Peak Oil, Food Systems, and Public Health

Peak oil is the phenomenon whereby global oil supplies will peak, then decline, with extraction growing increasingly costly. Today's globalized industrial food system depends on oil for fueling farm machinery, producing pesticides, and transporting goods. Biofuels production links oil prices to food prices.

We examined food system vulnerability to rising oil prices and the public health consequences. In the short term, high food prices harm food security and equity. Over time, high prices will force the entire food system to adapt. Strong preparation and advance investment may mitigate the extent of dislocation and hunger.

Certain social and policy changes could smooth adaptation; public health has an essential role in promoting a proactive, smart, and equitable transition that increases resilience and enables adequate food for all. (*Am J Public Health.* 2011; 101:1587–1597. doi:10.2105/AJPH.2011.300123)

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PEAK OIL IS THE POINT AT which national and world oil supplies will peak, then decline in coming decades, with extraction growing increasingly costly per unit retrieved. Figure 1 shows how industrial food production systems depend heavily on petroleum for fueling farm machinery, producing pesticides, and transporting ingredients and food.[1–3] Also, as petroleum prices rise, cropland is diverted to biofuels production, affecting food supply. Oil so permeates today's food systems that, as prices escalate, business-as-usual processes will be unlikely to provide food security. As Kirschenmann wrote,

> the end of cheap energy will force us to begin redesigning our food economy as a subsystem of the ecosystem.[4(p110–111)]

Public health has an essential role to play in joining with others to promote a healthy and equitable transition to an oil-independent, more resilient[5] food system.

The challenge of ensuring future food security is compounded by the ecological and resource threats intertwined with that of peak oil, including climate change, population growth, projected peaks in other fuel sources (e.g., coal, natural gas, uranium), soil depletion and contamination, water shortages, and urbanization.[6] These threats—and our responses to them—will affect public health and society, not only directly through food security, but also via myriad economic, social, and environmental pathways.

Food systems are systems—complex, and comprising all entities, processes, and relationships from soil and seed to table and waste.[7,8] In a system, changes to one component ramify elsewhere[9,10]; systems-based solutions account for complexity to minimize unintended negative consequences.[11] We aim to leave the reader with a big picture understanding of the issues and their interconnections and related leverage points. Although we emphasize the tremendous implications of peak oil for international food security and agriculture, we focus on the US context.

Without effective intervention, peak oil will exacerbate existing inequities; US food insecurity today falls disproportionately on the poor, minorities, single-parent families, and children.[12] Farmers and other workers could also suffer disproportionately as their costs rise, potentially without adequate compensation in food prices. Small and midsize farms and other businesses may not be able to adapt quickly to rising fuel prices if they have investments in petroleum-dependent equipment.

We describe petroleum and dependence upon it in industrialized food systems, and how oil scarcity may affect food production and food security. As petroleum prices escalate, short-term consolidation of industrial agriculture and potentially significant increases in food insecurity may occur. Food systems are likely to adapt to an oil-constrained future in 4 ways: reduced oil in food production, increased food system energy efficiency and renewable energy, changed food consumption patterns, and reduced food transportation distances. These shifts may present substantial challenges for public health and equity; nonetheless, they may ultimately contribute to a more sustainable food system. We discuss the role for public health in working with others to ensure as proactive, smooth, and equitable a transition as possible. We also present policy and practice recommendations.

Public health is a relative newcomer to both peak oil and agricultural issues. We have much to learn from the farmers, communities, advocates, consumers, sociologists, and scientists who have been addressing the issues over time. Public health, in turn, is a needed ally.

PETROLEUM

Petroleum is energy-dense and easily transported, and its supplies, although plentiful and inexpensive, have always been finite. Over the course of the last century, petroleum has revolutionized food production and modern life; it is now the dominant US fuel source and a primary input in producing chemicals and materials. Most electricity, however, is powered by nonoil sources, particularly coal.

The stored, concentrated energy of fossil fuels is a limited resource. There is broad scientific and governmental recognition of peak oil as a phenomenon,[13–15] although skeptics and deniers remain.[16] By many estimates, the peak will occur by 2030 or has already occurred.[15,17] One 2010 *New York Times* article projected a time horizon up to 100 years,[18] but there are reasons to doubt

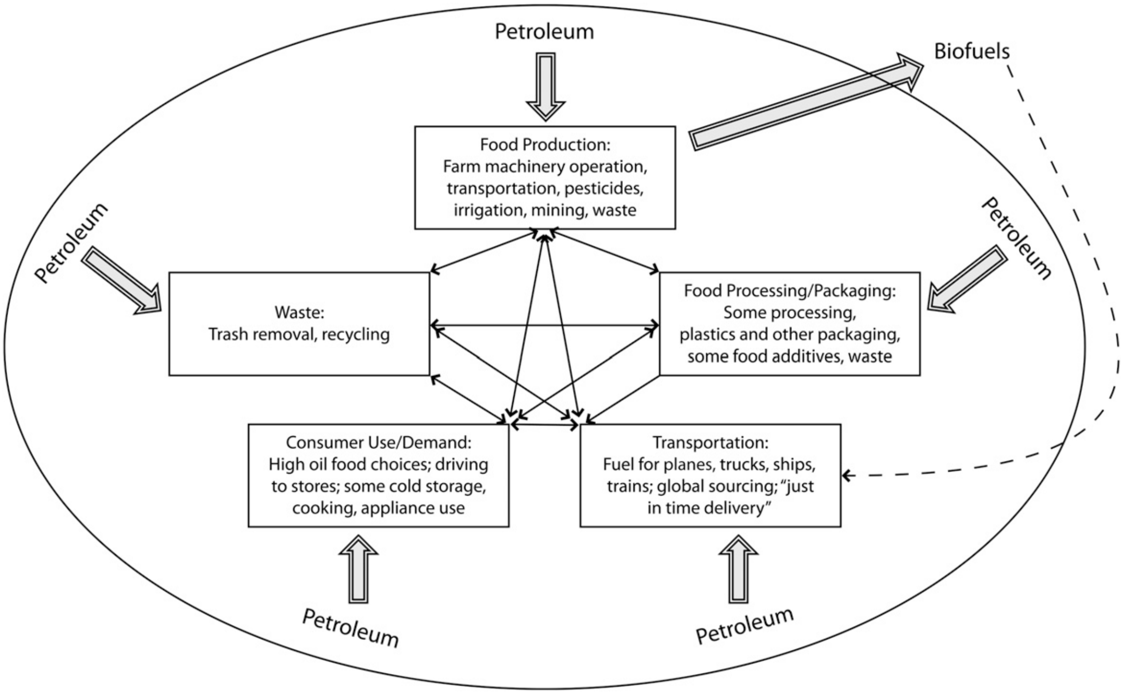

FIGURE 1—Petroleum use in the industrial food system before peak oil.

such estimates.[19] Rate of decline projections reflect not only oil supply, but also projections for population, the extent to which oil prices affect demand, and development of replacement fuel sources. A slow decline would allow time for adapting agriculture and other sectors; a rapid decline could portend short-term catastrophic food insecurity. Such projections are not mutually exclusive; we could experience slow overall decline with episodic extreme shortages.

Some food system petroleum can be replaced with renewable energy (e.g., solar, wind, and geothermal power) plus human and animal labor. That shift requires time, funds, and initiative, however, and may still not produce enough power to support current US lifestyles, nor the spread of such lifestyles worldwide.[20,21]

Further, to date, no cost-effective, environmentally sound alternative exists for gasoline or diesel, critical fuels for transportation and heavy equipment operation.[15,22–24] Plant-based liquid biofuels require much water[25] and energy to manufacture, produce low energy returns per energy invested, and have incentivized conversion of rainforest, prairie, and wetlands to cropland—releasing, by one estimate, 17 to 420 times more carbon dioxide than their burning would mitigate.[26] Moreover, these fuels create competition between mouths and gas tanks. Research continues into less-damaging ways to make liquid biofuels.[27–29] Without a viable substitute for gasoline and diesel, existing practices in the food system will not continue.

Rising oil prices will not affect all industry sectors proportionate to their consumption. Rather, society will make choices regarding optimal uses. Essentials such as food may be prioritized—whether by the market or purposeful strategy—and more luxury goods (including luxury foods) eschewed. Industries with powerful advocacy sectors may also be relatively spared.

OIL-DEPENDENT FOOD SYSTEMS

Industrial food production has thrived on inexpensive oil, seeking to maximize crop yields while minimizing consumer prices. The industrial economy's fundamental principles—specialization, standardization, and economies of scale—have been increasingly applied to agriculture since World War II. Particularly since the 1960s, new technologies have transformed agricultural yields in the United States and globally.

Most food crops eaten in the United States are produced on large land tracts planted in monocultures (single crops). Animals are raised separately from crops in large confinement facilities, eating specially formulated feeds made from grains and manufactured inputs, including antimicrobial drugs, rendered animal proteins, and arsenical compounds. Chemical fertilizers, irrigation, pesticides, herbicides, and new seed varieties were the immediate stimulants of the 20th-century yield increases, but petroleum was, and continues to be, their essential energy source. Petroleum contributes most ingredients for manufacturing the pesticides and herbicides essential for controlling pests and weeds that thrive in monoculture production and supplies the energy to mine, process, and deliver phosphate and potash to farms. (Natural gas is the primary ingredient in most nitrogen fertilizers.) Petroleum also supplies energy to manufacture and operate the farm equipment that prepares the soil, sows and harvests crops, and irrigates fields. Finally, petroleum transports agricultural inputs such as pesticides and feed, agricultural products, and food.

Oil facilitates globalization of the food supply. In 2005, the United States imported 44% of fruits and 16% of vegetables, including a significant portion of those eaten when local produce is available.[30] Even within the United States, food travels long distances. One Iowa study found that conventional produce traveled on average 1494 miles to institutional markets.[31] Production and processing often occur where costs are lowest.[32] An emphasis on "just in time" delivery means more trips are made. The petroleum impacts of these food supply chains vary, as fuel efficiency varies by orders of magnitude across vehicle types. Short trips in inefficient trucks or family vehicles often consume more energy per unit of food than do lengthy trips by train or ship. Regardless, as oil prices rise, long-distance transportation will increasingly become a luxury, leading to substantial changes in food distribution networks to supply healthy diets.[33]

Despite large absolute amounts of petroleum used in food and ingredient transportation, transportation plays a relatively minor role in food greenhouse gas emissions (2% to 4%) and total energy use (5% to 10%).[1,34–38] Transportation plays a larger role in food petroleum footprints, although specific estimates have not been identified.

Oil in the food system has helped produce a plentiful and inexpensive food supply. The result, however, has not been salubrious. In 2004, the US food supply contained 800 more calories per person per day than in 1960,[39] and in 2008, food purchases comprised about half the percentage of disposable income it did in the early 1960s.[40] By enabling overabundant, calorie-dense foods, petroleum contributes to diseases of over-nutrition, such as obesity, cardiovascular disease, diabetes, and some cancers.[41] High agricultural yields and speed are achieved at the expense of flavor that could help motivate more produce consumption, food safety, and the health and safety of workers and rural communities. Antimicrobial drugs heavily used in food animal production also contribute to the epidemic of antimicrobial resistance compromising these drugs' effectiveness for human use.[42–45]

Multiple policy drivers contribute to food system oil intensity. United States farm policy has particularly incentivized oil-dependent monocultures. The United States also provides direct fuel subsidies to agriculture—$2.4 billion in 2004.[46] Further incentives come from transportation policies that subsidize oil-inefficient modes of transportation, and subsidies to petroleum industries, including, some would say, a military policy aimed at maintaining imported oil supplies.

LOWER-OIL FOOD PRODUCTION

Food producers can reduce oil in multiple ways. They can choose energy-efficient vehicles and shift to renewable energy including installing solar, wind, and geothermal energy systems, shifting some labor back to humans and farm animals, and devoting portions of cropland to sustainable biofuels production. Fuel is also conserved with methods such as no-till agriculture, under which soil is not tilled (broken apart), leading to fewer runs with farm equipment. Unfortunately, most no-till agriculture today leads to increased herbicide and fertilizer usage; however, low-input methods are continually improving. Producers can replace heavy pesticide use with integrated pest management, crop rotation, and raising multiple plants and animals on the same farm. Chemical fertilizers can be replaced with compost, crop rotation, reduced tillage, and other soil management practices that also increase drought tolerance. Further reductions may be achieved by selecting plant and animal species adapted for local conditions and bred for attributes such as pest or disease resistance and drought tolerance. Figure 2 describes this lower-oil agriculture, in which the food system is a subsystem of the ecosystem.

The lower-oil agriculture we describe is not a return to the past. Rather, the shift is toward knowledge-intensive ecological agriculture, combining new science and localized data analysis with historical wisdom to manage ecological forces in their complexity and relationships for resilient food yields.

Observers question whether low-input methods can produce sufficient food to feed the world's growing population and achieve yields comparable to those of industrial agriculture. Numerous studies and United Nations (UN) reports suggest they probably can, and should be pursued, along with expanded research to improve and locally adapt methods.[47–55] Some agribusiness firms and others remain skeptical.[56] The UN and World Bank–convened International Assessment of Agricultural Knowledge, Science and Technology for Development concluded that the primary challenge for food security is to increase sustainable agricultural productivity at the national level to achieve greater food sovereignty.[57]

PETROLEUM FOOTPRINTS

Through history, solar-powered agriculture generally has produced more energy than it has consumed.[4] The fossil fuel era reversed the equation; now it takes about 7.3 to 10 calories of energy inputs to produce, process, and transport each calorie of food energy.[3,58] Pimentel et al. estimated that feeding each American requires approximately 528 gallons of oil equivalents annually (including nonoil energy).[59] The US Department of Agriculture (USDA) found a 16.4% rise in per capita US food system energy use just between 1997 and 2002—most importantly because of convenience and restaurant foods using mechanical instead of human labor for food processing, preparation, and cleanup. Although this electrical energy generally comes from nonpetroleum sources, it is indicative of broader trends in outsourcing tasks to fossil fuels.

We did not find analyses comparing petroleum use across multiple food categories, although several studies have compared energy use.[3,22,60] Table 1 presents USDA's energy use findings, showing that snacks, frozen foods, canned foods, spices, and condiments used the most energy per capita. This finding is not limited to electrical energy use; the category also tops the list when one limits the calculation to petroleum-heavy functions such as farming and freight. Healthier foods including fish, fruit, and vegetables required less. The figures do account for home cooking fuel, which can use petroleum but does not need to.[1] The USDA's table aggregates the "snacks, etc." category across multiple sectors,

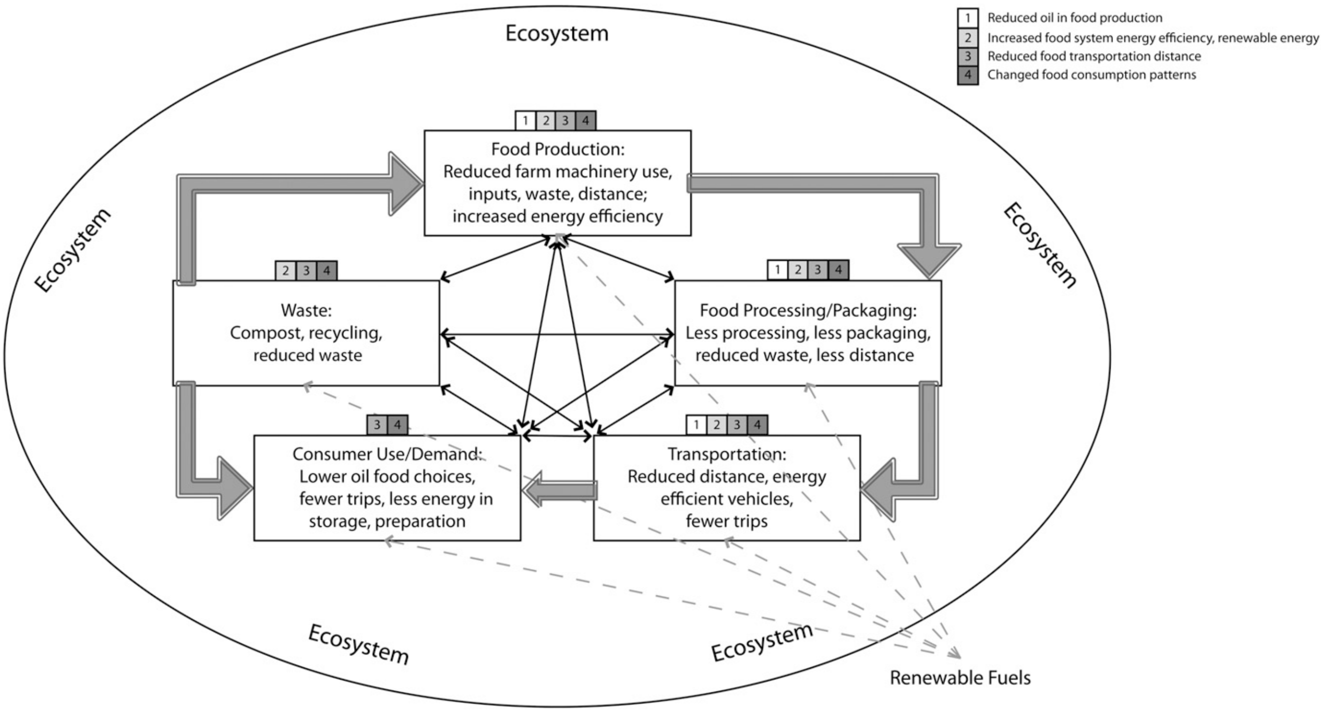

FIGURE 2—After adaptation to peak petroleum, food system as a subsystem of the ecosystem.

inflating its apparent impact, and listing meat types separately, obscuring their far higher summed impact. Although high values for food processing and retail may reflect dominance of electrical processes, these functions will also be affected by peak oil, as petroleum prices are linked with those for other fuels.

How should people eat to lower dietary petroleum? Although further life cycle analysis is needed, the most important steps include: eat lower on the food chain (industrial meat includes the embodied energy of both grain feed and animals), replace out-of-season produce with seasonal items whenever possible, avoid air-transported produce, and seek sustainably produced and regional foods transported in higher-efficiency vehicles. At all food system levels, it is essential to minimize food waste—currently about 1400 calories per person per day in the United States.[61] Finally, drivers should minimize mileage in car trips to stores and restaurants.

HOW OIL SCARCITY MAY AFFECT FOOD SYSTEMS

In high-income countries such as the United States, rising oil prices could lead in the short term to negative environmental impacts and increased corporate concentration (fewer corporations, each holding a greater market share). Over the longer term, high oil prices will necessitate a shift toward more resilient food production, distribution, and consumption.

Potential Industrial Agriculture Intensification and Food Price Rises

Several reasons exist for a possible short-term consolidation of industrial agriculture.[62] First, larger operations may have more resources than small and midsized producers to buffer against financial challenges and invest in new equipment. Second, as food prices rise, farmers have a financial incentive to increase production to reap the benefits—often by increasing fossil-fueled interventions and by removing lands from conservation programs. Third, high prices and economic dislocation can result in fewer consumers able to afford more sustainably produced foods, thus challenging that market. Finally, as rural economies struggle with high fuel prices and families struggle with high food bills, political factors may lead to increased governmental investment in industrial agriculture.[63] All these shifts could further drain petroleum resources and limit options for timely adaptation.

Another short-term response to high petroleum prices is that farmers are motivated to shift cropland from food to biofuels production, exacerbating food price volatility. Prices rise for crops whose production is cut to make room for biofuels. Naylor et al. examined 7 articles modeling 9 scenarios of biofuels' impacts on crop prices.[63] In all scenarios, prices for all or most commodities rose, although estimates varied. Mean price impacts (range in parentheses) were corn: +28% (2.5% to 65%); wheat: +17% (1.7% to 33%); soy: +18% (–11% to 76% [averaged across soy meal and soybean oil]); and sugar: +24% (–8% to 66%).[63]

In 2006 to 2008, the world observed what could be a foreshadowing of oil price rises and their short-term impacts on food systems. Oil prices hit $147 per barrel in July 2008,[64] up from $35 in January 2005.[65] Food prices spiked in the United States and

TABLE 1—Per Capita Energy Use (Petroleum and Nonpetroleum Combined; Thousand BTU) by Food Category and Stage of Food Production, 2002

	Farm and Agribusiness[a]	Food Processing	Packaging[b]	Freight Services[a]	Wholesale/Retail	Total
Individual food categories						
Snacks, frozen and canned foods, spices, and condiments	679	1422	370	205	1040	3716
Alcoholic beverages	217	719	596	203	928	2663
Beverages	135	765	600	125	857	2482
Baking products	212	1129	144	114	780	2379
Poultry products	694	585	87	103	368	1837
Sugar and sweets	187	632	136	71	378	1404
Dairy products	473	438	85	79	327	1402
Beef	562	360	37	90	315	1364
Fresh vegetables	672	25	29	166	428	1320
Cereal products	199	468	8	70	351	1096
Pork	410	262	27	60	209	968
Other meats	394	249	24	55	151	873
Fresh dairy	284	251	46	44	162	787
Processed fruits and vegetables	123	289	72	47	203	734
Fresh fruits	315	14	16	68	260	673
Fats and oil products	131	203	38	29	113	514
Eggs	201	69	9	23	63	365
Fish	89	81	9	15	111	305
Total	5977	7961	2333	1567	7044	24 882
Animal products summed	3107	2295	324	469	1706	7901
Meats summed	2060	1456	175	308	1043	5042
Fruits/vegetables fresh/processed summed	1110	328	117	281	891	2727

Note. This table presents per capita energy usage for selected categories of food items (2002), based on national level data. Figures were not broken down by energy type, and thus insights about petroleum use are inferential.

Source. Adapted from Canning et al.[1]

[a] Especially high petroleum usage.

[b] Moderate petroleum usage.

around the world, leading to exceptional food insecurity rates in the United States and pushing an estimated 42 million additional people worldwide into the undernourished category.[66] Studies have identified numerous contributors to the food price rises,[67–71] but oil price is considered quite important. Direct effects on farm costs from high oil prices were compounded by indirect effects on food prices, particularly from substitution to biofuels production and a rising trend of stock market speculation in food commodities, which increased the dependence of food prices on broader economic and market trends. Accordingly, when rising oil prices impacted even nonfood areas of the economy, food prices were affected.

The implications of oil price–influenced economic downturn and volatility go beyond food prices. There are disproportionate impacts for the poor, reducing their ability to afford food, gasoline, and heating oil. Rising fuel prices may hit farmers and other food system workers hard. The high cost of equipment investment—not to mention the time it takes to learn new systems and obtain new jobs—places these workers at risk.[72] As in the recession of 2008 and 2009, farmers and other entrepreneurs may also struggle to obtain credit.

Ironically, the extra grain used to fuel the United States' meat diet and ethanol production provides some level of buffering capacity that could lessen peak oil's immediate impacts—if that grain cropland were returned to producing human food.

Food Insecurity

Already today, 1.02 billion people worldwide are undernourished,[73] and even in the United States 14.6% of the population is food insecure.[74] As oil scarcity impacts food production quantities and prices, food insecurity will worsen. The UN projects that there will be 9.1 billion humans in 2050, and that with expected changes in wealth and meat consumption, world food production will need to rise by 70% to feed them all.[75] Unfortunately, as populations have grown, per capita food production has declined substantially, and declines are expected to continue[71] even without peak oil. In the United States, population is projected to climb by nearly 30% by 2050,[76] necessitating a rise in food availability here as well. At the same time, food production capacity will be challenged not only by high oil prices, but also by soil and water degradation and depletion, climate change, biodiversity loss, and social and political disagreements.[57]

TABLE 2—Needed Policy and Social Changes to Support a Smooth Food System Transition as Oil Prices Rise

Policy and Social Changes	Promoting change
Planning and preparing (many of these are ongoing)	
Conduct monitoring, including surveillance of food prices, nutrition, food security, and equity.	Planning bodies, academic partners, with government funding
Develop and use planning infrastructure. Convene stakeholders, set standards, develop plans.	Local, state, regional, national, international government bodies; food policy councils; interagency work groups; emergency planning
Scrutinize proposed solutions for unintended consequences including through use of Health Impact Assessment, and develop interventions to address these.	Planning bodies, academic partners, with government funding
To recruit a new generation of farmers, efforts are needed to make agriculture a more desirable and economically stable profession, including through policy efforts to stabilize farm prices, subsidizing both farm and health insurance.	Farm Bill,[92] health care policy
Educate and communicate with the public, policymakers, farmers, and others about future oil scarcity and benefits of early adaptation.	Media, governmental communications
Addressing short-term consequences of rising oil prices	
Ensure as equitable distribution of food as possible as prices rise, including through expanded food assistance programs, expanded funds for home and community food production and distribution, and possible new mechanisms such as rationing.	Farm Bill; additional local, state, federal, international policies
Provide aid to support adaptation and crisis response internationally, where food security impacts will be more dire.	Farm Bill, federal agencies
Restrict the concentration and market power of the major food corporations and retailers.	Farm Bill, enforce competition laws, regulate fair prices
Adaptation 1: Reduced oil in food production	
Incentivize lower-oil food production methods and farm transitioning	Farm Bill, climate policy carbon offsets
Make available information and technical assistance for farmers. Provide training to new agricultural workers and retrain existing ones.	Farm Bill, economic stimulus and green jobs programs
While ensuring an adequate safety net and transition plan, move away from incentives for high-oil food production, including relevant policies in Farm Bill; funds for infrastructure and marketing to support industrial production.	Farm Bill, climate policy, trade policy, check-off programs
“Internalize the externalities”—require firms to pay more fully for costs such as environmental and social impacts.	Environmental policy enforcement, legal challenges, ecotaxation
Fund agricultural and economic research to optimize and regionally adapt low-oil agricultural methods and systems, including developing appropriate plant and animal breeds.	Farm Bill, state land grant university funding
Adaptation 2: Increased food system energy efficiency and renewable energy	
Regulate and incentivize energy efficiency in farm, cargo, and consumer vehicles and equipment.	Climate policy, energy policy, transportation policy, Farm Bill
Invest in research and incentives for renewable energy transitions.	Climate policy, energy policy, Farm Bill
Adaptation 3: Changed food consumption patterns	
To the extent possible, work to ensure availability and accessibility of healthy food to enable meeting dietary needs.	Farm Bill, food policy councils, CDC, state and local health departments, planning departments, agriculture departments, etc.
Support consumer education and social marketing about relative oil inputs in different foods and about making lower-oil food choices generally. Link to public health cobenefits.	CDC; state, local health department funding; foundation and corporate-sponsored campaigns; HHS/USDA interagency working group to increase visibility of adhering to DRI for total protein and reducing animal protein
Provide incentives for purchasing lower-oil foods to provide demand-driven incentives to shift the food supply.	Tax or subsidy incentives through state and local governments
Support psychological, communications, and behavioral economics research on effectively, relatively painlessly shifting oil-relevant social norms and expectations, and individual behavior, while avoiding alienating the public.	CDC; state, local public health budgets
Challenge food industry formulations, placements, and marketing that make it difficult even for motivated consumers to avoid overconsumption.	Legal challenges, voluntary programs, FDA regulation

Continued

TABLE 2—*Continued*

Adaptation 4: Reduced food transportation distance	
Develop regionally adapted nutrition guidance for year-round foodshed eating under dietary guidelines. Develop food preservation–safety information.	CDC authorization
Support re-regionalizing efforts including development of local production, processing, distribution, marketing infrastructures, and maintenance of food reserves for emergencies.	Farm Bill, food policy councils
Integrate agricultural change with regional and urban planning.	Food policy councils, zoning policy, other planning policy
Transition away from reliance on food imports and exports.	Trade policy, marketing and social norms efforts
Government and other institutional purchasers shift their purchasing to help stimulate development of re-regionalized food economies.	Legislation mandating governmental purchasing changes, incentives for local/regional purchasing and disincentives for nonlocal/nonregional
Plan for and continue to support food aid in areas of critical need; plan for cross-foodshed emergency support.	Bilateral and multilateral aid policy, planning policy
Study and model food production and delivery systems and impacts of policy decisions on health outputs associated with food.	Farm Bill, state and local governments, CDC authorization
Promote worker safety and health in changed conditions, including through training, regulation, research, and mandating OSHA oversight of all agricultural workplaces	OSHA standards and enforcement, OSHA policy, NIOSH funds

Note. CDC = Centers for Disease Control and Prevention; DRI = dietary reference intake; FDA = United States Food and Drug Administration; HHS = United States Department of Health and Human Services; NIOSH = National Institute for Occupational Safety and Health; OSHA = Occupational Safety and Health Administration; USDA = United States Department of Agriculture.

Food insecurity has significant public health consequences. The World Bank found that a 35% food price increase—within the range seen in the previous biofuels scenarios—would result in an additional 80 million undernourished individuals worldwide.[77] One analysis found that undernutrition already results in 35% of child mortality and 11% of disease burden globally.[78] Consequences of nutritional deficiency, particularly in young children, can be lifelong and multigenerational and can include not only physical effects but also reduced educational attainment and economic productivity, and lower birth weight in offspring.[79,80] Even at less severe deprivation levels, already common in the United States, high prices and food insecurity can lead to significant stress, with implications for individual, family, and social well-being. Further, needs such as medicine and shelter may be sacrificed to pay for food.

Food Systems Adapting to Oil Scarcity

Transitioning to a postpetroleum food system is not optional. The extent to which peak oil represents food catastrophe or challenge will be driven not only by the rate of decline in oil production, but also by how rapidly we shift to more resilient food production, distribution, and consumption; the priority given to food among essential uses of oil; and efforts to ensure equity. As described earlier, rising oil prices may initially reinforce industrial food systems. Eventually, however, economic forces may lead to substantial adaptations to enable the population to be fed. There will be challenges along the way, including in public health and equity. Public health has a key role to play in joining with others to encourage smart and rapid transitions now, to reduce the risk of catastrophic impacts if oil prices rise quickly.

We expect the following 4 adaptations to occur: (1) reduced oil in food production, (2) increased food system energy efficiency and renewable energy, (3) changed food consumption patterns, and (4) reduced food transportation distances.

Reduced oil in food production. Multiple studies have found farm production to respond little to energy prices in the short term,[81] although a USDA analysis suggested that farm energy use did decline as energy prices rose from 2002 to 2006.[1] Eventually, however, farmers will respond to price and need to shift to lower-oil food production methods such as those described previously. Financial incentives and assistance will be needed to facilitate this transition, as well as training and retraining to provide the workforce for these more labor-intensive methods. A concern is that, by the time these investments are seriously needed, governmental ability to invest in far-reaching change may be limited. Social or financial insecurity can also limit openness to innovation.

A shift to lower-oil agriculture will improve long-term food security. Further positive health effects may include reduced pesticide exposures, improved water quality, and reduced development of antimicrobial resistance.[44,45] Some negative health effects of this transition may occur, not only from the stress of forced change, but also from a learning curve and transition period in which food yields may be substantially reduced.

Increased food system energy efficiency and renewable energy. As oil prices rise, equipment energy efficiency will increasingly be prioritized throughout the food system. Food transporters (including consumers) will recognize cost savings from energy-efficient vehicles, with air-transported items becoming especially impractical. Planning smartly at the consumer, farm, corporate, and systemic levels will minimize trips. Food producers will reduce reliance on oil-fueled mechanical devices by scaling farm size and equipment appropriately, optimizing methods, and innovation in products and processes. Petroleum use related to marketing, such as excess food packaging, will be trimmed. Considerably expanded investment is needed to improve renewable energy technologies and reduce costs rapidly. This adaptation will have benefits in environment, cost savings (particularly after investments are paid off), and job creation. Further work is needed, however, to address important limitations of biofuels and other renewable energy technologies.

Changed food consumption patterns. Evidence from economics suggests that food purchasing decisions are only somewhat responsive to small price changes, and that it could take substantial price rises before economic incentives motivate significant dietary change.[82] Additionally, psychology and behavioral economics literature suggests that as stresses increase (as in economic downturns), consumers may be more likely to opt for foods their rational brains would decline, such as those that are more costly and less healthy.[83,84]

Nonetheless, price will eventually motivate consumers to eat less of those foods requiring the most oil to produce, process, and transport. As described earlier, these tend to be less-healthy options, so such a change could ultimately benefit the public's health. Unfortunately, produce prices and overall food prices are also affected. Public health voices will be needed to amplify pressure on governments to prioritize access and affordability of nutritious diets.

Food satisfies needs beyond nutrition, including pleasure, security, culture, and habit; convenience foods are seen by many as essential because of demanding lifestyles and women's roles. Many will resent adapting habits, particularly in the face of inequities. Food security, community food security, and other interventions can mitigate these consequences. A systems approach is critical to minimize unanticipated consequences, health impacts, and costs.

Reduced distances in food transportation. Although transportation is not the top oil usage in the food system, it is significant. Eventually, oil prices are likely to rise high enough to reduce globalization and incentivize re-regionalizing food networks.[33]

In the "foodshed" concept, regions varying in size appropriate to local circumstances aim to supply and process as much of their own food as possible.[85] These areas are generally broad; extreme "locavore" goals such as the "100-mile diet" may be neither optimal nor feasible. Foodsheds allow for sourcing elsewhere those items for which local production is inefficient or impractical.[86] For example, experts are currently assessing the portion of food the Northeastern United States foodshed could produce under optimal conditions and evaluating ways to aggregate production and delivery.[87]

There are multiple challenges in re-regionalizing food:

- Nutrition: Re-regionalizing food will require planning and education to enable populations to meet dietary guidelines. Adequate year-round nutrition should still be feasible in many or most areas, as it was historically, based on wise choices of local and seasonal foods, protein from sources such as legumes and grains plus some meat, food preservation, plus

Public Health Roles in Addressing Peak Oil, Based on Core Functions

Assessment

Engage in relevant surveillance and monitoring, including examining nutrition, food security, variation in ability to obtain healthy diets, related health outcomes, and food prices.

Evaluate the efficacy, effectiveness, efficiency, and equity of the previously described interventions to adapt to peak oil.

Scrutinize proposed solutions for potential unintended consequences, communicate about these, and develop interventions to address these.

Conduct research including to develop and refine responses to peak oil health threats, improve adaptation, and identify costs and benefits of differing approaches.

Study and model food production and delivery system and impacts of policy decisions on health outputs associated with food.

Policy development

Amplify the public health voice in peak oil–relevant policy debates, including the Farm Bill (renewed every 4–5 years, most recently in 2008), climate policy, transportation policy, local planning policy, trade policy, and aid policy. Highlight the potential public health ramifications of inaction. Speak out through letters to the editor and in other venues. Strengthen coalitions of public health environmental, health policy, nutrition, chronic disease epidemiology, social and behavior, and other professionals to collaborate on policy development and advocacy.

Health departments and other public health professionals should collaborate with planners and local stakeholders on planning and emergency planning efforts relevant to peak oil adaptation and allocating adequate food and petroleum reserves.

Monitor and, where appropriate, challenge food and agribusiness industry actions.

Convene bodies to grapple with equity concerns in food allocation, in face of not only peak oil but also potential concurrent economic dislocation. Mechanisms of reallocation might include rationing, expanded food assistance programs, expanded funds for community food production, distribution networks, and funds for home production.

Assurance

Educate about how to obtain healthy diets with available foods.

Communicate about energy impacts of varying food choices, including developing peak oil–adapted dietary messages. Inform, educate, motivate, and empower the public regarding dietary change—especially where change is both health-promoting and environment protecting.

Ensure a competent public health workforce, including providing training in agricultural policy and other functions needed to address new realities.

Mobilize community and regional partnerships including food policy councils to identify and address food system concerns.

methods such as covered hoop-houses for winter produce production. Wilkins and Gussow demonstrated this in detail for the Northeast.[88] Public health will have a critical role in adapting nutrition messages to the new reality, and in communicating about food preservation and forage safety. Additionally, re-regionalized food systems will require adjusting cultural norms and tastes, particularly regarding seasonal eating and food variety.

- Sprawl: Most cities were built on the country's most fertile land; cities and their surrounding sprawl now cover that essential farmland.[89] As rising gasoline prices discourage commuting, repurposing developed areas for food production may become a priority. Yet, relocating families and communities, demolishing buildings, and tearing up roads is socially distressing, energy intensive, and expensive. Remediating contaminated, compacted soils presents additional challenges.[90] Smaller farms may be better able to work around geographic discontinuities. A burgeoning movement today is exploring the necessary zoning changes, soil remediation, production techniques, and distributional models to scale up urban and periurban production and make its products more affordable and accessible.
- Geography: Some areas will find it nearly impossible to support existing population levels on local or regional inputs, including areas of Alaska and the Southwest. Production capacity in other areas exceeds population needs. Planning must take account of these realities to optimize outcomes, including the possibility of fostering geographic shifts in population.

Despite challenges, a foodshed model offers potential public health and community cobenefits. Food security can increase as regions join in concerted planning. Consuming less-processed food and reducing meat consumption could improve physical health.[44] Reduced truck miles could mean reduced vehicle crash injuries and exposures to particulate air emissions, which have been linked with respiratory illnesses and cardiovascular morbidity and mortality.[92] Foodshed production can constrain foodborne outbreak size, as fewer consumers may be exposed to any single contamination event. Finally, there can be health cobenefits based on foodshed systems' contributions to equitable area economic development.

STRATEGIES AND ROLES FOR PUBLIC HEALTH

The previously mentioned food system adaptations may be forced upon us as petroleum prices rise, but proactive efforts can minimize their negative consequences. In Table 2, we identify a set of needed social or policy changes and suggest tools for promoting them.

The table first presents "planning and preparing" strategies needed both in advance of oil price rises and on an ongoing basis. These strategies include monitoring, working with stakeholders on planning, scrutinizing for unintended consequences, building a more economically secure cohort of farmers with an adequate safety net, and educating and communicating about the threat. To address short-term consequences of rising oil prices, key efforts include working to remedy inequities, providing domestic and international food assistance, and addressing the increases in corporate concentration that may ensue.

To adapt to (1) reduced oil in food production, society will have to create the needed financial support, technical assistance, training, and both positive and negative incentives to help businesses move in needed directions. Research to optimize methods will be needed. Smoothing the adaptation to (2) increased energy efficiency may require incentives, transition support, research, and regulation. Public health has a particular role to play in facilitating (3) healthy changes in eating patterns, including working to ensure adequate healthy food is available, accessible, and affordable. Additional efforts will include lifecycle analysis to better understand petroleum footprints, and educating about, incentivizing, and promoting lower-oil social norms while challenging pressures in the opposite direction. Finally, (4) reducing transportation distance and adapting to a foodshed-like model will require educating the public about optimal food choices under new constraints. It will also require planning, including plans for cross-foodshed exchange when needed.

The box on the previous page describes key public health roles, based on the field's 3 core functions: (1) assessment (i.e., surveillance, evaluation, consideration of unintended consequences, research), (2) policy development (i.e., providing a public health voice in policy discussions, engaging in collaborative planning efforts, including efforts to address equity), and (3) assurance (i.e., health education, communication about food petroleum content, training the public health workforce in agricultural issues and other needed topic areas, and working with others to mobilize partnerships). Throughout, it is critical to attend to equity, account for complexity, and engage multidisciplinary partners in planning, to minimize unintended negative consequences.

We recognize that many of the needed approaches lie outside public health's traditional domains, in fields such as agriculture, planning, or community food security.[93] In some of these areas, public health can be a partner and supporter; in others, it can carve out public health–relevant domains from which to lead. Indeed, public health professionals are increasingly developing their own expertise in these interdisciplinary domains, responding to the field's mission to "[fulfill] society's interest in *assuring conditions* in which people can be healthy [emphasis added]."[94(p7)] The threat to such conditions, and the public health cobenefits of action, demand our field's attention.

CONCLUSIONS

Although it is difficult to predict the future, we can say that even if plentiful oil lasts another 100 years, this resource is finite. Renewables are unlikely to provide enough fuel for today's US lifestyles in the foreseeable future. Of course, food systems are systems; they can adapt to challenges and use alternate functions to withstand disruptions. As we describe, presuming our food system remains oil-dependent when prices escalate, we can expect significant short-term food price increases, but agriculture and food industries may face little disruption or even be strengthened.

Systems can cross thresholds that force deeper change. As prices rise further, we describe 4 likely adaptations: reduced oil in food production, increased food system energy efficiency and renewable energy, changed food consumption patterns, and reduced food transportation distances. These adaptations can come with substantial food insecurity (caloric and nutritional), concomitant social and individual disruption, and health consequences. We can ease the adjustment with planning and efforts to promote advance transitioning to more sustainable and healthy food production, plus heavy investment in research and incentives.

Perhaps the largest challenge is that few want to think about peak oil and other ecological threats such as climate change and soil depletion—never mind committing to precautionary change. Most of us prefer to continue the status quo, particularly if it has worked previously, if we have invested in it, and if it functions acceptably well. Change carries cost and risk. So, however, does inaction.

There are benefits of bringing public health's strengths to bear in partnering with communities, organizations, and governments. Our efforts can not only mitigate harms, but they can also facilitate survival in the face of peak oil, and bend society toward a more resilient and food-secure future.

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Contributors

R. A. Neff led the writing, analysis, and revisions, and managed the project. C. L. Parker initiated the project, contributed to the writing, and provided expertise in peak oil. F. L. Kirschenmann contributed to the writing, and provided expertise in agriculture and peak oil. J. Tinch contributed to the writing. R. S. Lawrence contributed to the writing, and provided expertise and oversight. All authors shared in interpretation, analysis, and responses to reviews.

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