CHAPTER 7

From Empty World to Full World

Given the undeniable importance of entropy to the economic process, and the resulting fact that "sustainable economic growth" is an oxymoron,[1] how do we explain the unwavering devotion to continuous economic growth by economists, policy makers, and the general public in the face of ecological and natural resource limits? Apparently, people believe that the economic system faces no limits to growth or that the limits are far off. The laws of thermodynamics ensure that there are limits to growth. Now we must briefly address the question of how close those limits are.

Certainly for most of human history, including the time when modern economic theory was being developed, human populations and levels of resource use were quite low. Material and energetic limits to growth appeared so far off that it seemed sensible to ignore them and concentrate on developing a system that efficiently allocated the much scarcer labor, capital, and consumer goods. But since the development of market economies and neoclassical explanations thereof, both human populations and per-capita levels of resource use have been increasing exponentially. The success of the market system reduced the relative scarcity of market goods and increased that of nonmarket goods and services provided by the

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[1] To reiterate, we do not believe that sustainable growth of the "psychic flux" of satisfaction (what we would call development, not growth) is an oxymoron as long as that flux is not produced by ever-increasing natural resource consumption. However, as far as we know, economic growth as measured by GDP has never occurred without increased throughput. Even when each unit of GNP requires fewer resources, the net outcome has always been greater throughput. While this need not be the case, the free market economy seems poorly suited for promoting the activities that provide improved human well-being without increasing throughput.

BOX 7-1 HOW CLOSE ARE WE TO A FULL WORLD?

Exponential growth occurs when a system keeps growing at a certain rate. For example, from 1900 to 2000, the per-capita material output of the global economy grew at about 2.3% per year. As a rule of thumb, one can calculate the doubling time of a given growth rate by dividing 72 by that growth rate. This means that per-capita output doubled more than three times during the twentieth century, an increase of more than ninefold. Over the same period, the human population has increased from 1.6 billion to 6.1 billion, almost a fourfold increase. The total increase in material output has increased more than 36 times this century.[a] How many more times can our material output double?

Our situation may have parallels to a well-known riddle. If the area of a petri dish covered in bacteria doubles every hour, you inoculate the dish at noon on day one and it is completely full at noon two days later (and thereafter the population crashes because it has exhausted its food source and inundated the petri dish with waste), when is the dish half full? The answer, of course, is at 11 A.M. on the final day. At 9 A.M., ⅞ of the resources available for continued growth are still present. The question right now for humans is: How close is it to noon?

Humans, of course, are very different from bacteria, and the Earth is different from a petri dish. Humans can control their rate of reproduction and, to an extent, the quantity of resources they use. The Earth hosts numerous ecosystems capable of providing renewable resources and processing wastes. However, human adaptation to resource scarcity requires taking time to develop new technologies, new institutions, and new ways of thinking—perhaps a great deal of time. Essentially, the closer it is to noon, the less time we have to develop and implement the necessary changes to show that we actually are substantially different from bacteria in a petri dish. (See figure 7.1.)

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[a] *Calculations by author from data found in Chapter 5 of J. B. Delong,* Macroeconomics, *Burr Ridge, IL: McGraw-Hill Higher Education, 2002.*

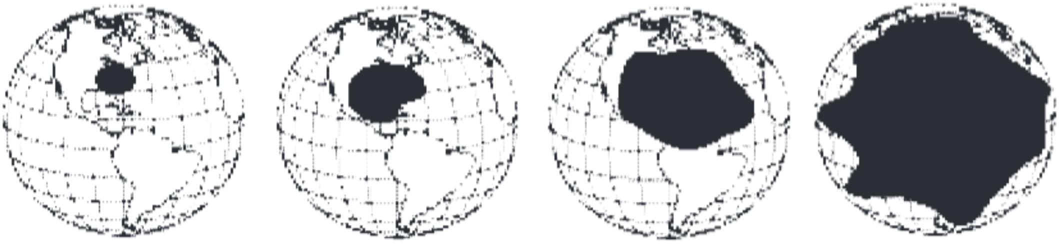

Figure 7.1 • How close are we to a full world?

sustaining system. What follows is a very quick assessment of how full the world is and how close we are to resource exhaustion.

> **THINK ABOUT IT!**
> *The world is always "full" of some things and "empty" of others. In the "full world," what is it that the world is relatively full of? Relatively empty of? How is the fullness with respect to some things related to the emptiness with respect to others?*

FOSSIL FUELS

As fossil fuels run the world economy and are among the most well studied of the resources required to sustain us, we will assess their limits first. At first glance, exhaustion hardly seems imminent. Economists tell us that price is a measure of scarcity, yet the price of crude oil averaged $18.63 per barrel between 1869 and the present (in 1996 dollars) and is scarcely any different today.[2] However, as we mentioned earlier, we can extract fossil fuels at virtually any rate we want, and it is the scarcity of flow that determines prices, not the scarcity of stocks (a point we return to in Chapter 11). In the regions with the vastest reserves, installed extraction capacity, more than the size of underground stocks, determines flow rates. Best estimates suggest that if we continue to extract oil at the same rate, we will exhaust probable stocks in about 40 years, yet the Energy Information Administration estimates that global demand for oil will increase by 50% over the next 20 years.[3] As we said above, the net energy returns to fossil fuel exploration are declining dramatically. The same is true for new discoveries, which peaked in 1962 at 40 billion barrels per year[4] and fell to 6 billion barrels per year in the 1990s. Consumption currently stands at 26 billion barrels per year, exceeding new discovery rates by a factor of 2 to 4.[5] While the rate of increase in global oil consumption began to decline after 1973, the world still used over twice as much oil since 1970

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[2] WTRG Economics, 2000. Online: http://www.wtrg.com/prices.htm.

[3] Energy Information Administration, 2002. Online: http://www.eia.doe.gov/oiaf/aeo/aeotab_21.htm. Figure of 50% increase is from 2001–2020.

[4] J. J. MacKenzie, Oil as a Finite Resource: When Is Global Production Likely to Peak? World Resources Institute, 2000. Online: http://www.wri.org/wri/climate/jm_oil_000.html.

[5] When a new oil field is discovered, it is very difficult to say exactly how much oil exists. Also, some sources report increased estimates of recoverable oil from a previously discovered source as a new discovery, while others do not; thus the discrepancy in estimates. MacKenzie (ibid.) cites a 2:1 ratio for 1996, and L. F. Ivanhoe cites a 6:1 ratio for major discoveries during the 1990s. Hubbert Center Newsletter # 2002/2, M. King Hubbert Center for Petroleum Supply Studies, Petroleum Engineering Department, Colorado School of Mines, Golden, CO, 2002.

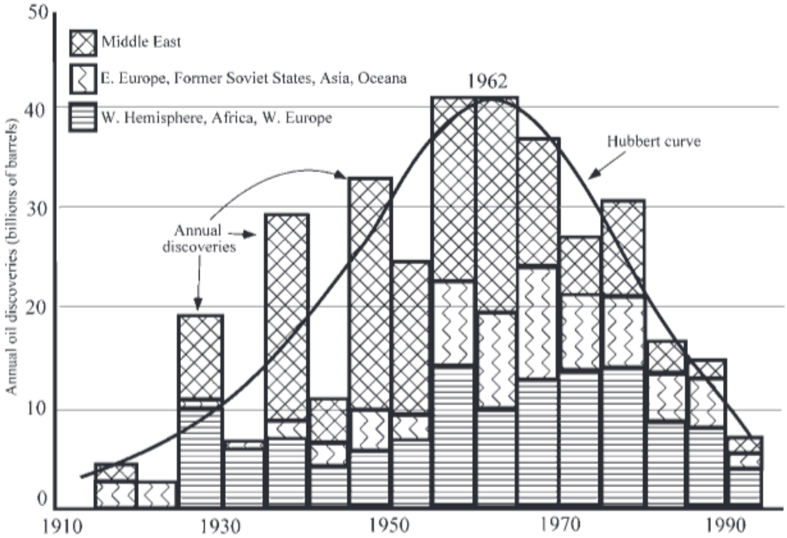

Figure 7.2 • A. Hubbert curve for oil discovery. The bars represent the average amount of crude oil discovered worldwide during each 5-year period from 1912 to 1992. The line known as the Hubbert curve is the weighted average of global oil discovered from 1915 to 1992. (Source: Adapted from L. F. Ivanhoe, King Hubbert, updated. Hubbert Center Newsletter # 97/1. Online: http://hubbert.mines.edu/news/v97n1/mkh-new2.html.)

than for all of human history prior to 1970.[6] What is the net result of all this?

M. King Hubbert, while working as a petroleum geologist for Shell Oil Company, developed a theory of nonrenewable resource extraction, graphically depicted in the **Hubbert curve**. Figure 7.2 shows a Hubbert curve for oil discoveries using actual data, and Figure 7.3 shows a Hubbert curve for oil production using estimates of future production. In 1954, Hubbert used this theory to predict that oil production in the U.S. would peak in between 1967 and 1971—a prediction that was treated with considerable skepticism. In reality, it peaked in 1970. Using this same methodology, leading industry experts are now predicting that oil production will peak sometime between 2003 and 2020. Peak production follows peak discovery with a time lag, and global oil discoveries have been in fairly steady decline since their 1962 peak. As oil demand continues to grow and production peaks then declines, prices will skyrocket. While oil exhaustion may not be imminent, the end of the era of cheap oil is.[7]

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[6] The area under the curve in Figure 7.3 shows total oil production, which is almost identical to consumption. You can see that the area under the curve from 1973 to the present is nearly two and a half times greater than that from 1869 to 1973.

[7] C. J. Campbell and J. H. Laherrère, The End of Cheap Oil, *Scientific American*, March 1998.

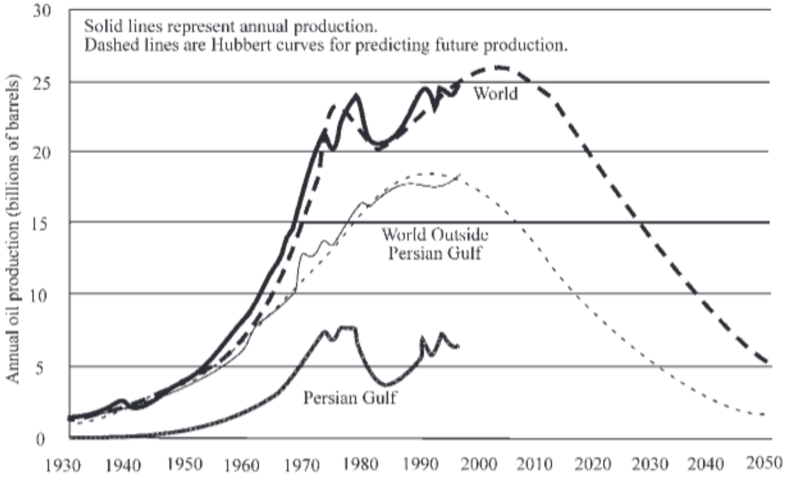

Figure 7.3 • **A Hubbert curve for oil production. Global production of oil, both conventional and unconventional (solid black line), recovered after falling in 1973 and 1979. But a more permanent decline is less than 10 years away, according to the authors' model, based in part on multiple Hubbert curves (dashed lines). A crest in the oil produced outside the Persian Gulf region now appears imminent. (Source: Adapted from C. J. Campbell and J. H. Laherrère, The End of Cheap Oil. *Scientific American*, March 1998.)**

Given the vast supplies of solar power available as a substitute, does it matter if we exhaust oil supplies? Developing solar energy as a substitute will take considerable time, and sophisticated analyses of oil prices accounting for both scarcity and information effects suggest that oil prices may rise suddenly and rapidly.[8] Also, because solar energy strikes the Earth as a fine mist, large areas of land are needed to capture that energy in significant quantities. With current technologies and without disrupting agriculture, forestry, or the environment, the amount of solar energy that could be captured in the U.S. would meet only 20–50% of our current energy demands. And we could not get around this problem simply by using lower-wattage light bulbs. Food production and transportation in the United States currently consumes three times as much hydrocarbon energy as it provides in carbohydrate energy.[9] One grain-fed steer

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[8] D. B. Reynolds, The Mineral Economy: How Prices and Costs Can Falsely Signal Decreasing Scarcity, *Ecological Economics* 31(1): 155–166 (1999).

[9] D. Pimentel and M. Pimentel, Land, Energy and Water: The Constraints Governing Ideal U.S. Population Size, 1995. Online: http://www.npg.org/forum_series/land_energy&water.htm. Negative Population Growth, Inc. Forum Series. Georgescu-Roegen rightly pointed out that the notion of producing carbohydrates from hydrocarbons was absurd, and when this was first presented as an option, he also accurately predicted that we would move in the other direction first. N. Georgescu-Roegen, *The Entropy Law and the Economic Process*. Cambridge, MA: Harvard University Press, 1971. However, in the short-term direct conversion of oil to food might be more efficient than Western agriculture.

"consumes" some 284 gallons of petroleum in the process of becoming our dinner.[10] Returning to animal traction to power our farms would require additional land devoted to fodder to feed the draft animals. With existing technologies, less fossil fuel means less food.

MINERAL RESOURCES

Mineral resources are also growing scarcer. As noted earlier, the richest, most available ores are used first, followed by ores of decreasing quality. We previously used hematite ore from the Mesabi range in Minnesota, which is about 60% pure iron. That ore is now exhausted, and we must use taconite ore, at about 25% pure iron.[11] The situation with other ores is similar. At least metal can be recycled, and other materials are adequate substitutes. If we consider topsoil as a mineral resource, the situation looks more serious. Rates of topsoil depletion in the U.S. are currently 100 times the rate of formation.[12] Globally, experts estimate that 40% of agricultural land is seriously degraded, and this number is as high as 75% in some areas.[13] Currently, the most widely used substitute for declining soil fertility is petroleum-based fertilizers.

WATER

Among the more threatening of the imminent shortages is that of freshwater. While water is the quintessential renewable resource, thanks to the hydrologic cycle, global water consumption has tripled over the last 50 years, and it continues to climb. Humans are pumping rivers dry and mining water from aquifers faster than it can be replenished. While global climate change may lead to a wetter climate overall as increased evaporation leads to increased rainfall, increased evaporation will also dry out the land much more quickly. Many climatologists believe the net result will be intense downpours interspersed with severe drying. In addition, global climate change is likely to affect where water falls, leading overall to greater risks of both flooding and drought.[14]

The dominant use of water (70%) is agriculture, so a water shortage

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[10] M. Pollan, "Power Steer," *New York Times Magazine*, March 31, 2002.

[11] J. Hanson, Energetic Limits to Growth. Online: http://www.dieoff.com/page175.htm. Also appeared in *Energy Magazine*, Spring 1999.

[12] D. Pimentel and M. Pimentel. Land, Energy and Water: The Constraints Governing Ideal U.S. Population Size, 1995. Online: http://www.npg.org/forum_series/land_energy&water.html.

[13] World Resources Institute, *People and Ecosystems: The Fraying Web of Life*. Washington, DC: WRI, 2000.

[14] C. J. Vörösmarty, P. Green, J. Salisbury, and R. B. Lammers. Global Water Resources: Vulnerability from Climate Change and Population Growth, *Science* 289: 284–288 (July 14, 2000).

will likely translate into hunger before thirst. The estimated water deficit (extraction of water greater than the recharge rate) in northern China is 37 billion gallons, which produces enough food to feed 110 million people.[15] The Ogallala aquifer in the United States has turned the arid western plains into a breadbasket, but it is being depleted at a rapid rate. In some areas the irrigation potential has already been depleted, and tens of thousands of additional acres will lose irrigation over the next 20 years at current depletion rates.[16]

The use of river water for irrigation has already led to one of the planet's worst environmental catastrophes in the Aral Sea. In every continent, important aquifers are falling at rates between 2–8 m per year.[17] Currently, about 1.2 billion people lack access to potable drinking water,[18] less than one-third of the world's population enjoys abundant water supplies,[19] and some studies suggest that nearly 50% of the world's population will be living in water shortage areas by 2025.[20] The World Bank warns that continued reduction in aquifers could prove catastrophic.[21] *Fortune* magazine suggests that water shortages will make water the oil of the twenty-first century, "the precious commodity that determines the wealth of nations."[22]

Projections concerning future water supplies are highly uncertain. First, we lack adequate data.[23] Second, consumption patterns and technology can dramatically change the demand for water. Third, as mentioned, climate change can have serious impacts on the hydrologic cycle, increasing evaporation rates and changing rainfall patterns.[24]

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[15] L. Brown, Water Deficits Growing in Many Countries: Water Shortages May Cause Food Shortages. Earth Policy Institute, Eco-Economy Updates, August 6, 2002.

[16] M. Glantz, ed., 1989: Forecasting by Analogy: Societal Responses to Regional Climatic Change. Summary Report, Environmental and Societal Impacts Group NCAR, 1989. Summary based on a study by D. A. Wilhite, Center for Agricultural meteorology and Climatology, University of Nebraska, Lincoln. Online: http://www.meteor.iastate.edu/gccourse/issues/society/ogallala/ogallala.html; also http://www.uswaternews.com/archives/arcsupply/7staco14.html.

[17] L. Brown, Water Deficits Growing in Many Countries. Earth Policy Institute, Eco-Economy Updates, August 6, 2002. Online: http://www.earth-policy.org/Updates/Update15.html.

[18] U.N. Department for Policy Coordination and Sustainable Development, Critical Trends: Global Change and Sustainable Development. New York: United Nations, 1997.

[19] Vōrōsmarty et al., op. cit.

[20] L. Burke, Y. Kura, K. Kassem, C. Revenga, M. Spalding, and D. Mcallister. Pilot Analysis of Global Ecosystems: Coastal Ecosystems. Washington, D.C.: WRI, 2000.

[21] Brown, op. cit. Online: http://www.earth-policy.org/Updates/Update15.html.

[22] N. Currier, *The Future of Water under Discussion at "21st Century Talks."* United Nations Chronicle, on-line edition Volume XL, Number 1 2003. Online: http://www.un.org/Pubs/chronicle/2003/webArticles/013003_future_of_water.html.

[23] *Science* 297(5583): 926–927 (August 9, 2002).

[24] Vōrōsmarty et al., op. cit.

RENEWABLE RESOURCES

The fact that we live in a full world is even more obvious when it comes to "renewable" resource stocks. For virtually every renewable stock of significance, the rate of extraction is limited by resource scarcity, not by a lack of adequate infrastructure. It is a shortage of fish, not fishing boats, that has stagnated fish harvests over the last few years. The Food and Agriculture Organization (FAO) of the United Nations estimates that 11 of the world's 15 major fishing areas and 69% of the world's major fish species are in decline and in need of urgent management. For instance, cod catches dropped by 69% from 1968 to 1992. West Atlantic bluefin tuna stocks dropped by more than 80% between 1970 and 1993.[25] Similarly, it is a shortage of trees, not chainsaws, that limits wood production. As commercially valuable species are depleted, we turn to harvesting others that were formerly considered trash. As a result, for both fish and timber, the number of commercially valuable species has increased dramatically over recent decades.

Many economists cite this ability to substitute one species for another as evidence that there are no limits to potential harvests. However, when one fish species is exhausted because too many boats are going after too few fish, the whole fishing fleet is available to deplete any new stocks we may identify. Having virtually exhausted rapidly reproducing species such as cod, we now pursue species such as orange roughy, which may take as long as 30 years to reach sexual maturity. We run the risk of harvesting such species to extinction before we even acquire sufficient data to estimate their sustainable yields.[26]

While there is serious cause for concern for the resource exhaustion of raw material inputs into the economy, these may pale in insignificance when compared to the dangers presented by the depletion and destruction of ecosystem services. Ecosystem services are destroyed directly by the harvest of their structural components, primarily the renewable resources of which they are composed, and less directly by waste emissions. Forest cover is currently being depleted in the poorer countries at the rate of about 140,000 km^2 per year,[27] and if the World Trade Organization's

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[25] FAO of the U.N. Focus: Fisheries and Food Security, 2000. Online: http://www.fao.org/focus/e/fisheries/challeng.htm.

[26] For example, one study found a 60–70% decline in total biomass of one stock of orange roughy in less than 10 years of fishing. P. M. Smith, R. I. C. C. Francis, and M. McVeigh. Loss of Genetic Diversity Due to Fishing Pressure. *Fisheries Research* 10: 309–316, 1991. Cited in M. Lee and C. Safina, The Effects of Overfishing on Marine Biodiversity. A SeaWeb Background Article originally published in *Current: The Journal of Marine Biology*, 1995. Online: http://web.tricountynet.net/~cgclark/marinebiodiversity.htm.

[27] World Resources Institute, People and Ecosystems: The Fraying Web of Life, Washington, DC: WRI, 2000.

efforts to liberalize trade in forest products goes forward as planned, the rate of deforestation is expected to increase.[28] The Ramsar convention on wetlands is an intergovernmental treaty providing a framework for the conservation of wetlands and their resources, yet 84% of the wetlands supposedly protected by the treaty are threatened.[29] While we understand marine ecosystems less than terrestrial ones, it seems unimaginable that healthy fish populations do not play a vital role in these ecosystems and the scarcely understood mechanisms by which they provide ecosystem services. For example, we know that oysters provide the valuable service of filtering entire estuaries and have seen this service drastically reduced in the Chesapeake Bay. Virtually all other ecosystems confront similar threats through depletion of their component stocks.

WASTE ABSORPTION CAPACITY

People have worried about resource exhaustion at least since the time of Malthus, but concern over the excessive accumulation of waste is more recent. Every economic activity produces waste. As humans overwhelm the waste absorption capacity of ecosystems at local and global levels, we suffer in two ways. First, accumulating toxins have direct negative effects on humans. Second, the toxins damage ecosystems and degrade the ecosystem services on which we depend. Accumulating evidence suggests we are overwhelming the waste absorption capacity of the planet for several classes of wastes.

The most prominent category of waste in the news today is CO_2 emissions. In spite of an impressive ability of ecosystems to absorb CO_2, there is irrefutable evidence that it is currently accumulating in the atmosphere, and almost consensus in the scientific community that this will lead to global climate change. International recognition of the seriousness of the problem has led to international discussions, but at the time of this writing, the world's worst emitter of greenhouse gases has refused to participate in international accords. Even if the United States did participate, the reductions proposed under the Kyoto protocol would fail to limit CO_2 emissions to the waste absorption capacity of the environment, and would therefore at best merely slow the rate of global warming.[30] In the absence of major changes in human behavior, global warming will have dramatic

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[28] P. Golman and J. Scott, et al. Our Forests at Risk: The World Trade Organization's Threat to Forest Protection. Earthjustice Legal Defense Fund, 1999.

[29] M. Moser, C. Prentice, and S. Frazier. A Global Overview of Wetland Loss and Degradation Conference Proceedings, vol. 10. Online: http://www.ramsar.org/about_wetland_loss.htm.

[30] R. Watson et al. (2001) Climate Change 2001: Synthesis Report. Summary for Policy Makers. Intergovernmental Panel on Climate Change. Online http://www.ipcc.ch/.

impacts on global ecosystems. This is particularly true because so many remaining ecosystems are islands in a sea of humanity, and the species they contain will be unable to leave their islands in response to changing conditions.

No less threatening than global warming are the waste emissions from mineral resources. Heavy metals are highly toxic to humans. As these metals are elements, there is no waste absorption capacity *per se*; once in the environment or in our aquifers, they remain indefinitely. These elements are normally highly diluted in nature or out of reach of living systems; humans have extracted and purified them and released them into the environment in dangerously high concentrations. Many of them tend to bioaccumulate; when ingested, they are not released, so predators retain all that has been consumed by their prey. Many fish species have dangerously high levels of mercury and other metals, which cause human birth defects and worse when consumed, not to mention their impacts on other species.

Nuclear wastes are also elements and far more toxic than the other heavy metals. Nuclear wastes do break down, but not on a human time scale. Plutonium, one of the most toxic substances known, has a half-life of 24,300 years. At minimum, we must sequester such waste for ten times that long—nearly fifty times as long as civilization has existed.

Halogenated hydrocarbons are another class of particularly dangerous manmade mineral wastes. Chorofluorocarbons are the best known and they are now banned. However, other ozone-depleting halogenated hydrocarbons are still being produced. The ozone layer is still growing thinner, and it is not expected to recover until 2050.[31] Ozone depletion threatens not only human health, but also global plant and animal life. The Antarctic ozone hole poses a particularly serious threat to phytoplankton production in the southern seas. In addition to its key role at the bottom of the oceanic food chain, phytoplankton may play an important role in sequestering carbon dioxide, and its depletion may contribute to global warming.[32]

Other halogenated hydrocarbons are classified as persistent organic pollutants (POPs). International negotiators are currently calling for a ban on the most notoriously harmful POPs. These chemicals are now found in every ecosystem on Earth. Among their other negative traits, some of them seem to mimic hormones and are capable of affecting the reproduc-

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[31] U.S. Environmental Protection Agency, Questions and Answers on Ozone Depletion. Online: http://www.epa.gov/docs/ozone/science/q_a.html.

[32] R. C. Smith, B. B. Prezelin, K. S. Baker, R. R. Bidigare, N. P. Boucher, T. Coley, D. Karentz, S. MacIntyre, H. A. Matlick, D. Menzies, M. Ondrusek, Z. Wan, and K. J. Waters. Ozone Depletion: Ultraviolet Radiation and Phytoplankton Biology in Antarctic Waters, *Science* 255: 952–959 (1992).

tive capacity of many species. As their name implies, POPs will continue to persist in the environment for many years to come, in spite of the ban. In the meantime, industry is busy introducing new chemicals, many with a very similar structure to the most toxic ones, at the rate of over 1000 per year. We frequently do not become aware of the negative impacts of these chemicals for years or even decades. And while it may be possible to perform careful studies about the damage caused by a single chemical, outside of the laboratory, ecosystems and humans will be exposed to these chemicals in conjunction with thousands of others.[33]

Pollution in some areas is becoming so severe that it threatens human health, ecosystem function, and even large-scale climate patterns. For example, a recent study has shown that a 3-km-thick layer of pollution over South Asia is reducing the amount of solar energy striking the Earth's surface by as much as 15% in the region, yet preventing heat from the energy that does pass through from leaving. In addition to threatening hundreds of thousands of premature deaths, the pollution cloud is likely to increase monsoon flooding in some areas, while reducing precipitation by as much as 40% in others.[34]

In summary, it would appear that the global sink is becoming full more rapidly than the global sources of natural resources are being emptied. This is understandable in view of the fact that sinks are frequently freely available for anyone to use, that is, they are rival and non-excludable. In contrast, sources are more often rival and excludable resources that are under the discipline of property, either privately or publicly owned and managed.

A rapid assessment of the resources on which the human economy depends suggests that we are now in a full world, where continued physical expansion of the economy threatens to impose unacceptable costs. Whereas historically people have been most worried about resource depletion, the source problem, it appears that the most binding constraint on economic growth may be the waste absorption capacity of the environment, the sink.

BIG IDEAS to remember

- Exponential growth
- Doubling time
- Hubbert curve
- Source and sink limits
- Measures of "fullness" of the world

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[33] A. P. McGinn, Why Poison Ourselves? A Precautionary Approach to Synthetic Chemicals. World Watch Paper 153. Washington, D.C.: World Watch, 2000.

[34] P. Bagia, Brown Haze Looms Over South Asia, *Science* 13 (2002).