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The Liberation of the Environment

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The passage of time has connected the invention of the wheel with more than ten million miles of paved roads around the world today, the capture of fire with six billion tons of carbon going up in smoke annually. Must human ingenuity always slash and burn the environment? This essay and this volume suggest a more hopeful view. Indeed, the liberator of our title is human culture. Its most powerful tools are science and technology. These increasingly decouple our goods and services from demands on planetary resources.

Most observers emphatically designate the present as a period of intense environmental degradation. Surely, human numbers must weigh heavily, and they are highest now. Present world population stands at about 5.7 billion and each month increases by a number equivalent to the population of Sweden, Somalia, or New Jersey.

But for what period should we feel nostalgia? Has there been a golden age of the human environment? When was that age?

- In 1963, before the United States and Soviet Union signed the Limited Test Ban Treaty—after more than four hundred nuclear explosions in the atmosphere?
- In 1945, after much of the forest in Europe had been cut to provide fuel to survive World War II?
- In 1920, when coal provided three quarters of global energy, and choking smogs shrouded London and Pittsburgh?

- In 1870, when the Industrial Revolution boomed without filters in Silesia, Manchester, and Massachusetts?
- In 1859, before Edwin Drake first drew petroleum from an underground pool in Pennsylvania, when hunters slaughtered tens of thousands of whales for three million gallons of sperm oil to light American lamps?
- In the 1840s, when land-hungry farmers, spreading across North America, Australia, and Argentina, broke the plains and speedily shaved the native woods and grasses?
- In 1830, when cholera epidemics in many cities and towns literally decimated the populations that dumped their wastes in nearby waters?
- In 1700, when one hundred thousand mills interrupted the flow of every stream in France?
- In the late 1600s, when dense forests, once filled with a diversity of life, became seas of sugarcane in coastal Brazil and the Caribbean?
- In 1492, before Columbus stimulated reciprocal transatlantic invasions of flora and fauna? (The Old World had no maize, tomatoes, potatoes, green beans, groundnuts, sunflowers, cocoa, cotton, pineapple, vanilla, quinine, or rubber.)
- In the tenth century, before the invention of efficient chimneys, when people in cold climates centered their lives around a fireplace in the middle of a room with a roof louvered high to carry out the smoke—and much of the heat as well?
- In 55 B.C., when Julius Caesar invaded Britain and found less forest than exists today?
- In the centuries from Homer to Alexander, when the forests of the Eastern Mediterranean were cleared?
- Before the domestication of cows, sheep, pigs, and goats, when hunters caused a holocaust of wild creatures?
- In neolithic times, when building a house used up to thirteen tons of firewood to make the plaster for the walls and floor?

Environmental sins and suffering are not new (see, for example, Diamond, 1994; NACLA, 1991; Starbuck, 1964; and Turner et al., 1990). Humans have always exploited the territories within reach. The question is whether the technology that has extended our reach can now also liberate the environment from human impact—and perhaps even transform the environment for the better. My answer is that well-established trajectories, raising the efficiency with which people use energy, land, water, and materials, can cut pollution and leave much more soil unturned. What is more, present cultural conditions favor this movement.

ENERGY

Two central tendencies define the evolution of the energy system, as documented by Nebojša Nakićenović (this volume). One is that the energy system is freeing itself from carbon. The second is rising efficiency.

Carbon matters because it burns; combustion releases energy. But burnt carbon in local places can cause smog and in very large amounts can change the global climate. Raw carbon blackens miners' lungs and escapes from containers to form spills and slicks. Carbon enters the energy economy in the hydrocarbon fuels, coal, oil, and gas, as well as wood. In fact, the truly desirable element in these fuels for energy generation is not their carbon (C) but their hydrogen (H). Wood weighs in heavily at ten effective Cs for each H. Coal approaches parity with one or two Cs per H, while oil improves to two H per C, and a molecule of natural gas (methane) is a carbon-trim CH_4.

The historical record reveals that for two hundred years the world has progressively lightened its energy diet by favoring hydrogen atoms over carbon in our hydrocarbon stew. We can, in fact, measure this *decarbonization* in several different ways. As engineers, we can examine the changing ratio of the tons of carbon in the primary energy supply to the units of energy produced. From this perspective, the long-term, global rate of decarbonization is about 0.3 percent per year—gradual, to be sure, but enough to cut the ratio by 40 percent since 1860.

As economists, we can assess decarbonization as the diminishing requirement for carbon to produce a dollar's worth of economic output in a range of countries. Several factors dispose nations toward convergent, clean energy development. One is the changing composition of economic activity away from primary industry and manufacturing to services. End users in office buildings and homes do not want smoking coals. America has pared its carbon intensity of gross domestic product per capita per constant dollar from about three kilos in 1800 to about three-tenths of a kilo in 1990. The spectrum of national achievements also shows how far most of the world economy is from best practice. The present carbon intensity of the Chinese and Indian economies resembles those of America and Europe at the onset of industrialization in the nineteenth century.

Physical scientists can measure decarbonization in its elemental form, as the evolution of the atomic ratio of hydrogen to carbon in the world fuel mix. This analysis reveals the unrelenting though slow ascendance of hydrogen in the energy market. All the analyses imply that over the next century the human economy will squeeze most of the carbon out of its system and move, via natural gas, to a hydrogen economy (Ausubel, 1991). Hydrogen, fortunately, is the immaterial material. It can be manufactured from something abundant, namely water; it can substitute for most fuels; and its combustion to water vapor does not pollute.

Decarbonization began long before organized research and development in energy, and has continued with its growth. Many ways to continue along this trajectory have been documented. Still, the displacement of carbon remains the largest single environmental challenge facing the planet. Globally, people on average now use 1,000 kilograms of carbon per year compared, for example, to 120 kilograms of steel.

Part of economizing on carbon is economizing on energy more broadly. Efficiency has been gaining in the generation of energy, in its transmission and distribution, and in the innumerable devices that finally consume energy. In fact, the struggle to make the most of our fires dates back at least 750,000 years to the ancient hearths of the Escale cave near Marseilles. A good stove did not emerge until A.D. 1744. Benjamin Franklin's invention proved to be a momentous event for the forests and wood piles of America. The Franklin stove greatly reduced the amount of fuel required. Its widespread diffusion took a hundred years, however, because the colonials were poor, development of manufactures sluggish, and iron scarce (Reynolds and Pierson, 1942).

As Arnulf Grübler explains (this volume), we often fail to appreciate the speed and rhythms of social clocks. Many technological processes require decades or longer to unfold, in part because they cluster in mutually supportive ways that define technological eras every fifty years or so. The good news is that in a few decades most of our devices and practices will change, and major systems can become pervasive in fifty to one hundred years. It is also good news that latecomers to technological bandwagons can learn from the costly experiments of pioneers and that no society need be excluded from the learning. Evolutionary improvement and imitation transform the economy. Two percent per year may sound slow to a politician or entrepreneur, but maintained for a century it is revolutionary.

In energy and other sectors, the efficiency gains may have become more regular as the processes of social learning, embodied in science and technology, have taken root. In the United States since about 1800, the production of a good or service has required 1 percent less energy on average than it did the previous year. Nevertheless, embracing the full chain from the primary energy generator to the final user of light or heat, the ratio of theoretical minimum energy consumption to actual energy consumption for essentially the same mix of goods and services is still probably less than 5 percent (Ayres, 1989). No limit to increasing efficiency is near.

But engineers are working hard and getting results, as Ausubel and Marchetti dramatize (this volume) with a panorama of the past and future of electricity. In about 1700 the quest began to build efficient engines, at first with steam. Three hundred years have increased the efficiency of the devices from 1 to about 50 percent of their apparent limit. The technology of fuel cells may advance efficiency to 70 percent in another fifty years or so. While the struggle to improve generators spans centuries, lamps have brightened measurably with each decade. Edison's first lamp in 1879 offered about fifteen times the efficiency of a paraffin candle. The first fluorescent lamp in 1942 bettered Edison's by thirty times, and the gallium arsenide diode of the 1960s tripled the illumination efficiency of the fluorescent. Moreover, lamps are not the only means for illumination. The next century is likely to reveal quite new ways to see in the dark. For example, nightglasses, the mirror image of sunglasses, could make the night visible with a few milliwatts. We will speed efficiently to what we see. Using the same energy consumed by a present-day car, magnetically levitated trains in low-pressure tubes could carry a passenger several thousand kilometers per hour—connecting Boston and Washington in ten minutes.

LAND

Agriculture is by far the greatest transformer of the environment. Cities, paved roads, and the rest of the built environment cover less than 5 percent of the land in the forty-eight contiguous American states. Crops occupy about 20 percent of this land and pasture 25 percent. Crops cover 35 percent of France and 10 percent of China. Agriculture has consumed forests, drained wetlands, and voided habitats; the game is inherently to favor some plants and animals over others. Farms also feed us.

Yet since mid-century the amount of land used for agriculture globally has remained stable; and, as Paul Waggoner explains (this volume), the stage is set to reduce it. A shift away from eating meat to a vegetarian diet could roughly halve our need for land. More likely, diets will increase in meat and calories; under such conditions, the key will be the continuation of gains in yield resulting from a cluster of innovations including seeds, chemicals, and irrigation, joined through timely information flows and better-organized markets.

In fact, US wheat yields have tripled since 1940, and corn yields have quintupled. Despite these accomplishments, the potential to increase yields everywhere remains astonishing—even without invoking such new technologies as the genetic engineering of plants. The world on average grows only about half the corn per hectare of the average Iowa farmer, who in turn grows only about half the corn of the top Iowa farmer. Importantly, while all have risen steadily for decades, the production ratio of these performers has not changed much. Even in Iowa the average performer lags more than thirty years behind the state of the art. While cautious habits and other factors properly moderate the pace of diffusion of innovations, the effects still accumulate dramatically. By raising wheat yields fivefold during the past four decades, Indian farmers have in practice spared for other purposes an area of cropland roughly equal to the area of the state of California.

What is a reasonable outlook for the land used to grow crops for ten billion people, a probable world population sixty or seventy years hence? Future calories consumed per person will likely range between the 3,000 per day of an ample vegetarian diet and the 6,000 that includes meat. If farmers fail to raise global average yields, people will have to reduce their portions to keep cropland to its current extent. If the farmers can lift the global average yield about 1.5 percent per year over the next six or seven decades to the level of today's European wheat, ten billion people can enjoy a 6,000-calorie diet and still spare close to a quarter of the present 1.4 billion hectares of cropland. The quarter spared, fully

300 million hectares, would equal the area of India. Reaching the level of today's average US corn grower would spare for ten billion people half of today's cropland for nature, an area larger than the Amazon basin—even with the caloric intake of today's American as the diet.

The present realities of large amounts of land in Europe and North America reverting from farm to woodland, and high public subsidies to farmers, make the vision more immediate.[1] Beyond a world of ten billion people, it is not crazy to think of further decoupling food from land. For more green occupations, today's farmers might become tomorrow's park rangers and ecosystem guardians. In any case, the rising yields, spatial contraction of agriculture, and sparing of land are a powerful antidote to the current losses of biodiversity and related environmental ills.

WATER

Watts and hectares are yielding more. What about water? Chauncey Starr (this volume) points out that water is both our most valuable and most wasted resource. In the United States, total per capita water withdrawals quadrupled between 1900 and 1970. Consumptive use increased by one-third between just 1960 and the early 1970s, to about 450 gallons per day. However, since 1975, per capita water use has fallen appreciably, at an annual rate of 1.3 percent (US Geological Survey, 1993). Absolute US water withdrawals peaked about 1980.

Alert to technology as well as costs, industry leads the progress, though it consumes a small fraction of total water. Total industrial water withdrawals plateaued a decade earlier than total US withdrawals and have dropped by one-third, more steeply than the total. Notably, industrial withdrawals per unit of GNP have dropped steadily since 1940, from fourteen gallons per constant dollar to three gallons in 1990. Chemicals, paper, petroleum refining, steel, food processing, and other sectors have contributed to the steep dive (US Geological Survey, 1987). Not only intake but discharge per unit of production are perhaps one-fifth of what they were fifty years ago.

Law and economics as well as technology have favored frugal water use. Legislation, such as the US Clean Water Act of 1972, encouraged the reduction of discharges, recycling, and conservation, as well as shifts in relative prices. Better management of demand reduced water use in the Boston area from 320 million gallons per day in 1978 to 240 million gallons in 1992 (Stakhiv, 1996).

Despite such gains, the United States is a long way from exemplifying the most-efficient practice. Water withdrawals for all users in the industrialized countries span a tenfold range, with the United States and Canada at the highest end (OECD, 1991). Allowing for differences in major uses (irrigation, electrical cooling, industry, public water supply), large opportunities for reductions remain. In the late 1980s wastewaters still made up over 90 percent of measured US hazardous wastes. Importantly, as agriculture contracts spatially, its water demand will likewise tend to shrink.

In the long run, with much higher thermodynamic efficiency for all processes, removing impurities to recycle water will require small amounts of energy. Dialytic membranes open the way to such efficient purification systems. Because hydrogen will be, with electricity, the main energy carrier, its combustion may eventually provide another important source of water, perhaps 50 gallons per person per day at the level of final consumers, or about one-fourth the current withdrawal in water-prudent societies such as Denmark.

MATERIALS

We can reliably project decarbonization, food decoupled from acreage, and more efficient water use. What about an accompanying *dematerialization*? Wernick, Herman, Govind, and Ausubel define (this volume) dematerialization primarily as the decline over time in the weight of materials used to meet a given economic function. This dematerialization too would spare the environment. Lower materials intensity of the economy could translate into preservation of landscapes and natural resources, less garbage to sequester, and less human exposure to hazardous materials.

In fact, the intensity of use of diverse primary materials has plummeted over the twentieth century. Lumber, steel, lead, and copper have lost relative importance, while plastics and aluminum have expanded. Many products—for example, cars, computers, and beverage cans—have become lighter and often smaller. Although the soaring numbers of products and objects, accelerated by economic growth, raised municipal waste in the United States annually by about 1.6 percent per person in the last couple of decades, trash per unit of GDP dematerialized slightly.

The logic of dematerialization is sound. Over time new materials replace old, and theoretically each replacement should improve material properties per unit of quantity, thus lowering the intensity of use. Furthermore, as countries develop, the intensity of use of a given material (or system) declines as each country arrives at a similar level of development. The new arrivals take advantage of learning curves throughout the economy.

But superior materials also tend to make markets grow and thus take a kind of revenge on efficiency, offsetting the environmental benefits of each leaner, lighter object by enabling swarms of them to crowd our shelves. And our shelves lengthen. In Austin, Texas, the residential floor area available per person almost doubled in the past forty-five years—unsurprising when we consider that five people resided in the average US home in 1890 and 2.6 do now.

So far, trends of dematerialization are equivocal. Yet, as Robert Frosch theorizes (this volume), the potential surely exists to develop superior industrial ecosystems that reduce the intensity of materials use in the economy, minimize wastes, and use persisting wastes nutritiously in new industrial food webs. Since 1990 recycling has accounted for over half the metals consumed in the United States, up from less than 30 percent in the mid 1960s (see Wernick and Ausubel, 1995). The trick is to make waste minimization a property of the industrial system even when it is not completely a property of an individual process, plant, or industry. Advancing information networks may help by offering cheap ways to link otherwise unconnected buyers and sellers to create new markets or waste exchanges.

LIBERATION FROM THE ENVIRONMENT

I have focused primarily on trajectories, strategies, and technologies that lessen pollution and conserve landscape. It would hardly make sense to do so unless we wish to expand human notions of the rights of other species to prosper or at least compete. Klaus Michael Meyer-Abich explicitly argues (this volume; see also Meyer-Abich, 1993) that we must stand up for the "co-natural world," with which humans share Earth. We must take seriously the Copernican insight about Earth's position in the cosmos and not simply replace geocentricism with anthropocentricism. As advised by the great early nineteenth-century natural historian Alexander von Humboldt, we should participate in the whole as part of a part of a part of it, together with others. We may draw parallels between expanding notions of democracy and enfranchisement *within* human societies with respect to class, gender, and race, and our broadening view of the ethical standing of trees, owls, and mountains.

Yet the condition for our widespread willingness to take the Copernican turn is surely the successful protections we have achieved for our own health and safety. Recall how deaths from the human environment have changed during the last century or two (Ausubel et al., 1995; McKinlay and McKinlay, 1977).

First, consider "aquatic killers" such as typhoid and cholera, the work of bacteria that thrive in water polluted by sewers. In 1861 Queen Victoria's husband, Prince Albert, died of typhoid fever reportedly contracted from Windsor's water. Indeed, until well into the nineteenth century, townsfolk drew their water from ponds, streams, cisterns, and wells. They threw wastewater from cleaning, cooking, and washing on the ground, into a gutter, or into a cesspool lined with broken stones. Human wastes went into privy vaults—shallow holes lined with brick or stone, close to home, sometimes in the cellar. In 1829, New Yorkers deposited daily about one hundred tons of excrement into the city's soil.

Between 1850 and 1900 the share of the American population in towns grew from about 15 to about 40 percent. The number of cities with populations over fifty thousand grew from ten to more than fifty. Overflowing privies and cesspools filled alleys and yards with stagnant water and fecal wastes. The environment could not be more propitious and convenient for typhoid, cholera, and other water-borne diseases. They reaped 11 percent of all American corpses in 1900.

But by 1900, towns were also building systems to treat their water and sewage. Financing and constructing such facilities took several decades. By 1940 the combination of water filtration, chlorination, and sewage treatment stopped most of the aquatic killers in the United States. Refrigeration in homes, shops, trucks, and railroad boxcars took care of much of the rest. Chlorofluorocarbons (CFCs), the agents in today's thinning of the ozone layer, were introduced in the early 1930s as a safer and more effective substitute for ammonia in refrigerators; the ammonia devices tended to explode.

More killers have come by air, including tuberculosis (TB), diphtheria, influenza and pneumonia, measles, and whooping cough, as well as scarlet fever and other streptococcal diseases. In some years during the 1860s and 1870s, TB was responsible for 15 percent of all deaths in Massachusetts. Earlier in the nineteenth century, diphtheria epidemics accounted for 10 percent of all deaths in some regions of the United States. Influenza A is believed to have caused the Great Pandemic of 1918–1919, when flu claimed about a quarter of all corpses in the United States and probably more in Europe. (My own existence traces directly to this pandemic; my grandfather's first wife and my grandmother's first husband both died in the pandemic, leading to the union that produced my father.)

Collectively, the aerial killers accounted for almost 30 percent of all deaths in America in 1900. Their main allies were urban crowding and unfavorable living and working conditions. The aerial diseases began to weaken a decade later than the aquatics, and then weakened by a factor of seven over thirty years. Credit goes to improvements in the built environment: replacement of tenements and sweatshops with larger and better-ventilated homes and workplaces. Credit is also due to medical interventions. However, many of these, including vaccines and antibiotics, came well after the aerial invaders were already in retreat.

Formerly, most aerial attacks occurred in winter, when people crowded indoors; most aquatic kills occurred in summer, when organic material ferments speedily. Thus, mortality in cities such as Chicago used to peak in summer and winter. In America and other industrialized countries in temperate zones, the twentieth century has seen a dramatic flattening in the annual mortality curve as the human environment has come under control. In these countries, most of the faces of death are no longer seasonal.

Thus, when we speak of technological development and environmental change, it is well to remember first that our surroundings often were lethal. Where development has succeeded and peace holds, we have made the water fresher, the air cleaner, and our shelters more resistant to the violence of the elements. In the United States, perhaps 5 rather than 50 percent of deaths now owe to environmental hazards and factors, including environmentally-linked cancers. The largest global change is that humans—vulnerable, pathetic mammals when naked—have learned how to control their environment. Science and technology are our best strategies for control, and our success is why we now number nearly six billion.

But here is a catch for *homo faber,* the toolmaker. Our technology not only spares resources but also expands the human niche, within particular time frames. As Robert Kates explains (this volume), the intertwining of population, resources, and technology looks quite different depending on the time frame that one uses. From the greatest distance, human population appears to have surged three times. The first was associated with the invention of toolmaking itself, lasted about a million years, and saw human numbers rise to five million. The second surge swelled our population a hundredfold to about five hundred million over the next eight thousand years, following the domestication of plants and animals. Today we are midway into a third great population surge, which may level off at eleven billion or so three to four hundred years after the modern scientific and industrial revolution began.

But if one looks instead at the size of populations of regions over thousands of years, what goes up eventually comes down. In Egypt, Mesopotamia, the Central Basin of Mexico, and the Mayan lowlands, reconstructed population records show waves in which the population at least doubled over a previous base and then at least halved from that high point. Social learning works, but not forever. Societies flourish but they also forget and fail.

Shortening the time scale to recent centuries, we observe above all a systematic change in vital rates. Many countries have passed through the "demographic transition" from high death and birthrates to low death and birthrates. Technology certainly accounts for much of the increase in child survival and longevity, but no one can securely explain the changes in fertility, which ultimately determines the size of humanity. With respect to technology and fertility, the "pill" and its possible successors—while certainly more reliable—do not introduce an essential discontinuity in birth control. Many strategies against conception have always existed; parents have always essentially controlled family size. Though technology can ease implementation, population stabilization is a cultural choice (Marchetti et al., 1996). Fertility rates have been falling in most nations and are below levels needed to replace the current populations in Europe and Japan, which may implode. Perhaps the idea of the small family, which originated in France around the time of the Revolution, will become the norm after 250 years.

Still, recent population growth, which peaked globally at 2.1 percent per year around 1970, is unprecedented. The effect is that in the coming interval of a few decades human society will need to house, nurture, educate, and employ as many more people as already live on Earth. In the present era of lengthening lives and rising numbers, it appears, rather ironically, that our environmental achievement has been to liberate us from the environment.

In fact, high incomes, great longevity, and large population concentrations have been achieved in every class of environment on Earth. We manufacture computers in hot, dry Phoenix and cool, wet Portland. We perform heart surgery in humid Houston and snowy Cleveland. Year round we grow flowers in the Netherlands and vegetables in Belgium. The metro in Budapest runs regardless of the mud that slowed Hungarians for a thousand years. In Berlin and Bangkok we work in climate-controlled office buildings. We have insulated travel, communications, energy generation, food availability, and almost all major social functions from all but the most extreme environmental conditions of temperature and wind, light and dark, moisture, tides, and seasons.

The Japanese have even moved skiing and sand beaches indoors. In the world's largest indoor ski center, Ski-Dome near Tokyo, the slope extends 490 meters by 100 meters, with a thrilling drop of 80 meters that satisfies the standards of the International Ski Federation for parallel slalom competition. On the South Island of Kyushu, Ocean-Dome encloses 12,000 square meters of sandy beach and an ocean six times the size of an Olympic pool, filled with 13,500 tons of unsalted, chlorinated water kept at a warm 28°C. A wave machine produces surf up to three-and-a-half meters high, enough for professional surfing. Palm trees and shipwrecks provide the context.

In fact, careful records of human time budgets show that not only New Yorkers and Indians but also Californians, reputed nature enthusiasts, average only about one-and-a-half hours per day outside (Jenkins et al., 1992). Fewer than 5 percent of the population of industrialized nations work outdoors. In developing countries, the number is plummeting and should be below 20 percent globally by 2050. As Lee Schipper shows (this volume), life-styles revolve around the household. The achievement of ten thousand years of human history is that we have again become cave dwellers—with electronic gadgets.

THE LIBERATION OF THE ENVIRONMENT

For most of history thick forests and arid deserts, biting insects and snarling animals, ice, waves, and heat slowed or stopped humans. We built up our strength. We burned, cut, dammed, drained, channeled, trampled, paved, and killed. We secured food, water, energy, and shelter. We lost our fear of nature, especially in the aggressive West.

But we also secured a new insecurity. Although we have often cultivated the landscape with judgment and taste, we now recognize that we have transformed more than may be needed or prudent. Certainly, we would redo many episodes given the chance, particularly to protect precious habitats.

Some of our most arrogant behavior has been recent. Together the United States and the Soviet Union rocked Earth with close to two thousand nuclear blasts during the Cold War. The French, British, Chinese, and Indians also signaled their presence. The fifty-year bombing spree appears finally to be nearing an end.

Attitudes worldwide toward nature, and perhaps inseparably toward one another as humans, are changing. "Green" is the new religion. Jungles and forests, commonly domains of danger and depravity in popular children's stories until a decade or two ago, are now friendly and romantic. The Amazon has been transformed into a magical place, sanctified by the ghost of Chico Mendes, the Brazilian rubber tapper. Environmental shrines, such as the Great Sarcophagus at Chernobyl, begin to fill the landscape. The characterization of animals, from wolves to whales, has changed. Neither the brothers Grimm nor Jack London could publish today without an uproar about the inhumanity of their ideas toward nature—and I would add, with regard to gender and race as well.

Although long in preparation, great cultural changes can sweep over us in decades once under way. Moreover, standing against them is hopeless when they come. Magyar nobles vigorously opposed the spread of Protestantism and in 1523 declared it punishable by death and by the confiscation of property; despite all the edicts, Protestantism took firm hold in Hungary. In the nineteenth century in Europe and America a rising moral feeling made human beings an illegitimate form of property. Within about fifty years most countries abolished slavery. Many countries vocally rejected women's suffrage at the outset of the twentieth century. Now, politicians, though still mostly male, would not dream of mentioning the exclusion of women from full citizenship in most parts of the world.

The builders of the beautiful home of the US National Academy of Sciences in Washington, D.C., inscribed it with the epigraph, "To science, pilot of industry, conqueror of disease, multiplier of the harvest, explorer of the universe, revealer of nature's laws, eternal guide to truth." Finally, after a very long preparation, our science and technology are ready also to reconcile our economy and the environment, to effect the Copernican turn.[2] In fact, long before environmental policy became conscious of itself, the system had set decarbonization in motion. A highly efficient hydrogen economy, landless agriculture, industrial ecosystems in which waste virtually disappears: over the coming century these can enable large, prosperous human populations to co-exist with the whales and the lions and the eagles and all that underlie them—if we are mentally prepared, which I believe we are.

We have liberated ourselves from the environment. Now it is time to liberate the environment itself.

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NOTES

1. For discussion of the re-creation of the "Buffalo Commons" in the US Great Plains, proposed by geographers Deborah and Frank Popper, see Matthews (1992). For a net estimate of changes in land use from growth of cities as well as changes in farming and forestry in the United States over the next century, see Waggoner et al. (1996).
2. For more information on required rates and amounts of change, see Ausubel (1996).

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