chapter nine

The potential of Onondaga County to feed its own population and that of Syracuse, New York: Past, present, and future

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9.1.1 *The changing state of fossil fuel availability and its potential to impact food production systems*

The world today faces enormous problems related to population and resources. These ideas have been discussed intelligently and, for the most part, accurately in many papers from the middle of the last century (e.g., Ehrlich, 1968; Meadows et al., 1972; Odum, 1971; Hubbert, 1969, 1974). However, these concepts largely disappeared from scientific and public discussion, in part because of an inaccurate understanding of both what those earlier papers said and the validity of many of their predictions (Hall and Day, 2009). Today, most environmental science textbooks focus

far more on the adverse environmental impacts of fossil fuels than on the implications of our overwhelming economic and even nutritional dependence on basic resources and the implications of their depletion. This failure to bring the potential reality and implications of peak oil—indeed, the peak of most major economic and agricultural commodities—into scientific discourse and teaching is a grave threat to industrial society.

The possibility of a huge, multifaceted failure of a substantial part of industrial civilization is so completely beyond the understanding of our leaders that we are almost totally unprepared for it. One reason is that general public acceptance and policy actions have rarely occurred for large environmental and health issues—from smoking to flooding in New Orleans—before several decades of evidence of negative impacts have confronted decision makers. The increasing availability of inexpensive petroleum, at least until the middle of this past decade, allowed the "papering over" of energy supply issues by, for example, replacing lost soil nutrients due to erosion with cheap fossil-fuel derived fertilizers, allowing fishing boats to fish ever more distant regions, concentrating animals away from their feed production, and encouraging the mass migration of people from problem-rife cities to suburbs.

Everything we do displays an astonishing dependence on oil. Beyond shoe leather and bicycles, virtually no extant forms of transportation exist for ourselves or our food that are not based on oil—and even our shoes and bicycle tires are now generally made of petroleum products. Food production, transportation, and processing are extremely energy intensive, to the degree that they use nearly 20% of the energy consumed in the United States. Clothes, furniture, and most pharmaceuticals are made from and with petroleum, and most existing jobs would cease to exist without petroleum.

The very large volume of fossil fuels used in the United States means that each of us has the equivalent of 60–80 hardworking laborers to "hew our wood and haul our water," as well as to grow, transport, and cook our food; make, transport, and import our consumer goods; provide sophisticated medical and health services; and so forth. A North American taking a hot shower in the morning has already used far more energy than probably two-thirds of the Earth's human population will use in an entire day. Oil is especially important for the transportation of ourselves, our goods, and our services; for the production of gas for heating, cooking, and some industries; and as a feedstock for fertilizers and plastics. But one would be hard-pressed to have any sense of this extreme oil dependence in our public debates and on our university campuses beyond complaints about the increasing price of gasoline: This is despite a situation similar to the summer of 2008 and five years of flat oil production, assuaged only by the subsequent, and many would say ensuing, financial collapse that decreased demand for oil.

No substitutes for oil have been developed on anything like the scale required, and most of those that exist are very poor net energy performers. Despite considerable potential, renewable sources (other than hydropower or traditional wood) currently provide less than 1% of the energy used in the United States and the world. Until 2008, the annual increase in the use of each fossil fuel was generally much greater than the total production (let alone increase) in electricity from wind turbines and photovoltaics (EIA, 2010a). Our new sources of "green" energy simply increase along with (rather than displacing) the traditional ones.

Petroleum possesses important and unique qualitative attributes, including a very high energy density and transportability (Cleveland, 2005), that lead to high economic utility and the magnitude of current use that makes its future supply prospects worrisome, including its role in food production. The relation between petroleum supply and potential demand will be the continuing issue, rather than the point at which oil actually runs out. Barring the continuation of our present worldwide recession, demand will continue to increase as human populations, petroleum-based agriculture, and economies (especially Asian) continue to grow. Petroleum supplies had been growing most years since 1900 at 2–3% per year, a trend that most investigators think cannot continue and in fact ceased in 2005 (e.g., Campbell and Laherrere, 1998; Heinberg, 2003).

How much oil and gas are left in the world? A lot remains, although probably not a lot relative to our increasing needs, and maybe not a lot that we can afford to exploit with a large financial and, especially, energy profit. We will probably always have enough oil to oil our bicycle chains. But will we have anything like the quantity that we use now at prices that allow for the things we are used to having? The issue of how much oil remains usually does not develop from the perspective of "When will we run out?" but rather "When will we reach 'peak oil' globally?" Worldwide, we have consumed a little more than a trillion barrels of oil. The current debate centers on whether 1, 2, or even 3.5 trillion barrels of economically extractable oil remain to be consumed. Fundamental to this debate, yet mostly ignored, is an understanding of the capital, operating, and environmental costs to find, extract, and use whatever new sources of oil remain to be discovered and to generate whatever alternatives we might choose to develop. Thus, the investment issues, in terms of both money and energy, will become ever more important.

Several prominent geologists have suggested that the peak production rate of conventional oil occurred for the world in 2004–2005 (e.g., Deffeyes, 2005; Campbell, 2010). A preliminary peak of all petroleum liquids (including unconventional oil, natural gas liquids, and so on) occurred in 2008. This peak was surpassed in 2010–2011, mainly due to increased production in biofuels. If global demand regains its prerecession growth, regardless of technology or price, global petroleum supplies will not be

likely to continue to increase or even to maintain current levels. The arguments of these geologists and their organization, the Association for the Study of Peak Oil (ASPO), spearheaded by the analyses and writings of geologists Colin Campbell and Jean Laherrere, have the support of many other geologists who more or less agree that dozens of oil-producing countries have already reached production peaks. These investigators also believe that essentially all regions of the Earth favorable for oil production have been well explored for oil, so there are few surprises left, except perhaps in regions that will be nearly impossible to exploit. The costs of exploiting lower-grade or harder-to-reach oil deposits have been made clear to the world by the Gulf of Mexico oil spill of 2010.

Thus, we have entered the second half of the age of oil (Campbell, 2006). In the first half of the age, oil supply grew year by year; in the second half, the importance of oil will continue, but will be coupled with a year-by-year decline in supply. The impacts of the peak and decline appear to be modulated somewhat by the continuation of an "undulating plateau" at the peak, the general decline in economic growth for much of the world, and some help from still-abundant natural gas. We are of the opinion that it will not be possible to fill in the growing gap between supply and demand of conventional oil with, for example, liquid biomass alternatives on the scale required (Hall et al., 2008), and even were that possible, the investments and time required to do so would mean that we needed to get started some decades ago (Hirsch et al., 2005).

Clearly, we are at a "bumpy plateau" in oil production, as predicted by Campbell (2004). As petroleum extraction declines, it causes prices to increase, but then the increased oil price constrains economic growth, which decreases oil use and prices to the point that demand rises again, and so on—the chickens and eggs can keep going for some time. That is why many "peak oilers" speak of a bumpy plateau. However, if potential demand keeps growing, then the difference between a steady or declining supply and an increasing demand presumably would continue upward pressures on price. When the decline in global oil production begins in earnest, we will see the end of cheap oil and an economic climate very different from even the difficult times now.

9.1.2 *Historical energy costs of production and transport*

Two important agricultural transitions increased productivity and changed the way America's farmers grew and supplied food. The first was the transition from draft animals to mechanized tractors that took place in the early 20th century (EIA, 2002). The second took place after World War II when the military-industrial complex shifted from producing tanks, planes, and munitions to mass-producing tractors, combines, and fertilizers. This shift from draft animals to machines, combined with advances in fertilizer production, led to a radical restructuring of agriculture in the United States and an enormous increase in output per hectare and per unit of human labor. The era of solar-powered agriculture came to an end, and our dependency on fossil-fuel-powered farming began.

Modern agriculture is extremely fossil-fuel intensive. It is dependent on large tractors and combines and the production of the fertilizers and pesticides needed to sustain high yields on continually degrading land. Food is transported long distances by ship, rail, and truck to be processed, and then longer distances to reach American dinner tables. Pirog and Benjamin (2003) have estimated that fresh produce travels 1,500 miles on average from production to consumption.

A decline in the production rate of petroleum has troublesome implications for our current agricultural system. According to Pimentel and Pimentel (1979), one manpower is equal to roughly 1/10 horsepower, so a 10-man-hour workday produces one horsepower-hour of work. A gallon of gasoline used in a 20% efficient engine can perform the equivalent of about 10 horsepower-hours, or 100 manpower-hours, of work (Pimentel and Pimentel, 2008). Therefore, a gallon of gasoline (about $3 in 2010) would generate about 100 times the daily work output of a hardworking human, at less than 0.5% of the cost.

Early U.S. grain farms, based primarily on human labor, required about 373 man-hours per 100 bushels of wheat and 344 man-hours per 100 bushels of corn. By 1900, with draft animals and steel plows now an integral part of farming, the man-hours were reduced by more than half for corn and nearly 70% for wheat, though during that period yields remained steady. After World War II, agriculture efficiency rose dramatically, with man-hours per 100 bushels in 1955 reduced to 18 for wheat and 22 for corn. By 2000, further efficiency gains and increased fossil energy inputs had reduced the human labor inputs to 8 hours per acre for wheat and 3.3 for corn (see Figures 9.1 and 9.2).

The transition from draft animals to tractors did more than increase the efficiency of human labor. Farms grew larger, and although the frontier officially closed in 1890, a new frontier of land became available to farmers: land previously dedicated to growing fodder for their animals (Olmstead and Rhode, 2001). The horse and mule population for the United States peaked in 1920 at about 26 million, with about 20 million of those being dedicated work animals. These populations had fallen to less than 4 million by 1960. The percentage of farms reporting only tractors (no horses or mules) grew from 8% in 1940 to 55.8% just 14 years later (see Table 9.1). By 1999, the number of equine animals (horses, ponies, mules, and donkeys) on farms totaled just 3.2 million, though the total U.S. equine population, including recreational horses, was up to 5.25 million (USDA, 1999).

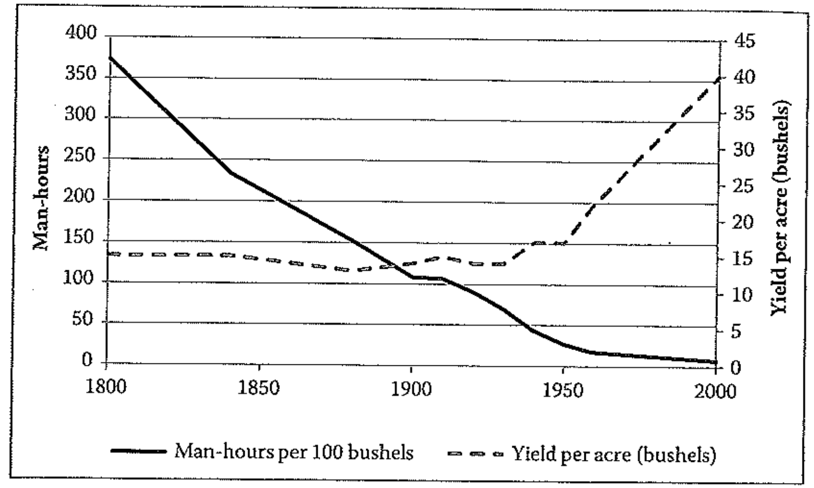

Figure 9.1 Wheat, yield, and yield per human effort. 1 hectare = 2.54 acres. (1800–1960 data from Rasmussen, W. D., *Journal of Economic History*, 22, 578–591, 1962; Year 2000 data from Pimentel, D., and Pimentel, M., *Food, energy and society*, 3rd ed., Boca Raton, FL: CRC Press, 2008.)

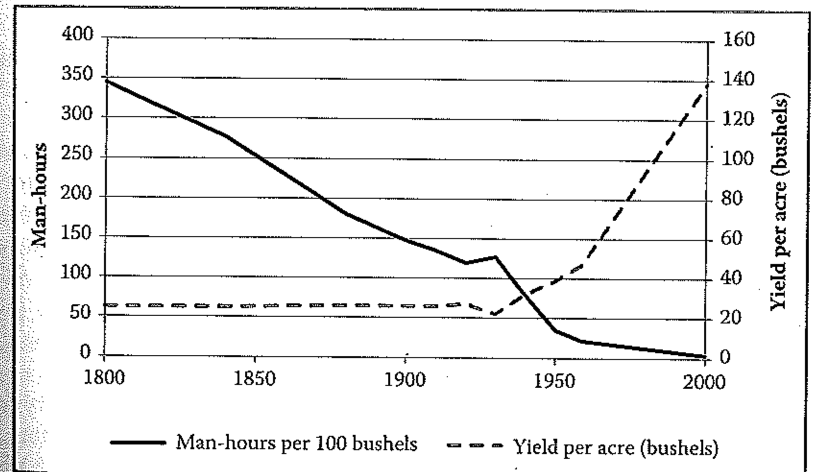

Figure 9.2 Corn, yield, and yield per human effort. (1800–1960 data from Rasmussen, W. D., *Journal of Economic History*, 22, 578–591, 1962; Year 2000 data from Pimentel, D., and Pimentel, M., *Food, energy and society*, 3rd ed., Boca Raton, FL: CRC Press, 2008.)

Table 9.1 Use of Draft Animals and Tractors on Mid-Atlantic States Farms, 1940–1954

Percentage of mid-Atlantic states farms reporting:	Year			
	1940	1945	1950	1954
Horses/mules and no tractors	41.5	24.3	15.8	6.6
Horses/mules and tractors	24.9	31.7	25.3	17.2
Tractors only	8.1	18.4	38.3	55.8
No tractors or horses/mules	25.4	25.6	20.6	20.4

Source: U.S. Census Bureau, *United States Census of Agriculture*, 1954, Washington, DC: USCB, 1956/1957.

The general trend of agriculture in the United States has been supplementing human labor, initially with animal power and later with fossil fuels. The net result has been a very large increase in the amount of grain produced per farmer per year. Less commonly understood is that there has been a great *decrease* in the productivity of each unit of *energy* invested. Perhaps the single most important way in which fossil fuel contributed to agricultural productivity was the widespread application of the Haber-Bosch process to fertilizer production following World War II when large-scale ammonium production facilities were no longer needed to produce ordnance. In addition, there was a widespread application of fossil fuels in the extraction of phosphorus in Florida and Morocco. Finally, a whole suite of additional agrochemicals, pesticides, and herbicides were produced that require fossil fuels as a feedstock.

Although draft animals and fossil-fuel-powered machines improved the efficiency of human labor on farms, yields did not rise substantially until the advent of chemical fertilizers and hybrid seeds, especially in the 1960s. Steinhart and Steinhart (1974) studied the rising energy inputs into U.S. agricultural production and found that by 1970 the energy inputs into the food system were nearly 10 times that of the food energy consumed by Americans. Fertilizer use grew quickly after the 1950s and then leveled out after concerns arose about eutrophication of wetlands and waterways and improved application techniques became available (see Figure 9.3). Cleveland (1995a) found improving agricultural efficiency after the low was reached in 1978 for the ratio of food energy output per unit of energy input, reversing the near-linear increase in energy inputs.

The mechanization of farming also reduced the number of crop types grown on each farm. On average, farms in 1900 produced five different crop types. By 2000, this number was reduced to one (Dimitri et al., 2005). In 2010, a single farmer driving a 60-foot-wide field cultivator tractor was able to work 43 acres in one hour, burning only 0.32 gallons of diesel per acre (University of Minnesota Extension, 2009). It appears that both labor and energy efficiency have increased recently (Cleveland, 1995a, 1995b).

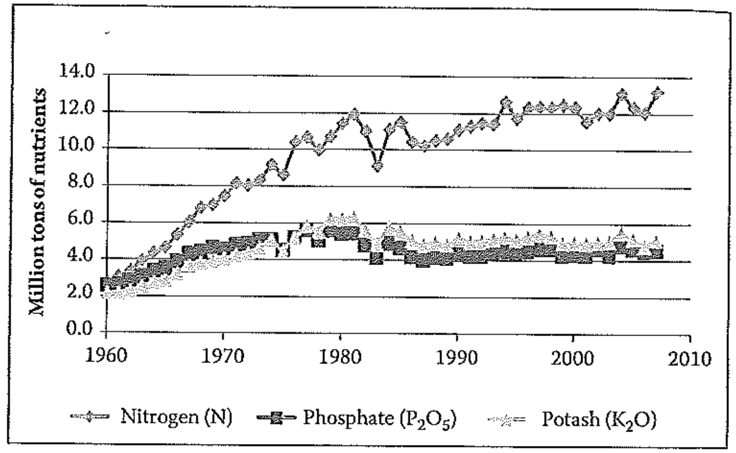

Figure 9.3 U.S. fertilizer consumption, 1960–2008. (From U.S. Department of Agriculture, 2010a, Fertilizer use and price [online database accessed July 25, 2010], http://www.ers.usda.gov/Data/FertilizerUse/.)

9.1.3 *Current national patterns of food production and distribution*

The availability of cheap oil has led to the changes in the agriculture system that we now practice. We use massive, but decreasing, areas of land to produce the agricultural products we need, plus a large quantity for export. We use genetically modified (but highly fertilizer dependent) high-yield seed varieties, large quantities of petroleum-requiring pesticides, and fertilizers on a single species to generate massive output per acre. The 2007 U.S. Agriculture Census indicates that the total land area devoted to agricultural production is 922 million acres. This is a decline of more than 6 million acres since 2002. At the same time, farm expenses used to purchase feeds, fertilizers, chemicals, and gasoline and other fuels are estimated to have increased from about $40 billion in 2002 to around $90 billion in 2007.

Likewise, the availability of cheap oil has also changed consumption patterns. For instance, based on the 2007 U.S. Agriculture Census, an average American consumes 2,775 kcal per day, 28% more than in 1970 (USDA, 2002). More than 3,700 kcal are available per capita per day in the United States, but 27% of food is wasted by final consumers (Kantor et al., 1997). American consumers are also eating more meat compared to the past (USDA, 2002). The U.S. livestock population consumes more than seven times as much grain as the U.S. human population consumes directly; if this grain were consumed in a plant-based diet, it could feed 840 million people (Pimentel and Pimentel, 2003).

As the tastes of American consumers change and the demand increases for produce not traditionally available year-round and not grown in a particular area, the distance produce travels has increased, and the energy consumed by this transport has also increased. Pirog and Benjamin (2003) at Iowa State University, as noted earlier, indicate that on average fresh produce travels 1,500 miles. Weber and Matthews (2008) calculate that the total freight required for food and food products in 1997 amounted to approximately 1.2 trillion tonne-km (0.82 trillion short ton-mi), or 12,000 tonne-km (8,200 short ton-mi) per household. They estimate the average final delivery distance of food to be 1,640 km (1,020 mi), with total supply chain transportation of 6,760 km (4,200 mi).

In Onondaga County, New York, the 2007 U.S. agricultural census indicates that the number of farms declined from 725 in 2002 to 692 in 2007, with a 1% reduction in the land area devoted to farms. Additionally, the county grew more grains for feeds than in the past (see below). A quick walk through the top four grocery chains operating in Syracuse and Onondaga County shows that many of the fruits, vegetables, grains, and other food items now come from other states such as California and Florida, as well as from other countries such as China, Chile, and Mexico.

The same liberalization of markets that helps boost U.S. exports also increases competition for American farmers and growers. Now, Florida orange groves compete for market share with not only California but also Brazil. Upstate New York apple farmers find competition from Washington State and Chinese fruit shipped halfway around the world. This global specialization and competition is predicated on large amounts of cheap fossil fuels, mostly petroleum products.

9.1.4 *Overview and history of the city of Syracuse and Onondaga County*

The Syracuse Metropolitan Area is located within Onondaga County in central New York State (see Figure 9.4). Syracuse is the subject of an Urban Long-Term Research Area (ULTRA-Ex) study through a grant from the National Science Foundation. Some of the questions that drive the research include: What is the socioecological metabolism (SEM) of a Rust Belt city? How has it changed over time? How might it be vulnerable to future external factors such as restrictions in oil availability? How might city revitalization emphasizing natural ecosystem processes via green infrastructure affect the SEM at both the city/regional and the household/neighborhood levels in the future?

In order to begin to answer these questions, one must first have a proper understanding of the metabolism of the city and its surroundings, meaning the stocks, flows, and investments of energy used now to feed and employ the residents of the city and the surrounding population in Onondaga County.

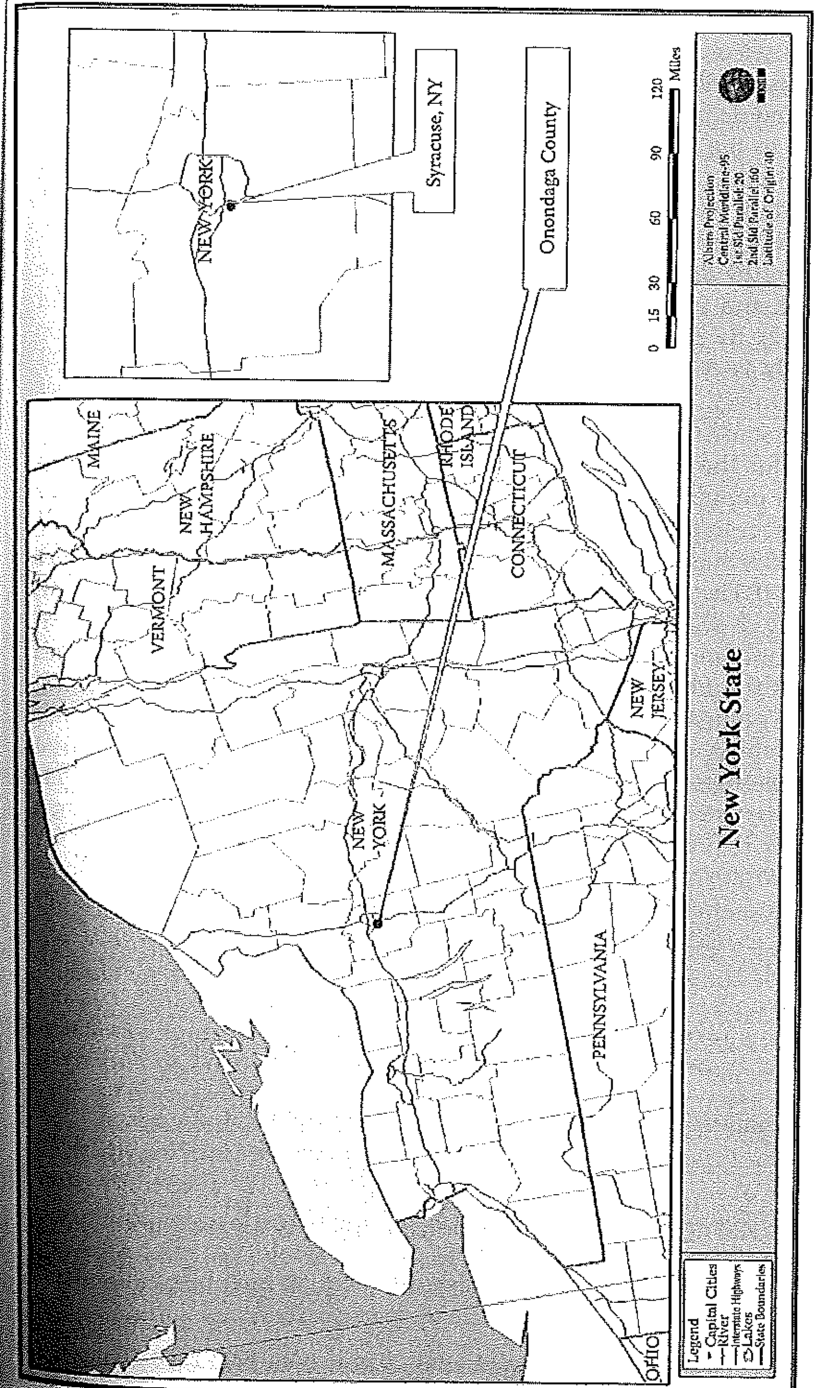

Figure 9.4 New York State map, with Onondaga County and the city of Syracuse (*inset*) as well as major roads. (Original map, created in ESRI Arcview 9.2 by Aileen Guzman, Syracuse University College of Geography, community geographer.)

This perspective includes food as an especially important energy flow. Our study focuses on the food energy production and demand in Syracuse and Onondaga County, as well as the associated fossil energy required to grow, process, and deliver the food products to the consumer.

Prior to the 1700s, Onondaga County was home to some two thousand members of the Onondaga tribe (Hodge, 1907), who lived well on the abundant fish, game, and agriculture. Ephraim Webster was the first European-American to settle Onondaga County, in 1786. Disbanded soldiers from the Revolutionary War were granted tracts of land in Upstate New York and further displaced many of the Onondaga (Anderson and Flick, 1902). By 1825, Onondaga County had a population of over 48,000 and nearly 78,500 hectares (194,000 acres) under cultivation (Macauley, 1829). However, only 100 homes purportedly existed at that time in the city of Syracuse (Macauley, 1829). Syracuse grew in population and prominence after the completion of the Erie Canal in 1825 and by 1835 had reached a population of 4,100 (Anderson and Flick, 1902). The chief economic driver in the 19th century was salt production.

By 1855, Syracuse had grown from a small village to a city of more than 25,000. The salt industry fueled the economic and population growth of the city. It was later replaced by the chemical, automotive, electrical devices, and metals industries. By 1902, over 150 separate industries employed the 130,000 residents living in Syracuse (Anderson and Flick, 1902). The population of the city peaked in 1950 at 218,830, while the county reached a peak population of 472,746 in 1970 (see Figure 9.5). Industrial

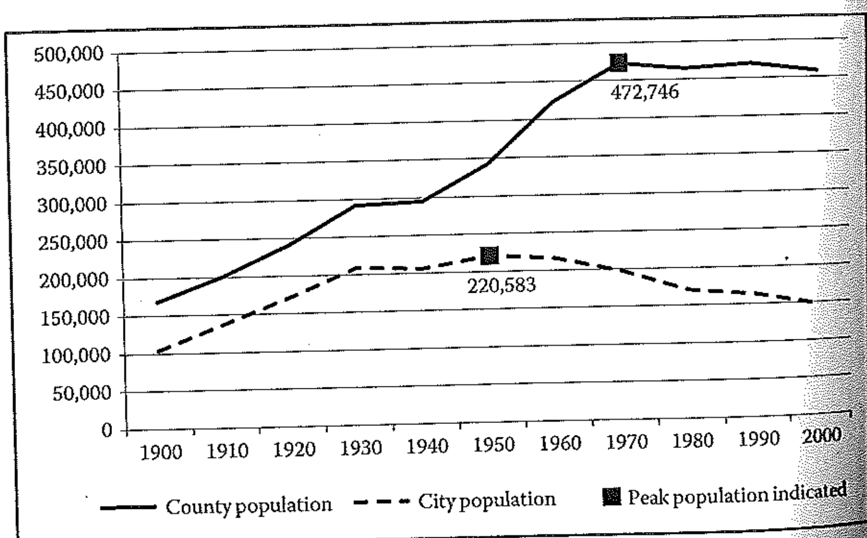

Figure 9.5 Syracuse and Onondaga County population, 1900–2000. (From U.S. Census Bureau, 2000.)

Table 9.2 Population and Economic Statistics for Onondaga County, 1990–2008

	1990	2000	2006–2008 (est.)	Change 1990–2000 (%)
Total population	468,973	458,336	452,633	–2.2
Housing units	190,878	196,633	—	+3.0
Persons per unit	2.46	2.33	—	–5.3
Registered passenger vehicles[a]	208,515	264,831	278,200	+27
Mean travel time to work (min)	18.3	19.3	18.7	+5.5
Persons per square mile	601	587	581	–2.3
Persons in commercial employment	178,212	177,360	182,964	–0.4
Persons in industrial employment	49,968	38,354	35,417	–23
Roadway mileage[b]	3,032.4	3,052.0	3,081.5	+0.6

[a] No data available for 1990; earliest available data at county level from 1996 (New York State Department of Motor Vehicles).
[b] No data available for 1990; earliest available data at county level from 1998 (New York State Department of Transportation).

production began declining in the 1970s and continues to decline to this day. As industries left the area, the population began to decline. The main economic activity in Onondaga County today is in the commercial sector—namely, health care, education, and retail—although agriculture continues to be an important source of economic production.

The post–World War II trend in land development in Onondaga County, like in a majority of the United States, has been a migration from the city and inner suburbs to new suburban developments built on formerly productive farmland (Kunstler, 1993). This urban-to-suburban migration continues today, as the city population continues to decline at a rate faster than the relatively stable county population (see Figure 9.5) The number of housing units increased by 3% from 1990 to 2000, a time when the population declined by 2.2% (see Table 9.2).

9.1.4.1 *A brief history of inputs and outputs in Onondaga County*

Solar energy and especially biomass were the major energy inputs into early Onondaga County. Forests provided wood for heat. Firewood was abundant. In the United States, some 5 million acres per year were cleared for new farmland (Schurr, 1960). In 1850, the per capita consumption of firewood was estimated to be 4.5 cords,* with more than 90% of it

* A cord is a measure of wood, comprising a stack 4 feet wide, 4 feet high, and 8 feet long, estimated to contain 20 million BTU (or 21 GJ) when burned (USDA, 2004).

consumed in the household (Schurr, 1960). To keep comfortably warm, an American family would use 17.5 cords of firewood a year. Firewood remained the primary fuel for home heating until coal overtook it in the late 19th century (EIA, 2002).

Energy inputs into the commercial and industrial sectors also relied heavily on solar inputs. The salt industry used wood to boil saltwater in kettles initially, then solar salt works were incorporated in 1821 reducing the biomass fuel need (Anderson and Flick, 1902). The remainder of energy inputs came from mills that tapped into the region's hydrological power (also solar) and small amounts of imported oils for light. Fossil fuels became available initially in the form of small amounts of coal imported from Pennsylvania. The importance of coal grew with the advent of the coal-fired boiler used in most trains and ships by the 19th century.

Syracuse lies at a natural intersection of east-west and a north-south low elevation transportation corridors. Draft animals such as mules and horses provided the propulsion to barges on the Erie Canal and local transportation by carriage. Locomotive service began in 1839 when the rail line from Albany to Utica was extended to Syracuse (Anderson and Flick, 1902). In 1926, the city boasted that the area was serviced by six interurban electric lines and that 181 passenger trains arrived and departed each day (City of Syracuse, 1926). Personal automobiles replaced the streetcars in the early 20th century. The first Franklin automobile, which was produced in Syracuse, was sold in 1902. Over the next few decades, the light and heavy rail systems in Syracuse were dismantled or rerouted, and the automobile became the transportation vehicle of choice. Home furnaces, previously fueled with coal, were switched over to "cleaner" home heating oil. Eventually, a majority of furnaces were replaced when natural gas service was installed in the city and later the surrounding areas.

9.1.4.2 *Trends in Onondaga County energy consumption, 1990–2000*

Onondaga County experienced a 2.2% decline in population from 1990 to 2000 (see Table 9.2), and the population of the city of Syracuse declined at an even faster rate—from 163,860 in 1990 to 147,306 in 2000, a decline of 10.1%. Rolf Pendall (2003) has termed the phenomenon in central New York as "sprawl without growth." Between 1982 and 1997, central New York (which includes Syracuse, Utica, and Rome) urbanized more than 160,000 acres despite a population decline (Pendall, 2003). The trend in relocating from urban neighborhoods to suburban locations requires increased energy consumption to power larger suburban homes and for transportation during longer commutes and travel from suburban neighborhoods to schools and shopping centers. Many times, these suburban developments are built on the highest quality farmland. From 1990 to 2000 in Onondaga County, the total anthropogenic energy consumption increased 14%. Per capita energy

Table 9.3 Estimated Energy Use in Onondaga County in 1990 and 2000

	Total energy in Petajoules ($J \times 10^{15}$)			Gigajoules per capita		
	1990	2000	Change	1990	2000	Change
Residential energy use	24.9	29.8	20%	53	65	23%
Commercial energy use	25.2	32.3	28%	54	70	30%
Industrial energy use	13.4	13.2	−1%	29	29	—
Transportation energy use	34.2	35.6	4%	73	78	7%
Total	*97.7*	*110.9*	*14%*	*209*	*242*	*16%*

Onondaga County energy consumption was estimated by Ngo and Pataki (2008): New York State level historical energy consumption (EIA, 2010b) was prorated based on population and employment. Individual sectors were adjusted based on percent of statewide gasoline consumption, home heating fuel choice, heating degree days.

Source: Balogh, S., Simulating the potential effects of plug-in hybrid electric vehicles on the energy budget and tax revenues for Onondaga County, New York, M.S. thesis, State University of New York, College of Environmental Science and Forestry.

consumption increased 16% (see Table 9.3). Residential and commercial sector energy use increased greater than 20%, and transportation energy consumption increased by 4%. Industrial energy use declined slightly.

9.1.5 *Objectives*

Our objectives in this chapter are to answer the following questions:

1. Can we feed the current population of the city of Syracuse and of Onondaga County from local agricultural production?
2. Has Onondaga County been calorically self-sufficient in agricultural production over the last century?
3. What changes to the current production and distribution systems would be necessary to meet the nutritional needs of the present citizens of Onondaga County?
4. How would a decline in fossil fuel availability affect local food production?

9.2 *Methods*

We estimated food production and use by constructing:

1. A *demand* model that calculates the farm-derived food demand from humans in Onondaga County
2. A *supply* model that calculates historical caloric production and crop yields from U.S. Department of Agriculture (USDA) published statistics on the area and production of major crops in Onondaga County

and also a spatial analysis of historical farmland in Onondaga County
3. A *foodshed* model that calculates the land needed to support the county's population over time
4. An *energy-flow* model that quantifies the current fossil energy costs for agricultural inputs and transportation and examines the change in energy consumption associated with a potential shift from national/global food supply chains to local food production and delivery.

We then synthesize and compare the outputs of these models to examine historical food security and self-sustainability of the county. Our detailed methods are described below.

9.2.1 *Demand model: Food requirements of Onondaga County residents*

For the demand model, we used historical U.S. per capita food availability (USDA, 2005; FAO, 2010) to estimate the daily amount of calories available to feed the average Onondaga County resident. Though differences in diet and food availability may have existed regionally, we assume that the diet of the average citizen in Syracuse and Onondaga County is no different than that of the average American. This seems reasonable, given that Syracuse is considered an "average" American city for marketing purposes, with gross domestic product, age, ethnic makeup, and so on thought to be similar to the national mean.

We calculated annual food demand in kcal for Onondaga County and the city of Syracuse by multiplying the daily per capita food availability (in kcal) for a given year by 365 days, and then by the respective population. Results are reported in Tcal (1×10^9 kcal). Similarly, to calculate the food requirement by weight to feed Syracuse and Onondaga County residents, we used FAO and USDA food availability statistics by food type and by individual crop. The recommended USDA diet includes seven major categories: sweeteners, grains, dairy, meats and other proteins, fats and oils, fruit, and vegetables. We assigned individual foods and food subgroups to these major categories (for example, see Table 9.4). We then calculated the annual food supply quantity needed, by weight (in Mt), to meet demand from Syracuse and Onondaga County by multiplying the food supply quantity in kg/person/yr by the respective populations.

9.2.2 *Supply model: Historical production*

Our objective with the supply model was to determine crop yields in metric tons per hectare and the total caloric output of major crops of

Table 9.4 U.S. per Capita Food Availability by Weight, Calories, and Protein Supply in 2007

Item	Food supply quantity (kg/capita/yr)	Food supply (kcal/capita/day)	Protein supply quantity (g/capita/day)
Grains	170	925	26.9
Cereals	111.6	830	24.4
Sweeteners	67.6	629	0.2
Fats and oils	40.2	830	2.8
Oil crops	5.4	61	2.5
Vegetable oils	29.1	661	0.2
Animal fats	5.7	108	0.1
Fruits	111	116	1.3
Vegetables (incl. potatoes)	186	80	3.6
Meat and other proteins	168	602	53.4
Bovine meat	41.2	114	14
Pig meat	29.7	131	8
Poultry meat	50.7	199	18.2
Eggs	14.3	54	4.2
Tree nuts	3.8	27	0.8
Pulses (legumes)	4.2	39	2.6
Fish, Seafood	24.1	38	5.6
Dairy	253.8	373	21.9
Grand total	*938.2*	*3555*	*110.1*

Sources: U.S. Department of Agriculture, 2005, Nutrient availability data set, [online database accessed July 25, 2010], http://www.ers.usda.gov/Data/FoodConsumption/NutrientAvailIndex.htm; Food and Agriculture Organization, 2010, FAOSTAT food balance sheets [online database accessed July 25, 2010], http://faostat.fao.org/site/368/default.aspx.

Onondaga County from historical data appearing in the U.S. Agriculture and Market Census from 1910 to 2007. The U.S. agricultural census publishes production data and the number of acres in production for each state at the county level. The USDA has also estimated crop production in Onondaga County for the years between agricultural censuses, starting in 2002.

We selected the crops with the highest total annual production, based on the relevance to our study and availability of data: oats, wheat, grain from corn, silage from corn, alfalfa hay, other hay, beans, potatoes, rye, soybeans, and apples. There are several important vegetable crops grown in Onondaga County—for example, onions, garlic, and, in lesser amounts, tomatoes, squash, zucchini, and others—but the data series for these crops are less contiguous, and the caloric output from these vegetables is much smaller than the major crops listed above.

Agricultural production is measured in bushels (most grains), cwt (hundred lb.; e.g., potatoes), or short tons (e.g., hay). Farmland harvested is reported in acres. To calculate agricultural production in calories, yields are first expressed by weight, using a pounds-per-bushel conversion factor (University of Missouri Extension, 2010) and then converted to kilograms (0.454 kg = 1 lb.). Finally, we multiply by 2.47 acres/hectare and divide by 1,000 (1,000 kg = 1 metric ton) to determine yield in metric tons/hectare for each crop. We used caloric values for each crop (in raw form) from the USDA Nutrient Data Laboratory (USDA, 2010d) to calculate total output in calories and correct for water weight differences between harvest weight and percent water in the USDA database.

We used data obtained from the U.S. agricultural census from 1910 to 2002 to determine the area devoted to farmlands in Onondaga County historically. The current area devoted to farmlands was obtained from the Onondaga County Planning Agency. For the city of Syracuse, we obtained historical land use from 1950 to 2000 from the Onondaga County Planning Agency. The most current land use maps and data (2008) were obtained through the Syracuse University community geographer. These data are based on the 2008 tax parcel map from the Syracuse City Assessor's Office.

We analyzed the distance from farms to the two major farmers' markets located in Syracuse, namely, the Central New York Regional Farmers Market and the Downtown Syracuse Farmers Market. We attempted to obtain a current list of farms participating in those farmers' markets, but that information was not available publicly. We therefore relied on data from the Farmers Market Federation of New York (2010) to estimate the average distance from farms to the farmer's markets using the distance calculator of ArcGIS.

9.2.3 *Foodshed model: Land area requirements calculated from top-down and bottom-up analyses*

The term *foodshed* originated with Walter Hedden (1929) and was reintroduced in 1991 by Arthur Getz (1991; see Peters et al., 2009 for further history of the concept). The foodshed model is used to calculate the land area required to produce the nutritional requirements for a given population. The analogy of a watershed is apt, in that the foodshed is defined by a structure of supply. Though not strictly defined, Kloppenburg et al. (1996) noted that foodsheds have no fixed or determinate boundaries. They are a function of multiple and overlapping features such as plant communities, soil types, ethnicities, cultural traditions, and culinary patterns (Kloppenberg et al., 1996).

For the purposes of this chapter, we will use the term *foodshed* to denote the agricultural land area requirement to meet the nutritional needs of a defined population, specifically, Onondaga County. Using the historical local yields calculated from the production analysis and the demand in tons calculated above, we were able to determine the historical foodshed (in hectares) for Onondaga County and the city of Syracuse. We substituted proxy yields for components of the representative diet where specific production yields for Onondaga County were unavailable (e.g., fruits, sugars, fats, etc.).

We calculated the hectares of food production required to meet the nutritional demands of Onondaga County residents for each of the seven major categories of the USDA recommended diet—sweeteners, grains, dairy, meats and other proteins, fats and oils, fruit, and vegetables—by dividing demand in tons by the local yield (in tonnes/ha). Next, we compared it with the land in agricultural production and the total land area in the county to determine the relative food security. Our detailed methods for determining land area requirements for each food category follow.

9.2.3.1 *Sweeteners*

An average American eats 69 kilograms of sweeteners per year (FAO, 2010). The amount of sweeteners in the American diet has increased 19% from 1970 to 2005 (Wells and Buzby, 2008). We assumed sweeteners could be generated locally from sugar beets. They are adaptable to cold weather climates and are grown currently in 12 U.S. states (Asadi, 2007). The average yields for U.S. sugar beets are about 40 metric tons (wet) per hectare, of which 17% by weight is extractable sugars—meaning an average yield of 7 tonnes of sugar per hectare (Asadi, 2007). To estimate the historical yields, we assumed that early 20th-century yields would follow a trend similar to corn production, with 1910 yields being approximately a third of current yields and a linear trend in increasing production levels.

9.2.3.2 *Grains*

An average American eats 111 kilograms of grains per year. We assumed that wheat is the grain of choice for Syracuse and Onondaga County residents and represents 80% of grain demand. Corn and corn products meet remainder of grain demand (20%).

9.2.3.3 *Dairy*

An average American consumes 250 kilograms of dairy products per year. We used milk consumption to represent dairy demand. The demand for milk before losses was divided by the average production of dairy cows

Table 9.5 Yearly Ration for Lactating Dairy Cows and Assumed Equivalent Food Demand

	% of food (by weight)	Tons/yr/head	Assumed for model calculations
Corn silage	60%	14.42	13.1 metric tons
Alfalfa hay	13%	3.05	Hay: 4.5 metric tons
Orchard grass	7%	1.79	
SBOM (48%)	5%	1.12	Soybeans: 2 metric tons
Soybeans	2%	0.53	
Corn grains	10%	2.44	Corn: 2.2 metric tons
Distillers grain	3%	0.61	

for the year to determine the number of lactating cows needed to support dairy demand in Onondaga County. To estimate the hectares needed to produce the feed for these cows, we used the average yearly ration (see Table 9.5) for dairy cows from the Virginia Cooperative Extension (2007).

9.2.3.4 *Meats and other proteins*

We took the USDA Food and Nutrient Intakes by Region data and determined percentages of meats consumed in the Northeast (see Table 9.6). We multiplied these percentages by the annual demand for meat products to determine how much of each commodity was required. We then calculated the hectares of land to support production of each type of meat. We assumed fish were imported and could not be harvested locally for this study. We also assumed that the food production in the "nuts" category need not be produced by large monoculture crops, but could be successfully grown in urban, suburban, and rural areas.

- *Beef:* An average beef animal weighs 1,200 pounds and yields approximately 456 pounds of beef (Thiboumery and Jepson, 2009). We assumed that beef cattle's diet is similar to that of dairy cows.

Table 9.6 Proportion of Meat/Other Protein by Type Consumed on Average in the Northeastern US

Meat product	Percent consumed
Beef	32%
Pork	20%
Chicken	20%
Eggs	12%
Fish	10%
Nuts	6%

- *Pork:* The average hog weighs 250 pounds and produces 133 pounds of pork (Thiboumery and Jepson, 2009). Hogs require an average 5.9 kg of grain for every net kg of animal product (Pimentel and Pimentel, 2003).
- *Chicken:* The average broiler weighs 5.5 pounds and contains 3.75 pounds of meat (USDA, 2010c; PoultryHub, 2010). Chickens require 2.3 kg of feed (grain) for every kg of animal product (Pimentel and Pimentel, 2003).
- *Eggs:* The average chicken produces 290 eggs per year. Each kg of eggs produced requires 11 kg of grain feed (Pimentel and Pimentel, 2003).
- *Fish:* This source of protein is excluded from this study because, other than recreational fishing, all seafood is imported into Onondaga County.

9.2.3.5 *Fats and oils*

Soybean oil is the most commonly used oil in the United States for food consumption. A 60-lb. bushel of soybeans yields 11 lb. (18%) oil and 47 lb. soybean meal (North Carolina Soybean Producers Association, 2007). We assumed that 80% of the fats and oils category could be met through soybean oil, and the remaining demand could be met by butter, as a coproduct of milk production. We multiplied oil consumption by 5.55 to approximate tons of total soybeans that need to be grown. Then, we divided that value by the yearly estimated soybean yield to calculate the hectares needed to meet oil demand. Pre-1960 yields were not available and were assumed to be 1.0 tonnes/ha.

9.2.3.6 *Fruit*

We used New York State data to determine the yield per acre of common fruit crops. We weighted the different yields per hectare by multiplying pounds per acre for 1992 for each commodity by the total acres in production to determine the total pounds produced. We then determined for each commodity the percentage of total production. We multiplied the average yield per acre by the percentage produced to calculate a weighted average yield per acre for all fruit in New York State (see Table 9.7). We then converted the yield from lb./acre to tonnes/ha: 15,250 lb./acre = 6.919 tonnes/acre = 2.8 tonnes/ha. We used this value to estimate fruit yields in Onondaga County.

9.2.3.7 *Vegetables*

We used the average of bean yields (1.3 tonnes/ha) and yields for potatoes* (varies by year) for Onondaga County to estimate the land area needed to meet vegetable demand.

* Potatoes are included in vegetable category by the USDA.

Table 9.7 Fruit Yield Data for New York State

	1992 yield (million lb.)	Percent of total production	Average yield (lb./acre)
Apples	1,170	72%	17,500
Sweet cherries	2.2	<1%	3,953
Tart cherries	31	1.9%	5,904
Peaches	14	<1%	6,998
Pears	33	2%	11,750
Grapes	360	20%	9,792
Blueberries	1.4	<1%	1,910
Strawberries	8.7	<1%	3,450
Total	1,620	100%	

These figures were used to estimate average fruit yield for Onondaga County.
Source: U.S. Department of Agriculture, 2010, Fruit historic data, [online database accessed July 25, 2010], http://www.nass.usda.gov/Statistics_by_State/New_York/Historical_Data/Fruit/Fruitindex.htm.

9.2.4 *Energy requirements of food production and transport*

9.2.4.1 *Food production*

Besides solar insolation, energy inputs into agriculture come from three major sources:

1. Human labor
2. Fossil fuel inputs used in mechanical equipment
3. Fossil fuels used in the fabrication of chemical fertilizers and pesticides

Irrigation, when required, sharply increases energy inputs. Irrigated corn requires about three times the energy of rain-fed corn to produce similar yields (Pimentel et al., 2004).

Prior studies have examined the embodied energy of agricultural products (see Steinhart and Steinhart, 1974; Pimentel and Pimentel, 1979, 2003). We used the most recent energy input/output data available (Pimentel and Pimentel, 2003, 2008) to estimate the total energy inputs required to produce the agricultural outputs in Onondaga County in 2007. For example, to calculate the total input energy to produce corn in Onondaga County, we took the actual yield in kcal and divided by 4.23 (a food to input energy ratio of 4.23:1 from Pimentel and Patzek, 2008). This method was used also to estimate the current energy required to produce the food needed to meet demand in Onondaga County in 2000. We broke down food production and demand into the seven USDA

Table 9.8 Energy Inputs into Food Production

Food type	Farm inputs (petroleum)	Energy outputs (food)	Protein kcal output/ input ratio	Total kcal output/ input ratio
Grains (average of corn and wheat)	6,532,000 (kcal/ha)	19,149,000 (kcal/ha)	n/a	3:1
Sweeteners (sugar beet)	27.39 (GJ/ha)	99.1 × 17% sugar (GJ/ha)	n/a	0.62:1
Silage	6,284,000 (kcal/ha)	25,284,000 (kcal/ha)	n/a	4.02:1
Vegetables (dry beans)	2,740,000 (kcal/ha)	4,954,000 (kcal/ha)	n/a	1.81:1
Fruits (apples)	18,000,000 (kcal/ha)	9,587,000 (kcal/ha)	n/a	0.53:1
Dairy	Feed: 30 (kcal); fossil Fuels: 36 (kcal)	1 (kcal milk protein)	0.015:1	0.073:1
Chicken	Feed: 19 (kcal); fossil fuels: 22 (kcal)	1 (kcal chicken protein)	0.024:1	0.136:1
Beef	Feed: 122 (kcal); fossil fuels: 78 (kcal)	1 (kcal beef protein)	0.005:1	0.021:1
Pork	Feed: 65 (kcal) × 0.5 (waste); fossil Fuels: 35 (kcal)	1 (kcal pork protein)	0.015:1	0.10:1
Eggs	Feed: 20 (kcal); fossil fuels: 13 (kcal)	1 (kcal egg protein)	0.030:1	0.085:1
Oils (soybeans)	1,827,000 (kcal/ha)	7,584,000 × 18% oil (kcal/ha)	n/a	0.75:1

Source: Pimentel, D., and Pimentel, M., *Food, energy and society*, 3rd ed. (Boca Raton, FL: CRC Press, 2008); U.S. Department of Agriculture, Nutrient Data Laboratory, 2010, USDA national nutrient database [online database accessed April 4, 2010], http://www.nal.usda.gov/fnic/foodcomp/search/ (used to calculate per total kcal for dairy, chicken, beef, and pork).

categories used above and used the energy input estimations described below (see Table 9.8).

Using the energy input/output data shown in Table 9.8 and the caloric output from 2007 derived from the supply model above, we estimated the agricultural energy inputs. Likewise, we used the output from the demand model to estimate the agricultural energy inputs needed to satisfy the total food demand for the city of Syracuse and Onondaga County.

Table 9.9 Efficiency of Agricultural Transport Modes

	BTU per ton mile	kcal per tonne-km[d]
Tractor-trailer[a]	n/a	340
Box truck[b]	5,346	3,663
1-ton pickup truck[c]	9,928	6,802

[a] Pimentel, 1980.
[b] 13 mpg * 2 tons = 26 ton mi per gallon. At 139,000 BTU/gal of diesel, BTU per ton mile = 5,346
[c] 14 mpg * 1 ton = 14 ton mi per gallon. At 139,000 BTU/gal of diesel, BTU per ton mile = 9,928
[d] 3.9683 kcal/BTU

9.2.4.2 *Transportation*

Energy consumption for food transportation is a function of the distance from farm to processing and distribution centers, the distance from the distribution centers to retail grocery stores, and the efficiency of the mode of transportation. Transport by tractor-trailer makes up the majority of long-haul transportation for agricultural products, followed by transportation by rail. To compare the short-distance transportation by smaller vehicles (i.e., box-style delivery trucks and 1-ton pickups), with the efficiencies from long-haul transport, we tabulated the energy used (converting from BTU per ton-mile to kcal per tonne-km) for each mode (see Table 9.9).

We assumed that 10% of the current food demand is currently met by local food production, and half of that local food is transported by delivery box-trucks and pickups. We assumed the remaining food products are transported by tractor-trailer. We used the estimated food demand for Onondaga County for 2007 from the demand model above. From these assumptions, we calculated a rough estimate of food transport energy consumption. Our goal was to examine the energy savings or cost associated with increased local food production. We then calculated the transportation energy inputs for two alternate scenarios:

1. 50% of food is produced locally and 50% of this food is transported by box-truck and 1-ton pickup to market.
2. 100% of the food is produced locally, with half of the food transported by box-truck and half by 1-ton pickup trucks.

9.3 Results

The human food demand in Onondaga County reached a peak in 1990 of 610 Tcal and then fell slightly to 589 Tcal by 2006.

Onondaga County farms have increased their caloric output since the 1930s despite a consistent decline in the area dedicated to farming. This can be attributed to rising yields and the shift to more productive crops such as hybrid corn. However, given the rising population and dietary choices, both the demand and foodshed models estimate that at no time in the 20th and 21st centuries has Onondaga County had the potential to be self-sufficient in agricultural production. The land in production in Onondaga County in 2006 is only 15% of the land needed to satisfy food demand according to the demand model. Today, the land in production would not be sufficient for even a low meat or vegetarian diet. Hence, we conclude that Onondaga County must receive a net energy subsidy from elsewhere for its people to be fed.

We estimate that the actual agricultural production in Onondaga County requires 1.16 million barrels (7.1 Petajoules) of oil-equivalent, with dairy requiring the largest percentage of energy inputs. The consumption of the equivalent of 2.5 million barrels of oil (15.1 Petajoules) would be required to feed the population in Onondaga County.

Transporting the food consumed in Onondaga County represents 11% of the total energy inputs. If the county were able to produce half of the food required to feed its population, the transportation energy requirements would be cut by 43%.

Our results are detailed below.

9.3.1 *Human food requirements for Syracuse and Onondaga County*

The population in Onondaga County peaked in the 1970s. The estimated caloric and metric tons of food demand, however, continued to grow through the 1990s before falling slightly by 2006 (see Table 9.10 and Figure 9.6).

9.3.2 *Food production in Onondaga County*

Yield increased for most field crops from 1900 through 2008, though some crops, such as beans, alfalfa, and hay, did not have a clear trend (see Figure 9.8). Total food production (in kcal) was relatively high in the early 20th century, declined until reaching a low in the 1930s, then rose again (see Figure 9.7), despite the fact that the total area farmed in Onondaga County has declined since at least the 1940s (see Figure 9.9).

There has been a large shift in crops grown over time. Initially, a large portion of local crops consisted of oats and potatoes, presumably for horses and human consumption. Agriculture in Onondaga County since the 1960s has been dominated by corn and dairy production. By 2007, dairy production accounted for 22% of total production by energy content, and corn was nearly two-thirds of gross output (see Table 9.11).

Table 9.10 Per Capita kcal, Population, Caloric Demand, and Demand by Weight for the City of Syracuse and Onondaga County Residents, 1910–2006

Year	Per capita food consumption (kcal)	Population		Demand (Tcal)		Demand (kt)	
		Syracuse	Onondaga County	Syracuse	Onondaga County	Syracuse	Onondaga County
1910	2,868	137,249	200,298	144	210	109.2	159.3
1920	2,868	171,717	241,465	180	253	136.6	192.1
1930	2,868	209,326	291,606	219	305	166.5	232.0
1940	2,868	205,967	295,108	216	309	163.8	234.8
1950	2,749	220,583	341,719	221	343	172.2	266.7
1960	2,749	216,038	423,028	217	424	168.6	330.2
1970	2,868	197,208	472,746	206	495	156.9	376.1
1980	2,982	170,105	463,920	185	505	159.8	435.8
1990	3,561	163,860	468,973	213	610	153.9	440.6
2000	3,557	147,306	458,336	191	595	140.7	437.8
2006	3,565	140,658	452,978	183	589	130.6	420.7

Tcal (teracalories) = 1×10^9 kcal; kt (kilotonnes) = 1,000 metric tons.

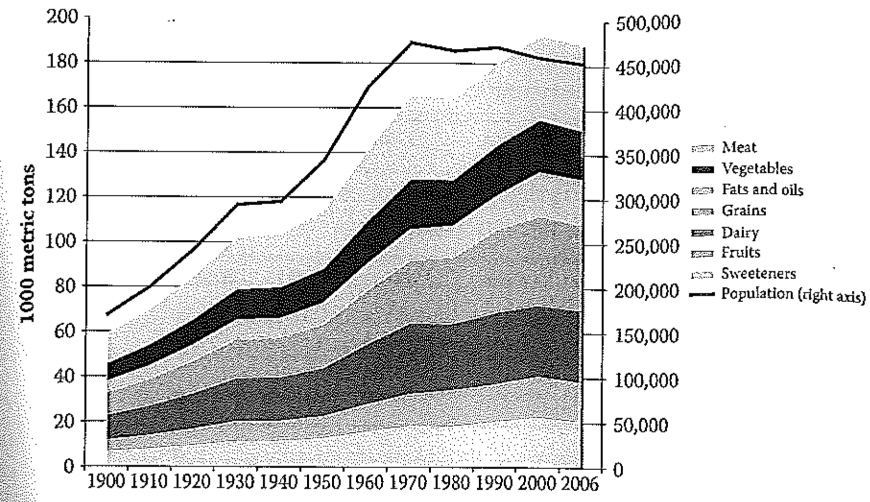

Figure 9.6 Food demand for Onondaga County by category (in thousand metric tons) and population, 1910–2006.

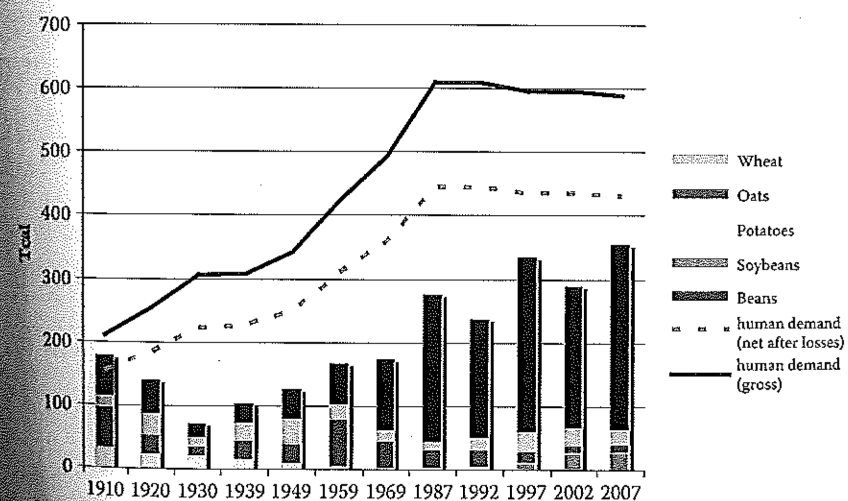

Figure 9.7 Production of major crops in Onondaga County, 1910–2007. The total energy required by humans is also included. The dashed line indicates gross demand, and the dotted line indicates net demand after losses. Smaller crops, e.g., potatoes, rye, beans, apples, were included but are not visible at this scale.

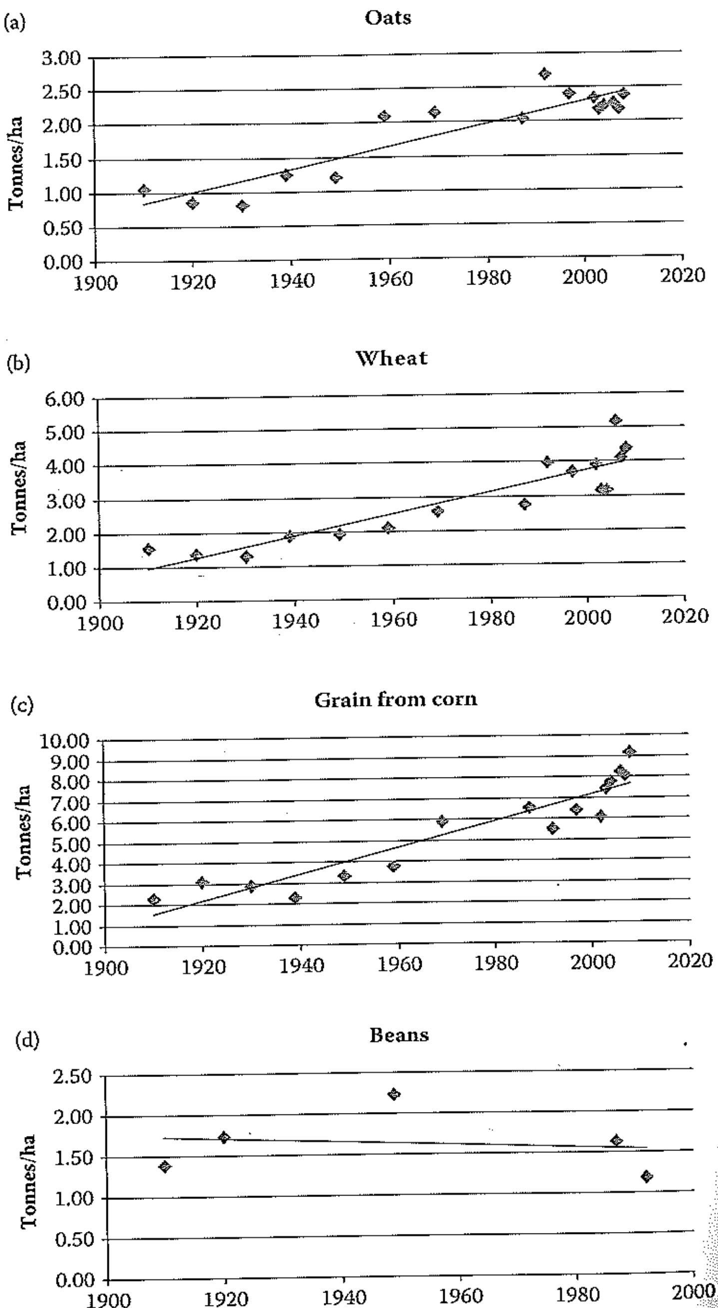

Figure 9.8 Agricultural yield in metric tons per hectare from 1910 to 2008 in Onondaga County.

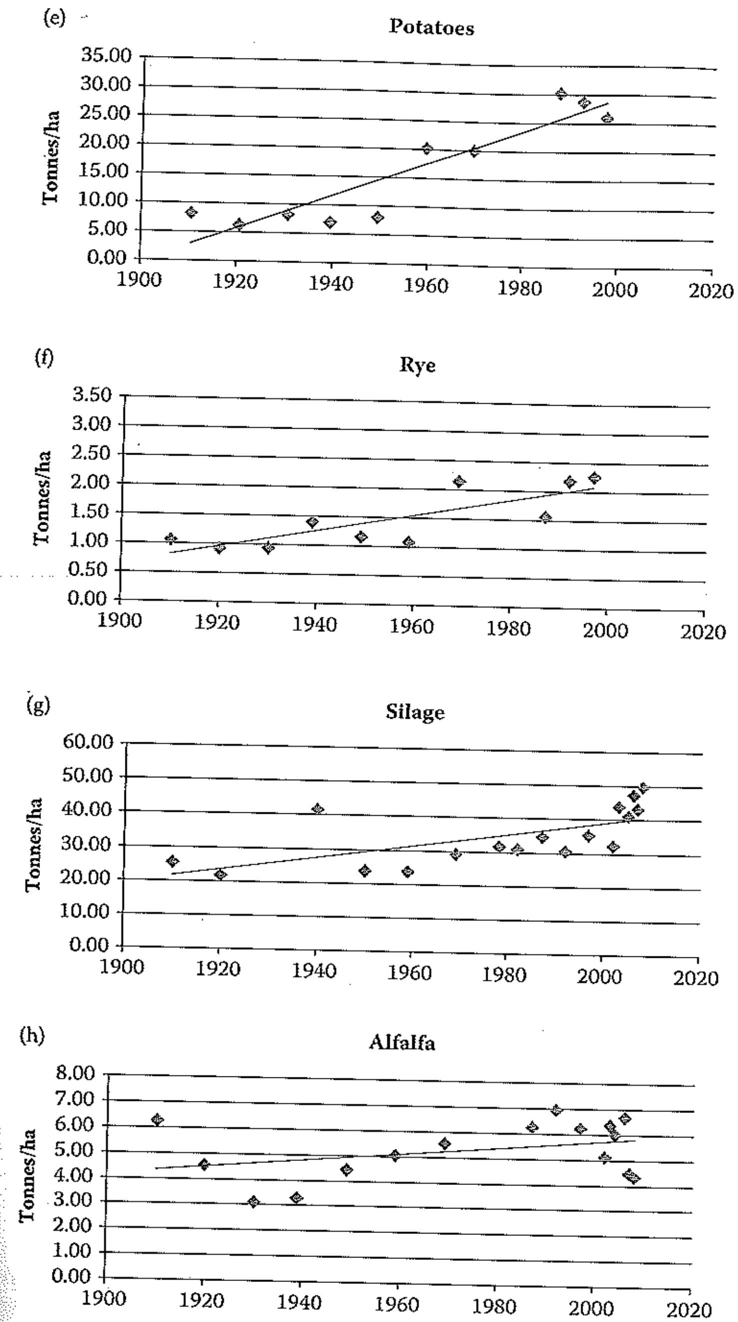

Figure 9.8 Continued

(i)

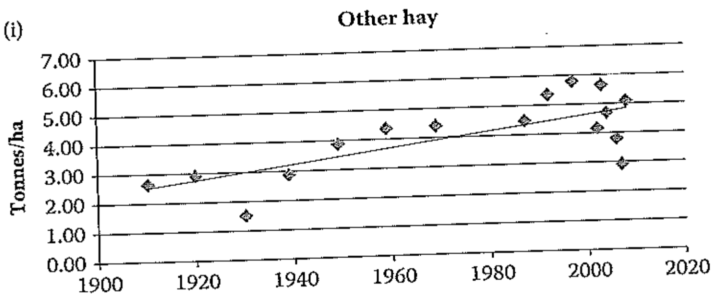

Figure 9.8 Continued

9.3.2.1 *Land under agricultural production in Onondaga County and Syracuse*

The total agricultural land in Onondaga County has declined from 177,251 hectares in 1900 (91% of the county) to 61,763 hectares (30%) in 2006 (see Figure 9.10). At the same time, the number of farms in the county decreased from 4,564 in 1990 to 692 in 2007 (see Figure 9.11). Aside from the decrease in the total land area and number of farms in Onondaga County, the total land area allotted for crops has declined, from 97,824 hectares in 1924 to 43,020 hectares in 2007. Likewise, the area of cropland harvested has also declined from 91,114 hectares in 1924 to 37,238 hectares in 2007 (see Figure 9.9).

Not all lands devoted to farms are harvested. Based on these results, about 50% of the total farmland is harvested. The rest of the land is used

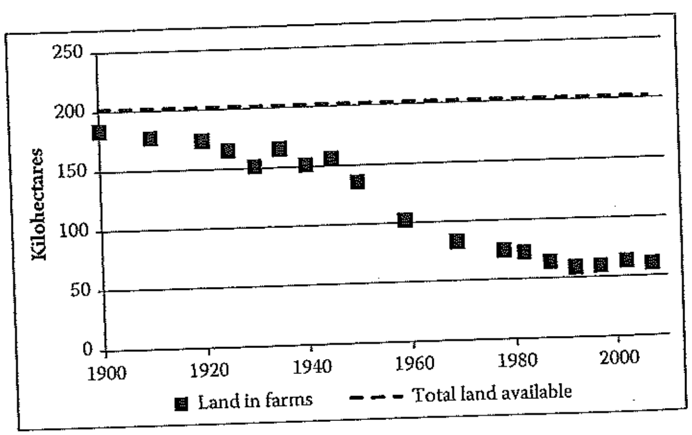

Figure 9.9 Total cropland and harvested cropland (in thousand hectares) for Onondaga County, 1900–2007. Using linear best fit lines. The difference between the two lines appears to be fallow land or unharvested crops. (From U.S. Census Bureau, *United States Census of Agriculture* [various editions], Washington, DC: USCB, 1900–2007.)

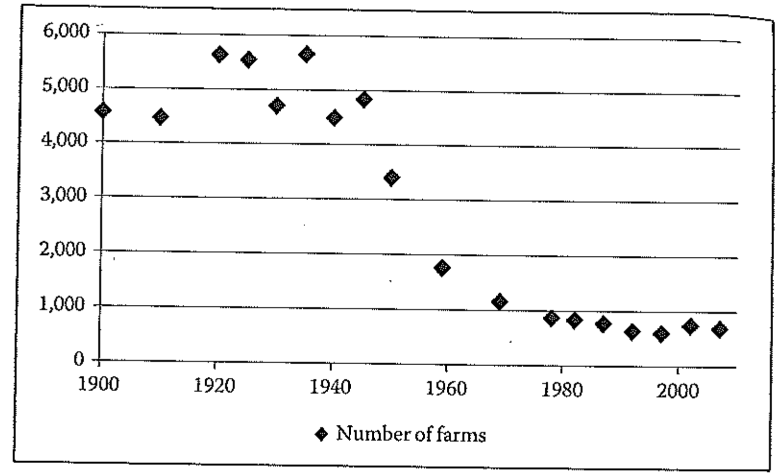

Figure 9.10 Total land area (in thousand hectares) in farms for Onondaga County, 1900–2007. (From U.S. Census Bureau, *United States Census of Agriculture* [various editions], Washington, DC: USCB, 1900–2007.)

either as pasture, storage, living quarters, or forested land or simply remains idle. At the same time, based on Figure 9.11, we can observe that not all land devoted to crops is utilized. The area of total cropland not in use ranges from 7% to 33%.

Table 9.11 Production of Major Crops in Onondaga County in 2007

Product	Amount produced (kt)	Calories produced (Tcal)
Oats	3.3	12.7
Wheat	6.2	22.7
Corn	80.2	293
Rye	2.39	0.8
Beans	0.4 (est.)	1.4
Potatoes	0.4	0.3
Soybeans	7.5	25.3
Silage	265	n/a
Hay	19.1	n/a
Alfalfa	32.1	n/a
Dairy	198	99.2
Eggs	2.6	3.3
Beef	0.04	2.5
Chicken	*	*
Total	*617 (without forage, 300)*	*461*

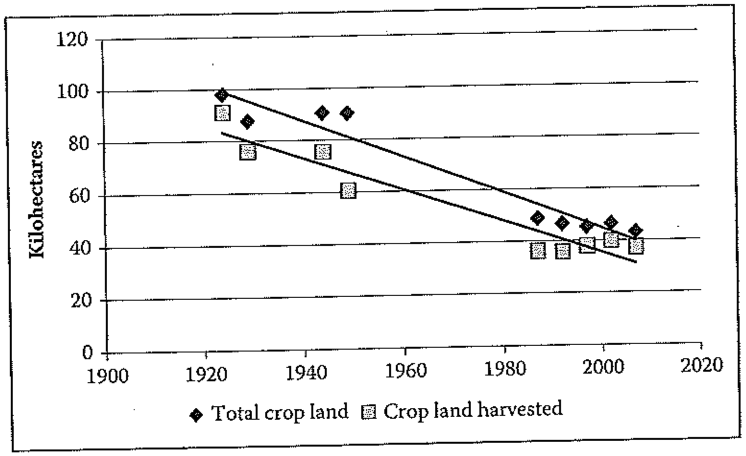

Figure 9.11 Number of farms in Onondaga County, 1900–2007. (From U.S. Census Bureau, *United States Census of Agriculture* [various editions], Washington, DC: USCB, 1900–2007.)

9.3.2.2 *Distance from local farms to farmers' markets*

The average distance of farms participating in the downtown Syracuse Farmers Market is 13 miles, while that for the regional farmers' market was 17 miles. These two were chosen for the analysis because they are the two most popular farmers' markets in Syracuse. Aside from these two markets, there are six other farmers' markets located throughout Onondaga County that are open during the summertime (New York State Department of Agriculture and Markets, 2010). The closest farm that participates in the two farmers' market is located approximately 7 miles away.

9.3.3 *Foodshed model*

The foodshed model combines population data, per capita demand for specific categories of food, and historical yields for crops in Onondaga County to estimate the number of hectares required to grow food locally to feed the residents of Onondaga County. Given the assumptions in the foodshed model, at no time in the 20th century or since could Onondaga County been self-sufficient in food production (see Figure 9.12).

9.3.4 *Energy cost of feeding today's population*

The Onondaga County caloric human food requirement for 2000 was estimated to be 559 Tcal (2.3 Petajoules), and the energy inputs required to produce this much food was estimated at more than 3,600 Tcal (15.1 Petajoules), equivalent to approximately 2.5 million barrels of oil (see

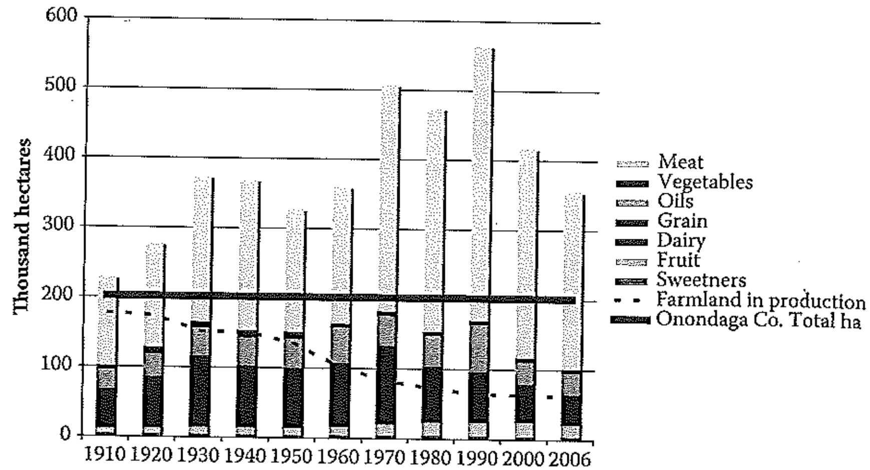

Figure 9.12 Agricultural footprint to feed the population of Onondaga County as calculated from the demand model and historical yields in Onondaga County vs. farmland in production and total available land in Onondaga County.

Table 9.12). Transportation energy adds an additional 447 Tcal of energy inputs (see Table 9.13a), for a total of 4,047 Tcal to grow and transport food to Onondaga County grocery stores. The energy required to transport goods to the area is approximately 11% of the total energy inputs.

Table 9.12 Estimated Fossil Energy Inputs Required to Meet Onondaga County Food Demand in 2000

Category	Demand (Tcal)[a]	Energy output/ input ratio[b]	Estimated input requirements (Tcal)
Sweeteners	105.7	0.62	170
Fruits	21.6	0.53	41
Dairy	64.2	0.073	879
Grains	143.2	2.93	49
Fats and oils	131.5	0.41	321
Meat	97.9	—	—
Chicken	20	0.136	147
Pork	20	0.10	200
Beef	31	0.021	1,476
Eggs	11.7	0.085	364
Vegetables	30.9	1.81	17
Total			*3,664*

[a] Calculated as: Onondaga population × FAO per capita caloric availability for 2000 × 365 (see Table 9.10 for total caloric demand by year).
[b] See Table 9.8.

Table 9.13 Transportation Energy Required for Agricultural Products to Onondaga County

	Mode	Kilotonnes delivered	Average distance (km)	Kilotonne-km	Efficiency (kcal/tonne-km)	Energy consumed (Tcal)
(a) 2000 demand, assuming 10% local production and transportation with an average 44 km from farm to market; imported food assumed to travel an average distance of 3,300 km						
Imported food	Tractor-trailer	394 (90%)	3,300	1,300,000	340	442 (99%)
Local food	Tractor-trailer	22 (5%)	44	963	340	0.3
	Box truck	11 (2.5%)	44	482	3,663	1.8
	1-ton pickup	11 (2.5%)	44	482	6,802	3.3
Total						447
(b) Scenario: 50% local food production and transportation						
Imported food	Tractor-trailer	219 (90%)	3,300	722,300	340	246 (90%)
Local food	Tractor-trailer	109 (5%)	44	4,816	340	1.6
	Box truck	55 (2.5%)	44	2,408	3,663	8.8
	1-ton pickup	55 (2.5%)	44	2,408	6,802	16.4
Total						272
(c) Scenario: 100% local food production and transportation by small trucks only						
Local food	Box truck	104,542 (50%)	44	2,090,840	3,663	16.0
	1-ton pickup	104,542 (50%)	44	2,090,840	6,802	29.8
Total						45.8

Table 9.14 Estimated Energy Inputs into Specific Crops Important in Agricultural Production in Onondaga County in 2007

Product	Metric tons produced[a]	Gcal/metric ton[b]	Calories produced (Tcal)[c]	EROI ratio used to derive energy cost[d]	Energy inputs (Tcal)
Oats			12.7	3.1	4.1
Wheat			22.7	2.4	9.4
Corn			293	2.9	100
Rye			0.8	2.4	0.3
Beans			1.4	1.8	0.8
Potatoes			0.3	1.2	0.2
Soybeans			25.3	4.2	6.1
Silage	240,718	0.8	196	4.0	48.8
Hay	19,183	1.7	0.03	5.0	6.6
Alfalfa	30,112	2.3	0.07	6.2	11.0
Dairy (2002)			99.2	0.1	1,360
Eggs			3.3	0.1	39.0
Beef			2.5	0.02	119.5
Chicken	1,339	6,842.3	0.003	0.1	0.03
Total					*1,706*

[a] New York Agricultural Statistics Service, *Onondaga County farm statistics, August 2009* (Albany: New York Agricultural Statistics Service, 2009)
[b] Pimentel, D., and Pimentel, M., *Food, energy and society*, 3rd ed. (Boca Raton, FL: CRC Press, 2008)
[c] As calculated in Table 9.11
[d] Pimentel, D., and Pimentel, M., *Food, energy and society*, 3rd ed. (Boca Raton, FL: CRC Press, 2008); also as calculated in Table 9.8

Therefore, food production and transport to meet the requirements of Onondaga County residents requires approximately 6.4 (3,600/559) kcal of embodied energy (fossil fuel and other inputs) to produce 1 kcal of food energy. We estimate that actual agricultural production in 2007 in Onondaga County required 1.7 Tcal (7.1 Petajoules) of energy inputs, with dairy requiring the largest percentage of energy inputs (see Table 9.14).

Despite the decreased efficiency of small trucks when compared to large tractor-trailers, shifting half of the food production to the local level would reduce agricultural transportation energy costs by about 39% (see Table 9.13b). If all of the food were grown locally, the transportation energy demand could by reduced by 90% (see Table 9.13c). This is because of the large distances we assume for imported food. Were we to grow food 100–500 miles away and ship it by tractor trailer this might require less energy for shipping than local food.

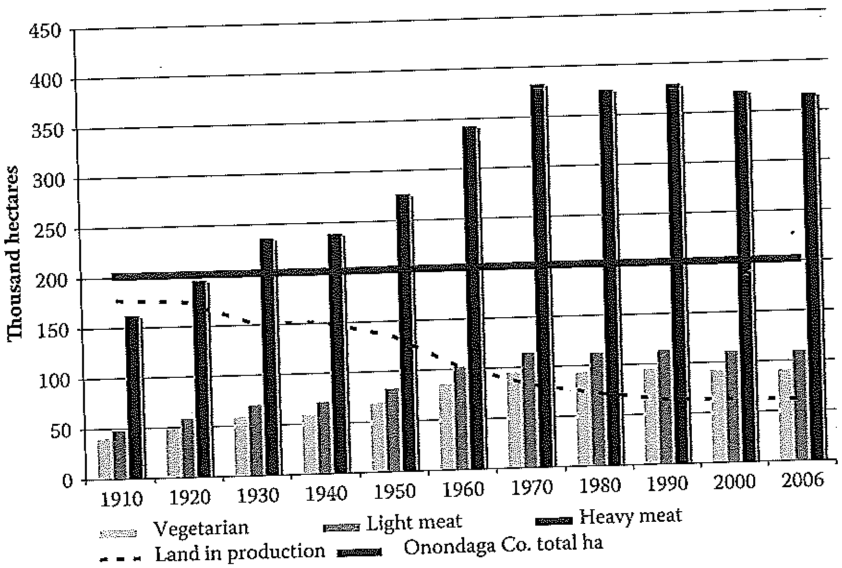

Figure 9.13 Agricultural footprint to feed the population of Onondaga County as calculated with Peters et al. (2007) assumptions.

9.4 Discussion

Our analysis indicates that, despite being situated in a moderately productive agricultural county with only moderate population density, and despite recent increases in the productivity of crops, the total food production for the county is insufficient to meet the demand for food of the county or even the city of Syracuse. Only 30% of the county is in agricultural production at this time. If all possible agricultural land (i.e., that proportion of the county in production in 1920) were utilized, it would be possible to feed the city and county a reduced-protein diet.

The most important implications of this study relate to the probability that oil, now heavily used for growing and transporting food in the developed world, may be much less available in the future. While this study is important in determining the degree to which local food production could feed Syracuse, it also shows that transportation energy appears less important than the energy necessary to grow the food itself, especially for a protein-intensive diet.

9.4.1 Land area requirements

Peters et al. (2007, 2008) calculated the area in acres required to feed a population center in Upstate New York, basing their study on three diets with increasing land requirements: vegetarian, light meat, and heavy meat diets. They assumed that a vegetarian diet requires 0.5 acres (0.2 ha) per capita, while a diet with small amounts of meat and dairy per day (2 oz.) requires 0.6 acres (0.24 ha) per capita in New York State. A diet more consistent with the current average diet, with a large amount of meat, requires more than 2 acres (0.81 ha). To compare our results to those of Peters et al., we multiplied these land area requirements by the city and county population to determine the foodshed for the region over time. Next, we compared the foodshed calculation outputs against the land in production and all available land in Onondaga County to determine the proportion of food needs that could be met by local production.

The total number of hectares needed exceeds the farmland in production (see Figure 9.13). Using the required hectares per capita for the range of diets from Peters (vegetarian, light meat, and heavy meat) to estimate the historical foodshed for Onondaga shows that the land in production from 1910 through 1960 could support the county's population at a lower level of meat consumption. By the 1970s, however, hectares required for the population exceeded the available land, even for a vegetarian diet. As early as 1920, a diet rich in meat required a foodshed that exceeded the land in production, and after 1930, it exceeded the total land within the county borders (see Figure 9.13).

The land in production in 2000 satisfies only a fraction (17%) of the heavy meat diet's land requirement described in Peters et al. (2007, 2008) and our demand model and only 56% and 67% of the land needed to sustain a light meat or vegetarian diet, respectively (see Table 9.15). Interestingly, according to Peters et al.'s estimates, the land area requirement for the city of Syracuse could be met for a vegetarian or light meat diet by the production in the surrounding area of Onondaga County.

We compared the output from our demand analysis and the high meat foodshed from Peters et al. (see Figure 9.14). Both models calculate a similar number of hectares to support the population in 2006 (356 vs. 366 kilohectares), even though their methods differ. By the 2000s, the demand analysis estimates a decreasing land area needed to support the population. In earlier decades, however, the demand model estimates a much higher land area is required to support the population, a reflection of poorer yields in the past.

9.4.2 "Local" food

Onondaga County is bordered by four counties that do not have large cities and also produce a large amount of agricultural products. Peters, Bills, Wilkins, et al. (2009) calculate that the food demand of the city of Syracuse and the surrounding population centers could be met by the surrounding area. They discuss the arbitrary nature of "local" food production and the varying definitions offered other studies. It seems

Table 9.15 Farmland Needed for Food Self-Sufficiency for the Residents of the City of Syracuse and of Onondaga County

Diet	Land area requirement (ha/capita)	Population (2000)		Land area requirement (ha)		Land in production (2000)	Percent satisfied
		Syracuse	Onondaga County	Syracuse	Onondaga County		
Our demand model	0.91	147,306	458,336	134,235	417,668	63,301	15%
Heavy meat[1]	0.81	147,306	458,336	119,318	371,252	63,301	17%
Light meat[1]	0.24	147,306	458,336	35,353	110,000	63,301	56%
Vegetarian[1]	0.20	147,306	458,336	29,461	91,667	63,301	67%

[1] Peters foodprint acreage (2007).

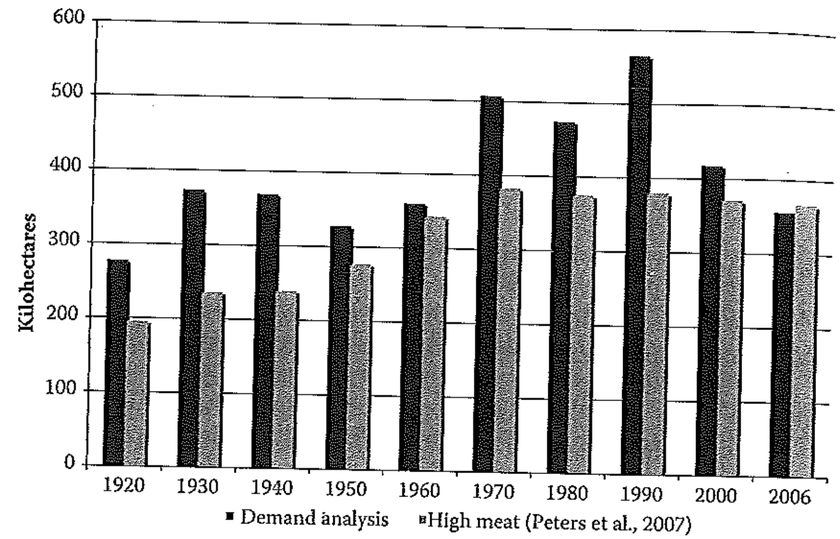

Figure 9.14 Comparison of the hectares required to feed human population of Onondaga County based on (a) our demand model and (b) Peters et al. (2007) high-meat-diet land requirements.

reasonable, given the relatively low population density in the surrounding counties—112 people per square mile versus the relatively higher 588 people/sq. mi. in Onondaga County (USCB, 2010)—that the production in the five-county region could meet the food demand of the combined population. Of course, transporting food from longer distances would mean an increase in transportation energy costs.

9.4.3 *Land quality/urban farming potential*

Vacant land in Syracuse has tested positive for high levels of lead and other contaminants (Johnson and Bretsch, 2002). Urban gardeners in other major cities have demonstrated the potential for producing large amounts of food in small areas using intensive farming methods and increased manual labor (see Dervaes Family, 2010; Allen, 2010). Cubans were able to produce copious amounts of organic food on previously contaminated land during the "Special Period" after the Soviet Union cut off their subsidized oil, using a composting system and raised beds to ensure soil quality (Altieri et al., 1999).

Will Allen, a leader in urban agriculture, trains community members to grow nutritious, affordable food, assuring the urban population a source of fresh food despite the prevailing political or economic forces that shape their area (Allen, 2010). His systems approach to urban farming captures compostable materials from the waste stream, which allows his gardens to create new soil and use the heat from the composting process to heat small greenhouses. More importantly, the nonprofit Growing Power improves the health, self-esteem, and self-sufficiency of the economically disadvantaged. A future study under the Syracuse ULTRA-Ex will examine the potential for food production on vacant urban lands and will compare using that same land to grow trees to increase ecosystem services to the urban population.

Our study assumed that vacant land could be repurposed into farms that achieve the average yields in Onondaga County. However, as Hall et al. (2000) note, in most cases the best farmlands are those already in production, and bringing additional land into production means incorporating more marginal, less productive lands. The soil in currently vacant or fallow farmland may be of poorer quality. Sprawl and suburbanization have also claimed many of the former fertile farmlands. In many cases, the topsoil and vegetation are stripped during construction. After the foundations are built, infill and a thin layer of topsoil are added. Until the new grass and plantings take root, the entire area is subject to soil erosion. On the other hand, suburban lawns might be considered as good farmland close to farmers, with the forest mostly cleared, irrigation systems installed, and fertile soil.

9.4.4 *Diet*

This study assumed that the local population would shift their current diet of highly processed and convenient food to a diet high in fresh food that is available only on a seasonal basis. A local food diet might require increased food preparation time and a change in menu and shopping habits, and foods that were previously available year-round would become scarce when out of season.

The results of this study and others (Pimentel and Pimentel, 2003, 2008; Peters et al., 2007, 2008) demonstrate that the percentage of meat and dairy products in a region's diet strongly affect the land area required to support that population. Our data show that Onondaga County is more likely to become self-sufficient if residents adopt a vegetarian or low meat diet. Reducing the meat intake to a few small portions per week, as in the Peters et al. scenario, would decrease the additional area needed to feed the population in Onondaga County from more than 350,000 to around 100,000 hectares.

9.4.5 *Energy inputs*

Our boundaries for the energy inputs into agricultural production end at the distribution point. To be sure, further energy is consumed to package, process, store, and display the food, as well as the energy required by the consumer to travel to and from the store, refrigerate, store, and then cook the food. It was our assumption that the distribution, storage, and cooking energy costs would be comparable in a locally based food system to the current American system, but this may not be the case. Local food production would require the construction or addition of processing capacity to handle the large volume of locally produced fruit and vegetables. Meat products pose a similar dilemma. Local butchering and meat-processing facilities would need to be encouraged or rules relaxed to allow farmers to sell directly to the public. Also, consumers themselves would have to do more of the processing, for instance, canning and freezing to extend seasonal foods. These practices may increase energy consumption, as individual consumers are less efficient than large processing and canning facilities.

The energy subsidies needed to produce a kilocalorie of food energy do not increase along the trend line as suggested by data published by Steinhart and Steinhart (1974) and in fact indicate an increasing efficacy. One average kcal of food energy requires a minimum input of approximately 6 kcal of fossil energy, down from 9 or 10 in 1970. This decline in inputs is consistent with the results of Cleveland (1995a), who calculated that agricultural efficiency had improved after reaching a low in 1978 and by 1990 the ratio of food output per unit of energy had increased to levels comparable with the 1950s.

Although some 3,700 kcal of food is available per capita per day (FAO, 2010), Kantor et al. (1997) have estimated that on average 27% of food produced on American farms is not consumed by the population. They determined that the largest proportions of food loss are in the fresh produce, dairy, and grains categories. Less waste occurs in categories such as meat, oils, and sweeteners. The USDA estimates that this ratio has remained fairly consistent since the 1970s (Kantor et al., 1997). For our demand model, which calculates caloric demand based on population, available calories, and eating habits, we assumed net consumption of food is 27% less than the gross food availability across all food categories. However, it is difficult to say whether a local food system might incur more or less waste than in the current system.

9.4.6 *Potential implications of a low-energy future on agricultural self-sufficiency in Onondaga County*

Pimentel estimates that the energy spent on growing, processing, transporting, storing, and preparing food is approximately 19% of U.S. energy consumption (pers. comm.). We found that just over 4,000 Tcal (17 Petajoules) was required to grow and transport the food demand of Onondaga County. This is equivalent to 15% of the 111 Petajoules of energy estimated to be consumed each year in the county. Our calculation does not include the energy to process, store, or prepare food. Our just-in-time system of food production and delivery, and our reliance on long-distance shipping by tractor-trailer, however, renders us vulnerable to any future energy supply disruptions.

The price of fertilizers increased rapidly in the summer of 2008 as energy prices reached an all-time high, before falling back by the end of the year (Huang, 2009). Increased competition for grain exports and falling per capita production led to a "run on rice" later that year, as developing nations held tightly to their excess supply and other nations scrambled to secure imports (Christiaensen, 2009). In a future with decreasing energy availability and increased variability of crop yield due to climate change, this type of event may continue to plague developing nations and could raise food commodity prices for consumers living in exporting nations such as the United States. For these reasons, communities may need to assess their food security and encourage more local and sustainably grown food.

If the production rate of oil, the economy, and fuel prices maintain an undulating plateau as some energy analysts predict, food prices could also destabilize and fluctuate rapidly. Farmers' future profits could be reduced during periods of increasing fuel prices; during economic downturns, collapsing food prices could be equally devastating.

It is also important to note that over time, land under agricultural production degrades. A highly productive piece of farmland requires increased fertilizer inputs to maintain high yields. Similarly a more marginal farm can raise yields by increasing the amount of fertilizer used. However, this relationship is nonlinear, and at high levels of fertilizer use, the response becomes asymptotic (Hall et al. 2000). Hall et al. (2000) believe that as the farmlands degrade over time due to nutrient depletion and erosion, any disruption in inputs would reduce yields to a level below the original yields obtained on the site without inputs (see Figure 9.15). Locally produced soil nutrient additives, such as compost, require human and fossil energy inputs to separate, collect, compost, and then apply to the soil.

9.4.7 Possible impact of biofuel production on food production

A decline in the availability of petroleum products, especially gasoline and natural gas, could increase the demand for liquid biofuels and biomass to heat homes during the cold Northeast winters. Subsidies and mandates by the U.S. government have already led to increased corn production for ethanol (Vedenov and Wetzstein, 2008). In 2006, 27% of U.S. corn crop was converted to ethanol (USDA, 2010e). Biofuels cannot be transported through petroleum pipelines (water is soluble in ethanol, and pipes would corrode) and therefore must be shipped by tanker truck or rail car. Since the energy return on energy invested for ethanol is already precariously low (by some accounts, negative), increasing the shipping distance of ethanol can turn a marginal net energy positive fuel into a net

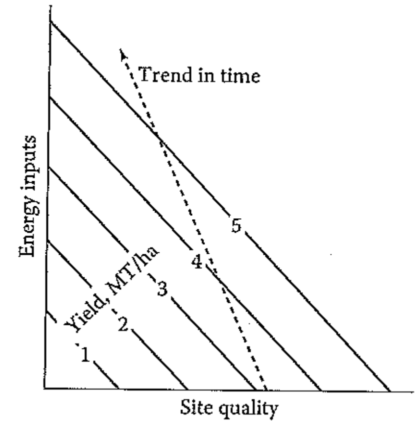

Figure 9.15 Isopleths of agricultural yield. (From Hall, C. A. S., Perez, C. L., and Leclerc, G., *Quantifying sustainable development: The future of tropical economies*, San Diego, CA: Academic Press, 2000.)

energy loser (Murphy et al., 2010). Therefore the pressure may be to produce these fuels locally. Home heating fuel costs rose in 2008, prompting some to switch to wood and other biomass heating systems, just as consumers did during the energy crises during the late 1970s and early 1980s. Both the demand for liquid biofuels for transportation and the potential shift toward biomass for home heating may put the future of local food production at odds with local energy production.

9.5 Conclusions

Our study shows the vulnerability of a medium-size city to oil supply disruptions because of the energy intensity of its food production systems. Our study also shows the potential of, but also the difficulty of, adjusting to a world with less oil. Examination of the historical, current, and future potential for agricultural self-sufficiency can provide insight for local, regional, and state leaders. Even though it might be possible to meet the caloric requirements of the people of the city of Syracuse and of Onondaga County from food production within the county (and certainly within the local five counties) by adapting our diet and increasing land in farms, this assumes that the oil and petrochemical inputs will be available to maintain current levels of agricultural production.

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