Revisiting the Limits to Growth After Peak Oil

In the 1970s a rising world population and the finite resources available to support it were hot topics. Interest faded—but it's time to take another look

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In recent decades there has been considerable discussion in academia and the media about the environmental impacts of human activity, especially those related to climate change and biodiversity, but far less attention has been paid to the diminishing resource base for humans. Despite our inattention, resource depletion and population growth have been continuing relentlessly. The most immediate of these issues appears to be a decline in oil reservoirs, a phenomenon commonly referred to as "peak oil" because global production appears to have reached a maximum and is now declining. However, a set of related resource and economic issues are continuing to come home to roost in ever greater numbers and impacts—so much so that author Richard Heinberg speaks of "peak everything." We believe that these issues were set out well and basically accurately by a series of scientists in the middle of the last century and that events are demonstrating that their original ideas were mostly sound. Many of these ideas were spelled out explictly in a landmark book called *The Limits to Growth,* published in 1972.

In the 1960s and 1970s, during our formative years in graduate school, our curricula and our thoughts were strongly influenced by the writings of ecologists and computer scientists who spoke clearly and eloquently about the growing collision between increasing numbers of people—and their enormously increasing material needs—and the finite resources of the planet. The oil-price shocks and long lines at gasoline stations in the 1970s confirmed in the minds of many that the basic arguments of these researchers were correct and that humans were facing some sort of limits to growth. It was extremely clear to us then that the growth culture of the American economy had limits imposed by nature, such that, for example, the first author made very conservative retirement plans in 1970 based on his estimate that we would be experiencing the effects of peak oil just about the time of his expected retirement in 2008.

These ideas have stayed with us, even though they largely disappeared, at least until very recently, from most public discussion, newspaper analyses and college curricula. Our general feeling is that few people think about these issues today, but even most of those who do so believe that technology and market economics have resolved the problems. The warning in *The Limits to Growth*—and even the more general notion of limits to growth—are seen as invalid.

Even ecologists have largely shifted their attention away from resources to focus, certainly not inappropriately, on various threats to the biosphere and biodiversity. They rarely mention the basic resource/human numbers equation that was the focal point for earlier ecologists. For example, the February 2005 issue of the journal *Frontiers in Ecology and the Environment* was dedicated to "Visions for an ecologically sustainable future," but the word "energy" appeared only for personal "creative energy"—and "resources" and "human population" were barely mentioned.

But has the limits-to-growth theory failed? Even before the financial collapse in 2008, recent newspapers were brimming with stories about energy- and food-price increases, widespread hunger and associated riots in many cities, and various material shortages. Subsequently, the headlines have shifted to the collapse of banking systems, increasing unemployment and inflation, and general economic shrinkage. A number of people blamed at least a substantial part of the current economic chaos on oil-price increases earlier in 2008.

Although many continue to dismiss what those researchers in the 1970s wrote, there is growing evidence that the original "Cassandras" were right on the mark in their general assessments, if not always in the details or exact timing, about the dangers of the continued growth of human population and their increasing levels of consumption in a world approaching very real material constraints. It is time to reconsider those arguments in light of new information, especially about peak oil.

Early Warning Shots

A discussion of the resource/population issue always starts with Thomas Malthus and his 1798 publication *First Essay on Population*:

> I think I may fairly make two postulata. First, that food is necessary to the existence of man. Secondly, that the passion between the sexes is necessary, and will remain nearly in its present state.… Assuming then, my postulata as granted, I

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Figure 1. The global population has doubled in the last four decades, as exemplified in this crowded market in India. Although some regions suffer from poverty, the world has avoided widespread famine mostly through the increased use of fossil fuels, which allows for greater food production. But what happens when we run out of cheap oil? Predictions made in the 1970s have been largely ignored because there have not been any serious fuel shortages up to this point. However, a reexamination of the models from 35 years ago finds that they are largely on track in their projections.

> say, that the power of population is indefinitely greater than the power in the earth to produce subsistence for man. Population, when unchecked, increases in a geometrical ratio. Subsistence increases only in an arithmetical ratio. A slight acquaintance with numbers will shew the immensity of the first power in comparison of the second.

Most people, including ourselves, agree that Malthus's premise has not held between 1800 and the present, as the human population has expanded by about seven times, with concommitant surges in nutrition and general affluence—albeit only recently. Paul Roberts, in *The End of Food,* reports that malnutrition was common throughout the 19th century. It was only in the 20th century that cheap fossil energy allowed agricultural productivity sufficient to avert famine. This argument has been made many times before—that our exponential escalation in energy use, including that used in agriculture, is the principal reason that we have generated a food supply that grows geometrically as the human population has continued to do likewise. Thus since Malthus's time we have avoided wholesale famine for most of the Earth's people because fossil fuel use also expanded geometrically.

The first 20th-century scientists to raise again Malthus's concern about population and resources were the ecologists Garrett Hardin and Paul Ehrlich. Hardin's essays in the 1960s on the impacts of overpopulation included the famous "Tragedy of the Commons," in which he discusses how individuals tend to overuse common property to their own benefit even while it is disadvantageous to all involved. Hardin wrote other essays on population, coining such phrases as "freedom to breed brings ruin to all" and "nobody ever dies of overpopulation," the latter meaning that crowding is rarely a direct source of death, but rather results in disease or starvation,

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Figure 2. A village on one of Bangladesh's coastal islands was devastated by a cyclone in 1991, in which a total of more than 125,000 people were killed. Large storms had caused destruction in 1970, and would again in 2006. Although people in areas such as these are aware of the risk, overcrowding often prevents them from moving to safer regions.

which then kill people. This phrase came up in an essay reflecting on the thousands of people in coastal Bangladesh who were drowned in a typhoon. Hardin argued that these people knew full well that this region would be inundated every few decades but stayed there anyway because they had no other place to live in that very crowded country. This pattern recurred in 1991 and 2006.

Ecologist Paul Ehrlich argued in *The Population Bomb* that continued population growth would wreak havoc on food supplies, human health and nature, and that Malthusian processes (war, famine, pestilence and death) would sooner rather than later bring human populations "under control" down to the carrying capacity of the world. Meanwhile agronomist David Pimentel, ecologist Howard Odum and environmental scientist John Steinhart quantified the energy dependence of modern agriculture and showed that technological development is almost always associated with increased use of fossil fuels. Other ecologists, including George Woodwell and Kenneth Watt, discussed people's negative impact on ecosystems. Kenneth Boulding, Herman Daly and a few other economists began to question the very foundations of economics, including its dissociation from the biosphere necessary to support it and, especially, its focus on growth and infinite substitutability—the idea that something will always come along to replace a scarce resource. These writers were part and parcel of our graduate education in ecology in the late 1960s.

Meanwhile Jay Forrester, the inventor of a successful type of computer random-access memory (RAM), began to develop a series of interdisciplinary analyses and thought processes, which he called system dynamics. In the books and papers he wrote about these models, he put forth the idea of the coming difficulties posed by continuing human population growth in a finite world. The latter soon became known as the limits-to-growth model (or the "Club of Rome" model, after the organization that commissioned the publication). The models were refined and presented to the world by Forrester's students Donella Meadows and Dennis Meadows and their colleagues. They showed that exponential population growth and resource use, combined with the finite nature of resources and pollution assimilation, would lead to a serious decline in the material quality of life and even in the numbers of human beings.

At the same time, geologist M. King Hubbert predicted in 1956 and again in 1968 that oil production from the coterminous United States would peak in 1970. Although his predictions were dismissed at the time, U.S. oil production in fact peaked in 1970 and natural gas in 1973.

These various perspectives on the limits to growth seemed to be fulfilled in 1973 when, during the first energy crisis, the price of oil increased from $3.50 to more than $12 a barrel. Gasoline increased from less than $0.30 to $0.65 per gallon in a few weeks while available supplies declined, because of a temporary gap of only about 5 percent between supply and projected demand. Americans became subject for the first time to gasoline lines, large increases in the prices of other energy sources, and double-digit inflation with a simultaneous contraction in

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Figure 3. In 1979 motorists were forced to line up for rationed gasoline during a period of oil-price shocks and reduced production. Such events were compelling support for the argument that the world's population could be limited by a finite amount of natural resources.

total economic activity. Such simultaneous inflation and economic stagnation was something that economists had thought impossible, as the two were supposed to be inversely related. Home heating oil, electricity, food and coal also became much more expensive. Then it happened again: Oil increased to $35 a barrel and gasoline to $1.60 per gallon in 1979.

Some of the economic ills of 1974, such as the highest rates of unemployment since the Great Depression, high interest rates and rising prices, returned in the early 1980s. Meanwhile, new scientific reports came out about all sorts of environmental problems: acid rain, global warming, pollution, loss of biodiversity and the depletion of the Earth's protective ozone layer. The oil shortages, the gasoline lines and even some electricity shortages in the 1970s and early 1980s all seemed to give credibility to the point of view that our population and our economy had in many ways exceeded the ability of the Earth to support them. For many, it seemed like the world was falling apart, and for those familiar with the limits to growth, it seemed as if the model's predictions were beginning to come true and that it was valid. Academia and the world at large were abuzz with discussions of energy and human population issues.

Our own contributions to this work centered on assessing the energy costs of many aspects of resource and environmental management, including food supply, river management and, especially, obtaining energy itself. A main focus of our papers was *energy return on investment* (EROI) for obtaining oil and gas within the United States, which declined substantially from the 1930s to the 1970s. It soon became obvious that the EROI for most of the possible alternatives was even lower. Declining EROI meant that more and more energy output would have to be devoted simply to getting the energy needed to run an economy.

The Reversal

All of this interest began to fade, however, as enormous quantities of previously discovered but unused oil and gas from outside the U.S. were developed in response to the higher prices and then flooded into the country. Most mainstream economists, and a lot of other people too, did not like the concept that there might be limits to economic growth, or indeed human activity more generally, arising from nature's constraints. They felt that their view was validated by this turn of events and new gasoline resources.

Mainstream (or neoclassical) economics is presented mostly from the perspective of "efficiency"—the concept that unrestricted market forces seek the lowest prices at each juncture, and the net effect should be the lowest possible prices. This would also cause all productive forces to be optimally deployed, at least in theory.

Economists particularly disliked the perspective of the absolute scarcity of resources, and they wrote a series of scathing reports directed at the scientists mentioned above, especially those most closely associated with the limits to growth. Nuclear fusion was cited as a contender for the next source of abundant, cheap energy. They also found no evidence for scarcity, saying that output had been rising between 1.5 and 3 percent per year. Most importantly, they said that economies had built-in, market-related mechanisms (the invisible hand of Adam Smith) to deal with scarcities. An important empirical study by economists Harold J. Barnett and Chandler Morse in 1963 seemed to show that, when corrected for inflation, the prices of all basic resources (except for forest products) had not increased over nine decades. Thus, although there was little argument that


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Figure 4. In drought-stricken southeast Ethiopia, displaced people wait for the official distribution of donated water. Children who try to make off with the resource hours ahead of the appointed time are chased off by a man with a cane. Such incidents demonstrate that water is another resource often available only in limited quantities.

parameter	predicted	actual
population	6.9 billion	6.7 billion
birth rate per 1,000 people	29	20
death rate per 1,000 people	11	8.3
values vs. 1970 levels (set at 1.0)		
	predicted	**actual**
resources	0.53	
copper		0.5
oil		0.5
soil		0.7
fish		0.3
pollution	3.0	
CO_2		2.1
nitrogen		2
per capita industrial output	1.8	1.9

Figure 5. The values predicted by the limits-to-growth model and actual data for 2008 are very close. The model used general terms for resources and pollution, but current, approximate values for several specific examples are given for comparison. Data for this long a time period are difficult to obtain; many pollutants such as sewage probably have increased more than the numbers suggest. On the other hand, pollutants such as sulfur have largely been controlled in many countries.

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Figure 6. Oil is not the only resource that may have peaked, with use outstripping the Earth's ability to support the level of consumption. In Sardinia, off the coast of Italy, commercial fishermen's catches are down by 80 percent compared to what their fathers used to haul in.

the higher-quality resources were being depleted, it seemed that technical innovations and resource substitutions, driven by market incentives, had and would continue indefinitely to solve the longer-term issues. It was as if the market could increase the quantity of physical resources in the Earth.

The new behavior of the general economy seemed to support their view. By the mid-1980s the price of gasoline had dropped substantially. The enormous new Prudhoe Bay field in Alaska came online and helped mitigate to some degree the decrease in production of oil elsewhere in the U.S., even as an increasing proportion of the oil used in America was imported. Energy as a topic faded from the media and from the conversations of most people. Unregulated markets were supposed to lead to efficiency, and a decline in energy used per unit of economic output in Japan and the U.S. seemed to provide evidence for that theory. We also shifted the production of electricity away from oil to coal, natural gas and uranium.

In 1980 one of biology's most persistent and eloquent spokesmen for resource issues, Paul Ehrlich, was "trapped," in his words, into making a bet about the future price of five minerals by economist Julian Simon, a strong advocate of the power of human ingenuity and the market, and a disbeliever in any limits to growth. The price of all five went down over the next 10 years, so Ehrlich (and two colleagues) lost the bet and had to pay Simon $576. The incident was widely reported through important media outlets, including a disparaging article in the *New York Times Magazine.* Those who advocated for resource constraints were essentially discredited and even humiliated.

So indeed it looked to many as though the economy had responded with the invisible hand of market forces through price signals and substitutions. The economists felt vindicated, and the resource pessimists beat a retreat, although some effects of the economic stagnation of the 1970s lasted in most of the world until about 1990. (They live on still in places such as Costa Rica as unpaid debt from that period.) By the early 1990s, the world and U.S. economies basically had gone back to the pre-1973 model of growing by at least 2 or 3 percent a year with relatively low rates of inflation. Inflation-corrected gasoline prices, the most important barometer of energy scarcity for most people, stabilized and even decreased substantially in response to an influx of foreign oil. Discussions of scarcity simply disappeared.

The concept of the market as the ultimate objective decider of value and the optimal means of generating virtually all decisions gained more and more credibility, partly in response to arguments about the subjectivity of decisions made by experts or legislative bodies. Decisions were increasingly turned over to economic cost-benefit analysis where supposedly the democratic collective tastes of all people were reflected in their economic choices.

For those few scientists who still cared about resource-scarcity issues, there was not any specific place to apply for grants at the National Science Foundation or even the Department of Energy (except for studies to improve energy efficiency), so most of our best energy analysts worked on these issues on the weekend, after retirement or *pro bono.* With very few exceptions graduate training in energy analysis or limits to growth withered. The concept of limits did live on in various environmental issues such as disappearing rain forests and coral reefs, and global climate change. But these were normally treated as their own specific problems, rather than as a more general issue about the relationship between population and resources.

A Closer Look

For a distinct minority of scientists, there was never any doubt that the economists' debate victory was illusory at best, and generally based on incomplete information. For example, Cutler J. Cleveland, an environmental scientist at Boston University, reanalyzed the Barnett and Morse study in 1991 and found that the only reason that the prices of commodities had not been increasing—even while their highest quality stocks were being depleted—was that for the time period analyzed in the original study, the real price of energy had been declining because of the exponentially increasing use of oil, gas and coal, whose real prices were simultaneously declining. Hence, even as more and more energy was needed to win each unit of resources, the price of the resources did not increase because the price of energy was declining.

Likewise, when the oil shock induced a recession in the early 1980s, and Ehrlich and Simon made their bet, the relaxed demand for all resources led to lower prices and even some increase in the quality of the resources mined, as only the highest-grade mines were kept open. But in recent years energy prices increased again, demand for materials in Asia soared and the prices of most minerals increased dramatically. Had Ehrlich made his bet with Simon over the past decade, he would have made a small fortune, as the price of most raw materials, including the ones they bet on, had increased by 2 to 10 times in response to huge demand from China and declining resource grades.

Another problem is that the economic definition of efficiency has not been consistent. Several researchers, including the authors, have found that energy use—a factor that had not been used in economists' production equations—is far more important than capital, labor or technology in explaining the increase in industrial production of the U.S., Japan and Germany. Recent analysis by Vaclav Smil found that over the past decade the energy efficiency of the Japanese economy had actually decreased by 10 percent. A number of analyses have shown that most agricultural technology is extremely energy intensive. In other words, when more detailed and systems-oriented analyses are undertaken, the arguments become much more complex and ambiguous, and show that technology rarely works by itself but instead tends to demand high resource use.

Likewise oil production in the U.S. has declined by 50 percent, as predicted by Hubbert. The market did not solve this issue for U.S. oil because, despite the huge price increases and drilling in the late 1970s and 1980s, there was less oil and gas production then, and there has been essentially no relation between drilling intensity and production rates for U.S. oil and gas since.

There is a common perception, even among knowledgeable environmental scientists, that the limits-to-growth model was a colossal failure, since obviously its predictions of extreme pollution and population decline have not come true. But what is not well known is that the original output, based on the computer technology of the time, had a very misleading feature: There were no dates on the graph between the years 1900 and 2100. If one draws a timeline along the bottom of the graph for the halfway point of 2000, then the model results are almost exactly on course some 35 years later in 2008 (with a few appropriate assumptions). Of course, how well it will perform in the future when the model behavior gets more dynamic is not yet known. Although we do not necessarily advocate that the existing structure of the limits-to-growth model is adequate for the task to which it is put, it is important to recognize that its predictions have not been invalidated and in fact seem quite on target. We are not aware of any model made by economists that is as accurate over such a long time span.

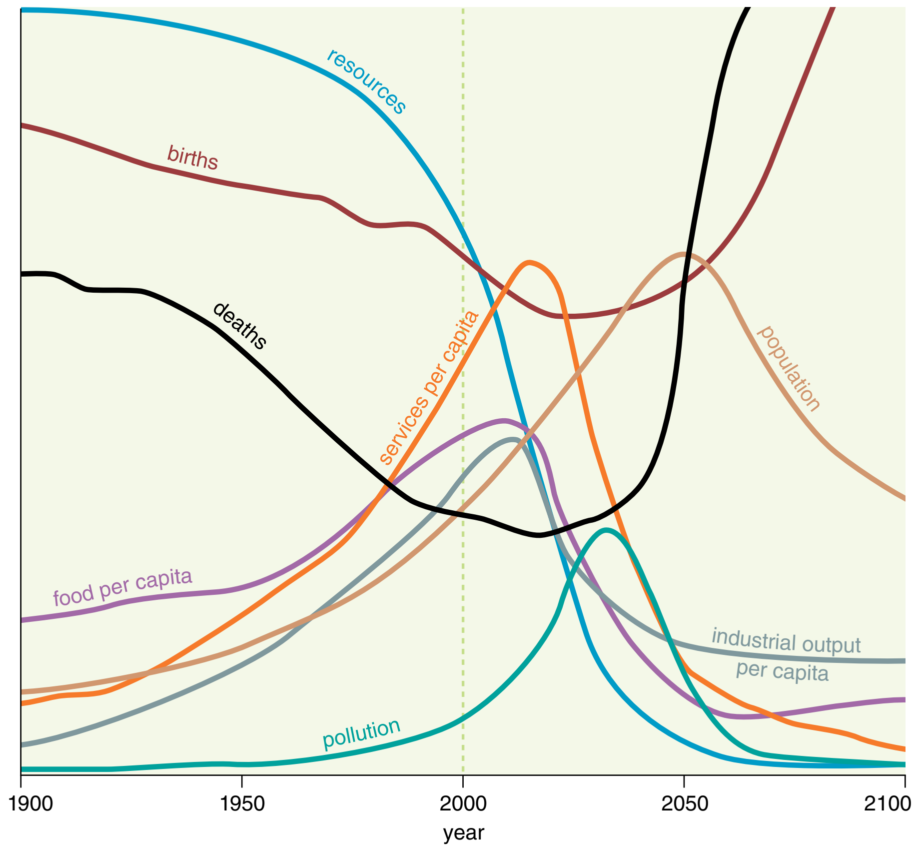

Figure 7. The original projections of the limits-to-growth model examined the relation of a growing population to resources and pollution, but did not include a timescale between 1900 and 2100. If a halfway mark of 2000 is added, the projections up to the current time are largely accurate, although the future will tell about the wild oscillations predicted for upcoming years.

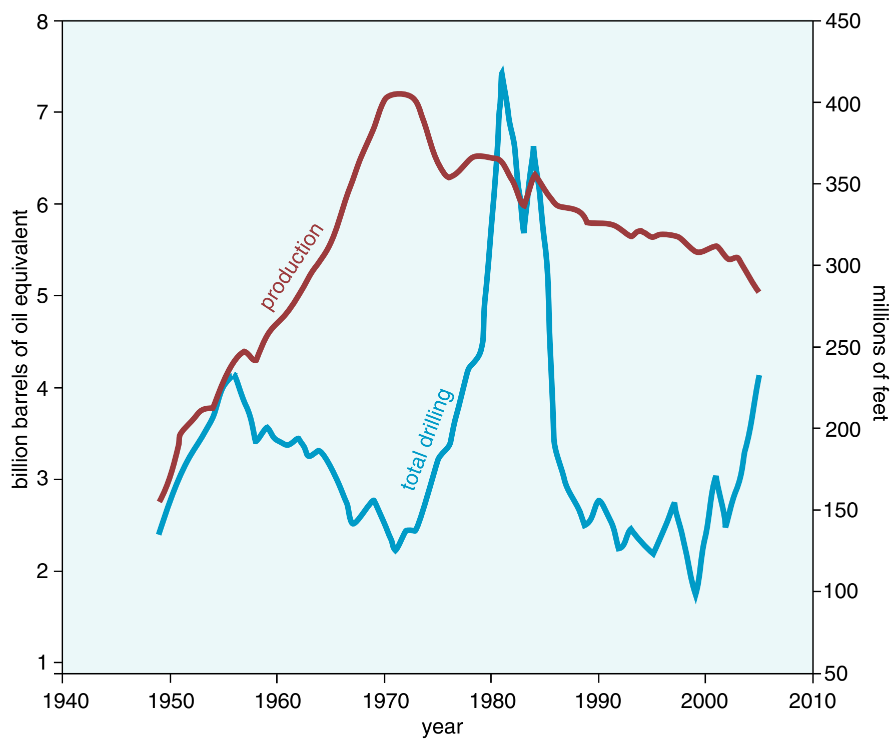

Figure 8. The annual rates of total drilling for oil and gas in the United States from 1949 to 2005 are shown versus the rates of production for the same period. If all other factors are kept equal, EROI is lower when drilling rates are high, because oil exploration and drilling are energy-intensive activities. The EROI may now be approaching 1:1 for finding new oil fields.

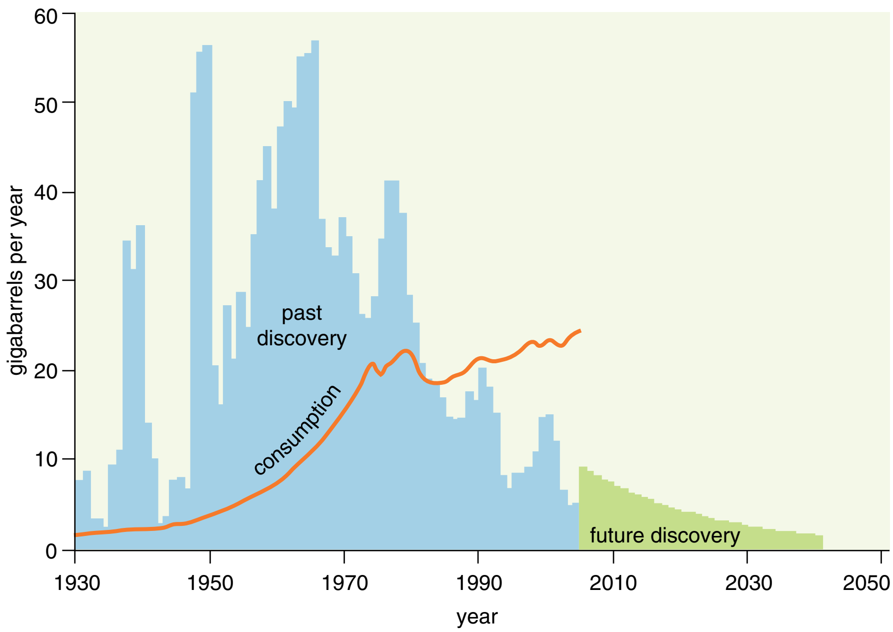

Figure 9. The rate at which oil is discovered globally has been dropping for decades *(blue)*, and is projected to drop off even more precipitously in future years *(green)*. The rate of worldwide consumption, however, is still continuing to rise *(red line)*. Thus, the gap between supply and demand of oil can be expected to widen. Data courtesy of the Association for the Study of Oil and Gas.

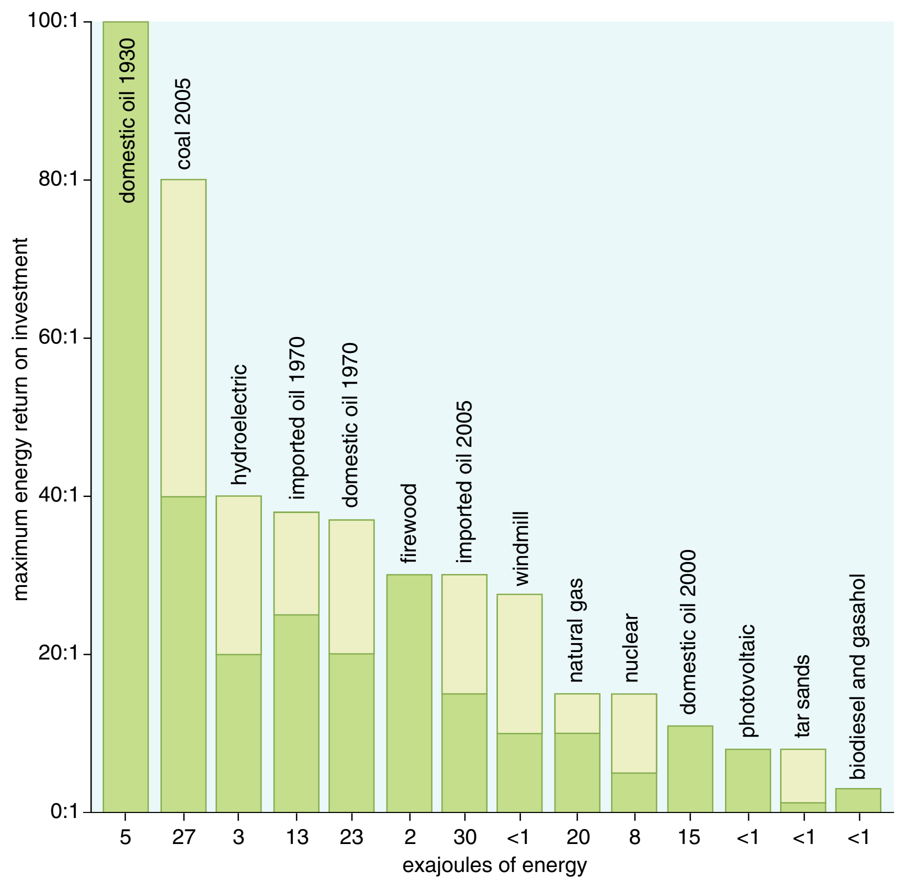

Figure 10. The energy return on investment (EROI) is the energy cost of acquiring an energy resource; one of the objectives is to get out far more that you put in. Domestic oil production's EROI has decreased from about 100:1 in 1930, to 40:1 in 1970, to about 14:1 today. The EROI of most "green" energy sources, such as photovoltaics, is presently low. (Lighter colors indicate a range of possible EROI due to varying conditions and uncertain data.) EROI does not necessarily correspond to the total amount of energy in exajoules produced by each resource.

Avoiding Malthus

Clearly even the most rabid supporter of resource constraints has to accept that the Malthusian prediction has not come true for the Earth as a whole, as human population has increased some seven times since Malthus wrote his article, and in many parts of the world it continues to grow with only sporadic and widely dispersed starvation (although often with considerable malnutrition and poverty). How has this been possible?

The most general answer is that technology, combined with market economics or other social-incentive systems, has enormously increased the carrying capacity of the Earth for humans. Technology, however, is a two-edged sword, whose benefits can be substantially blunted by *Jevons's paradox,* the concept that increases in efficiency often lead to lower prices and hence to greater consumption of resources.

And technology does not work for free. As originally pointed out in the early 1970s by Odum and Pimentel, increased agricultural yield is achieved principally through the greater use of fossil fuel for cultivation, fertilizers, pesticides, drying and so on, so that it takes some 10 calories of petroleum to generate each calorie of food that we eat. The fuel used is divided nearly equally between the farm, transport and processing, and preparation. The net effect is that roughly 19 percent of all of the energy used in the United States goes to our food system. Malthus could not have foreseen this enormous increase in food production through petroleum.

Similarly, fossil fuels were crucial to the growth of many national economies, as happened in the United States and Europe over the past two centuries, and as is happening in China and India today. The expansion of the economies of most developing countries is nearly linearly related to energy use, and when that energy is withdrawn, economies shrink accordingly, as happened with Cuba in 1988. (There has been, however, some serious expansion of the U.S. economy since 1980 without a concomitant expansion of energy use. This is the exception, possibly due to the U.S.'s outsourcing of much of its heavy industry, compared to most of the rest of the world.) Thus, most wealth is generated through the use of increasing quantities of oil and other fuels. Effectively each person in the United States and

Europe has on average some 30 to 60 or more "energy slaves," machines to "hew their wood and haul their water," whose power output is equal to that of many strong people.

Thus a key issue for the future is the degree to which fossil and other fuels will continue to be abundant and cheap. Together oil and natural gas supply nearly two-thirds of the energy used in the world, and coal another 20 percent. We do not live in an information age, or a post-industrial age, or (yet) a solar age, but a petroleum age. Unfortunately, that will soon end: It appears that oil and gas production has reached, or soon will reach, a maximum. We reached that point for oil in the U.S. in 1970 and have also now reached it in at least 18, and probably the majority, of the 50 most significant oil-producing nations. The important remaining questions about peak oil are not about its existence, but rather, when it occurs for the world as a whole, what the shape of the peak will be and how steep the slope of the curve will be as we go down the other side.

The other big question about oil is not how much is left in the ground (the answer is a lot) but how much can be extracted at a significant energy profit. The EROI of U.S. petroleum declined from roughly 100:1 in 1930, to 40:1 in 1970, to about 14:1 in 2000. Even these figures are relatively positive compared to EROI for finding brand-new oil in the U.S., which, based on the limited information available, appears likely to approach 1:1 within a few decades.

Historically most of the oil supplies in the world were found by exploring new regions for oil. Very large reservoirs were found rather quickly, and most of the world's oil was found by about 1980. According to geologist and peak-oil advocate Colin Campbell, "The whole world has now been seismically searched and picked over. Geological knowledge has improved enormously in the past 30 years and it is almost inconceivable now that major fields remain to be found."

Energy Scarcity

The world today faces enormous problems related to population and resources. These ideas were discussed intelligently and, for the most part, accurately in many papers from the middle of the last century, but then they largely disappeared from scientific and public discussion, in part because of an inaccurate understanding of both what those earlier papers said and the validity of many of their predictions. Most environmental science textbooks focus far more on the adverse impacts of fossil fuels than on the implications of our overwhelming economic and even nutritional dependence on them. The failure today to bring the potential reality and implications of peak oil, indeed of peak everything, into scientific discourse and teaching is a grave threat to industrial society.

The concept of the possibility of a huge, multifaceted failure of some substantial part of industrial civilization is so completely outside the understanding of our leaders that we are almost totally unprepared for it. For large environmental and health issues, from smoking to flooding in New Orleans, evidence of negative impacts has historically preceded general public acceptance and policy actions by several decades.

There are virtually no extant forms of transportation, beyond shoe leather and bicycles, that are not based on oil, and even our shoes are now often made of oil. Food production is very energy intensive, clothes and furniture and most pharmaceuticals are made from and with petroleum, and most jobs would cease to exist without petroleum. But on our university campuses one would be hard pressed to have any sense of that beyond complaints about the increasing price of gasoline, even though a situation similar to the 1970s gas shortages seemed to be unfolding in the summer and fall of 2008 in response to three years of flat oil production, assuaged only when the financial collapse decreased demand for oil.

No substitutes for oil have been developed on anything like the scale required, and most are very poor net energy performers. Despite considerable potential, renewable sources (other than hydropower or traditional wood) currently provide less than 1 percent of the energy used in both the U.S. and the world, and the annual increase in the use of most fossil fuels is generally much greater than the total production (let alone increase) in electricity from wind turbines and photovoltaics. Our new sources of "green" energy are simply increasing along with (rather than displacing) all of the traditional ones.

If we are to resolve these issues, including the important one of climate change, in any meaningful way, we need to make them again central to education at all levels of our universities, and to debate and even stand up to those who negate their importance, for we have few great intellectual leaders on these issues today. We must teach economics from a biophysical as well as a social perspective. Only then do we have any chance of understanding or solving these problems.

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