Energy and Public Health: The Challenge of Peak Petroleum

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SYNOPSIS

Petroleum is a unique and essential energy source, used as the principal fuel for transportation, in producing many chemicals, and for numerous other purposes. Global petroleum production is expected to reach a maximum in the near future and to decline thereafter, a phenomenon known as "peak petroleum."

This article reviews petroleum geology and uses, describes the phenomenon of peak petroleum, and reviews the scientific literature on the timing of this transition. It then discusses how peak petroleum may affect public health and health care, by reference to four areas: medical supplies and equipment, transportation, energy generation, and food production. Finally, it suggests strategies for anticipating and preparing for peak petroleum, both general public health preparedness strategies and actions specific to the four expected health system impacts.

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Dramatic improvements in human health during the last 150 years have coincided with unprecedented economic growth and prosperity. This progress has depended on intensive energy use, much of it from fossil fuels such as coal, petroleum, and natural gas. Petroleum is thoroughly integrated into the modern economy, playing key roles in transportation, heating, agriculture, and manufacturing.

The supply of plentiful, cheap petroleum is expected to peak within the next few decades, and to decline thereafter. Petroleum will not disappear, but production will fall even as demand rises. Petroleum scarcity will have wide-ranging impacts across society, including in the health sector, and will require a range of adaptations. This transition will be technically and socially challenging, costly, and possibly abrupt.

The transition through "peak petroleum" has been discussed in popular and technical literature: there is an Association for the Study of Peak Oil and Gas; there are several websites and blogs (available from: URL: http://www.peakoil.com, http://www.hubbertpeak.com, http://www.peak-oil-news.info, http://www.oildecline.com, and http://www.postcarbon.org, and include one that focuses on health [http://peakoilmedicine.com]); and there is a growing "gray literature." However, there is virtually no peer-reviewed literature on the health consequences of peak petroleum, reflecting a near absence of discussion within the public health and health-care systems. The transition will likely affect human health in several ways. This article introduces the concept of peak petroleum to health professionals, reviews anticipated health impacts, and outlines steps to anticipating, preparing for, reducing, and adapting to these effects.

THE SCIENCE OF PETROLEUM

Petroleum is a unique energy source; it is energy-dense, relatively stable, portable, and abundant. For thousands of years, in places from Babylon to Romania to China—where it oozed from the ground—petroleum was recognized and used as medicine, as fuel, and for other purposes. However, the petroleum era has been brief in historical terms; large-scale production dates only from the mid-19th century.[1] The first commercial oil well was drilled in 1848 near Baku, in modern-day Azerbaijan, and the Drake well in Titusville, Pennsylvania, launched the U.S. industry in 1861. During the last 150 years, petroleum has assumed a defining role in the world's economy. It is the principal source of liquid fuel for transportation, and it plays an important role in chemical manufacturing, power generation, and other uses.[2]

Petroleum was formed by geologic processes dating from the Cretaceous and Jurassic periods, 90 to 150 million years ago, when vast amounts of zooplankton, algae, and other organic material were deposited on ocean floors. This material contained organic molecules with energy in carbon-hydrogen bonds, derived principally from photosynthesis. Over geologic time, some of these deposits were buried in sediment, pressurized by the overburden, and heated. At depths below 7,500 feet, heat and pressure decomposed large organic molecules into fragments of between five and 20 carbons, forming the liquid we know as petroleum. At lower depths, below 15,000 feet, greater heat and pressure further decomposed organic molecules to one-carbon fragments, yielding methane (natural gas). Most of the petroleum thus formed seeped to the surface and biodegraded, but some was trapped in impermeable rock formations, forming the reservoirs that are tapped today. Variations in this process resulted in nonconventional forms such as oil sands, tar sands, heavy oil, bitumen, and oil shale.

Chemically, petroleum consists of aliphatic molecules such as ethylene and propylene and aromatic molecules such as benzene, toluene, and xylene. There may be small amounts of other substances such as sulfur. At oil refineries, crude petroleum undergoes pyrolysis (or "cracking") to yield a variety of short-chain aliphatics, and catalytic reforming produces specific desired aliphatics and aromatics.

A very broad range of petrochemical products derives from these precursors. For example, ethylene is a starting point for the production of polyethylene, polyesters, vinyl chloride, and polystyrenes; propylene is used to produce acetone, epoxy resins, polycarbonate, and acrylic polymers; butadiene is a building block of synthetic rubber; benzene is made into epoxy resins, nylons, and polyurethanes; and xylene is used in polyester production. Many pharmaceuticals as well as familiar plastics, resins, solvents, textile fibers, lubricants, pesticides, fertilizers, cleaners, and other products are made from petrochemicals.

However, the majority of petroleum now extracted—in the range of 85%—is used to produce fuels. Most of these are transportation fuels such as gasoline, diesel fuel, and jet fuel, while some, such as fuel oil, liquefied petroleum gas, and propane, are used for heating and power generation. Petroleum accounts for more than 90% of transportation fuel, but only for 2% of electricity generation. When refined, a 42-gallon barrel of crude oil yields about 20 gallons of gasoline, 10 gallons of diesel fuel and heating oil, four gallons of jet fuel, and smaller amounts of other products.

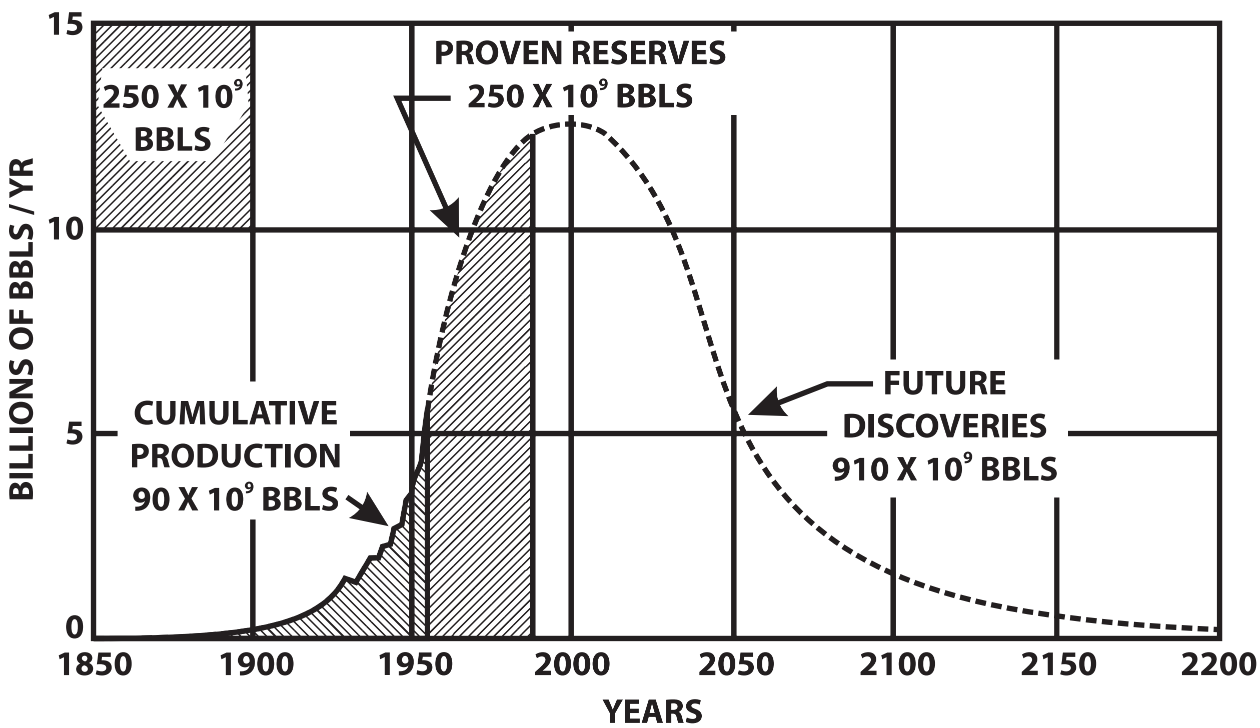
PEAK PETROLEUM

Petroleum is a finite resource. Because it formed over millions of years, and is being used faster than it is being formed, it is nonrenewable on any human time scale; supply will at some point fall short of demand. The point at which petroleum production peaks and begins to decline is known as "peak petroleum."

In the mid-1950s, a petroleum geologist named M. King Hubbert published a model of oil field production over time.[3] Hubbert hypothesized that when the total endowment of a limited resource such as oil is known, and the rate of production (which in this case equals consumption) is established, the date of peak production can be predicted with relative precision. In this approach, production increases over time, reaching a peak when half of the recoverable resources have been extracted. After that point, production inexorably declines at the same rate at which it grew (Figure 1). Using the estimated total petroleum reserves in the contiguous 48 U.S. states, which had been essentially undisputed since the 1940s, and historic rates of production, Hubbert predicted that production from continental U.S. oil reserves would peak in the early 1970s. This prediction was borne out. Since then, production has peaked in other major oil fields, such as those in the North Sea off the United Kingdom (in about 1999) and Norway (in about 2001).[4] This phenomenon will at some point occur on a global scale.

There has been considerable debate about the timing of the global Hubbert's peak. Debate focuses, in part, on the magnitude of existing reserves. There is scientific uncertainty in the measurement of reserves, there are no standard protocols for reporting reserves, and both private firms and national governments have incentives not to report their reserves accurately.[5] Estimates of reserves have tended to increase over time with the discovery of new oil finds. Current estimates suggest about 1,300 billion barrels.[6] (The U.S. Geological Survey proffers far higher estimates, up to 2,120 billion barrels.)[7] At current world rates of extraction and consumption (82 million barrels per day, or nearly

Figure 1. Hubbert's original 1956 diagram showing predicted ultimate world petroleum production, based upon assumed initial reserves of 1,250 billion barrels[a]



Source: Hubbert MK. Nuclear energy and the fossil fuels. American Petroleum Institute Drilling and Production Practice Proceedings. Spring 1956:5-75. Also available from: URL: http://www.hubbertpeak.com/hubbert/1956/1956.pdf [cited 2008 May 8].

[a]Peak was predicted at approximately the year 2000—a date that proved to be premature.

BBLS = barrels

30 billion barrels per year), these reserves would last approximately four decades. As one recent industry report noted:

> While major new finds cannot be ruled out, recent statistics do provide worrisome signals. Reserve estimates have increased over time but the annual average increase in proven oil reserves, which stood at 4.5% in the 1980s, has slowed down considerably since the early 1990s to around 1%. Discoveries only replaced some 45% of production since 1999. In addition, the number of discoveries is increasing but discoveries are getting smaller in size. The 25 biggest fields hold some 33% of discovered reserves and the top 100 fields 53%; all but two of the giant fields were discovered before 1970.[8]

Published estimates of the date of world peak petroleum vary considerably (Figure 2). Not only do estimates of reserves vary, but there are also differing approaches to projecting population growth, economic growth, and future petroleum demand. Dr. Shokri Ghanem, of the National Oil Corporation of Libya, offered a useful summary at the Organization of Petroleum Exporting Countries' 2006 Oil and Money Conference, on the occasion of being named Petroleum Executive of the Year:

> . . . While some of the more pessimistic oil specialists are declaring that peak oil has already been passed, or at best is here now, others believe it is not going to arrive before 2010. Some optimists give the world a little more breathing space—that is to say up to 2020, and perhaps even up to 2030. However, all in all, most would appear to agree that peak oil output is not very far away for all of us. It could take place sometime within the next decade or so, which in fact means that there is not much time left for a world economy to be driven largely by oil.[9]

Peak petroleum will mark the beginning of a long, gradual decline in petroleum production and availability. Petroleum will remain available for some time, but it will no longer be readily extracted, inexpensive petroleum. Meanwhile, world demand for petroleum is predicted to increase in coming decades. With rising demand and declining supply, market forces will operate to increase petroleum prices. All parts of society, including the health sector, will be affected.

TRANSITIONING THROUGH PEAK PETROLEUM

The transition through peak petroleum may be gradual and gentle, or it may be abrupt and disruptive. An extensive literature, ranging from the apocalyptic[10,11] to the reassuring,[12–14] has explored various scenarios.[15–25] The U.S., with its heavy reliance on petroleum, may be particularly vulnerable to the effects of an abrupt transition.[26] At least six factors will affect the transition: when the peak occurs, how fast petroleum supplies decline thereafter, how fast demand increases, geopolitical factors, how fast alternative technologies emerge, and how well society prepares itself.

When the peak occurs

The timing of the peak, as noted previously, is uncertain. Most estimates place it within the first two or three decades of the 21st century. If the peak is delayed, there will be more time for replacement technologies to develop and for adaptive preparations to be made.

How fast supplies decline

If petroleum supplies decline rapidly, all things being equal, the adjustment will be more challenging. Both the availability and the price of petroleum products may be volatile. In addition, rapid decline will leave less time to implement adaptive behaviors and replacement technologies. An important determinant of the rate of decline is drilling and extraction technology. This technology has advanced rapidly in recent years, increasing the ease and decreasing the cost of extracting "hard-to-get" petroleum, and thereby expanding recoverable reserves. Moreover, as petroleum prices rise, more expensive extraction technologies become economical to use. Wells that were partially exhausted and abandoned as unprofitable at a time of cheap oil can be revived using more costly techniques.

For example, California's Kern River oil field was discovered in 1899 and was highly productive for decades, but by the late 20th century, output had dropped to 10,000 barrels per day. High-pressure steam extraction technology reversed this trend, boosting production to 85,000 barrels per day by 2007. At Indonesia's giant Duri oil field, dating from 1941, production had dropped to 65,000 barrels per day by the mid-1980s, but two decades later rose to more than 200,000 barrels a day using this same technology.[27] As prices rise and technology improves, even more dramatic technical advances will allow exploitation of unconventional oil reserves such as tar sands. Such developments will slow the rate of decline of petroleum availability.

How fast demand increases

Increasing worldwide demand for petroleum will affect the transition in important ways. Global petroleum demand is currently at 84 million barrels per day, and it is predicted to increase by 1% to 2% per year, reaching 116 million barrels per day by 2030.[6] Much of this increasing demand will occur in developing nations. For example, China's passenger car fleet, the fastestgrowing in the world, is expanding at more than three times the world rate. In 2007, 4.7 million cars were sold in China, up 23.4% from 2006.[28] The potential market is huge; there are only 10 cars for every 1,000 people in China and 12 for every 1,000 in India, compared with 765 per 1,000 people in the U.S. and 472 per 1,000 people in Europe,[29,30] and the Chinese and Indian governments have made the automobile sector a pillar of economic development.[31] In India, production and sale of the world's cheapest automobile—the $2,500 Tata Nano subcompact—which began in 2008, will bring personal vehicles within reach of millions of drivers.[32] This growth will contribute to a rapid increase in global demand for petroleum. A more rapid rise in

Figure 2. Estimated dates of world peak petroleum[a]

Projected date	*Source and background*
2005	K.S. Deffeyes (oil company geologist and Princeton professor)[b]
Approximately 2006	C.J. Campbell (oil company geologist)[c]
2006–2007	A.M.S. Bakhtiari (Iranian oil executive)[d]
2007–2009	M.R. Simmons (investment banker)[a]
Before 2010	D. Goodstein (California Institute of Technology vice provost)[e]
2010	C. Skrebowski (petroleum journalist)[f]
Before 2016	OPEC[g]
2021–2112	U.S. Department of Energy, Energy Information Administration[h]
2003–2020	U.S. Geological Survey[i]
2020–2030	U.S. Department of Energy, Oak Ridge National Laboratory[j]
After 2025	Shell Oil[k]
After 2030	Cambridge Energy Research Associates (consulting firm)[l]
After 2030	International Energy Agency[m]
No foreseeable peak	M.C. Lynch (energy economist and president of Strategic Energy and Economic Research, an energy consulting firm)[n]

[a]Adapted from Hirsch RL, Bezdek R, Wendling R. Peaking of world oil production: impacts, mitigation, & risk management. Science Applications International Corporation Report for the U.S. Department of Energy, 2005 [cited 2008 May 8]. Available from: URL: http://www.netl.doe.gov/publications/others/pdf/Oil_Peaking_NETL.pdf

[b]Deffeyes KS. Beyond oil: the view from Hubbert's peak. New York: Hill and Wang; 2005.

[c]Campbell CJ. The coming oil crisis. Brentwood (UK): Multi-Science Publishing Company Ltd.; 2004.

[d]Bakhtiari AMS. World oil production capacity model suggests output peak by 2006–2007. Oil & Gas Journal; 2004 Apr 26.

[e]Goodstein D. Out of gas: the end of the age of oil. New York: W.W. Norton & Company; 2004.

[f]Skrebowski C. Megaprojects analysis explained. Energy Bulletin 2006 Jun 21 [cited 2008 May 8]. Available from: URL: http://www.energybulletin.net/17422.html

[g]Ghanem S. Is the era of cheap oil really over? OPEC Bulletin 2006;11-12:60-3. Also available from: URL: http://www.opec.org/library/OPEC%20Bulletin/2006/psd/OB11_122006.pdf [cited 2008 May 8].

[h]Wood JH, Long GR, Morehouse DF. Long-term world oil supply scenarios. Energy Information Administration, Department of Energy (US). 2004 [cited 2008 May 8]. Available from: URL: http://www.eia.doe.gov/pub/oil_gas/petroleum/feature_articles2004/worldoilsupply/oilsupply04.html

[i]Magoon LB. Are we running out of oil? U.S. Geological Survey Open File Report 00-320. 2000 [cited 2008 May 8]. Available from: URL: http://pubs.usgs.gov/of/2000/of00-320/of00-320.pdf

[j]Greene DL, Hopson JL, Li J. Running out of and into oil: analyzing global depletion and transition through 2050. ORNL/TM-2003/259. Oak Ridge (TN): Office of Science and Technical Information; 2003. Also available from: URL: http://www-cta.ornl.gov/cta/Publications/Reports/ORNL_TM_2003_259 [cited 2008 May 8].

[k]Davis G. Meeting future energy needs: choices and possibilities. The Bridge 2003;33:16-21. Also available from: URL: http://www.nae.edu/nae/bridgecom.nsf/weblinks/MKUF-5NTQDH?OpenDocument [cited 2008 May 8].

[l]Jackson PM. Why the "peak oil" theory falls down: myths, legends, and the future of oil resources. Cambridge (MA): Cambridge Energy Research Associates; 2006.

[m]International Energy Agency. World energy outlook 2006 [cited 2008 May 8]. Available from: URL: http://www.iea.org/textbase/nppdf/free/2006/weo2006.pdf

[n]Lynch MC. The new pessimism about petroleum resources: debunking the Hubbert model (and Hubbert modelers). Minerals and Energy—Raw Materials Report 2003;18:21-32.

OPEC = Organization of the Petroleum Exporting Countries demand means greater divergence between demand and supply.

Geopolitical factors

Much of the world's remaining petroleum is found in nations that are politically unstable. Abrupt political changes, armed conflicts, and similar events in these nations could interrupt petroleum availability, causing short-term shortages. Similarly, natural disasters could interrupt petroleum extraction, refining, and/or delivery, as occurred in the Gulf of Mexico in 2005 following Hurricane Katrina. Such disasters are predicted to become more frequent as climate change advances.[33,34]

How fast alternative technologies emerge

Alternative energy sources or technologies could reduce the demand for petroleum and ease the transition through peak petroleum. Several such transportation alternatives are shown in Figure 3. At present, no alternative energy source or technology is close to replacing petroleum-based transportation on a large scale.

Contextual factors

At least three additional contextual factors—climate change, globalization, and suburbanization—will affect the transition through peak petroleum. First, as global climate change intensifies, the need to limit greenhouse gas emissions will be increasingly recognized.[33] As shown in Figure 3, coal is the most plentiful and affordable alternative to petroleum as a transportation energy source. However, coal is a leading source of carbon dioxide emissions. Accordingly, there will be pressure not to rely on coal for transportation. Second, in an increasingly integrated global economy, many products—from clothing to computers, from medical supplies to food—are transported from overseas on ships and aircraft that use petroleum-based fuels. As transportation costs rise, the costs of such products will rise as well.[35] This will have an impact throughout the economy, including in the health sector. Third, the U.S. population has become heavily suburbanized during recent decades. Suburban development features heavy automobile dependence, implying petroleum dependence; neither mass transit nor non-motorized travel can be widely used in dispersed, low-density communities.[36–39] Thus, the growing scarcity of petroleum will collide with growing dependence on automobile travel. These three factors will complicate the challenges of peak petroleum.

An emerging literature addresses adaptation to a post-petroleum world, including energy policy proposals,[40] urban design strategies,[41] financial investment recommendations,[42–44] and even survival guides.[45,46] However, little of this literature addresses health issues. Petroleum scarcity will impact public health and health care in at least four areas: medical supplies and equipment, transportation, energy generation, and food production.

PEAK PETROLEUM'S IMPACT ON PUBLIC HEALTH AND HEALTH CARE

Medical supplies and equipment

Petroleum scarcity will have direct impacts on the availability and production of materials for which petroleum is a feedstock, and on the production and distribution of equipment in which petroleum plays a role.[47] This includes pharmaceuticals, supplies, packaging, and capital equipment.

Many pharmaceuticals are developed from petroleum feedstocks.[48] For example, aspirin is produced from phenol, a petroleum-based molecule, through the Kolbe-Schmitt reaction. Some antibiotics are produced through fermentation of esters and alcohols, and nitrogen mustard is made from propylene glycol, all of which derive from petroleum. Many antihistamines, antibiotics, antineoplastics, and psychoactive medications are made from phenols, acids, anhydrides, alkanoamines, and aldehydes, which are made from petroleum feedstocks.[49] In addition, celluloses and polymers—some from petroleum—are needed for both tablet binders and pill coatings, and petroleum-based molecules are used to make the plastic bottles and safety caps in which medicines are packaged.

Fortunately, pharmaceutical precursors can be synthesized from sources other than petroleum. While alternative synthetic pathways could be costly, production volumes are small relative to other industrial applications, and chemical costs are a relatively small part of final pharmaceutical prices. Therefore, petroleum scarcity is unlikely to have a major impact on pharmaceutical prices (Personal communication, Richard Pariza, Cedarburg Pharmaceuticals, November 2006). However, each drug approval by the Food and Drug Administration (FDA) includes approval of a specific synthetic pathway, and FDA approval is required to "change the synthesis of the drug substance, including a change in solvents and a change in the route of synthesis" or "to add or delete an ingredient, or otherwise to change the composition of the drug product."[50] If petroleum scarcity creates a need to alter pharmaceutical synthetic pathways, especially if this happens suddenly, it could result in time-consuming delays.

Figure 3. Potential alternatives to petroleum-based transportation

Alternative	*Comment*
Natural gas	• Volatile world supply • Difficulty of long-distance transport • Current absence of infrastructure for fueling vehicles
Coal gasification	• Plentiful coal to use as source • Gasification is energy-intensive (low EROI) • Energy source is often coal-fired plants, contributing to greenhouse emissions[a] • Currently limited coal gasification facilities[b]
Electric vehicles	• Currently limited by battery storage capacity causing limited vehicle range • Electricity often generated from coal-fired plants, contributing to greenhouse emissions[a]
Hydrogen-powered vehicles	• Hydrogen often produced using electricity from coal-fired plants, contributing to greenhouse emissions • Hydrogen fuel cells currently limited by cost, durability, and efficiency[c] • On-board hydrogen storage raises substantial safety concerns
Biofuels	• Currently limited production capacity • Debatable energy efficiency with possible low EROI[d,e] • Requires natural gas and electricity to produce • Heavy demand on farmland[f,g] • Potential impacts on price of corn and other food staples[h] • Pricing affected by market distortions through government subsidies
Mass transit	• Limited existing infrastructure • Impractical in low-density communities • Lack of public support
Non-motorized travel (walking, bicycling)	• Best suited to short distances • Co-benefits: physical activity, reduced air pollution • Requires urban planning innovations to encourage widespread adoption

[a]Hirsch RL, Bezdek R, Wendling R. Peaking of world oil production: impacts, mitigation, & risk management. Science Applications International Corporation Report for the U.S. Department of Energy, 2005 [cited 2008 May 8]. Available from: URL: http://www.netl.doe.gov/publications/others/pdf/Oil_Peaking_NETL.pdf

[b]Yamashita K, Barreto L. Energyplexes for the 21st century: coal gasification for co-producing hydrogen, electricity and liquid fuels. Energy 2005;30:2453-73.

[c]National Research Council, National Academy of Engineering. The hydrogen economy: opportunities, costs, barriers, and R&D needs. Washington: National Academies Press; 2004.

[d]Shapouri H, Duffield JA, Wang M. The energy balance of corn ethanol: an update. Department of Agriculture, Office of the Chief Economist, Office of Energy Policy and New Uses (US). Agricultural Economic Report No. 813. July 2002. Also available from: URL: http://www.transportation.anl.gov/pdfs/AF/265.pdf [cited 2008 May 8].

[e]Pimentel D, Patzek TW. Ethanol production using corn, switchgrass, and wood; biodiesel production using soybean and sunflower. Natural Resources Research 2005;14:65-76.

[f]Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P. Land clearing and the biofuel carbon debt. Science 2008;319:1235-8.

[g]Worldwatch Institute. Biofuels for transport: global potential and implications for energy and agriculture. London: Earthscan Publications Ltd.; 2007.

[h]Runge CF, Senauer B. How biofuels could starve the poor. Foreign Affairs 2007;86:41-53.

EROI = energy return on investment

Many medical supplies contain plastics derived from petroleum (Figure 4).[48,51] For example, catheters and intraveneous solution bags are often made with polyvinyl chloride (PVC), whose synthesis begins with ethylene and benzene. Ethylene is made from natural gas (65%) and petroleum (35%), and benzene is derived almost completely from petroleum. Polyethylene, with a similar feedstock composition, is used for more rigid products such as syringes, splints, and bedpans. Styrene and butadiene—main components of synthetic surgical gloves—are made almost exclusively from petroleum feedstock (Personal communication, Kevin Swift, American Chemistry Council, January 2007). In fact, much of modern antiseptic practice depends on the use of disposable plastic materials, which are petroleum-based. Petroleum is used to make lubricants, gels, rubbing alcohol, gowns, toothbrushes, sterile wrapping, and countless other medical supplies.

Figure 4. Examples of petroleum-based medical supplies[a–d]

Petroleum jelly	Bandages	Syringes
Radiological dyes	Birth-control devices	Tubing
Rubbing alcohol	Eyeglasses/soft contacts	Vaporizers
Skin balms	Hearing aids	Blood bags
Speculum probes	Heart valves	Splints
Prosthetics	Stethoscopes	Oxygen masks

[a]Johnston C. Modern medicine and fossil fuel resources [cited 2008 May 8]. Available from: URL: http://mysite.verizon.net/vze495hz/id19.html

[b]Illinois Oil and Gas Association. Petroleum products in our daily lives [cited 2008 May 8]. Available from: URL: http://www.ioga.com/Special/PetroProducts.htm

[c]Need Project. Petroleum. Intermediate energy infobook, 2007 [cited 2008 May 8]. Available from: URL: http://www.need.org/needpdf/infobook_activities/IntInfo/Petro1.pdf

[d]Health Care Without Harm. Alternatives to polyvinyl chloride (PVC) and di(2-ethylhexyl) phthalate (DEHP) medical devices [cited 2008 May 8]. Available from: URL: http://www.noharm.org/details.cfm?type=document&id=591

Given the dependence of medical supplies on petroleum, scarcity would result in rising prices and, in the case of abrupt interruptions of supply, possible shortages of some supplies. During the 1973 oil crisis, plastic syringe manufacturers reported shortfalls in benzene and ethylene feedstocks, increased prices, and delayed delivery of product to end users.[51] More recently, for items as prosaic as Band-Aids®, rising petroleum prices have been reflected in rising purchase prices,[52–54] a trend likely to continue with petroleum scarcity.

Transportation

The major use of petroleum is for transportation. If there are shortfalls in petroleum supply, then health functions that require transportation may be interrupted. If petroleum is expensive, then health costs related directly or indirectly to transportation will rise.

Transportation plays a direct role in health care and public health in many ways. Some clinical services depend directly upon transportation, including ambulances, medical evacuation helicopters, and aircraft that deliver organs for transplantation. Many public health services are equally dependent upon transportation. For example, restaurant inspectors, rodent control personnel, and visiting nurses must travel throughout their communities to perform their duties.

Health workers who commute by automobile need access to gasoline. In the event of a short-term interruption of gasoline supplies, as occurred in 1973 and 1979, personnel shortages at health-care facilities may be expected. Similarly, patients who travel to health facilities in personal vehicles may have difficulty if gasoline is unavailable, or if prices rise beyond their reach. In rural areas, for example, long travel distances to clinics and pharmacies have been identified as a barrier to care,[55,56] and have been associated with a range of adverse outcomes such as asthma mortality,[57] less cancer screening,[58] suboptimal breast cancer treatment,[59,60] and higher cancer mortality.[61] Treatment regimens that require repeated clinical encounters—in fields ranging from dermatology to physical therapy, from renal dialysis to drug addiction treatment, and from prenatal care to mental health—could be affected.[62] Health facilities depend on transportation of people and goods in many other ways—the service personnel who visit a hospital to repair a computer terminal or a computerized axial tomography scanner, the food distributor whose trucks deliver food products to the hospital cafeteria, and the wholesaler whose trucks bring cleaning supplies, toilet paper, and soap. Interruptions in these and other services may occur at times of a petroleum shortfall. These challenges will be more marked in rural and suburban areas, where travel is relatively more automobile-dependent, than in urban areas, where mass transit and non-motorized travel (walking and bicycling) can replace motor vehicles.

Finally, transportation costs are "embedded" in the costs of many health-care products. Supplies and equipment that are shipped long distances to market will become more costly as transportation prices rise. This will contribute to rising health-care costs.

Energy generation and heating

Electrical energy in the U.S. is generated predominantly from coal (52%), nuclear reactors (21%), natural gas (14%), and renewable sources such as hydroelectric power and wind (9%); petroleum accounts for only 3% of electrical energy production.[4] Therefore, petroleum scarcity is unlikely to have a major direct impact on electric power generation. However, policy makers and utility companies may turn to coal to replace some of the energy currently derived from petroleum. For example, electric or hydrogen vehicles might replace gasoline-powered automobiles, and the energy for these new technologies is likely to come from coal-fired power plants. This could result in substantial increases in air pollution loads, including particulate matter, hydrocarbons, and oxides of sulfur and nitrogen, which could in turn threaten public health.[63] It would also result in increased carbon dioxide emissions, contributing to climate change.

Hospitals maintain emergency power supply systems as backup sources of power.[64] These are typically generators that use natural gas or diesel fuel.[65,66] Shortfalls of petroleum could jeopardize these backup energy systems. Moreover, hospitals in cold climates could face dramatic increases in the cost of heating oil in the event of petroleum scarcity. Following the 1979 oil shock, hospital costs for fuel oil rose substantially.[67] In 1981, for example, it was reported that Hartford Hospital's annual fuel oil budget had climbed from $100,000 to $1.7 million in 20 years.[68]

Effects on agriculture

Global food production has increased dramatically since the 1950s thanks to technical advances collectively known as the Green Revolution.[69] Several components defined the Green Revolution: mechanization, irrigation, agrochemicals, and the development of new strains of plants.

Each of these innovations, with the exception of new seed strains, is heavily dependent on petroleum. For example, the enormous harvesters that permit large-scale farming, the irrigation systems that deliver water to otherwise arid land, and the trucks that deliver produce from California to the East Coast, all run on petroleum-based fuel. The two major categories of agrochemicals are pesticides and fertilizers. Pesticides are widely used to control insects and other pest species; pesticide manufacturing is heavily dependent on petroleum feedstocks.[70] Fertilizers provide fixed nitrogen, an essential component of plant growth, far more efficiently than soil bacteria (often associated with the roots of legumes) can provide it. Fertilizer is manufactured through the energy-intensive Haber-Bosch process, using electricity, and the hydrogen molecules that are fixed to nitrogen come from a fossil fuel—coal, oil, or, more recently, natural gas. Scarcity of petroleum and natural gas will increase the price of both pesticides and fertilizers. The same is true of other nitrogen-based agricultural chemicals, such as the urea used in cattle feed.[71]

Food travels long distances from farm to market. A large share (by volume) of the U.S. diet is imported—an estimated 32% of fruits and nuts, 13% of vegetables, 10% of meats, 79% of fish and shellfish, 11% of wheat, 11% of rice, and 16% of wine and beer during the period 2000–2005.[72] The concept of "food miles" captures and quantifies this phenomenon.[73] Various analyses have calculated the "weighted average source distance" produce travels to U.S. consumers' tables as between 1,346 and 1,500 miles.[74] The transport costs associated with this travel are included in food prices.

For these reasons, modern agriculture has been described as "eating fossil fuels."[75,76] Food contains large amounts of "embodied energy"—the energy in the fertilizers, pesticides, machinery, and transportation that underlie food production and shipment.[77] One pound of lettuce contains 80 calories of food energy, but to grow, wash, package, and transport it from a California field to an East Coast market requires more than 4,600 calories of fossil fuel energy—or more than 50 calories of fossil fuel energy in for every calorie of food energy out.[71]

The central role of petroleum in agriculture and the central role of adequate food for health suggest that petroleum scarcity may affect health via this pathway. Agricultural impacts will manifest differently in different regions. In wealthy nations such as the U.S., the food supply is generally adequate, but about 11% of households—12.6 million households—are food-insecure, meaning that they have difficulty at some time during the year in providing enough food for all their members due to lack of resources.[78] Because food production in wealthy countries relies heavily on agrochemicals, mechanization, and long-distance transport, it is keenly sensitive to petroleum cost and availability. As a result, petroleum scarcity could seriously compromise food production. As prices rise, wealthier people are likely to cope, but the level of food insecurity may increase among those with fewer resources.

In poor nations, the food supply is far more precarious, and petroleum scarcity could have severe consequences. On the other hand, less mechanized agriculture and less use of agrochemicals suggest less dependence on petroleum, and perhaps greater resiliency to petroleum scarcity. The stakes are high. Worldwide, more than 850 million people are chronically hungry, nearly all of them in poor countries, and almost one in four of them is a child.[79] In Africa, one in four children is underweight as the result of undernutrition.[80] The cases of North Korea and Cuba are instructive.

North Korea experienced an abrupt shortage of petroleum and petrochemicals following the collapse of the Soviet Union between 1989 and 1991. No longer supplied with petroleum from donor nations, and unable to purchase it with hard currency, the nation suffered a drastic decline in agricultural output. Visitors during the 1990s described farm equipment and irrigation systems idle for lack of fuel, and critical shortages of fertilizer and pesticides. This petroleum scarcity, together with other problems such as obsolete equipment and flooding, caused a nearly 60% reduction in the output of rice and maize, the two staple crops. Although reliable data are unavailable, up to several million people (of a population of 22 million) were thought to have died in the resulting famine, and child malnutrition was widespread.[81–85]

A contrasting example is Cuba, which also lost access to subsidized petroleum and agrichemical imports following the fall of the Soviet Union. Imports of petroleum and farm chemicals declined by at least 50%. In response, agricultural production shifted from a highly mechanized, monocultural system to a low-input approach. Crop diversification and rotation were promoted. Cuba became a world leader in integrated pest management and in the use of biofertilizers, such as bacteria that fix nitrogen and that liberate phosphorus for uptake by plants. Production and storage were moved closer to urban areas to reduce transport costs. Urban agriculture was promoted, including personal gardening and farms within urban areas. Animals such as oxen were used to replace tractors. These techniques, together with policy changes such as reduced centralized price controls, resulted in a rebound in production.[86–88]

These examples illustrate both the potentially catastrophic results of petroleum scarcity on agriculture and the possibility of adaptive change. In coming decades, the impact of petroleum scarcity on agriculture will be complicated by other pressures, including climate change,[42,89–91] market demand for biofuels that will inflate some commodity prices,[92] and land degradation.[93] While it is difficult to project quantitatively the impact of petroleum scarcity on agricultural production, limits to the Green Revolution are likely to intensify hunger in some locations and therefore threaten health.

Other effects on health

Other effects on health are more speculative, but experience and evidence suggest several considerations. First, ripple effects of peak petroleum through the economy may cause significant economic slowdown, as occurred after the oil shocks of the 1970s. In this circumstance, employers may cut back on health-care benefits, increasing the ranks of the uninsured. This would have broad implications for health, and would place considerable strain on the public health system and on emergency departments.

A second possible impact is on mental health. The effects of peak petroleum will be far-reaching and disruptive, featuring alterations in transportation, food, and other familiar aspects of life. Rapid social change is a source of considerable stress.[94,95] Economic transitions,[96] disturbances such as the farm crisis of the 1980s,[97] displacement,[98] and acute disasters[99,100] have resulted in well-documented mental health burdens. This potential aspect of the transition through peak petroleum should be anticipated.

A third possible health impact is armed conflict. Resource scarcity, including petroleum scarcity, has been described as a potential trigger of regional wars,[23,101,102] and war poses multiple risks to public health.[103]

Equity considerations

Health disparities, defined by race, socioeconomic status, ethnic background, and other factors, characterize many aspects of public health.[104,105] Contributing to these health disparities are disparities in environmental exposures. Poor people, members of ethnic minorities, and other subpopulations are disproportionately likely to sustain dangerous environmental exposures and to be deprived of access to health-promoting environments. This fact has given rise to "environmental justice" as a core concept in the environmental health field.[106,107] Eliminating health disparities is a compelling goal for public health professionals.[108,109]

Many of the consequences of peak petroleum will fall disproportionately on at-risk populations, especially those who are poor. Rising fuel prices will place a special burden on poor drivers; this may be compounded by long commutes for those who cannot find affordable housing near where they work, and by aging vehicles with poor fuel efficiency. Similarly, upward pressure on natural gas prices will place a special burden on poor people confronting rising home utility bills. "Fuel poverty" is defined as when a household spends more than 10% of its income on home heating;[110] a similar concept may emerge for transportation.

But rising petroleum prices will also affect poor people indirectly, through rising prices for food, clothing, medications, and other consumer goods for which petroleum is a key input. If rising petroleum prices are accompanied by a broader economic downturn, as has been predicted,[10,11,20] then low-wage workers may be at disproportionate risk of job loss, loss of associated benefits such as health care, home foreclosure, and other negative impacts. These disproportionate impacts need to be anticipated and addressed.

THE PUBLIC HEALTH RESPONSE

The health-care and public health systems have confronted the possibility of fuel shortages previously. In the late 1970s and early 1980s, following the 1973 and 1979 oil crises, hospitals and health agencies discussed the need for "energy contingency planning."[111] A national organization, the National Alliance for Energy Contingency Planning for Health Resources, was formed in 1980, convening hospitals, hospital systems, suppliers, energy consultants, government agencies, insurers, health system agencies, and utility companies. One concern was that national and state gasoline rationing plans developed at the time generally gave priority to ambulances, but made no provision for supplying health-care workers.[112]

York Hospital, in Pennsylvania, purchased and filled a 4,500-gallon gasoline storage tank, and planned to allocate fuel to employees based on the distance they lived from the hospital. In Pittsburgh, hospitals made arrangements with the county transportation authority to rent buses to bring employees to work in the event of a gasoline shortage, and arranged for employees to have purchasing priority in gasoline stations. Hospitals also anticipated shortages of fuel oil, as utility companies were expected to assume that hospitals had independent generating ability. However, energy contingency plans were generally not implemented because the fuel supply rebounded quickly after 1979, the National Alliance for Energy Contingency Planning for Health Resources no longer exists, and few hospitals currently maintain such plans.

Looking forward, the health-care and public health systems need to anticipate and prepare for petroleum scarcity. Preparedness is a standard approach in public health, applied to exigencies as diverse as pandemic influenza, bioterrorism, and natural disasters. In fact, preparedness for peak petroleum can build on existing systems such as comprehensive emergency management planning and continuity of operations planning. Examples include the multisectoral planning for peak petroleum undertaken by Portland, Oregon,[113] and public health planning for peak petroleum in Marion County, Indiana.[114]

Primary prevention—interrupting a hazardous exposure or vaccinating against an infectious disease—is a preferred strategy in meeting public health challenges. With respect to peak petroleum, the options for primary prevention are limited. Conservation measures will prolong the available supply of petroleum, allowing more time for the transition to occur and blunting the impacts of petroleum scarcity on public health. Such measures generally lie outside the health sector, in the ambit of policy makers in energy, transportation, urban planning, and other domains. However, health scientists may provide scientific evaluation of various conservation measures, and health planners may implement conservation measures within the health sector. In lieu of primary prevention, much of the health response will consist of secondary and tertiary prevention, or adaptation—anticipating and controlling the health impacts of petroleum scarcity.

Initial steps include forecasting and scenario-building. At least two kinds of scenarios need to be developed, corresponding to acute and chronic shortages. Brief interruptions of fuel may occur for periods of days to weeks, and the efforts of the early 1980s can serve as a starting point for planning. Long-term petroleum scarcity, in contrast, will unfold over years or even decades, and there are few precedents. Health professionals need to carry out some of this work within the health sector, but much of it needs to be implemented in conjunction with experts in energy, transportation, urban planning, and related fields.

Data collection—linking traditional public health surveillance with other information such as travel and food data—will help promptly identify emerging trends from shortages of supplies to health burdens, so these can be addressed early. Partnerships are essential. (Portland's Peak Oil Task Force included an architect, an energy-efficiency expert, a public health professional, and a farmer, among others.[113]) Communication and education—also core public health functions—will be essential to convey solutions to members of the public and to policy makers. As solutions are developed, they will feature several common themes. One is the importance of efficiency—reducing unnecessary travel, conserving energy, and reducing waste. These strategies will help blunt the impact of peak petroleum, but they will also yield co-benefits including greater physical activity, climate change mitigation, financial savings, and reduced environmental pollution.[115] Redundancy, especially in vulnerable systems and supply chains, will help avert critical system failures and shortages. And localization—identifying local sources of products and services, to control prices and to avert interruptions of supply—emerges as an important strategy.

Anticipating, preparing for, and adapting to peak oil will require a broad program of research across the health sector. Quantitative modeling and scenario-building, as currently used in planning public health responses to infectious disease pandemics, terrorist attacks, and other challenges,[116,117] can be applied to peak petroleum. This research can help identify vulnerabilities, localize and quantify the effects of petroleum scarcity, and guide preparedness and adaptation activities. Many adaptation strategies, from innovative product development to alternative pharmaceutical synthetic pathways, need to be supported by applied research. Communication research is also important to determine the most effective ways to inform the public and policy makers about appropriate health protection measures. Finally, as adaptation plans are developed, they need to be tested, refined, and retested.

ADDRESSING HEALTH IMPACTS

The following sections address specific responses to the four aspects of health and health care discussed previously: supplies and equipment, transportation, energy, and agriculture.

Medical supplies and equipment

Short-term interruptions of petroleum may cause shortages of critical medical supplies. Planners should assess which supplies are most vulnerable to such interruptions and consider stockpiling those supplies. In addition, contingency planning can identify ways to cope with temporary shortages of supplies, such as sterilizing and reusing certain supplies. Specifying such plans in advance will permit empirical testing to assure safety and efficacy.

Long-term adaptation to scarce, expensive petroleum will involve replacing petroleum with other materials. There may be increased roles for traditional materials such as glass and for synthetic materials not derived from petroleum. Major manufacturers such as DuPont are investigating biomaterials such as carbohydrates to replace oil and gas as molecular building blocks. These products have promise for applications as diverse as rigid plastics and surgical bioglues.[118] Similarly, the pharmaceutical industry should consider developing alternative synthetic pathways for key medications, beginning with non-petroleum feedstocks, testing and verifying these pathways, and seeking regulatory approval in advance of when they are needed.

Transportation

Short-term interruptions of petroleum may seriously disrupt transportation. Planners should anticipate this possibility, using conventional continuity of operations methods. Contingency planning should address fuel rationing for essential health-care needs such as emergency vehicles and perhaps workforce commuting, mass transit, or other alternative means of moving people and supplies; temporary housing for health-care personnel at their workplaces; mobile health-care facilities to bring services to populations in need; recruiting retired health-care workers for temporary duty; and temporary suspension of nonessential functions.

Long-term adaptation to scarce, expensive petroleum will involve reducing transportation demand and changing transportation methods. Transportation demand can be reduced by locating health-care facilities near where patients live,[119] linking these facilities with mass transit, and relying on electronic communication to deliver some health-care services (although the electronic divide raises concerns about health disparities). For example, rural patients may receive prescribed medications at their clinics or physician offices rather than having to travel to pharmacies, an approach that has been shown to reduce travel demand associated with health care.[120] Similarly, health-care personnel may need to live near their workplaces, and perhaps in some cases reside at health-care facilities, recalling the original meaning of physician training through "residencies." Mass transit, increased reliance on walking and bicycling, and telecommuting may all help health workers carry out their duties with less travel. Health facilities may bring on-site some activities currently performed in remote locations, such as laundry services. Similarly, they may identify local sources of goods and services, such as locally grown food, to avoid the rising costs of long-distance shipping. Finally, health facilities may increase their investment in teleconferencing to reduce the need for staff to travel to distant meetings.

Shifting transport from motor vehicles to other modes of travel—mass transit, bicycling, and walking—could yield substantial health benefits apart from reduced petroleum reliance. More physical activity, reduced air pollution, and reduced traffic-related injuries and fatalities are all beneficial to the public's health. For example, decreased motor vehicle use reduced child pedestrian fatalities in New Zealand after the 1973 oil crisis[121] and childhood asthma attacks during the 1996 Atlanta summer Olympic Games.[122]

Energy

Short-term interruptions of petroleum may deprive hospitals and other health facilities of heating oil. Hospitals should consider stockpiling this fuel, and should plan for reduced use with such methods as turning thermostats down and closing parts of facilities.

Long-term adaptation to scarce, expensive petroleum will involve reducing energy demand and shifting to alternative energy sources. For example, heating oil may be replaced by biodiesel. Energy conservation measures in health-care facilities should include better insulation, more energy-efficient lighting and appliances, use of natural lighting, automatic shutoffs of lights and other equipment, and less use of heating and air-conditioning.[123] Two other resources—Green Guide for Health Care and Hospitals for a Healthy Environment—offer ideas for shifting to alternative energy sources.[124,125] These measures not only help adapt to petroleum scarcity, but they also offer environmental and economic benefits for facilities that implement them.

Agriculture

A sudden interruption of the petroleum supply could affect the delivery of food to health-care institutions. Institutions should assess their vulnerability to such interruptions and consider contingency plans, such as stockpiling food and water. In the long term, adapting to scarce, expensive petroleum may require profound changes in food production, including distributed, small-scale agriculture and increased reliance on locally grown foods, crop rotation to curtail fertilizer use, integrated pest management to reduce pesticide use, and nonmechanized methods of planting, harvesting, and processing foods.[126,127] Health facilities may anticipate these changes by identifying local food sources and shifting toward these sources in their food purchasing.

CONCLUSIONS

At some point early in the 21st century, likely well before midcentury, petroleum production will peak and then begin to decline. This will lead to rising prices for petroleum and for the many goods and services whose production and transport depend on petroleum. This transition will have far-reaching impacts on society, and the health sector will not be immune. Within the health sector, direct and indirect effects will be felt on medical supplies and equipment, transportation, energy, and food. Anticipation and planning, consistent with standard approaches to public health preparedness, can help adapt to these changes and minimize adverse effects on health. Health professionals need to anticipate, prepare for, reduce, and adapt to the effects of petroleum scarcity to protect public health in the coming decades.

The authors thank the following people for their input: Dan Bednarz, PhD (Energy & Health Care Consultants, Pittsburgh, Pennsylvania); Carol Henry, PhD, and Thomas Kevin Swift, PhD (American Chemistry Council, Arlington, Virginia); Richard Pariza, PhD (Cedarburg Pharmaceuticals, Grafton, Wisconsin); and Jeffrey Siirola, PhD (Eastman Chemical Company, Kingsport, Tennessee). None of these people received any compensation for contributing to this article.

An abbreviated version of this article was published as: Frumkin H, Hess J, Vindigni S. Peak petroleum and public health. JAMA 2007;298:1688-90.

The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry.

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