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Author
Holdren, John P.

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John P. Holdren

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TECHNOLOGY, ENVIRONMENT, AND WELL-BEING: SOME CRITICAL CHOICES

John P. Holdren*

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The Predicament

The complex relationship between the uses of technology and human well-being is at the heart of what has aptly been called "the predicament of mankind."[1] At the most elementary level of analysis, it is apparent that prosperity and indeed survival for human beings are contingent on uninterrupted flows of a variety of resources--including food, energy, fiber, water, and metals--and that maintaining these flows and deriving services from them is what technology is all about. There has been a persistent tendency to view malfunctions or potential malfunctions in this process largely in terms of shortfalls of the individual resources--the existence or prospect of a food shortage, a fuel shortage, a water shortage, and so on. The essence of the real predicament, however, resides not in the question of theoretical adequacy of one or several resources, but in the interactions of the resources and their associated technologies with each other and in the impact of the entire enterprise on the nontechnological environment.

The consequences of even a temporary energy shortage, for example, reverberate through all sectors of economic activity, generating or aggravating

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*Assistant Professor, Energy and Resources Program, University of California, Berkeley 94720. The opinions herein are the author's. This essay was presented at the Symposium on Growth in America, Wingspread Conference Center, Racine, Wisconsin (October 1, 1974), sponsored by the Woodrow Wilson International Center for Scholars.

materials shortages, food shortages, unemployment, and inflation, all of which in turn may exacerbate the initiating event itself. Massive diversion of investment capital and technical resources to meet the "crisis" of the moment--attempting to compensate for lack of foresight with brute force applied too late--weakens the system elsewhere and thus promotes crisis in other sectors later. Apparent solutions seized in haste and ignorance cut off options that will be only missed in future predicaments. (Consider the "solution" to finding housing for a swelling middle class disenchanted with central cities: building suburbs on the best agricultural land.)

The most fundamental difficulty of all is the environmental one, and it exists even in the unlikely event that foresight and organization are flawless. Simply stated, it is this: while the intelligent application of technology fosters human well-being directly, a reducible but not removable burden of environmental disruption by the same technology detracts from well-being. The negative effects may include not only damage to health, property, and human values, but perhaps most importantly, disruption of "public service" functions of natural systems (for example, nutrient cycling, climate regulation, pest control, water management and ocean fish production). These indispensable services are often not replaceable by technology at all; when they are replaceable it is generally at great expense and as part of a vicious circle--the side effects of more technology disrupting more natural services that must be replaced with still more technology.

This line of argument is not intended to suggest that technology *per se* is undesirable. The benefits of technology in support of human well-being have often exceeded its liabilities; and the expansion of *some* existing kinds of technology--and the development of needed new kinds--will continue to be warranted in the future by a favorable balance of benefits versus risks. I suggest, however, that a point will eventually be reached in the expansion of *any technology of production* where the incremental gains in well-being from further expansion do not compensate for the incremental losses caused by the technology's environmental impact. That such a point always exists follows from fundamental physical and biological principles; the encounter with it may be postponed by innovation, but it cannot be indefinitely evaded. I am convinced, moreover, that for some of today's important technologies of production--particularly in the areas of food and energy--the point beyond which further expansion is counterproductive has already been passed.

The problems that would be associated with this situation, even in a politically homogeneous, economically unstratified, and physically nongrowing world, are enormously multiplied in the *real* world of deep ideological divisions and territorial disputes, staggering inequities between rich and poor both within and among countries, and rapid growth in population and material consumption per capita (distributed in such a way as to enlarge even further the existing disparities). The competition among nations for access to resources and the political tensions that arise as a result, and the wasteful and dangerous diversion of human and material resources into military enterprises, are inextricably a part of the resources-technology-environment predicament. Just as these elements cannot be disentangled, moreover, the fate of the United States cannot be disentangled from that of the rest of the world; it is not plausible that our end of the boat can be made to stay afloat if the rest sinks.

If the foregoing is a reasonable outline of the characteristics and dimensions of the predicament, then the resolution is for the most part not to be found in devising and deploying bigger and better variations of the same basic kinds of technologies. This approach, which has comprised the knee-jerk response of most industrial nations to the symptoms they perceive, and which seems to be the first choice of many developing countries seeking a path to prosperity, will intensify the underlying stresses, not relieve them. The aim of this essay is to identify some elements of an alternative approach--some nontraditional goals and criteria for shaping technologies and institutions that will ameliorate, not aggravate, the contemporary predicament. But to make the need for such change persuasive, I shall first return in more detail to some of the main aspects of the present situation.

Interconnections of Contemporary Problems

That the technologies of exploiting different resources are far from independent is clear from a moment's reflection. It takes water and steel to produce fuel; fuel and water to produce steel; fuel, water, and steel to produce food and fiber; and so on. The higher the level of technological development, in general, the more intimate and demanding are the interconnections among different resources. Agriculture in the United States, Europe and Japan, for example, uses far more energy, steel, and fertilizer per unit of output than does agriculture in India and Indonesia. (In exchange for the additional investment and complexity, one obtains more output of food per unit of land and per unit of labor.) All else being equal, the interconnections among different resources also become more intense as the quality of the resource base diminishes. The amount of steel invested in securing petroleum, for example, is relatively low for onshore, shallow fields near centers of use, relatively high for fields offshore or deep or remote from centers of use.

That the physical links among resources are already tight enough to be very troublesome for rich countries and poor countries alike has been particularly vividly demonstrated by the worldwide petroleum squeeze of 1973 and 1974. Poor countries such as India can now scarcely afford to pay for imports of energy-intensive fertilizer, the price of which has soared upward with the price of petroleum; nor will she long be able to afford the imports of petroleum itself needed to run her own fertilizer factories and other agricultural functions. Indeed, the energy-fertilizer-food linkage is now making itself felt worldwide as an important contribution to the rising price of food.

In addition to the direct, physical interconnections among resources, there are also indirect but very important economic links. It is hard to doubt, for example, that the United States' need to increase food exports in order to pay for growing and increasingly expensive oil imports has contributed to the continuing upward spiral of U.S. domestic food prices.[2] The same phenomenon assures that there will be no uncommitted food reserves in the rich countries to alleviate prospective famines in countries too poor to pay for food on the world market. Hardly surprisingly, the United States government has also called attention to the possibility of using quotas or higher prices for exported food as retaliatory weapons against the oil-exporting nations. (No such policy has actually been effected, but the prospect is illustrative of the seamy side of resource interdependency.)

Other dimensions of the connection between resource problems and international relations are at least equally appalling. The United States exports not only food but also military hardware to generate the foreign exchange needed to pay for imported raw materials, as do many other industrial nations. The intensity and indiscriminateness with which the arms exporters hustle their wares in the international market seems to be increasing as resource-related balance of payments problems worsen. The result is encouragement and sustenance for the spiralling arms race in the poor countries, which is both a pathetic diversion of funds desperately needed there to increase the standard of living and a profoundly destabilizing force operating against world peace.

Apparently, foreign-exchange hungry industrial nations are also unwilling to refrain from exporting nuclear reactors, even though in practice this has the effect of introducing the capacity to manufacture nuclear weapons into the most politically volatile regions of the world. Historically, proliferation of fission bombs has been limited principally by the nonavailability of suitable fissionable material (which only the largest industrial nations have had the technical resources to produce) and, probably to a much smaller extent, by "good intentions" (as reflected in the Non-Proliferation Treaty of 1970). Proliferation has *not* been limited by lack of knowledge of how to construct a fission bomb, for such knowledge has been obtainable with modest effort by virtually any country for many years.[3]

The spread of nuclear reactors means we are left relying *only* on good intentions to prevent proliferation. Even a single reactor per country is significant: one of the size promised to Egypt by the U.S. in 1974 (600 electrical megawatts) produces enough fissionable plutonium each year to make about 25 fission bombs of the size dropped on Nagasaki. The "safeguards" provided by the Non-Proliferation Treaty and administered by the International Atomic Energy Agency, moreover, provide only for detection (*not* physical prevention) of diversion of reactor-produced material for explosive purposes, and even this only for nations that have signed and ratified it. (Many have not.) It hardly needs emphasizing that good intentions or fear of international censure provide a thin reed to grasp indeed. If there were any doubts about the reality or the immediacy of this issue, of course, India's nuclear explosion of May 1974 should have dispelled them.

If the energy/balance-of-payments squeeze has made industrial nations more eager to sell reactors, it has of course also made some developing countries more eager to buy them. This issue is so instructive as an example of present trends in technological development and their implications that it will be considered again in more detail later. Suffice it to say at this point that, although there is some semblance of a case for fission in developing countries without indigenous fossil fuels or hydroelectric potential, the intense desire to "go nuclear" may have other than economic origins in a country (like Egypt) with developed but unused hydro capacity or one (like Iran) with some of the cheapest oil in the world.

In sum, the world outlook with respect to resources and politics in the next several decades is far from encouraging. A continuing set of interlocking shortages is in prospect, which will generate not only direct adverse impact on human well-being but also increased political tensions and (perversely) increased military wherewithal for poor countries to relieve their frustrations aggressively. Resort to military action is possible not just in the case of poor countries unwilling to suffer quietly, but, with equal or greater likelihood, in the case of industrial powers whose high standard of living is threatened by denial of external resources. Conflicts over access to resources of undefined ownership, such as sea-bed minerals, comprise a potential tinderbox of growing magnitude; the confrontations over ocean-fishing rights that have already occurred may be but a feeble precursor of problems of this general nature yet to come. The probability that conflicts of *any* origin will expand into a nuclear exchange, of course, can hardly fail to be greater in 1985's world of perhaps fifteen or twenty nuclear nations than it has been the recent world of five.

The Cornucopian Vision and Its Defects: Logistics and Economics

The traditional technologist's dream is to banish such nightmares by fashioning a world of abundance for all. That is, we will produce more of everything, and do it cheaply enough that the poor can afford to become prosperous. There are unfortunately several defects in this cornucopian vision, some of which have already been alluded to. The first two stumbling blocks, which are related to each other, are logistics and economics. (By logistics is meant the scale and rate with which technology can be brought to bear.)

Cornucopians generally are preoccupied with the apparent theoretical capacity to supply a large (but fixed) population with basic raw materials over long spans of time. They refer to the vast stores of minerals available at low concentration in sea water and the first few miles of the earth's crust, and they argue that cheap and abundant energy from fission breeder reactors or controlled thermonuclear fusion will make these dilute mineral resources economically accessible (as well as permitting large-scale desalting of sea water to make the deserts bloom with food crops). For example, Weinberg and Hammond have argued that breeder reactors could supply a world population of 20 billion with twice the present U.S. per capita energy consumption for thousands of years, and that this is enough energy to squeeze a decent living from common rock and desert soils.[4] (Note that even ardent cornucopians do not postulate continued growth of population or material consumption per person beyond a few more doublings, for that cannot be sustained under *any* assumptions.)

Logistics is crucial, however, because civilization confronts not an "equilibrium problem" (Is there an imaginable world in which 20 billion people could be supported?) but rather an "initial-value problem" (How can we get from here to there, and especially with such a bad start?). Technology is not providing adequately for the *present* world population, and indeed the available data for the time period 1950-1970 indicate that the rich-poor gap in prosperity has been *widening*.[5] What new evidence is there to suggest that technology can now be mobilized (and paid for) quickly enough to begin to rectify this situation at a meaningful rate?

A particularly instructive perspective on the logistics issue has been provided by Harrison Brown, in emphasizing the importance of the capital stock of various materials (as distinguished from annual material throughput) as a measure of well-being.[6] (That is, the capital stock of 10 tons of steel per person in the United States--tied up in automobiles, buildings, bridges, productive machinery, and so on--is a more informative measure of well-being than the annual U.S. per capita "consumption" of steel of 600 kilograms.) To match the material prosperity of the United States in a poor country, using the same kinds of technology as have been used in the United States, one must essentially match this per capita capital stock for all the major raw materials of technological society. Now, consideration of logistics requires us to ask not merely whether enough material to do this worldwide exists, but how quickly it can be provided. In this connection, Brown has calculated that to provide the 1970 world population with the capital stock of industrial metals, per person, that prevailed in 1970 in the 10 richest nations would require, on the average, about 60 times the 1970 world production of these materials. (Production may grow above 1970 levels, of course, but so will population; and, under present patterns of consumption, most of the production will go not to establishing the material basis of prosperity in the poor countries but to replacing losses and further increasing the standing crop in the rich ones.) The real message of the calculation, and almost certainly that of any more careful consideration of logistics, is that present materials-intensive technologies would offer little hope of early prosperity to the poor countries even if global allocation of materials flows were to change dramatically.

On grounds of logistics, then, the cornucopian vision is of little immediate relevance. But even its ultimate relevance may be questioned on grounds of economics, for its economic viability seems in virtually every version to be predicated on the assumption that energy will be very cheap.* Examination of the actual prospects suggests that this assumption is most unlikely to prove valid. The advanced energy technologies with the greatest potential in terms of abundance--solar energy, controlled fusion, and fission breeder reactors--are all characterized by raw fuel that is free or nearly so, but the high capital costs likely to be associated with these technologies will lead to high overall energy costs despite free fuel.

The construction costs of today's water-cooled fission reactors are $500 to $600 per kilowatt of capacity, despite estimates little more than ten years ago that this figure would fall from $200 then to about $125 now. Inflation accounts only for part of the discrepancy. Breeder reactors are intrinsically trickier than the water reactors just described, with more severe operating conditions and correspondingly stringent demands on materials. They will probably be significantly more expensive to build, more than offsetting the cheapness of the fuel.

No one yet knows exactly what a fusion reactor will look like, but the operating conditions will be extreme: plasma temperatures of one hundred million degrees, a meter or so from superconducting magnets that must be kept within a few degrees of absolute zero; stresses near the failure point of the strongest alloys; magnetic fields a hundred thousand times the magnetic field of the earth; and destructive neutron-

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*The technologies on which the cornucopian vision rests--e.g., extraction of raw materials from sea water and common rock, desalting sea water for irrigation, and cultivation of marginal lands--are much more energy-intensive than typical contemporary practices, in which energy at 1974 prices already accounted for 10 to 20 percent of the cost of basic raw materials.[7] If energy use per unit of raw material triples, without a concomitant drop in the price of energy, then raw material prices will rise steeply. But to permit realization of the cornucopian vision, raw material prices would have to fall.

fluxes even more intense than in breeder reactors. Coping with these conditions may require the use of exotic materials in limited supply, and it will be expensive.

Solar energy on a large scale needs large collectors. Efficient collectors need exotic materials, which are expensive and may be scarce; less efficient ones (including photosynthesis) need more land area, another resource characterized by competing uses and rising prices. These points are not made to disparage solar energy; it has important advantages over the alternatives, but it is not likely to be cheap.

Of course, even *free* energy would not constitute a sufficient condition for making the cornucopian vision economically possible, because the technologies for extracting other raw materials, the technologies for transforming these materials and energy into useful goods and services, and the skilled labor to run these enterprises are and will likely remain expensive. Perversely, energy is important enough as a fraction of the cost of industrial activity that rising energy costs would doom the cornucopian vision, but not important enough that falling energy costs alone could bring it to pass.

Defects in the Cornucopian Vision: Environment

Even if the defects of the cornucopian vision with respect to logistics and economics could somehow be made to vanish, the attempt to realize it would surely founder on the environmental constraint. This would not be so, of course, if environmental damages consisted only of nuisances such as befouled beaches and roadside litter, of isolated threats to obscure species of plants and animals, and of a modest incidence of pollution-related disease in the most urbanized and industrialized regions. The conventional wisdom, although rarely so bluntly stated, has been that these are not unreasonable costs to pay in exchange for increased material abundance.

But the real environmental dilemma, as already noted, lies much deeper. Services even more fundamental to human well-being than those now provided by technology are supplied by biological and geophysical processes in the natural environment, and these services are susceptible to significant disruption by contemporary technology. Rising population and material consumption, relying on this technology, increase the demands on the "public service" functions of ecosystems while simultaneously reducing the capacity of these systems to meet the demands.

The character and vulnerability of natural "public service" functions have been discussed at length in the technical literature,[8-11] so only the most cursory listing of the main points will be undertaken here:

1. The greatest apparent potential for harm in the near future is by disruption of agricultural productivity. Agriculture depends on natural systems for control of most potential crop pests (through natural enemies and environmental conditions), for maintenance of soil fertility (through natural nutrient cycles and regulation of the pH of surface water), and for maintenance of favorable climatic conditions. The critical dependence of food production on the weather, in a world with virtually no food reserves, would be cause for serious concern in the face of natural climatic change alone; but worse, the activities of civilization can in principle superimpose faster

change on the natural cycles, and there is considerable evidence that this is either already occurring or is possible soon.[12]

2. Production of protein in the sea, of great importance because of the shortage of protein in the global diet, is vulnerable to disruption by overexploitation, disruption of coastal habitats, and pollution. The latter factors are particularly effective because marine systems are most productive and most sensitive precisely in the shallow near-shore waters where the human impact is greatest.
3. Beyond the loss of food production, the principal threats to human well-being from disruption of ecosystems consist of accumulation of toxic substances (including carcinogens, mutagens, and teratogens) in the environment--owing to overloading or circumventing natural chemical cycles--and alteration of environmental conditions governing agents of epidemic disease and the vectors that spread them.[13]
4. Scientific knowledge of the operation of environmental systems and the influence of civilization's activities is not adequate to predict in detail when, where, and in what forms the conceivable human environmental disasters will take place; but it is adequate to show that some such disasters are plausible at present or apparently soon to be achieved levels of technological activity. At the simplest level, this conclusion follows from a wide variety of studies comparing the impacts of our technology against the yardstick of global natural processes: we are equal to 6 to 20 times nature as a source of oil in the

oceans, half of nature as a source of sulfur in the atmosphere worldwide (and many times nature over regions of millions of square kilometers), 5 to 50 percent of nature as a source of particles in the atmosphere, perhaps equal to nature as a source of mercury in the environment, and we have increased the atmospheric concentration of carbon dioxide by 10 percent since 1900. Intervention on this scale is clearly capable of triggering regional and global consequences.

The widespread tendency to underestimate the environmental constraint comes not only from a lack of appreciation of the magnitude of the threat to human well-being, but also from excessive optimism as to the ease with which modest adjustments can ameliorate contemporary technology's environmental impact. This is of course not to say that reduction of technology's impact is impossible--to the contrary, the possibility and indeed the necessity of doing so is one of the principal burdens of this essay. But the task will entail far more than the largely cosmetic and generally uncoordinated measures that today pass for environmental protection.

Although a good many of the "technical fixes" that have been envisioned to clean up contemporary technology would be worthwhile, the shortcomings indicating that such measures alone will not be enough are easily identified. The main such shortcomings are suggested by the following questions (logistics and economics again loom large):

1. How fast can the fix be implemented (compared, for example, to the rate of expansion of the offending technology)? The answer depends on whether the fix can be retrofitted to old units (like some smog control devices), or whether instead its market penetration is limited by the rate of introduction of new units and the

"death rate" of old ones (consider the problem of a completely new type of automotive engine).

2. What degree of control does the fix provide, and what will we do for an encore after the gains have been erased by further growth? (For example, an 80 percent degree of emissions control permits a 5-fold expansion in the technology involved before total emissions reach the initial uncontrolled value again.)
3. How much will the fix cost, and who will pay for it? As a general rule, extracting pollutants becomes disproportionately expensive as the degree of control required becomes higher. (Going from 90 to 95 percent control may cost as much as did going from 0 to 90 percent). The larger the population and the consumption per capita, the larger the degree of control needed to maintain some fixed level of total emissions; the larger the degree of control, the larger the cost *per person*.
4. Will a "fix" for environmental impact in one form and one place aggravate the impact in other forms or other places? Shifting to electric automobiles would shift part of the environmental burden of personal transportation from the central cities to the vicinities of electric power plants. Use of tall stacks to reduce ground-level pollution by sulfur oxides in European cities has spread acid rain over the European countryside all the way to Scandinavia. Generating electricity with nuclear fission instead of with fossil fuels reduces air pollution at the expense of a still undetermined risk of catastrophe from accidents, sabotage, or terrorism.

For the most intractable environmental impacts, there appear to be no ultimate "fixes" short of controlling the level of use of the offending technologies. Carbon dioxide is produced by combustion of fossil fuels in quantities too large to contain, and it may already be influencing climate. Particles below one micron in diameter--emitted by combustion of fossil fuels and to a lesser extent by mining operations and agriculture--largely escape available controls; unfortunately, the size range below 1 micron is precisely the most serious both in terms of human health and the disruption of climate. The human factor may make designing foolproof safeguards against nuclear-fission disaster impossible. Conversion of an ever larger fraction of the earth's surface to intensive technological management in direct support of civilization's use of resources simplifies ecosystems, apparently decreasing *their* ability to perform their indispensable supporting functions for civilication. Finally, heat is the ultimate pollutant--it would eventually stop the growth of energy use, by generating major climatic disruption,* in the extremely unlikely event that nothing else stopped such growth first. This outcome is the result of the laws of thermodynamics; it can be postponed somewhat by technological cleverness, but it cannot be averted.

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*The hope is sometimes expressed that the cooling effects of extra particles in the atmosphere and (perhaps) a natural climatic cooling trend may fortuitously be counterbalanced by the warming effects of civilization's heat dissipation and addition of carbon dioxide to the atmosphere. Unfortunately, the most likely and imminent forms of climatic change involve not so much global warming or cooling as disruption of the circulation patterns that govern the *distribution* of temperature and rainfall. For this class of problems, the various influences of civilization are extremely unlikely to cancel and indeed quite likely to reinforce each other.

Technology in the United States: Symptoms of Overdevelopment

Most of the foregoing discussion has been framed in a global context, as the character of the problem seems to require. It is nevertheless useful at this point to focus more closely on some specific aspects of the situation in the United States, both because of the particular intensity and special dimensions which the enormous levels of resource use and technological complexity here lend to these problems, and because of the continuing role of the United States as an international model for sophisticated technological development.

The disproportionate share of global resource use accounted for by the United States and our correspondingly large share of responsibility for many forms of environmental impact have been widely noted.[14] The case of energy use is particularly instructive: the U.S. with about 5½ percent of the world's people accounts for about a third of the world's annual energy use, the per capita rate corresponding to 50 times India's and twice Sweden's.[15] This means that modest percentage increases in U.S. energy use have a large absolute impact on global requirements, and correspondingly, that modest percentage reductions in wasteful uses of energy here would have a significant absolute impact.

The high level of use of energy and other resources already attained in the United States also means that increasingly difficult problems of logistics and economics will be associated with maintaining a high growth rate on this large base. A fixed growth rate implies a constant doubling time, and it is transparently more difficult to double from 12 to 24 million barrels per day of petroleum refining capacity (for example) than it was to double from 6 to 12 million barrels per day in the same length of time. One common approach to this problem is to make each new individual unit bigger than were the units in the previous generation. This may offer economies of scale, but, all else being equal, it has the disadvantages of decreasing the number of firms with the resources to tackle the job, increasing the amount of capital that must be raised in one lump sum, increasing the amount of environmental damage that must be absorbed at one location (thus making sites harder to find), and increasing both the economic and environmental risk associated with making a major technological mistake.

As economists are wont to point out, of course, the pressure of growth stimulates substitution and technological innovation that can circumvent the limitations of resources and technologies previously relied upon. This, too, is a two-edged sword. In the case of the U.S. energy situation, for example, it is hard to escape the impression that desire to sustain rapid growth and increase self-sufficiency has motivated firms and the government to gamble ever larger stakes on unproved technologies. Some of these hasty technological gambles will fail expensively in economic terms, and others may present high risks of grave environmental errors that will be identified too late.

As noted above, the links between different resource sectors become tighter and more demanding as the sophistication of technology and the overall level of resource use increase. Many manifestations of this phenomenon can be identified in the United States: competing pressures for land, particularly coastal land, constraining the siting of large technological facilities; rising taxes owing to commercial valuation of suburban agricultural land, leading to higher food prices and/or the conversion of the agricultural land to residential and industrial use; competing demands for water constraining the development of coal and oil-shale resources in the West; growing uses for hydrocarbons as chemical building blocks, cutting gradually into the availability of hydrocarbons as fuels; and so on. The increasing importance of interactions among different technologies and between technology and the environment underlines the necessity of ever more sophisticated evaluation of technological alternatives before decisions are made. The environmental and economic stakes grow higher; the degree of reliance on elusive technological perfection to avoid disaster becomes greater; but the extraordinary pressures of growth itself operate against time-consuming deliberation. Witness the mounting pressure to "streamline" environmental-impact evaluations and licensing procedures for technological enterprises in this country and elsewhere.

The Example of Nuclear Power

The development and deployment of nuclear fission reactors for the commercial generation of electricity--in the United States, in other industrial nations, and most recently in the developing regions of the world--provides a striking illustration of many of the troublesome issues associated with the connection between technology and well-being.[16]

The technology is complex, capital-intensive, economical only in large unit sizes, and unforgiving of carelessness in manufacture, inattention in operation, or malicious intervention. Its great attractiveness lies in the cheapness, abundance, and compactness of the raw fuel, and in the absence of conventional air pollutants at the nuclear power plants themselves. The uniqueness of the technology's hazards lies in the quantity, toxicity, and longevity of the radioactive byproducts, which must be isolated from the human environment with extraordinary diligence, and in the direct connection between power-reactor technology and the capacity to manufacture nuclear weapons.

The early history of the commercial deployment of fission power plants in the United States, encompassing the years 1957 to 1970, was characterized by a variety of government subsidies and special regulations: government enrichment of fuel and purchase of by-product plutonium on very favorable terms; limitation of liability in the event of a major accident by Act of Congress, and assumption of most of the limited liability by the U.S. Treasury; and large government research expenditures on reactors and peripheral facilities, to the near exclusion of funding of research on alternative energy technologies. At the same time, commercial manufacturers of nuclear reactors understated their costs and sold early models as "loss leaders." All these measures were presumably justified in the minds of their supporters in industry and government by the vision of the great benefits to human well-being that cheap electricity from fission would eventually deliver. Without these measures of course, fission reactors would not have been economically competitive at the time with fossil-fuel burning power plants; with them, fission was made so alluring that electric utilities did something virtually unprecedented in this conservative industry's history, and perhaps in the recent history of industrial technology--they ordered dozens of large power reactors, at a capital investment of some billions of dollars, before a single example in this size range had operated commercially.[17]

In mid-1974, with 45 U.S. power reactors in operation, 60 under construction, and 105 more on order, it still cannot be known for certain whether these installations will operate reliably for the twenty or more years necessary to return the utilities' investment. No large commercial reactor has yet been retired and "decommissioned," so the costs of this cumbersome procedure are largely unknown. No scheme has yet been shown to be feasible for the isolation of the long-lived radioactive wastes from the environment for the necessary thousands of years. A controversy continues in the technical community as to whether safety precautions against catastrophic accidents in the principal U.S. reactor types are adequate. The possibility of diversion of fissionable materials from reactors for the production of nuclear bombs, not merely by nations but also by subnational groups of blackmailers or terrorists, has only in the past year begun to receive wide discussion in the general technical community and the public. And the "commercial nuclear fuel cycle" is not a cycle at all, because no commercial fuel-reprocessing capacity is in operation in the U.S.--the small reprocessing plant in upstate New York is out of commission until at least 1977 for modifications, and a new, larger G.E. plant, which has not worked after an investment of $60-80 million, is apparently being abandoned.

It is hard to escape the impression, then, that the pressure of growth (in this case the notion that a doubling of U.S. electricity generation every decade is necessary and desirable) and the vision of a technological panacea (cheap, clean energy from the atom) have led this country into a massive commitment that is at least premature. An objective re-evaluation of the problems and prospects of fission, together with those of the alternatives, would likely lead to a postponement of further reliance on fission until the major uncertainties concerning it are satsifactorily resolved--if they can be. In practice, such a re-evaluation is made highly improbable by the enormous financial, intellectual, and emotional investment that the government and the influential supporters of fission already have made in this technology. What is likely to occur instead is a transition to a still more capital-intensive, complex fission technology--the Liquid Metal (cooled) Fast (neutron) Breeder Reactor, or LMFBR. The technological, economic, and environmental uncertainties surrounding this reactor are, if anything, greater than those associated with the fission technologies relied upon today.

If expanding reliance on fission and the entrenched nature of the commitment to this technology are troublesome issues in industrial nations like the U.S., the corresponding issues are even more disturbing in the context of the poor countries. It is hard to imagine a technology less well suited to the conditions in most such regions. The required capital investment per unit of capacity is high, but capital in poor countries is in exceedingly short supply. The economies of scale for nuclear plants dictate large units, but the capacity of the poor countries to absorb electricity is usually small and dispersed. The level of technical sophistication required for operation, maintenance, and monitoring is high, and malfunctions are costly and difficult to repair. Most poor countries will have to rely on industrial-nation suppliers for enriched fuel and other peripheral services, in a world where such dependence is increasingly perceived not only as unfashionable but threatening; and countries that elect to invest in their own fuel-reprocessing plants obtain, along with this ingredient of independence, the capacity to fuel a nuclear-weapons program.

One must conclude, then, that poor countries are buying reactors for one or more of four main reasons: (a) the industrial nations are pushing their expensive fission technology for export with exceptional vigor; (b) for those countries with no economical indigenous energy resources, imported nuclear technology from industrial nations is preferable economically or politically to imported oil from Arab nations; (c) having a nuclear reactor is a sign of technical progressiveness (the influence of the rich-country role model); and (d) the temptation to become a nuclear-weapons power is irresistible. This picture inspires little confidence in the pattern of technology-transfer by which the poor countries are ostensibly to become better off.

An Alternative Approach to Technology and Well-Being: Some Modest Proposals

The foregoing survey has presented a pessimistic view of the present human predicament and the prospects that contemporary trends in the application of technology will improve it. Indeed, I must conclude with Kenneth Boulding[18] that much of what we have regarded as technological progress can most charitably be described as "suboptimization"--determining the best way to do that which ought not to be done at all. The realistic prognosis must now include continuing worldwide inflation, further widening of the prosperity gap between rich and poor, increased incidence of famine and quite possibly other environmentally related increases in death rates, heightened social unrest characterized by strikes, riots and terrorism, more frequent international confrontations over resources, a general level of international tension aggravated by all these factors, and a probability of nuclear conflict that increases not only in proportion to this level of tension but also in some (probably nonlinear) relation with the growing number of possessors of nuclear weapons.

What, then, must we do? Some thoughtful elements of a program have been separately set forth by a variety of authors: Sakharov,[19] Platt,[20] Illich,[21,22] the Ehrlichs,[14] Harrison Brown,[23] the Meadows group,[1] Daly,[24] and others.

It is clear, first of all, that no combination of policies and technologies can significantly ameliorate the predicament unless it confronts and overcomes the nontechnological roots of the problem: population growth, competitive nationalism, the maldistribution of wealth and opportunity, the illusion that economic throughput and material well-being are directly proportional, and the environmental hubris that supposes civilization to be self-supporting without help from natural ecosystems. The highest priority must therefore be given to measures that directly attack these driving forces.

The cornerstone of a rational program should be a great reduction in the growth of throughput of energy and materials in the rich countries. This approach would permit, in principle, an *acceleration* of the application of energy and materials to meet the genuine needs of the poor countries, *within a context of declining global growth.** In this way, the rich-poor gap in prosperity could begin to be removed--a prospect that supporters of rapid growth overall have often held out to the poor, but never delivered. At the

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*To see quickly why this is so, note for example that the richest third of the human population accounts for 85 percent of global energy use, leaving 15 percent to the remaining two thirds. Thus a reduction of only 18 percent (15/85) in the total energy use of the "rich" would permit a doubling of the total energy use of the "poor" without any increase in the global total.[25]

same time, the slower growth in the global rate of mobilization of energy and materials, and the much slower growth in the rich countries where certain environmental impacts of energy and materials technologies are now most severe, would significantly reduce the grave environmental risks that accompany continuation of recent trends.

The success of such a scheme of course depends strongly on the success of programs to limit the growth of populations. Only at lowered population growth rates can the relatively high growth in use of energy and materials *per capita* that is needed in the poor countries be achieved within an economically and environmentally sustainable rate of total growth. In the rich countries, the effect of multiplying even small population increments by the very high per capita resource use and environmental impact already prevailing there makes it essential to approach a zero rate of population growth as soon as possible.[26]

Another essential ingredient of the approach advocated here is a massive, coordinated worldwide campaign of research, development, and implementation aimed at increasing the amount of human well-being actually delivered for each unit of throughput of energy and raw materials, while decreasing the amount of adverse environmental impact per unit of throughput. This proposal should be recognized as a prescription not for *less* technology but for better technology--more frugal, better focussed on the most compelling needs, more compatible with the fabric of the physical and social environments.

Some useful insights into how to attack the problem emerge from economist Herman Daly's concept of "ultimate efficiency" or the ratio of service to throughput.[27] It is instructive to write this as the product of two more ratios:

$$\frac{\text{service}}{\text{throughput}} = \frac{\text{service}}{\text{stock}} \times \frac{\text{stock}}{\text{throughput}}$$

Here "service" means a contribution to human well-being, and "stock" refers to the accumulated collection of artifacts that serve as the intermediaries between throughput of energy and materials on the one hand and services on the other. Clearly, one can increase this efficiency by reducing the stock of materials needed to provide a given service (a simple-minded example is making automobiles smaller) or by reducing the amount of throughput needed to maintain a given stock (e.g., making the automobiles more durable). There are abundant opportunities of both kinds in heavy industrial processes, in the design and packaging of consumer goods of all kinds, in the construction of residential and commercial buildings, in transportation and in the substitution of communication for transportation, indeed throughout the economy. A cohesive literature of this subject--how to do more with less--is only now beginning to emerge,[7,28] but one can surmise that sustained application of the sorts of ingenuity and technical skills that have been devoted in the past to weapons and space exploration would reap enormous rewards. (No doubt the major reason so little effort has historically been devoted to this task is that "throughput" has been cheap--or we thought it was--compared to the inputs of skilled labor and ingenuity needed to maximize the physical ratios defined above.)

The potential of increased technological efficiency notwithstanding, its pursuit must be tempered by two concerns. The first is that even the most efficient technology must be applied and expanded cautiously, lest the environmental impact of its throughput disrupt environmental services or social relationships of greater importance than the services the technology provides. (This consideration, as well as the interaction of different technologies with each other, can be embodied in Daly's formulation by noting that it is the ratio of *all* services--including environmental and social ones--to all technological throughput that is to be maximized.) The second concern is to avoid the pitfall of trading away too much diversity in the single-minded pursuit of efficiency. One must generally pay something extra in throughput for diversity--in this sense it is "inefficient"--but natural ecosystems seem to have "discovered" that diversity is good insurance against uncertainty about the future, and civilization would probably do well to learn from the example. Just how much of this insurance civilization should buy, and what it will cost, are questions that need further study.

Within these constraints, the potential for favorably altering the ratio of service to throughput by a major directed effort means that prosperity in the poor countries can be increased at a rate greater than the rate of growth of resource use itself, and that, even in rich countries where a drastic slowing of growth in energy use is called for, ingenuity can reduce the impact on the economy and on the prospects for increases in actual well-being. This possibility, together with increased awareness in the rich countries that their own well-being is imperilled by the social, economic, and environmental consequences of continuing present trends, comprise the only real basis for believing that the technological changes and rich-poor reallocations envisioned here can actually take place.

Obviously, the best approach to increasing the physical efficiencies will not be identical for all regions. It seems clear from the difficulties ennumerated earlier in this essay that new technology for the developing regions must be tailored to specific local conditions rather than transferred willy-nilly from industrial nations. Rather than centralization, technical complexity, standardization, and interdependence, the characteristics of new technologies for developing regions should be, insofar as possible, dispersal, simplicity, diversity, and independence. Durability and reliability, which often go hand in hand with simplicity, are also essential. It is evident that the technologies of industrial nations, as well, should in many instances now evolve away from complexity and centralization, and in all instances away from reliance on a standard of perfection in manufacture, maintenance and operation that is simply not attainable in practice.

Industrial nations, rich as they may seem to be, must also face up to the fact that they are not rich enough to do what must be done and waste resources on entirely frivolous economic fiascos as well. Supersonic transports, overbuilding of subsonic airbuses, the proliferation of unfillable luxury hotels and vacation condominiums--all these are economic blunders that will cause some well deserved bankruptcies,[2] but, unfortunately, only after desperately needed technical and economic resources have been wasted.

Military expenditures are in a category by themselves. No one can afford them, the poor even less than the rich, but everyone makes them--to a total of more than $200 billion per year worldwide.[29] This cannot be considered *merely* a waste, inasmuch as the expenditures profoundly threaten human well-being through what is bought even more than through what is not bought. The most powerful single lever at the disposal of industrial nations for narrowing the prosperity gap is to shut off uniformly all sales and gifts of military hardware to the poor countries, replacing these with offerings of technologies selected for their ability to contribute to genuine increases in well-being. Naturally the gesture will be a hollow one if the industrial nations do not at the same time divert their own expenditures on weaponry to productive purposes.

Epilogue

I am regularly informed in all solemnity that the sorts of drastic changes proposed here are economically, politically, and socially impractical or unrealistic. No one has yet devised a plausible scheme, for example, to see that reductions in throughput of resources in the rich countries (if this could actually be achieved) are translated into increased availability of resources for rational development in the poor countries. Little real progress has been made on global disarmament by the superpowers, and extensive proliferation of nuclear weapons is widely (if quietly) held to be inevitable. The issue of population growth continues to be widely underestimated or misperceived by scholars and governments alike. I believe it is past time for the social science community to devote its full attention to the resolution of these obstacles, just as the physical science and engineering community must devote theirs to the transformation of technology. For the alternative of proceeding along our present course is not only even less practical economically, politically, and socially than the demanding changes that are required, it is also impractical *physically*. The real question, for those concerned about "realistic" solutions, is whether our scholars and decisionmakers of all varieties can devise ways to bring human behavior into harmony with physical reality in time.

NOTES

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3. Mason Willrich and Theodore Taylor. *Nuclear Theft: Risks and Safeguards* (Cambridge, Mass.: Ballinger Books for the Ford Energy Policy Project, 1974).

4. Alvin Weinberg and Phillip Hammond. "Limits to the Use of Energy," *American Scientist 58*, p. 412, July-August, 1970.

5. Harrison Brown. "Population Growth and AFfluence: The Fissioning of Human Society," *Quarterly Review of Economics*, Spring 1975 (in press).

6. Harrison Brown. "Human Materials Production as a Process in the Biosphere," *Scientific American*, September 1970.

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9. The Institute of Ecology. *Man in the Living Environment* (Madison: University of Wisconsin Press, 1972).

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12. R. A. Bryson. "A Perspective on Climatic Change," *Science 184*, pp. 753-760, 17 May 1974.

13. Jacques M. May. "Influence of Environmental Transformation in Changing the Map of Disease," in *The Careless Technology: Ecology and International Development*, M. Taghi Farvar and John P. Milton, eds. (Garden City, N.Y.: The Natural History Press, 1972).

14. See, e.g., Paul R. Ehrlich and Anne H. Ehrlich. *Population, Resources, Environment* (San Francisco: W. H. Freeman, 1970 and 1972).

15. United Nations Statistical Office. *Statistical Yearbook of the U.N., 1972* (New York: United Nations Publications, 1973).

16. For a more extensive discussion of the technical difficulties of fission than is given here, see John P. Holdren, "Hazards of the Nuclear Fuel Cycle," *Science and Public Affairs: The Bulletin of the Atomic Scientists,* October 1974.

17. An interesting discussion of this point is given in Chapter VI of Resources for the Future, *U.S. Energy Policies: An Agenda for Research* (Baltimore: Johns Hopkins Press, 1968).

18. Kenneth Boulding. "Fun and Games with the Gross National Product--The Role of Misleading Indicators in Social Policy" in *The Environmental Crisis,* ed. Harold W. Helfrich, Jr. (New Haven, Conn.: Yale University Press, 1970).

19. Andrei D. Sakharov. *Progress, Coexistence, and Intellectual Freedom* (New York: W. W. Norton, 1968).

20. John Platt. "What We Must Do," *Science 166*, pp. 1115-1121 (16 May 1969).

21. Ivan Illich. *Celebration of Awareness: A Call for Institutional Revolution* (New York: Doubleday, 1970).

22. Ivan Illich, *Tools for Conviviality* (New York: Harper and Row, 1973).

23. Harrison Brown. "Scenario for an American Renaissance," *Saturday Review,* December 25, 1971, pp. 18-19.

24. Herman Daly, ed. *Toward a Steady State Economy* (San Francisco: W. H. Freeman, 1973).

25. A more detailed and perhaps more realistic example of the potential of reallocating the growth of energy use is given in John P. Holdren, "Energy and Prosperity," *Bulletin of the Atomic Scientists*, January 1975.

26. John P. Holdren. "Population and the American Predicament: The Case Against Complacency," *Daedalus 102* (4), Fall 1973, pp. 31-44.

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