large portion of the "biomass" that gets fed to animals exits the system through respiration and manure or is used to maintain the live animal population. Manure is recoverable as soil nutrient amendment, but as discussed in the *agricultural growing and production* section, concentration of animal production facilities has made this recovery less feasible. The rough animal food products resulting from the year's production amount to about 25% of the weight of feed given to the animals. This efficiency estimate is somewhat complicated by the fact that water consumed by animals is not explicitly included as an input in this mass flow model. Most of the water fed to animals (5.49 billion gallons per day) simply exits the system again through animal respiration and manure, but part of the weight of the animal food products shown will be water, especially in the case of raw milk.

While much of the plant material fed to livestock is not appropriate for human consumption (pasture, roughages), strong arguments can be made for improving the sustainability of the U.S. food system through reducing animal based food production. As mentioned earlier, fossil energy demand for producing animal protein through current grain-intensive means is nearly twice that for a pure vegetarian diet. In addition, livestock production as it is widely practiced today also has a significant impact on land use, water use and water quality, and air emissions. Reduced animal protein scenarios are undergoing life cycle based systems research by the Protein Foods, Environment, Technology and Society Programme (PROFETAS), a research project of the International Human Dimensions Programme on Global Environmental Change (IHDP)[136], with the end result being policy options. This is not to say that livestock management should be excluded from the food system. However, reducing meat consumption (and thus production demand) and replacing input intensive row crop grain production with carefully managed, integrated pasturing systems can have positive effects on many of the sustainability indicators presented here.

Nearly 40% of the food and feed crops produced in the U.S. were exported in 1995. While the U.S. is the second largest grain producer in the world and boasts the world's largest grain surplus, grain exports from the U.S. amount to only about five percent of global production and go primarily to feeding animals in Europe and Japan[137]. Interestingly, feed grains (grains fed to animals) are both the largest export *and* import by weight in the U.S. While it is recognized that international trade is complex and dependent on many factors, a simple assessment would point to this as an unnecessary inefficiency. The second largest agricultural import (by weight) into the U.S. is bananas. Agricultural imports experienced a 26% (by weight) increase from 1995 to 1999, with larger increases occurring in red meat and poultry (37%), fruits and nuts (46%), vegetables (36%), and cocoa and cocoa products (49%)[138].

While the previous year's stored grains and beans are greater than those stored in 1995, this is a bit of an anomaly. Over most years, the incoming and outgoing stored grains are closer in value. While there are a number of agricultural crops (such as cotton or industrial grade rapeseed) that are grown specifically for an industrial market and are thus not included in this food system diagram, a portion of the food and feed crop is also utilized by industrial sectors. Over 34,800 million pounds (622 million bushels) of corn were consumed for industrial uses in 1995/1996, including industrial starch and fuel and manufacturing alcohol[139]. Some edible oils and fats also are routed to industrial uses. Current efforts are underway to increase plant/crop-based fuel and industrial products, replacing petrochemical-based feedstocks with renewable, plant-based ones[140]. The diagram also shows two "processing losses" (from both animal products and plant products) that are arrived at by difference: these losses are not characterized, but it is anticipated that much of the weight loss is water. For example, the 10 pounds of fluid milk required to produce 1 pound of cheese would show up primarily as a water loss.

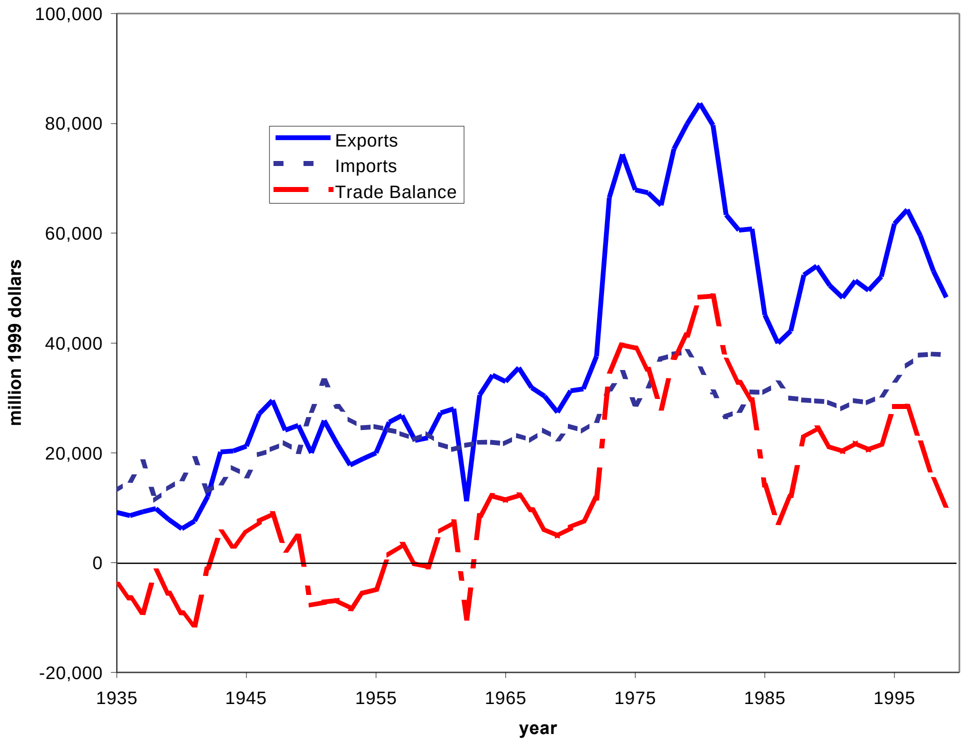
Finally, the annual edible food available to the U.S. population represents about 20% of the biomass inputs into the system. This amounts to 3800 kilocalories of food energy available per capita per day, nearly 15% more than what was available in 1970[124]. This available food is reduced 27% (by weight) due to spoilage and waste at the retail and consumer level[111]. Food loss at the consumer level is one of the larger losses in the entire food system. Inexpensive food, a desire for convenience, and perhaps the devaluing of food in our culture has led to a situation where edible food is considered disposable, despite the vast resources consumed to produce it. When the connection between consumption practices and production is made, great opportunities arise for reducing the environmental burden of agricultural production and the whole food system, as well as reforming economic and social stresses, simply through reducing demand by minimizing food loss.

Figure 4 shows the value (in present dollars) of agricultural imports and exports over the past 65 years. Growth in U.S. agricultural exports has largely exceeded the growth in imports, leading to a positive trade balance. However, agricultural imports have grown significantly in recent years. U.S. imports of agricultural commodities and products are projected to reach $39 billion in fiscal 2000, a 72% increase from 1990[141]. This growth is attributed to the strong U.S. dollar combined with slower growth or recessions elsewhere in the world. As a result, more and more of the production of the food that Americans eat is being moved outside the country.

Life Cycle Energy: Food System Energy Demand

Agriculture is ultimately a process of energy conversion: converting solar energy, along with various chemical and fossil energy inputs, into food energy that will sustain a human population. A series of technological changes in agriculture over the past century have greatly increased yields, but have also increased the amount of energy that is consumed in this conversion process. Many of the tasks that were formerly performed by the plant (extracting nutrients, restraining disease and insects) or by animals (self-foraging of feed) have been taken over by the farmer through the input of external energy (fertilizers, pesticides, fossil fuels)[142]. What's more, human labor in the agriculture of developed countries has been largely replaced by fossil fuel driven machinery. As a result, modern agriculture has developed a strong dependence on industrial inputs and industrial (largely fossil) energy. Pimentel calculates that the energy ratio (output energy divided by input energy, including inputs from human and animal labor) for producing corn in the U.S. has decreased from 5.8 in 1910 to 2.5 in 1983[143]. Thus, while agricultural technology has allowed greater yields in terms of bushels per acre as well as bushels per man-hour of labor, more primary energy is consumed in producing the same amount of food.

Figure 4. U.S. Agricultural Imports and Exports by Year



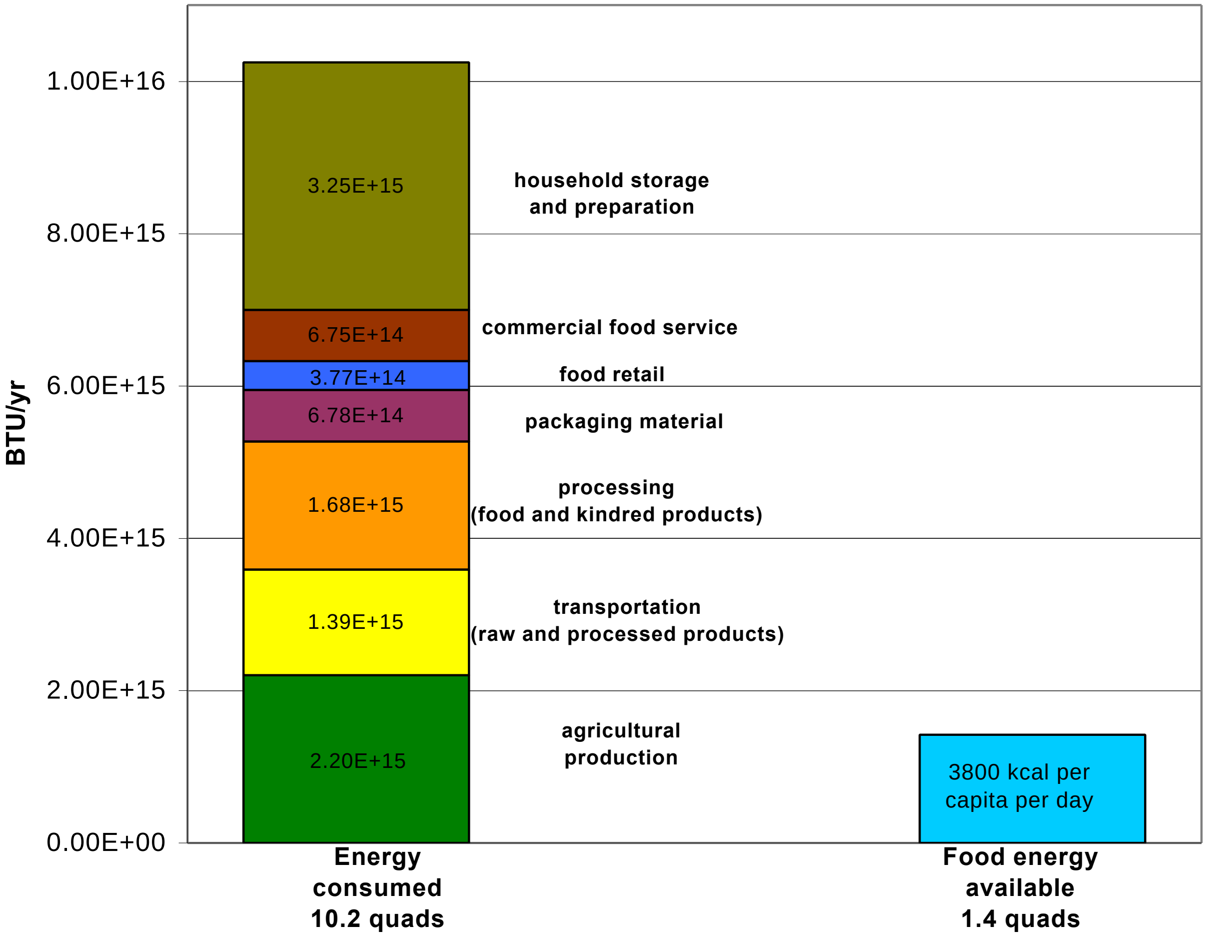
Yet, it is not only agricultural production that is a large consumer of energy in the U.S. food system. Figure 5 provides an estimate of the (industrial) energy that goes into supplying food in the U.S. Indeed, processing and packaging of food and household storage and preparation both require energy inputs of near or greater magnitude than agricultural growing and production. Details of the data compiled in Figure 5 is included in Appendix B.

By our estimates, agricultural production of food in the U.S. accounts for only 20% of the total energy consumed in the U.S. food system. Given that nearly 40% of U.S. agricultural production is exported, this fraction should likely be smaller (energy consumption data was not adjusted for exports). The manufacturing of chemical fertilizers and pesticides makes up almost 40% of the energy allocated to agricultural production. Another 25% is diesel fuel consumption. Energy use in agriculture reached a peak in 1978, but declined by 25% from 1978 to 1993, due primarily to reduction in direct use of energy (gasoline, diesel, natural gas) on farms[77]. Over the same period, the value of U.S. agricultural output increased by almost 47% (in 1987 dollars), causing the ratio of energy use to agricultural output to fall by 50% between 1978 and 1993[77]. By this measure, agricultural production has become more energy efficient.

The transportation component of Figure 5 is composed of energy in transporting raw and processed foods from manufacturing and distribution sights to areas of retail distribution as well as the estimated energy consumed in household food shopping trips. Transportation energy in the food system is a strong function of the distance between areas of production and areas of consumption. A Cold War era study estimated that the average food item in the U.S. travels 1300 miles[144]. Fresh produce in the U.S. travels an estimated 1500 miles[145], primarily because 90% of all fresh vegetables consumed in the U.S. are grown in the San Juaquin Valley of California[146]. In addition, the large quantities of off-farm inputs used in today's agriculture (seed, fertilizer, pesticides, animal feed) contribute to the energy consumed in transportation. Given the volatile nature of current energy prices, transportation and distribution are extremely vulnerable sectors of the current food system. While a recognizably simplified analysis, locating areas of production and handling of food physically close to areas of population density has great potential in reducing energy consumption and therefore improving the sustainability of the food system[147].

The "packaging material" component of Figure 5 represents the energy that goes in to making packaging for food and beverages. The value presented here is based on food related packaging material as it shows up in the Municipal Solid Waste stream and is most certainly a conservative estimate because it does not include a number of packaging categories that can not be exclusively attributed to foods. While the recycling of glass, steel, and aluminum containers aids in reducing the energy requirements for making food packages out of these materials, food grade plastics must be virgin material and thus require large amounts of petroleum based energy as feedstock.

Figure 5: Life Cycle Energy Use in Supplying US Food
(see Appendix B for sources and methodology)



Energy consumption in commercial food service in 1995 totaled 332 trillion BTU, 6.2% of the total commercial building energy consumption. Nearly a third of this energy was used for cooking. Food service is the most energy intensive user in the commercial building sector, consuming 246 BTU/ square foot of building space[148].

Household storage and preparation energy includes operation of refrigerators and freezers, energy for cooking (stoves, ranges and microwave ovens), operation of dishwashers, and the heating of water for dish washing. Over 40% of the food related household energy consumption is used in operating refrigerators. Improvements in appliance efficiencies have decreased refrigerator energy consumption over the past decade, but the number and size of refrigerators in American households continues to grow[149]. Cooking at home accounts for about 20% of the household food related energy use, while hot water heating (primarily for dishwashing) is estimated to be another 20%.

In total, providing the 3800 kilocalories of food energy available per capita per day in the United States is estimated to consume 10.2 quadrillion BTUs annually. This represents about 10% of the total energy consumed in the United States[148]. By our estimates, therefore, it takes about 7.3 units of (primarily) fossil energy to produce one unit of food energy in the U.S. food system. This estimate is somewhat lower than others presented. Pimentel[130] and Hall[150] both put the ratio of output food energy to input energy at 1:10.

The food system's dependence on industrial energy inputs is closely linked to the system's sustainability. Current agricultural and market practices heavily rely on the availability of cheap (relative to the cost of labor) concentrated energy, typically from fossil sources. Estimates of the remaining availability of crude oil vary somewhat[151-153], but it is certain that petroleum based fuels are a finite resource that can only continue to rise in price. Reliance on this unstable energy source makes the food system increasingly vulnerable. This vulnerability is further exacerbated by the centralization and consolidation trends in agricultural production and other stages of the food system. Consolidating farms, animal production facilities, meat packing plants, and food processing operations, and distribution warehouses often places further distance between food sources and buyers or consumers and requires added transportation energy for distribution. Energy consumed in managing and storing food in the household is also greatly affected by the current food distribution system. Many prepared or processed food items rely on refrigeration for storage (as opposed to dry goods). The replacement of neighborhood grocers and markets with "superstores" encourages people to stock the refrigerator rather than making daily purchases of fresh foods. Indeed, household refrigeration has become an assumed luxury where capacity often greatly exceeds need. Home refrigerator size continues to increase[154] while at the same time, fewer meals are eaten at home. It should be noted that great improvements in the energy efficiency of the food system could also be made by reducing demand through minimizing food loss, as mentioned in the previous section.

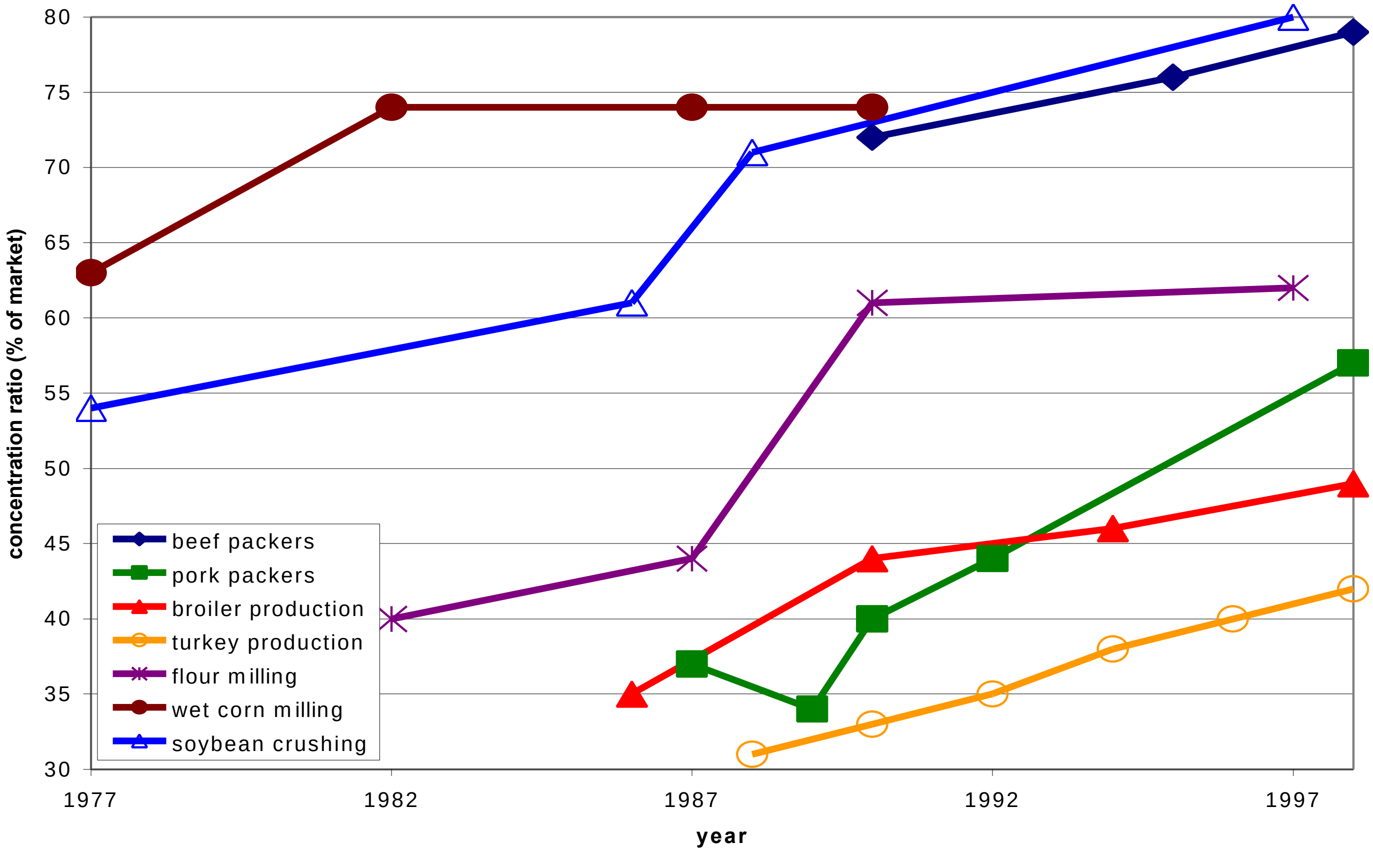
Life Cycle Management: Consolidation in the food system

The food system is managed by a diverse set of actors including farmers, the agriculture industry, food processing industry, retailers, and government. Market consolidation throughout the food system, however, is rapidly concentrating management decisions. Consolidation or concentration in food and agriculture is not a new phenomenon. Throughout the past century, there have been periodic concerns about a small number of non-farm businesses gaining excessive power in the market place. Indeed, the Sherman Antitrust Act of 1890 was passed in part because of farmers' concerns over concentration in the packing industry. These concerns were echoed three decades later, resulting in the passing of the Packers and Stockyards Act in 1921. Again in the 60s, national concern led to a comprehensive study by the federal government of competitiveness in food processing and retailing. Concentration in agribusiness firms has once again come to the forefront of agricultural policy: trepidation of non-competitive market practices spurred recent legislation (H.R. 1906) that will require mandatory reporting of prices paid for livestock by packers. With each passing decade, issues of market control and consolidation have become more complicated and difficult to address. Today's markets are global in scope and often dominated by multinational corporations; vertical integration has made it increasingly difficult to define market sector boundaries; an increasingly non-agrarian society is removed from the effects of consolidation on rural America and more tolerant of a concentrated agribusiness sector that may *appear* to provide immediate short-term, price-based benefit to consumers. A life cycle approach to assessing our food system should also consider how farms and agribusiness are organized and how they relate to each other. Here we will briefly consider the organization of the food system and how trends towards concentration may impact sustainability.

Evidence of consolidation arises in nearly every stage of the food system. Consolidation in the seed industry (see *origin of resource: social* section), food processing, food distribution, and food retailing has been discussed in previous sections. Consolidation is occurring in agricultural production (farms) as well, with larger farms greatly increasing their market share. Still, production agriculture remains close to the purely competitive economic model. That is, large numbers of independent producers compete in the same market, driving low costs, low prices, and relatively rapid innovation. However, agricultural producers are faced with input markets (seeds, chemicals) and buying markets (meat packers, grain mills, food processors) that are increasingly concentrated and dominated by a few firms. Disperse producers have little bargaining power in the market, even through association with large co-operatives, and become price-takers, not price-makers. This imbalance of market power can be further exacerbated through market and production contracts, as discussed in the *Agricultural growing and production: social* section of this report. The underlying fear in this imbalance is that long-term profit opportunities in the food sector will tip mostly away from producers and towards the large agribusiness firms. Given the economic recession that American farmers are experiencing in the wake of prosperity by much of the rest of the country, this may be a warranted fear.

There is no clear way of determining the extent of "competition" existing in a particular market. Market structure can be further complicated by the increasing number of alliances, partnerships, contracts, and less formalized relationships that exist between firms. One straightforward indicator still in use is the concentration ratio – the percentage of market power held by a certain number of the largest firms. As a rule of thumb, when the top four firms hold more than 40% of the market, competition begins to degrade and oligopolistic control is possible[19, 20]. Figure 6 shows the four firm concentration ratio for a number of agricultural markets. Many of the big buyers of U.S. agricultural products – beef packers, flour milling, soybean crushing – are highly concentrated by this indicator. What's more, concentration within these markets has been a steadily growing trend. According to one report, the concentration of economic power that has been occurring in the meat packing industry among the four largest firms is the most rapid increase ever experienced in the history of any American industry[155]. A federally appropriated study of market concentration in the red meat packing industry was conducted for the 1992-1993 year as seven separate projects, primarily by land grant university

Figure 6: Four Firm Concentration Ratios for Selected Agricultural Markets



researchers[156]. The study recognized that the market structure in the packing industry is complex and dynamic and required continual monitoring, but did not present strong, conclusive evidence of market power abuse. Interestingly, the analysis initially proposed to the Appropriations Committee emphasized the need to look at all of the segments of the market chain simultaneously in order to fully understand the impact of packer's actions on livestock prices. After compromising to opposition brought forth from meat packing industry lobbyists, the Appropriations Committee funded an approach that lost the holistic look at the market to independent studies of specific aspects[155].

Equal concern should be placed on another recent structuring trend in the food system: vertical integration. Vertical integration refers to the concentration of control along the supply chain, from gene to supermarket shelf. If one looks at the top firms in the various markets represented in Figure 6, the same names reoccur in numerous markets. ConAgra's market share, for example, is second in flour milling, second in dry corn milling, third in cattle feedlots, second in beef packers, third in pork packers, and fifth in broiler chicken production and processing[38]. Through its United Agri Products business, ConAgra is a leading distributor of crop protection chemicals, fertilizers and seeds both in the U.S. and in many international markets. ConAgra ranks second behind Phillip Morris in food processing, selling well known labels such as Armour, Swift, Butterball, Healthy Choice, Peter Pan Peanut Butter, and Hunt's. Another food system giant, Cargill, ranks first in grain elevator companies and animal feed plants, second in wet corn milling, dry corn milling and soybean crushing, third in flour milling, and fourth in turkey production and pork packing[38]. Until recently, Cargill was one of the largest seed firms in the world; although it has sold off its seed business, Cargill has maintained a connection to the gene and seed sector of the food system through joint ventures and alliances. Still another food system "integrator" is Archer Daniels Midland (ADM). Quaintly known as the "supermarket to the world" to National Public Radio listeners, ADM ranks first in flour milling, wet corn milling, soybean crushing and ethanol production, second in elevator companies, and third in dry corn milling[38]. A recent book by labor lawyer James Lieber details the federal government's 1996 price-fixing criminal case against ADM and some of its top executives, revealing the type of market control that this large food system corporation holds[157]. ADM now appears to be nurturing connections with Novartis, a Swiss-based, leading global firm in agrichemicals, seed, animal health, and human nutrition products.

Thus, it appears that there is a small number of dominant food chain "clusters" emerging. Much of the business world argues that such integration leads to increases in efficiencies that benefit both producers and consumers. Vertical integration raises a number of other issues, however. First, the mergers, joint ventures, alliances, agreements and other relationships between firms that form the "clusters" make the food system exceedingly complicated and difficult to describe. This limits society's ability to recognize non-competitive market practices.

Secondly, vertical integration is eliminating many of the open markets within the food chain. When firms control all sectors of the system - from seed and production inputs to grain buying, shipping and processing to animal production and processing to final on-the-shelf food items - there is little to no price discovery for intermediate products. In other words, intermediate products do not sell on the open market where prices are publicly known, but pass from one business entity of the firm to the next. Ninety five percent of the broiler chickens in the U.S. are produced under contract by fewer than 40 large farms. There is essentially no national competitive market for chicken feed, day old chicks or live broilers[38].

A third implication of both horizontal (within a market) and vertical integration is that decision making is concentrated to a small number of core firm executives. Independent farmers, family mills, and smaller processors are forced to resign their decision making – how and what to grow, when to buy and sell - to the food chain "cluster." As the Organization for Competitive Markets highlighted in a written testimony to the Senate Agriculture Committee, this contradicts economics lessons learned:

> In 1945, the Noble prize winning economist Frederick Hayek pointed out that a free enterprise, market economy is most efficient as long as the economic decisions about what to produce and how to produce are made by those closest to the economic circumstances of time and place. In other words when economic decisions are disbursed [*sic*] among many independent resource owners, in the aggregate, their decisions will result in the most efficient use of resources. Hayek went on to say that the more

> resources and economic decisions are concentrated in the hands of a few, whether they be government bureaucrats, as in the former Soviet Union, or powerful corporate executives of large companies with substantial market power, the less productive and the less efficient the economy will be[155].

Indeed, the tangible benefits that may arise from consolidation and concentration often reappear as externalized social and environmental costs. The indicators considered in this report point at many of these costs. Concentration in the food industry seems to magnify the risk of such external costs. Take, for instance, the rather simple example of hamburger that gets contaminated with *E. coli*. If the contamination occurs in a huge centralized beef packing plant, the losses and liabilities connected with the recall of millions of pounds of hamburger, as well as the number of people at risk, are far greater than if a similar contamination were to occur in a locally owned, diversified butcher shop. A recent research conference organized by the Economic Research Service of the USDA entitled "The American Consumer and the Changing Structure of the Food System" explored many elements of the increasing consolidation in the food system. Proceedings from this conference provide further investigation into this concern[158].

CONCLUSIONS

Numerous indicators considered in this assessment demonstrate that the U.S. food system is not economically, socially, or environmentally sustainable. The key indicators leading to this conclusion are summarized in Table 11.

Table 11: Summary of Key Indicators showing Unsustainable Trends of the U.S. Food System

	Economic	**Social**	**Environmental**
Production	– Rapid conversion of prime farmland – 84% of farm household income earned off-farm – Increasing number of farms report a net loss (48% in 1997)	– 52% of farmworkers are illegal – age of farm operators increasing; declining entry of young farmers	– depletion of topsoil exceeds regeneration – rate of groundwater withdrawal exceeding recharge in major agricultural regions – losses to pests increasing – reduction in genetic diversity
Consumption	– Costs of diet related diseases increasing	– Obesity rates rising – Diet deviates from nutritional recommendations	– 26% edible food wasted
Total system	– Marketing is 80% of food bill – Industry consolidation in food system threatens market competition	– Relation with food and its origin has been lost	– Heavy reliance on fossil energy – 7.3 units of energy consumed to produce one unit of food energy

The current system continues to rely on limited genetic resources that are rapidly moving out of public control and are managed by corporate interests. Farmers are shrinking in number and growing in age, with large percentages of agricultural producers unable to survive economically on income from farming ventures. Where field practices have not been completely mechanized, producers are forced to use cheap, illegal labor. Production is highly subsidized both by the government and by off-farm incomes of producers. Soil erosion continues at rates greatly exceeding soil regeneration, and global declines in fresh water availability threaten the sustainability of irrigation farming. Food related illnesses and deaths appear to be on the rise, demanding a reevaluation of the food processing and distribution system. The health and social costs of diet related diseases are accumulating, and a surprising amount of the edible food available in this country is lost at the consumer level, primarily due to easily preventable wastage. Heavy reliance on non-renewable energy poses additional environmental burdens and leaves the food system vulnerable to supply side price increases in fossil fuels.

Addressing these challenges through a life cycle based approach to the food system as presented in this report serves many important roles. First, a systems approach aids in reestablishing the connection between consumption behaviors and production practices. This connection has been largely lost from the American social consciousness. Food comes from the supermarket and little thought is given to what is involved in getting food to the market. The environmental movement has succeeded, to some extent, in establishing the link between consumption behaviors and environmental health, resulting in such behavioral changes as increased recycling. Establishing the link for the general public between food consumption and the related environmental and social burdens can create “only produce what we consume” attitudes and lead to reduced food wastage. A reduction in food consumption and wastage can lead directly to improved health and a corresponding reduction in the environmental stress of agricultural production, food distribution, and disposition. Benefits are compounded; for example, one calorie of food saved can result in a seven-fold reduction in the energy use across the life cycle. Direct marketing methods, especially those operating on the community supported agriculture model[159], help foster a recognition of the link between production and consumption. However, maintaining the connection between production and consumption is important at all levels of food planning and policy.

A life cycle perspective also assists in identifying particular areas within the food system where priorities should be placed. Often these areas are not the obvious or traditional portions of the system that receive attention. For example, discussion of the food system’s dependence on fossil energy often focuses on the consumption of fuels in operating tractors and equipment for agricultural production or the energy consumption in fertilizer manufacturing. Yet, the data in Figure 5 suggest that food related energy consumption in the home is of equal if not greater significance. As part of the European Union funded SusHouse (Strategies towards the Sustainable Household) research initiative, researchers in the Netherlands, Hungary and the UK have been focusing on how households obtain food, cook, and deal with kitchen waste. Normative scenarios of possible developments in shopping, cooking and eating in the year 2050 that utilize both technological and cultural innovations are being formulated and evaluated for their decreased environmental burden, economic burden, and acceptability to consumers[160].

The life cycle indicators presented here are useful in communicating the full impact of providing food in the U.S. This is not an end in itself, however. Further development and refinement of a methodology for measuring progress through such sustainability indicators is needed. It is our hope that the life cycle framework will be used by researchers, business analysts and planners, and policymakers in addressing the challenges at hand and moving the food system towards sustainability. Sustainability requires a long-term time perspective in seeking solutions, as well as attention to the balances and tradeoffs seen throughout the food system. Thus, research, planning, and policy must proceed with an integrated systems approach in order to arrive at sustainable solutions. Work on Food Consumption and Production Systems initiated by the European based Global Environmental Change Programmes[160] takes an important step in this direction. The words of Rick Welsh, a policy analyst with the Henry A. Wallace Institute for Alternative Agriculture, serve as encouragement to the seemingly daunting task of reorganizing our food system. He reminds us:

> that the structure of agriculture in this or any other country is not an evolutional or inevitable process, but a socially constructed arrangement of institutions, rules and relationships. The organization of agriculture today has resulted solely from decisions made by people, and can be altered and reorganized if enough people wish to alter or reorganize it[161].

ACKNOWLEDGEMENTS

Many of the indicators presented in this report were identified in a workshop on “A Life Cycle Perspective to Sustainable Agriculture Indicators” organized by the Center for Sustainable Systems in February, 1999 in Ann Arbor, Michigan. The workshop was funded through a grant from U.S. EPA region V. Over 50 participants from academia, federal and state government, farmers, and food industry representatives contributed to this workshop.

Guntra Aistars and Jonathan Bulkley of the Center for Sustainable Systems had a primary role in organizing the workshop. Dennis Keeney, Ron Meekhof, Michelle Miller, and David Pimentel have made valuable contributions in the preparation and review of this report.

REFERENCES

1. Hoag, D. L. *Agricultural crisis in America: A reference handbook*. ABC-CLIO, Inc., Santa Barbara, CA: 1999.
2. Sands, G. R., and T. H. Podmore. (2000) “A generalized environmental sustainability index for agricultural systems.” *Agriculture, Ecosystems and Environment* 79: 29-41.
3. Lewandowski, I., M. Härdtlein, and M. Kaltschmitt. (1999) “Sustainable Crop Production: Definition and Methodological Approach for Assessing and Implementing Sustainability.” *Crop Science* 39: 184-193.
4. Hansen, J. W. (1996) “Is Agricultural Sustainability a Useful Concept?” *Agricultural Systems* 50: 117-143.
5. USDA. (1996) *Secretary's Memorandum 9500-6: Sustainable Development*. U.S. Department of Agriculture, Washington, DC; <http://www.usda.gov/agency/oce/oce/sustainable-development/secmemo.htm>.
6. ISO. (1997) *Environmental management - Life cycle assessment - Principles and framework*. ISO 14040. The International Organization for Standardization, Geneva.
7. Sleeswijk, A. W., R. K. H. v. Zeijts, J. A. W. A. Reus, M. J. G. M.-v. Onna, H. Leneman, and H. H. W. J. M. Sengers. (1996) *Application of LCA to Agricultural Products*. report no. 130. Centre of Environmental Science Leiden University, Leiden, The Netherlands.
8. VITO. (1998) *Proceedings of the International Conference on Life Cycle Assessment in Agriculture, Agro-Forestry and Forestry*. Brussels, Belgium, 3-4 December.
9. VITO. (1996) *International Conference on Application of Life Cycle Assessment in Agriculture, Food and Non-Food Agro-Industry and Forestry: Achievements and Prospects*. Brussels, Belgium, 4-5 April.
10. Wang, M., C. Saricks, and M. Wu. (1997) *Fuel-Cycle Fossil Energy Use and Greenhouse Gas Emissions of Fuel Ethanol Produced from U.S. Midwest Corn*. Center for Transportation Research, Argonne National Laboratory.

11. Sheehan, J., V. Camobreco, J. Duffield, M. Graboski, and H. Shapouri. (1998) *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus*. NREL/SR-580-24089. National Renewable Energy Laboratory, Golden, Colorado.
12. Andersson, K., and T. Ohlsson. (1999) “Life Cycle Assessment of Bread Produced on Different Scales.” *International Journal of Life Cycle Assessment* 4(1): 25-40.
13. Moller, H., M. Vold, K. Toresen, and I. Ormstad. (1996) *Life Cycle Assessment of Pork and Lamb Meat*. International Conference on Application of Life Cycle Assessment in Agriculture, Food and Non-Food Agro-Industry and Forestry: Achievements and Prospects, VITO, Brussels, Belgium, 4-5 April.
14. Keoleian, G. A., and D. Menerey. (1994) “Sustainable Development by Design: Review of Life Cycle Design and Related Approaches.” *Air & Waste* 44: 645-668.
15. RAFI. (1995) *Utility Plant Patents: A Review of the U.S. Experience (1985 - July, 1995)*. RAFI Communique. Rural Advancement Foundation International, Winnipeg, Canada; <http://www.rafi.org/>.
16. USDA. (1997) *Seed Use, Costs, and Trade*. update on Agricultural Resources and Environmental Indicators. Economic Research Service, USDA, Washington, DC; <http://www.ers.usda.gov/Briefing/arei/arei.htm>.
17. RAFI. (1999) *The Gene Giants*. RAFI Communique. Rural Advancement Foundation International, Winnipeg, Canada; <http://www.rafi.org/>.
18. RAFI. (2000) *Suicide Seeds on the Fast Track*. RAFI Communique 64. Rural Advancement Foundation International, Winnipeg, Canada; <http://www.rafi.org/>.
19. Scherer, F. M. (1971), in "Industrial Market Structure and Economic Performance". Rand McNally & Company, Chicago, pp. 60.
20. O'Sullivan, A., and S. M. Sheffrin (1998) *Chapter 13: Oligopoly and Antitrust Policy*, in "Economics: Principles and Tools". Prentice Hall, Upper Saddle River, NJ.
21. Shapiro, R. (1999) *Open letter from Monsanto CEO to Rockefeller Foundation President Gordon Conway*. Last updated 4 October, 1999; <http://www.monsanto.com/monsanto/gurt/default.htm>.
22. Kaiser, J. (2000) “USDA to Commercialize 'Terminator' Technology.” *Science* 289(5480): 709-710.
23. Brown, N. J. (1981) *Biological Diversity: The Global Challenge*. Proceedings of the U.S. Strategy Conference on Biological Diversity, U.S. Department of State Publication, November 16-18, 1981.
24. Duvick, D. N. (1984) “Genetic Deversity in Major Farm Crops on the Farm and in Reserve.” *Economic Botany* 38(2): 161-178.
25. Soule, J., D. Carre, and W. Jackson (1990) *Ecological Impact of Modern Agriculture*, in "Agroecology", ed. C. R. Carroll, J. H. Vandermeer, and P. M. Rosset. McGraw-Hill Publishing Co., New York, pp. 175.
26. Wood, D., and J. M. Lenne (1999) Agrobiodiversity: Characterization, Utilization, and Management. New York, CABI Publishing.
27. CAST. (1999) *Benefits of Biodiversity*. Task Force Report No. 133. Council for Agricultural Science and Technology.
28. National Research Council. *Genetic Vulnerability of Major Crops*. National Academy Press, Washington, D.C.: 1972.
29. Altieri, M. A. *Biodiversity and Pest Management in Agroecosystems*. Haworth Press, New York: 1994.
30. Brown, W. L. (1983) “Genetic diversity and genetic vulnerability - An appraisal.” *Economic Botany* 37: 1-12.
31. Wolfe, M. S. (2000) “Crop strength through diversity.” *Nature* 406: 681-682.
32. McMullan, M., R. Jones, and D. Gallenberg. (1997) “Scab of wheat and barley: A re-emerging disease of devastating impact.” *Plant Disease* 81: 1340-1348.
33. Rissler, J., and M. Mellon. *The Ecological Risks of Engineered Crops*. The MIT Press, Cambridge, MA: 1996.
34. James, C. (1999) *Global Status of Commercialized Transgenic Crops: 1999*. ISAAA Briefs No. 12: Preview. International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY; <http://www.isaaa.org/Global%20Review%201999//briefs12cj.htm>.
35. EC. (2000) *Economic Impacts of Genetically Modified Crops on the Agri-Food Sector: A Synthesis*. Directorate-General for Agriculture, European Commission; <http://europa.eu.int/comm/dg06/publi/gmo/cover.htm>.
36. RAFI. (1998) *Seed Industry Consolidation: Who Owns Whom?* RAFI Communique. Rural Advancement Foundation International, Winnipeg, Canada; <http://www.rafi.org/>.
37. RAFI. (1997) *Bioserfdom: Technology, Intellectual Property and the Erosion of Farmers' Rights in the Industrialized World*. RAFI Communique. Rural Advancement Foundation International, Winnipeg, Canada; <http://www.rafi.org/>.
38. Heffernan, W., M. Hendrickson, and R. Gronski. (1999) *Consolidation in the Food and Agriculture System*. National Farmers Union.

39. USDA. (1999) *1997 Census of Agriculture*. AC97-A-51. U.S. Department of Agriculture; <http://www.nass.usda.gov/census/census97/volume1/vol1pubs.htm>.

40. Sorensen, A. A., R. P. Greene, and K. Russ. (1997) *Farming on the Edge*. American Farmland Trust, DeKalb, Illinois; <http://www.farmlandinfo.org/cae/foe2/foetoc.html>.

41. Harlin, J. M. (1995) *Rangeland to Cropland Conversions in the Western States: Implications for Soil Loss and Sustainability*. Forum of the Association for Arid Land Studies XI, International Center for Arid and Semiarid Land Studies, Lubbock, TX.

42. ERS. (2000) *The Aging of Farm Operators and Participation of Beginning Producers in Farming*. Issues Center report. Economic Research Service, U.S. Dept. of Agriculture; <http://www.econ.ag.gov:80/whatsnew/issues/beginning/index.htm>.

43. ERS (2000) *Farm Business Balance Sheet and Financial Ratios*, Economic Research Service, USDA. Last updated October 15, 1999; <http://www.ers.usda.gov:80/briefing/farmincome/fbsdmu.htm>.

44. Elitzak, H. (1999) “Desire for Convenience Drives Marketing Costs.” *FoodReview*, 22 (3). September-December 1999: 23-25.

45. Elitzak, H. (1999) *Food Cost Review, 1950-97*. Agricultural Economic Report 780. Food and rural Economics Division, Economic Research Service, U.S. Department of Agriculture, Washington, DC.

46. ERS (2000) *Farm Costs and Returns Home Page*, Economic Research Service, USDA. Last updated September 25, 2000; <http://www.ers.usda.gov:80/briefing/farmincome/car/>.

47. USDA. (1999) *Agriculture Fact Book 1999*. U.S. Dept. of Agriculture, Office of Communications, Washington, DC; <http://www.usda.gov:80/news/pubs/fbook99/contents.htm>.

48. Shields, D. Economic Research Service, USDA, personal communication, June 21, 2000.

49. USDA. (1997) *Agriculture Fact Book 1997*. U.S. Dept. of Agriculture Office of Communications, Washington, DC; <http://www.usda.gov:80/news/pubs/fbook97/contents.htm>.

50. ERS (2000) *United States and State Farm Income Data*, Economic Research Service, USDA. Last updated September 25, 2000; <http://www.ERS.USDA.gov/briefing/farmincome/finfidmu.htm>.

51. ERS (2000) *Farm Income Forecast*, Economic Research Service, USDA. Last updated Sept. 25, 2000; <http://www.ERS.USDA.gov/briefing/farmincome/fore/fore.htm>.

52. US Dept. of Commerce. (1977) *1974 Census of Agriculture*. U.S. Dept. of Commerce, Bureau of the Census, Washington, DC.

53. FAO (1999) *FAOSTAT*, Food and Agriculture Organization of the United Nations. Last updated 20 August 1999; <http://apps.fao.org/>.

54. Banker, D., and J. Perry. (1999) “More Farmers Contracting to Manage Risk.” *Agricultural Outlook*, January-February 1999. 6-7.

55. Dorgan, B. (1999) “Don't be Down on the Farm: How to Preserve a National Treasure.” *Washington Monthly* (September, 1999).

56. Kristof, N. D. "As Farm Life Worsens, the Toughest Wither," The New York Times, April 2, 2000. National addition, pg. 1.

57. USDA. (1998) *Agriculture Fact Book 1998*. U.S. Dept. of Agriculture, Office of Communications, Washington, DC.

58. Bureau of Labor Statistics. (2000) *Labor Force Statistics from the 2000 Population Survey*. U.S. Department of Labor, Washington, DC; <http://stats.bls.gov/pdf/cpsaat19.pdf>.

59. Bureau of Labor Statistics (2000) *Average hourly and weekly earnings of production or nonsupervisory workers on private nonfarm payrolls by industry*, Bureau of Labor Statistics. Last updated January 4, 2000; <http://www.bls.gov/webapps/legacy/cesbtab3.htm>.

60. Runyan, J. L. (1998) *Profile of Hired Farmworkers, 1996 Annual Averages*. Agricultural Economic Report No. 762. Economic Research Service, U.S. Dept. of Agriculture, Washington, DC.

61. NASS (2000) *Farm Labor (PFL-BB)*, National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture. Last updated May 19, 2000; <http://usda.mannlib.cornell.edu/reports/nassr/other/pfl-bb/>.

62. Mehta, K., S. M. Gabbard, V. Barrat, M. Lewis, D. Carrol, and R. Mines. (2000) *Findings from the National Agricultural Workers Survey (NAWS) 1997-1998*. Research Report No. 8. U.S. Department of Labor; <http://www.dol.gov/dol/asp/public/programs/agworker/report_8.pdf>.

63. Runyan, J. L. (1998) *Injuries and Fatalities on U.S. Farms*. AIB-739. Economic Research Service, U.S. Department of Agriculture, Washington, DC; <http://www.ers.usda.gov:80/epubs/htmlsum/aib739.htm>.

64. Schreinemachers, D. M. (2000) “Cancer Mortality in Four Northern Wheat-Producing States.” *Environmental Health Perspectives* 108(9): 873-881.

65. SRA Life Sciences (1999) *The Agricultural Health Study*. Last updated June 15, 1999; <http://www.sra-lifesciences.com/ag/>.
66. Center for Health Effects of Environmental Contamination (2000) *Agricultural Health Study*. Last updated February 2000; <http://www.cheec.uiowa.edu/misc/aghealth.html>.
67. Gray, G. M., B. D. Goldstein, J. Bailar, D. L. Davis, E. Delzell, F. Dost, R. S. Greenberg, M. Hatch, E. Hodgson, M. A. Ibrahim, J. Lamb, T. Lavy, J. Mandel, R. Monson, M. Robson, R. Shore, and J. S. Graham. (2000) "The federal government's Agricultural Health Study: A critical review with suggested improvements." *Human & Ecological Risk Assessment* 6(1): 47-71.
68. Fischer, J. R., and J. J. Zuiches. (1994) *Challenges Confronting Agricultural Research at Land Grant Universities*. Issue paper no. 5. Council for Agricultural Science and Technology, Ames, IA.
69. Horne, J., and W. J. Weida (2000) *Agricultural Research Policy: Serving Public, Rather than Private, Interests*, in "A Food and Agriculture Policy for the 21st Century", ed. M. C. Stumo. Organization for Competitive Markets, Lincoln, NE, pp. 25-29.
70. Albright, J. L., J. V. Craig, T. Grandin, H. D. Guither, J. J. McGlone, J. D. McKena, G. L. riskowski, W. R. Stricklin, and C. L. Stull. (1997) *The Well-Being of Agricultural Animals*. R 130. Council for Agricultural Science and Technology, Ames, IA.
71. Netting, J. (2000) "US Dispute over definition of animal distress." *Nature* 406: 668.
72. Jackson, W. *New Roots for Agriculture*. Friends of the Earth, San Francisco: 1980.
73. USDA. (1999) *1997 National Resources Inventory Summary Report*. Natural Resources Conservation Service, USDA, Washington, DC.
74. Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Shpritz, L. Fitton, R. Saffouri, and R. Blair. (1995) "Environmental and Economic Costs of Soil Erosion and Conservation Benefits." *Science* 267: 1117-1123.
75. Uri, N. D., and J. A. Lewis. (1999) "Agriculture and the Dynamics of Soil Erosion in the United States." *Journal of Sustainable Agriculture* 14(2/3): 63-82.
76. Office of the Vice President (2000) *Vice President Gore Announces Protection of 2.5 million acres of Environmentally Sensitive Farmland*. Last updated May 20, 2000; <http://www.fsa.usda.gov/pas/news/releases/2000/05/wh05192000.htm>.
77. ERS. (1997) *Agricultural Resources and Environmental Indicators, 1996-97*. agricultural handbook no. 712. Economic Research Service, USDA, Washington, DC.
78. Kellogg, R. L., and C. H. Lander. (1999) *Trends in the Potential for Nutrient Loading from Confined Livestock Operations*. The State of North America's Private Land, Chicago, IL, January 19-21, 1999; <www.nhq.nrcs.usda.gov/land/pubs/ntrend.html>.
79. EPA. (1996) *National Summary of Water Quality Conditions*. Office of Water, U.S. EPA, Washington, DC; <http://www.epa.gov/OW/resources/9698/sec_one.pdf>.
80. Keeney, D., and M. Muller. (2000) *Nitrogen and the Upper Mississippi River*. Institute for Agriculture and Trade Policy, Minneapolis, MN; <http://www.iatp.org/foodsec/library/admin/uploadedfiles/showfile.cfm?FileName=Nitrogen_and_the_Mississippi.doc>.
81. Pimentel, D., H. Acquay, M. Biltonen, P. Rice, M. Silva, J. Nelson, V. Lipner, S. Giordano, A. Horowitz, and M. D'Amore. (1992) "Environmental and Economic Costs of Pesticide Use." *BioScience* 42(10): 750-760.
82. Kellogg, R. L., R. Nehring, A. Grube, S. Plotkin, D. W. Goss, and S. Wallace. (1999) *Trends in the Potential for Environmental Risk from Pesticide Loss from Farm Fields*. The State of North America's Private Land, National Resources Conservation Service, USDA, Chicago, IL, January 19-21, 1999; <http://www.nhq.nrcs.usda.gov/land/pubs/pesttrend.html>.
83. Pimentel, D., L. McLaughin, A. Zepp, B. Lakitan, T. Kraus, P. Kleinman, F. Vancini, W. J. Roach, E. Graap, W. S. Keeton, and G. Selig (1991) *Environmental and economic impacts of reducing U.S. agricultural pesticide use*, in "Handbook on Pest Management in Agriculture", ed. D. Pimentel. CRC Press, Boca Raton, FL, pp. 679-718.
84. Porter, W. P., J. W. Jaeger, and I. H. Carlson. (1999) "Endocrine, immune and behavioral effects of aldicarb (carbamate), atrazine (triazine), and nitrate (fertilizer) mixtures at groundwater concentrations." *Toxicology and Industrial Health* 15(1-2): 133-150.
85. ERS. (2000) "Marketing Organic Foods." *Agricultural Outlook* (272). June-July, 2000.
86. ERS (2000) *U.S. Organic Agriculture*, Economic Research Service, USDA. Last updated April 4, 2000; <http://www.ers.usda.gov/whatsnew/issues/organic/>.
87. Willer, H., and M. Yussefi. (2000) *Organic Agriculture World-Wide: Statistics and Perspectives*. Sonderausgabe Nr. 74. Stiftung Ökologie & Landbau; <http://www.soel.de/inhalte/publikationen/s_74.pdf>.

88. Solley, W. B., R. R. Pierce, and H. A. Perlman. (1998) *Estimated Use of Water in the United States in 1995*. U.S. Geological Survey Circular 1200. U.S. Department of the Interior, Denver, CO; <http://water.usgs.gov/watuse/pdf1995/html/>.
89. Opie, J. *Ogallala: Water for a dry land*. University of Nebraska Press, Lincoln: 1993.
90. Miller, S. M., C. W. Sweet, J. V. DePinto, and K. C. Hornbuckle. (2000) "Atrazine and Nutrients in Precipitation: Results from the Lake Michigan Mass Balance Study." *Environmental Science & Technology* 34(1): 55-61.
91. Rygwelski, K. R., W. L. Richardson, and D. D. Endicott. (1999) "A Screening-Level Model Evaluation of Atrazine in the Lake Michigan Basin." *Journal of Great Lakes Research* 25(1): 94-106.
92. Schottler, S. P., and S. J. Eisenreich. (1997) "Mass Balance Model To Quantify Atrazine Sources, Transformation Rates, and Trends in the Great Lakes." *Environmental Science & Technology* 31(9): 2616-2625.
93. EPA. (1999) *National Air Pollutant Emission Trends Update, 1970-1997*. U.S. Environmental Protection Agency, Washington, DC.
94. EPA. (1999) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1997*. EPA 236-R-99-003. U.S. Environmental Protection Agency, Washington, DC; <http://www.epa.gov/globalwarming/publications/emissions/us1999/index.html>.
95. Altieri, M. A. (1999) "The ecological role of biodiversity in agroecosystems." *Agriculture Ecosystems & Environment* 74: 19-31.
96. Andow, D. A. (1991) "Vegetational diversity and arthropod population response." *Annual Review of entomology* 36: 561-586.
97. Gardener, J., and S. Clancy (1996) *Impact of Farming Practices on Soil Quality in North Dakota*, in "Methods for Assessing Soil Quality", ed. J. W. Doran, and A. J. Jones, Special Publication no. 49. Soil Science Society of America, Madison, WI.
98. ERS. (2000) "Rewarding Environmentally Friendly Farming." *Agricultural Outlook* (272). June-July, 2000.
99. Heffernan, W. D. (1999) *The Influence of the Big Three - ADM, Cargill and ConAgra*. Farmer Cooperatives in the 21st Century (conference), Des Moines, Iowa, June 9-11, 1999.
100. ERS. (2000) "Consolidation in Food Retailing." *Agricultural Outlook* (273). August 2000.
101. Davies, T., and D. M. Konisky. (2000) *Environmental Implications of the Foodservice and Food Retail Industries*. discussion paper 00-11. Resources for the Future, Washington, DC; <http://www.rff.org/disc_papers/PDF_files/0011.pdf>.
102. Gallo, A. E. (1999) *Food Advertising in the United States*, in "America's Eating Habits: Changes and Consequences", ed. E. Frazão, Agriculture Information Bulletin No. 750. Economic Research Service, Food and Rural Economics Division, USDA, Washington, DC.
103. Mays, J. J. "CDC Releases New Estimates on Foodborne Diseases," Associated Press, September 16, 1999.
104. Tauxe, R. V. (1997) "Emerging Foodborne Diseases: an Evolving Public Health Challenge." *Emerging Infectious Diseases* 3(4): 425-434.
105. Collins, J. E. (1997) "Impact of Changing Consumer Lifestles on the Emergence/Reemergence of Foodborne Pathogens." *Emerging Infectious Diseases* 3(4): 471-479.
106. FoodNet. (2000) *1999 Surveillance Results (Preliminary Report)*. Center for Disease Control and Prevention; <http://www.cdc.gov/ncidod/dbmd/foodnet>.
107. FSIS (1998) *Pathogen Reduction and HACCP Systems...and Beyond*, Food Safety and Inspection Service, USDA. Last updated Jan. 29, 1998; <http://www.fsis.usda.gov:80/OA/background/bkbeyond.htm>.
108. Cohen, M. L. (2000) "Changing patterns of infectious disease." *Nature* 406: 762-767.
109. Pimentel, D., and M. Pimentel (1996) *Food Processing, Packaging, and Preparation*, in "Food, Energy, and Society", ed. D. Pimentel, and M. Pimentel, revised edition. University Press of Colorado, Niwot, CO, pp. 186-201.
110. Franklin Associates Ltd. (1999) *Characterization of Municipal Solid Waste in the United States: 1998 Update*. prepared for Municipal and Industrial Solid Waste Division, EPA by Franklin Associates, Prairie Village, KS; <http://www.epa.gov/epaoswer/non-hw/muncpl/mswrpt98/98charac.pdf>.
111. Kantor, L. S., K. Lipton, A. Manchester, and v. Oliveira. (1997) "Estimating and Addressing America's Food Losses." *Food Review*, 20 (1). Jan-Apr.
112. Steever, T. (1999) *Food Bill Paid in Forty Days*, Farm Bureau. Last updated February 8, 1999; <http://www.fb.org/views/focus/fo99/fo0208.html>.
113. Putnam, J. J., and J. E. Allshouse. (1999) *Food Consumption, Prices, and Expenditures, 1970-97*. Statistical Bulletin No. 965. Economic Research Service, USDA, Washington, DC; <http://www.ers.usda.gov/epubs/pdf/sb965/index.htm>.

114. Nord, M., K. Jemison, and G. Bickel. (1999) *Prevalence of Food Insecurity and Hunger, by State, 1996-1998*. Food Assistance and Nutrition Report No. 2. Economic Research Service, USDA, Washington, DC.
115. Furst, T., M. Connors, C. A. Bisogni, J. Sobal, and L. W. Falk. (1996) “Food Choice: A Conceptual Model of the Process.” *Appetite* 26(3): 247-265.
116. Frazão, E. (1999) America's Eating Habits: Changes and Consequences, Agriculture Information Bulletin No. 750. Washington, DC, Economic Research Service, Food and Rural Economics Division, USDA; <http://www.econ.ag.gov:80/epubs/pdf/aib750/>.
117. Nestle, M., and M. F. Jacobson. (2000) “Halting the Obesity Epidemic: A Public Health Policy Approach.” *Public Health Reports* 115(January/February): 12-24.
118. USDA. (2000) *Dietary Guidelines for Americans*. US Dept. of Agriculture, Washington, DC; <http://www.usda.gov/cnpp/DietGd.pdf>.
119. Tippett, K. S., and L. E. Cleveland (1999) *How Current Diets Stack Up: Comparison with Dietary Guidelines*, in "America's Eating Habits: Changes and Consequences", ed. E. Frazão, Agriculture Information Bulletin No. 750. Economic Research Service, Food and Rural Economics Division, USDA, Washington, DC.
120. Frazão, E. (1999) *High Costs of Poor Eating Patterns in the United States*, in "America's Eating Habits: Changes and Consequences", ed. E. Frazão, Agriculture Information Bulletin No. 750. Economic Research Service, Food and Rural Economics Division, USDA, Washington, DC.
121. Allison, D. B. (1999) “The Direct Health Care Costs of Obesity in the United States.” *American Journal of Public Health* 89(8): 1194-1199.
122. Wolf, A. M., and G. A. Colditz. (1998) “Current estimates of the economic cost of obesity in the United States.” *Obesity Research* 6: 97-106.
123. Brasher, P. "USDA to test popular diets: Feds launch battle of the bulge," The Ann Arbor News, May 31, 2000. Ann Arbor, MI, pg. A4.
124. USDA-NASS (1999) *Chapter XIII: Consumption and Family Living*, in "Agricultural Statistics 1999", ed. U. S. D. o. A. National Agricultural Statistics Service. U.S. Government Printing Office, Washington, DC.
125. Mathios, A. D., and P. Ippolito (1999) *Health Claims in Food Advertising and Labeling: Disseminating Nutrition Information to Consumers*, in "America's Eating Habits: Changes and Consequences", ed. E. Frazão, Agriculture Information Bulletin No. 750. Economic Research Service, Food and Rural Economics Division, USDA, Washington, DC.
126. Burros, M. "U.S. Biotech Industry Still Refuses to Label or Safety Test -- Despite Increasing Consumer Concerns," The New York Times, September 8, 1999. New York.
127. Eisner, R. (2000) *Genes with Your Salsa? Public Pushes for Labeling of Genetically Modified Foods*, ABCNEWS.com; <http://www.purefood.org/ge/genesinsalsa.cfm>.
128. Weiss, R. "Giant U.S. Food Corporations & Biotech Industry Are Terrified of Mandatory Labels on GE Food," Washington Post, August 15, 1999. Washington, DC, pg. A17.
129. Brower, M., and W. Leon. *The Consumer's Guide to Effective Environmental Choices*. Three Rivers Press, New York: 1999.
130. Pimentel, D., and M. Pimentel (1996) *Energy Use in Fruit, Vegetable, and Forage Production*, in "Food, Energy, and Society", ed. D. Pimentel, and M. Pimentel, revised edition. University Press of Colorado, Niwot, CO, pp. 131-147.
131. EPA. (2000) *Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 1998*. EPA530-F-00-024. EPA Office of Solid Waste and Emergency Response, Washington, DC; <http://www.epa.gov/epaoswer/non-hw/muncpl/msw99.htm>.
132. Goldstein, N. (1997) “The State of Garbage in America.” *BioCycle* 38(4): 60-67.
133. USDA/EPA. (1999) *Waste Not, Want Not: Feeding the Hungry and Reducing Solid Waste Through Food Recovery*. U.S. Department of Agriculture and Environmental Protection Agency, Washington, DC; <http://www.epa.gov/epaoswer/non-hw/reduce/wastenot.htm>.
134. Goldstein, N., and D. Block. (1997) “Nationwide inventory of food residuals composting.” *BioCycle* 38(8): 46-57.
135. EPA. (1998) *Don't Throw Away That Food: Strategies for Record-Setting Waste Reduction*. EPA-530-F-98-023. Solid Waste and Emergency Response, U.S. EPA, Washington, DC; <www.epa.gov/osw>.
136. Aiking, H. (2000) “The Protein Foods, Environment, Technology and Society Programme (PROFETAS).” *IHDP Update, newsletter of the International Human Dimensions Programme on Global Environmental Change* (number 2). 4-5.
137. Meadows, D. H. (2000) *A World Food Production Quiz*. Sustainability Institute, Hartland Four Corners, VT.

138. ERS (2000) *Foreign Agricultural Trade of the United States (FATUS)*, Economic Research Service, USDA. Last updated April 4, 2000; <http://www.ers.usda.gov:80/briefing/AgTrade/htm/Data.htm>.
139. ERS. (1996) *Industrial Uses of Agricultural Materials: Situation and Outlook*. IUS-6. Economic Research Service, USDA, Washington, DC; <http://www.ers.usda.gov:80/epubs/pdf/ius6/index.htm>.
140. DOE. (1999) *The Technology Roadmap for Plant/Crop-Based Renewable Resources 2020*. DOE/GO-10099-706. Renewables Vision 2020 Executive Steering Group.
141. ERS. (2000) “U.S. Agricultural Imports Head Higher.” *Agricultural Outlook* (273). August, 2000.
142. Odum, H. T. *Environment, power, and society*. Wiley-Interscience, New York: 1970.
143. Pimentel, D., and W. Dazhong (1990) *Technological Changes in Energy Use in U.S. Agricultural Production*, in "Agroecology", ed. C. R. Carroll, J. H. Vandermeer, and P. Rosset. McGraw-Hill Publishing Company, New York.
144. US Department of Energy. (1969) *US Agriculture: Potential Vulnerabilities*. research report prepared by the Stanford Research Institute, Menlo Park, CA.
145. Barton, J. (1980) *Transportation and Fuel Requirements in the Food and Fiber System*. Agricultural Economic Report No. 444. Economic, Statistics, and Cooperative Service, USDA.
146. The Practical Farmer. (1994), vol. 9 (3). Fall Issue.
147. Günther, F. (2000) *Vulnerability in Agriculture: Energy Use, Structure and Energy Futures*. INES, Stockholm, Sweden, June 15; <http://www.etn.lu.se/~folke_g/jordbruk/INES.pdf>.
148. EIA. (1998) *Annual Energy Review 1998*. Energy Information Administration, US Dept. of Energy, Washington, DC; <http://www.eia.doe.gov/emeu/aer/contents.html>.
149. EIA. (1995) *Household Energy Consumption and Expenditures 1993*. DOE/EIA-0321(93). Energy Information Administration, U.S. Dept. of Energy, Washington, DC; <ftp://ftp.eia.doe.gov/pub/pdf/consumption/032193.pdf>.
150. Hall, C. A. S., C. J. Cleveland, and R. Kaufmann. *Energy and Resource Quality:*. Wiley Interscience, New York: 1986.
151. DOE (1999) *World Crude Oil and Natural Gas Reserves*, Energy Information Administration. Last updated 12/30/99; <http://www.eia.doe.gov/emeu/iea/table81.html>.
152. Rogner, H. H. (1997) “An Assessment of World Hydrocarbon Resources.” *Annual Reviews Energy & Environment* 22: 217-262.
153. Kerr, R. A. (2000) “Oil Outlook: USGS Optimistic on World Oil Prospects.” *Science* 289(number 5477): 237.
154. EIA *1997 Residential Energy Consumption Survey, appliance trends*. Last updated February 25, 2000; <http://www.eia.doe.gov/emeu/recs/recs97/decade.html#applianc>.
155. Organization for Competitive Markets. (1998) "OCM Testimony at Congressional and Administrative Hearings," June 10. OCM-T-1; <http://www.competitivemarkets.com/library/testimony/ocmt1.htm>.
156. GIPSA. (1996) *Concentration in the Red Meat Packing Industry*. Packers and Stockyards Programs, Grain Inspection, Packers and Stockyards Adminstration, USDA, Washington, DC; <http://www.usda.gov/gipsa/newsinfo/pubs/packers/conc-rpt.htm>.
157. Lieber, J. *Rats in the Grain: The Dirty Tricks and Trials of Archer Daniels Midland, The Supermarket to the World*. Four Walls, Eight Windows, New York: 2000.
158. (2000) The American Consumer and the Changing Structure of the Food System, Economic Research Service, USDA, Washington, DC and Arlington, VA, May 4-5, 2000; <http://www.ers.usda.gov/whatsnew/events/consumer.htm>.
159. SARE *Community Supported Agriculture*, Sustainable Agriculture Research and Education; <http://www.sare.org/csa/index.htm>.
160. Green, K. (2000) “Sustainability of Food Consumption and Production Systems.” *IHDP Update, newsletter of the International Human Dimensions Programme on Global Environmental Change* (number 2). 1,3.
161. Welsh, R. (1997) *Reorganizing U.S. Agriculture*. Policy Studies Report No. 7. Henry A. Wallace Institute for Alternative Agriculture, Greenbelt, MD.

Appendix A: Source and Methodology used in Creating *Figure 3: Life Cycle Materials: 1995 U.S. Food System Flow.*

Figure 3 compiles data from a number of sources. This appendix documents those sources and explicates concern or necessary clarification in the data. Data for the 1995 year is used throughout and was chosen because data on losses from the edible food supply were available for 1995.

Sources:

Plant based production, feed to livestock, animal - *Agricultural Statistics 1999*, National Agricultural Statistics Service, U.S. Dept. of Agriculture, 1999, U.S. Government Printing Office: Washington, DC; <http://www.usda.gov/nass/pubs/agr99/acro99.htm>.

Import/ Export - *Foreign Agricultural Trade of the United States (FATUS)*. 2000, Economic Research Service, USDA; <http://www.ers.usda.gov:80/briefing/AgTrade/htm/Data.htm>.

Data from Tables 2 and 3.

Industrial Uses - *Industrial Uses of Agricultural Materials: Situation and Outlook*. Economic Research Service, USDA, Washington, DC; IUS-6, August, 1996; <http://www.ers.usda.gov:80/epubs/pdf/ius6/index.htm>.

Edible Food Supply and Losses - Kantor, L.S., K. Lipton, A. Manchester, and v. Oliveira, *Estimating and Addressing America's Food Losses*, in *Food Review*. **20**(1). Jan-Apr 1997, Economic Research Service, USDA: Washington, DC.

Notes:

Feed to livestock, taken from Table 1-74 of *Agricultural Statistics*, is reported in equivalent feeding value of corn. In other words, the weight of “harvested roughage” presented is the amount of corn that would have the same feeding value as the harvested roughage fed to animals. In real numbers, these roughages (harvested roughage and pasture) would be much larger (perhaps double the value). The numbers are presented in Table 1-74 in this fashion because they are back-calculated from the number of animals fed using feed ration conversions (Allen Baker, ERS, personal communication). Flows into “Feed to Livestock & Poultry” (“feed grain imports”, other byproduct feeds”, “feed grains to animals”, oilseed cake & mill byproduct feeds”) are *not* in equivalent feeding value of corn.

The flow “other byproduct feeds” is the difference between “byproduct feeds” from Table 1-72 and the total of “oilseed cake and meal” and “mill products” from Table 1-70 in *Agricultural Statistics*. This difference should be primarily animal protein feeds and mineral supplements.

Appendix B: Sources and Methodology used in creating *Figure 5: Life Cycle Energy Use for the U. S. Food System*

This appendix details the source and calculation methodologies for the energy data presented in Figure 5. A noted omission from this compilation is the energy consumed by the seed industry in research, development, and production. Energy in food disposal (land fill, garbage disposal/ sewer treatment) is also not included.

Sources:

Agricultural production - *Agricultural Resources and Environmental Indicators, 1996-97*. Economic Research Service, USDA, Washington, DC; agricultural handbook no. 712, July 1997, .pg. 136.

The values presented by the ERS represent primarily direct energy used on farms and indirect energy consumed in the manufacturing of fertilizers and pesticides. The values are back-calculated from expenses data that have not been explicitly collected since 1993 (electricity use has not been recorded since 1991) (Mohinder Gill, ERS, personal communication). Energy use expenses in agriculture are now estimated/reported as an aggregate of many types/sources, making it difficult to back out use due to differences in prices. Values for different fuel types were extracted from Figure 3.3.1 in the ERS report and multiplied by fuel specific factors that account for energy consumed in the production of those fuels (see pre-combustion factors at end of this appendix). According to the 1994 edition of the Agricultural Resources and Environmental Indicators, the reported fertilizer and pesticide energy includes the energy used in production, packaging, transportation, and application (see text box “What is a BTU?,” pg. 107). A pre-combustion factor was not applied to the fertilizer and pesticide value.

Other indirect energy inputs into agriculture, such as the manufacturing of farm machinery and equipment, is not included here.

Transportation - *1997 Economic Census: Transportation. Commodity Flow Survey.* U.S. Dept. of Transportation, U.S. Dept. of Commerce, Washington, DC; EC97TCF-US. Single-mode ton-miles (truck, rail, water) were compiled for all agriculture related shipping identified in the census (live animals and live fish; cereal grains; other ag. products; animal feed and products of animal origin; meat, fish, seafood, and their preparations; milled grain products and preparations and bakery products; other prepared foodstuffs and fats and oils; alcoholic beverages; fertilizer). The Commodity Flow Survey does not cover shipments of agricultural products from the farm site to the processing centers or terminal elevators, but does cover the shipments of these products from the initial processing centers or terminal elevators onward. Multiple mode transport was considered insignificant (single mode accounted for greater than 89% of all ton miles in each agriculture related category) as were single modes with small contributions (air, parcel). Ton-miles were then multiplied by BTU/ton-mile estimates from Franklin Associates, Ltd. (Franklin Associates Ltd., *Energy Requirements and Environmental Emissions for Fuels Consumption*. 1992: Prairie Village, KS). These BTU/ton-mile numbers include pre-combustion energy for fuel acquisition. Truck transport was assumed to be diesel and 80% tractor trailer. Water transport was estimated at barge energy consumption levels.

Transport of food from retail outlets to homes has been estimated as follows: According to the DOE Transportation Energy Book (Davis, S. C., *Transportation Energy Data Book: Edition 19*. 1999, Oak Ridge National Laboratory for U.S. Department of Energy: Oak Ridge, TN. ORNL-6958.), U.S. households average 775 person trips for shopping a year, with an average vehicle occupancy for shopping of 1.7. This comes out to 8.7 vehicle shopping trips per household per week. The Food Marketing Institute (http://www.fmi.org/facts_figs/superfact.html) reports that U.S. households averaged 2.2 trips to the grocery store per week in 1999. We thus estimate that approximately 25.3% of shopping trips are for groceries. The Transportation Energy Book reports a total of 2.7786×10^{11} vehicle-miles for shopping, and 5822 BTU/vehicle-mile for the average automobile. Thus:

$$0.253*(2.7786\times10^{11})*5822 = 4.09 \times 10^{14} \text{ BTU}$$

This value was then multiplied by the gasoline pre-combustion factor.

The energy consumed in transporting agricultural products from farms to processing centers has not been explicitly included here due to lack of data. Some of the fuel consumed for this transport may be included in the agricultural production estimates.

Processing (food and kindred products industry) - *1994 Manufacturing Energy Consumption Survey*. Energy Information Administration, U.S. Dept. of Energy, Washington, DC; Table A10: Total Inputs of Energy for Heat, Power, and Electricity Generation by Fuel Type, Industry Group, Selected Industries, and End Use, 1994; <http://www.eia.doe.gov/emeu/mecs/mecs94/consumption/mecs5.html#mecs2cb>.

Totals from food and kindred products (SIC Code 20) were used here. Energy use is divided into fuel type in Table A10, and appropriate pre-combustion factors were applied to each fuel type.

Packaging – The embodied energy in food packaging materials was compiled from Municipal Solid Waste data (*Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 1998*. 2000, EPA Office of Solid Waste and Emergency Response: Washington, DC. EPA530-F-00-024) to estimate usage and Life Cycle Inventories for Packaging (*Life Cycle Inventories for Packagings: Volume I*. 1998, Swiss Agency for the Environment, Forests and Landscape: Berne, Switzerland. environmental series no. 250/I) to estimate the energy consumed in preparing packaging materials.

Only those packaging materials in the municipal solid waste (MSW) stream that could be specifically attributable to food packaging were included in this estimate: glass packaging, steel food cans, aluminum beer and soft drink cans, milk cartons and folding cartons, plastic soft drink & milk bottles. Other pieces such as corrugated boxes and plastic wraps which have packaging uses both in food and in other products were not included because the MSW characterization does not differentiate use of these materials. The following table contains the data used to generate the packaging energy value.

Table B1: Food Packaging Production Energy

Packaging material	Generated in MSW (thousand tons)	energy for production (million BTU/ton)	assumptions
Glass	10610	10.6	energy ave. of green, brown, & white glass
steel	2860	23.1	50% recycle without detinning
aluminum	1530	82.1	50% recycle
paper (milk & folding cartons	5880	45.7	liquid packaging board
plastics	1430	73.8	polyethylene, general

Food retail and commercial food service - *1995 Commercial Buildings Energy Consumption Survey*. Energy Information Administration, U.S. Dept. of Energy, Washington, DC; Table 1. Total Energy Consumption by Major Fuel, 1995; <ftp://ftp.eia.doe.gov/pub/consumption/commercial/ce95tb1.pdf>.

Food sales and food service values from Table 1 were used, multiplying by pre-combustion factors.

Household energy use – *Household Energy Consumption and Expenditures 1993*. Energy Information Administration, U.S. Dept. of Energy, Washington, DC; DOE/EIA-0321(93), October, 1995; <ftp://ftp.eia.doe.gov/pub/pdf/consumption/032193.pdf>.

While 1997 data is available from DOE for household energy consumption, it does not sub-categorize the data as far as the 1993 document. Included here is electricity consumption for refrigerators, freezers, electric range/stoves, microwave ovens, and electric dishwashers, from Table 3.1 (pg. 10) of the above document.

Natural gas use in appliances is not broken down into types of appliances in the Residential Energy Consumption Survey. Estimates from Michcon (natural gas distributor) suggest that cooking consumes about 57% of appliance natural gas. This fraction was then applied to the total appliance natural gas consumption reported in the 1997 Residential Energy Consumption Survey (*A Look at Residential Energy Consumption in 1997*. 1999, Energy Information Agency, U.S. Dept. of Energy: Washington, DC. DOE/EIA-0632 (97).)

Energy consumed in the heating of water that is used for cooking and food related cleaning was estimated as follows: The Energy Outlet, an energy conservation resource center, characterizes a typical household hot water demand (http://energyoutlet.com/res/waterheat/waterheater.html). They report that 12% of hot water goes to the tub, 37% to the shower, 26% to clothes washer, 14% to dishwashers, and 11% to sinks. Based on these estimates, we speculated that about 25% of water heating energy could be allocated to food preparation (sinks plus dishwasher). This factor was then applied to both the electric and natural gas consumption for water heating (Table CE4-1c in *A Look at Residential Energy Consumption in 1997*.

1999, Energy Information Agency, U.S. Dept. of Energy: Washington, DC. DOE/EIA-0632 (97).)

Food energy available for consumption - *Chapter XIII: Consumption and Family Living*, in "Agricultural Statistics 1999", ed. U. S. Dept. of Agriculture, National Agricultural Statistics Service. U.S. Government Printing Office, Washington, DC; <http://www.usda.gov/nass/pubs/agr99/acro99.htm>.

Food available for consumption per capita per day in 1994 was multiplied by the U.S. population in 1994 and by 365 days per year.

Pre-combustion factors:

In order to account for energy consumed in acquiring and supplying a particular fuel type, pre-combustion factors from Franklin Associates (Franklin Associates Ltd., *Energy Requirements and Environmental Emissions for Fuels Consumption*. 1992: Prairie Village, KS, Table A-5) were used.

Table B2: Pre-combustion energy factors for various fuels

electricity upstream factor	3
natural gas upstream factor	1.12
diesel upstream factor	1.18
LPG upstream factor	1.27
gasoline upstream factor	1.21
coal	1.02
residual fuel oil	1.17