Long-term Constraints on Human Activity

by

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INTRODUCTION

Mankind is constrained by problems of food, land, water, climatic change, energy, hazardous substances, non-fuel minerals, human stress and social tension, ecological stability, management, and global organization. In the past decade, speculation about how these and other constraints might impose 'outer limits' on human activity has become bewilderingly diverse, reflecting both the diversity of the world scientific community and the blurring of distinctions between technical, ethical, and ideological, conclusions. Governments, unused to assuming the worst in cases of scientific uncertainty (especially on a time-scale of decades or centuries), have tended to discount heavily the rising concern behind these speculations, and hence to foreclose important long-term options by imprudent short-term pragmatism

Yet this very emphasis on attacking acute and immediate problems has focused attention not merely on how Man might approach some outer limits, but also on why Man cannot approach some others. As we identify biophysical or other constraints whose avoidance or evasion will require social and institutional change, we begin to appreciate the difficulty of that change through our everyday efforts to overcome not ultimate biophysical constraints but more proximate managerial constraints. In short, even as we become aware of outer limits, inner limits arise to crowd them from our thoughts.

This dichotomy, or rather continuum, of limits can also be viewed in another way. The amount of most resources theoretically available under perfect management is extremely large; this is true not only of food but also of energy and most raw materials. However, the gap between theoretical and practical availability also tends to be extremely large, because of various constraints—geopolitical, social, technical, biological, economic, and so on The rate, difficulty, and side-effects, of overcoming these constraints, will vary widely from case to case, and will be assessed differently by different people. (This is partly because perceptions vary from sophisticated to nil in the sphere of purely social or political constraints, which are of course no less real or effective than 'hard' biophysical constraints.) In many cases and places, the constraints (of whatever nature) which stand between us and the more remote outer limits are so hard to overcome in a timely fashion that these outer limits seem to be of purely academic interest. Thus while we must bear in mind their long-term implications, our immediate task is to assess the nature and permeability of the far-more-obvious inner limits. But in order not to do this under false assumptions, we may have to reason backwards (Lovins, 1975*b*, 1975*c*) from outer limits, however remote they may seem on the short time-scale of much political action. Thus we may have to ask: What options must we retain for the long term, and what must we not do now if we are to retain those options? Otherwise we may 'jump from the frying-pan into the fire'.

This long-range-planning approach is commonly rejected in favour of reliance upon short-term technological fixes. One must therefore ask whether technology is inherently addictive, forcing society into further crises demanding further technological fixes—and so on, until the habit becomes socially unsustainable. This might occur if, for example, fixes are prescribed for biophysical symptoms rather than for underlying social disorders—a common result of misdefining some state of affairs as a 'problem' which must ex *hypothesi* have a 'solution'. If technology evades, obscures, or defers, social problems, rather than resolving them, then its ever-increasing use must eventually lead to social disequilibria without technical solution. Likewise, if technical change entails social change, then the pace of required social change must soon become excessive.

Many thoughful analysts are uneasy about these trends and about the rising dependence of all societies

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on rapidly devised and deployed technologies whose complex side-effects are unpredictable, unpredicted, or (most often) simply ignored. Yet this malaise seldom crystallizes into explicit consideration of the option of technological restraint: of trying to root out the underlying social problem rather than attacking its symptoms with technical diligence and therapeutic zeal This option—assessing the wisdom of intervening at all with our technical tools—is generally submerged by more 'practical' assessments of the nature and hazards of ad *hoc* solutions to what 'problem-solvers' perceive as their immediate problems Thus the possibility of social adjustment, for example of stimulated changes in social norms and goals, is generally dismissed by technologists who are unable to distinguish 'can' from 'should'—dismissed even as they strive to suppress the symptoms or signals which might bring about that adjustment, and even as they cheerfully assume that the equally difficult social adjustments which technical innovation requires will indeed occur on schedule. Social delays and disruption then tend to increase, and as delays become longer (compared with accelerating rates of change), instabilities also increase.

Pragmatists may say that these somewhat theoretical concepts are irrelevant to their needs: that problems must be sorted into a hierarchy of decreasing imminence and addressed as they arise Such a hierarchy does indeed exist; but it is a dangerously incomplete tool of decision-making—a tool whose use by those obsessed with the short term and with the boundless ingenuity of their successors has led to many of our present difficulties. Inner limits (Brown, 1974*b*; Congressional Research Service, 1975) are in general most imminent in food supply, then in energy supply, and lastly in mineral supply; but the imminence of food–population collisions in some regions (Brown, 1972, 1974*a*; Borgstrom, 1973) does not make other kinds of limits irrelevant anywhere. On the contrary it means that, while preparing as best we can for those collisions which it is too late to avoid, we should be addressing the problems that the survivors will have to cope with next—problems that we may have time to solve if we start now. In other words, we must break the cycle of short-term planning that has got us into our present acute difficulties (e.g Ehrlich, 1974).

Progressive social thinkers who are faced with long-term environmental problems often argue that they cannot afford to worry about the remote and abstract when surrounded by the immediate and concrete—that potential climatic or genetic instabilities are of academic interest in a world full of actual anarchy, war, famine, disease, injustice, and ignorance This thesis has an element of truth, but a greater element of folly The problems which overwhelm us today are often precisely those which, through a similar lack of vision and persistence, we failed to solve decades ago—problems which have built-in perceptual and responsive delays of many years. These delays ensure that most conventional institutions can only defer or disguise problems, not solve them.

We have thus to conclude that many of the major problems which we face today, and which so exercise our harried policy-makers, are *ipso facto* insoluble; for it takes time to solve problems, and all we have time for now is makeshift remedies The major problems of the next few years are likewise often insoluble, even though they are the only ones which our politicians are likely to perceive. The major problems of the late 1980s might just, and those of the 1990s may well, be soluble if attacked now, but not if deferred. Many modern institutions are trying to devise ad-hocracy to cope with immediate difficulties: few are trying to solve soluble problems, or even to find which they are. This paper accordingly seeks to identify and explore certain long-term problems that must be addressed promptly if we are to live to enjoy some of the later and more interesting limits to human activity

It is hard enough to apply synthetic rather than analytic discipline to history; it is far harder to do the same for events which will not occur for decades hence—particularly where present knowledge is not sufficient to prove that they will occur at all Yet it is far more important. The kernel of the incredible tangle of human problems is the principle of interrelatedness, expressed in so many different ways: 'Everything is connected', 'You can never do just one thing', or 'Only One Earth'. That this brief survey of present and emerging problems uses for didactic convenience a form of analytic framework does not mean that the reader, absorbing a wide range of seemingly disparate material, can safely do the same. Those who are the prisoners of their categories will not foresee the relationships between climatic change and food production, nor between energy conversion and climatic change, nor between food production and energy conversion—not until, that is, these and a myriad similar relationships, which work inexorably whether they are perceived or not, have drawn themselves unmistakably to the attention of everyone, the sower and the reaper of the future alike.

It would be improper for a state-of-the-world survey of this kind to rely upon or to endorse such common analytic categories as 'resources', 'pollution', or 'population' The first has an arrogantly anthropocentric ring, denying both economic and moral standing to that which Man does not endow with utility; the second suggests an interest more in the event than in its origin or effect; the third implies that a single variable can be validly dissociated from an enormously intricate and non-linear complex whose control, however it may be exerted, will hardly act through just one variable at a

time. Thus if such simplistic categories creep in, it must be with an apology

Let us now embark on our brief and selective review of some major biophysical constiaints—a survey that is intended not as an exhaustive catalogue, which would be tedious if it weie indeed possible, but rather to flag certain critical problems (especially those demanding action far in advance), and to convey something of the intensely integrative character of the needed perceptions and remedies.

FOOD

Recent reports (Brown, 1972, 1974*a*; Borgström, 1973) on the race between agriculture and population are ominous, especially for countries whose food prospects have long been unpleasant because of the terrible momentum inherent in a skewed age-structuie. A typical poor country that achieves replacement reproduction by A D. 2000 will stabilize shortly after the middle of the next century—at about 2 5 times its present population. If all countries achieve replacement reproduction by the year 2000, and if mortality does not greatly increase—both being assumptions that many experts consider too sanguine—then world population, now about 4 thousand millions, will stabilize nearly a century hence at 8-9 thousand millions or slightly more (Frejka, 1973)

Population growth is the driving force in the classic Malthusian confrontation with food supplies; but a new competitor, already half as important and becoming steadily more so, has emerged (Brown, 19'72, 1974*a*, 1974*b*; Borgstrom, 1973). This is rising affluence which, expressed as demand for animal proteins, is now a major claimant on scarce supplies of both grains and feedstock proteins. The latter are, on the whole, exported from poor to rich countries, where they are converted into 0 1–0 2 times as much animal protein of similar or lesser food-value but higher price Grains —comprising more than half the direct food-supply of the world and part of the indirect remainder—are consumed directly at a rate of about ½ kg per *caput* per day in most poor countries and less in some rich countries—but at over twice that rate in the latter countries' meat and beverages

Rising demand for animal protein is now colliding with three main limits on its production:

- Marine protein production, having risen by a remarkable –5%/yr during 1950–70, is now very close to its sustainable limit This is generally thought to be perhaps 100–120 million metric tons per year (the total catch is currently about 70), but only with far more vigilant control of over-fishing and marine pollution
- Beef production, already limited by the fertility of cattle, has now encountered (and in many areas exceeded) the sustainable limits of grazing. Further increases thus generally depend on intensive feedlot agriculture—at an energy cost of the order of 6–12 kg of coal equivalent per kg of beef protein (Slesser, 1973; Leach, 1975).
- The increase in soybean production in the past few decades has in most cases been due to increased planting; no significant intensification of areal yields is in sight, and demand continues to rise much faster than supply.

Costly, unexpectedly slow, and ecologically risky, intensification, rather than areal expansion, has accounted for most increases in world crop-yields since 1950—for $\sim^4/_5$ of those since 1970 (Brown, 1974*a*). Readily irrigable land and the water needed to irrigate it have latterly become extremely scarce and now seldom occur in the same region: accordingly, further intensification tends to be subject to diminishing returns. The long-term fertility of established farmlands is jeopardized not only by the poorly understood chemical, ecological, and mechanical, stresses of intensification, but also by indirect population pressures. These pressuies, surveyed by Eckholm (1976), include for example overgrazing (which helps to drive the 2–10 km/yr advance of the southern Sahara), deforestation of uplands (this may increase lowland flooding), increased farming of fragile uplands (this may silt lowland irrigation systems), urbanization of prime farmland, and the direct and indirect side-effects of mining.

Such forces are rapidly changing the world food market, in the manner of the world energy market, from the buyer's to the seller's province. A global politic of food (especially protein) scarcity is now emerging, with disquieting implications both for hungry people and for world political stability. This new political fabric will surely reflect:

- Competition for exportable grain between countries of widely varying wealth.
- A growing world tendency for main world suppliers of agricultural commodities to withold supplies from hungry customeis for domestic political reasons, regardless of the morality of interdependence.
- Greatly increased volatility of prices in all countries because supply deficits in the past three years have virtually eliminated the two main buffers: the post-1960 U.S. land-bank is now almost empty, and world grain stocks have recently been at their lowest levels in modern history. 'Domino' response of prices to relatively small perturbations will therefore become more common.
- The increasing monopoly power of midwestern North America, which controls about $^2/_3$ of the

world's exportable cereals and a very high percentage * of the world's exportable soybeans.

- The resulting vulnerability of world food supplies to weather in a single region—a region that is subject to a regular 20-years' drought cycle which is due to recur about now.
- As scarcities increase, a tendency to view food as a strategic commodity to be controlled in accordance with political goals.

These problems (Brown, 1972, 1974*a*, 1974*b*; Borgstrom, 1973) are not merely imminent but already upon us: we have no safety margins left. Another 1972 international crop failure or 1932 U S Dust Bowl could now, with our scant reserves, trigger major regional disasters.

LAND AND WATER

Salinization, erosion, laterization, overuse, paving, and other degradation, are tending to decrease irreversibly the world's net stock of arable land: Man may already have changed a tenth of all ice-free land to desert, and reduced total global vegetation by a third (Wilson & Matthews, 1970). This continuing, indeed accelerating, erosion of the Earth's carrying capacity (Eckholm, 1976) is by any measure one of the most critical environmental problems today, and will be with us for a very long time to come.

Of all potentially arable land (about 24% of the total area of ice-free land), only about 44% is now cultivated This does not mean, however, that 56% awaits the touch of the plough to spring to fertility; what it really means is that almost 56% is waterless, degraded, or despoiled. The near-saturation of much potentially arable land—83% of which is already cultivated in Asia, 88% in Europe, 64% in the USSR, 51% in North America—gives little cause for delight in a few lower figures (such as 22% for Africa, where many soils are lateritic and most are very poor). It is in general not possible to sustain a high net productivity in the humid tropics.

Massive irrigation was once seen as a short-term panacea—short-term because, without the most unrelenting and sophisticated control (which few societies have been able to sustain for very long) of drainage and of watershed land-use, irrigation can harm fertility by salinization or waterlogging of the soil Many experts now believe, however, that irrigation in most areas will be too little and too late. The growth-rate of irrigated areas of the world—nearly 3%/yr during 1950–70—will probably average only about 1%/yr over the next few decades: a mere 2–2 5 million sq km (2% of all ice-free land) is now irrigated, at great cost and with many unwelcome side-effects Properly irrigating the main arid and semi-arid regions of the world would require the total continental runoff—a physical impossibility—and water projects so large as to risk substantial changes in regional or global climate. Nor is it clear where such prodigious amounts of water could be found. Present rapid depletion of ground-water resources throughout the world will soon lead to widespread local shortages. The only other source of irrigation water seems to be desalination; this is costly, extremely energy-intensive (Lovins, 1975*a*), and severely restricted in its possible rate of deployment Moreover, when once irrigation water is somehow obtained, controlling soil salinity and hydrology and preventing siltation of water systems requires perpetual centralized management that is more exacting than most societies seem able or willing to provide (Eckholm, 1976).

Increasingly stringent water constraints suggest that agricultural innovation is less needed for intensively fertilized and irrigated land than for brackish water and for dry-farming in marginal lands with extreme climatic conditions and fluctuations This adaptive approach is relatively new, and will be slow to produce results analogous to those of 'green revolution' research Its social side-effects are hard to assess; its ecological effects, especially in such fragile systems as the marginal steppe, savanna, and tundra, are likely to be even more disruptive than are present enterprises

All areas desperately need cheap, simple, and foolproof technologies for conserving clean water, removing pathogens, and recycling dissolved nutrients. Water quality in many poor countries falls far short of World Health Organization safety standards, so posing immediate epidemiological hazards and greatly complicating the formidable problems of dense human settlements In the longer run, the absence of recovery technologies may impose an early outer limit on intensive agriculture through the escape into surface- and ground-waters of nitrogen, phosphorus, pesticides, and other agricultural additives

The long-term effects of these substances on soil microbiota are conjectural Industrial nitrogen fixation is now of very roughly the same amount annually as is computed from natural microbiological processes and is projected to increase by at least an order of magnitude by the end of this century; yet it is already viewed as a potentially severe hazard to water quality through both eutrophication and human toxicity. Phosphorus use is increasing about 2 7 times as fast as human population; its fate in the biosphere, and its long-term availability as a mineral resource, are largely unknown. Perturbations to the scarcely-known rates, routes, and reservoirs, of natural nutrient cycles through the introduction of such proposed genetic syntheses as nitrogen-fixing Bacteria symbiotic with non-leguminous plants

* A referee comments, however, on the 'recent major entry of Brazil into the soybean market' —Ed

might be large, and probably cannot be assessed in advance. Nor are they necessarily ecological only: increased nitrification leads (after some delay) to increased denitrification and hence to release of by-product N_2O (in a proportion dependent on soil conditions); photochemical products of this substance can in turn enhance ozone-destroying stratospheric reactions. Preliminary estimates (Schneider, in press) suggest that such an effect may be large enough to impose an important constraint on artificial nitrification by fertilizers or otherwise.

CLIMATIC CHANGE

That study of such a basic problem should be effectively starting only now bespeaks our ignorance of many basic details of interactions between geophysical processes and the biosphere. This essential subject has evaded scrutiny through a combination of disciplinary barriers, lack of resources (especially in tropical countries), and concentration on managed (i.e simple) ecosystems This ignorance of the impact of climatic change on life, and conversely of human activities on climate, means that intensive and expensive effort is now necessary on a world scale if we are to study climatic outer limits predictively rather than empirically. Such work seems especially urgent now that we know that several major human influences on global circulation (heat, carbon dioxide, and particulates) may tend to act in the same direction in certain respects (Bryson, 1972, 1974, 1975; Kellogg & Schneider, 1974; Schneider & Dennett, 1975), that Man may already be affecting global climate, particularly in the monsoon belt (Bryson, 1974; cf Mitchell, 1975), and that critical determinants of global climate and solar flux, such as the arctic pack-ice and the ozone shield, are more sensitive to perturbations than had been thought (e.g Schneider & Dennett, 1975; Schneider, in press)

There is already reason to view with grave concern major alterations of water flows, of evaporation patterns, and of surface optical properties (as in deforestation) (Wilson & Matthews, 1971). Moreover, unsuccessful attempts to resolve fully the well-known controversy over stratospheric chemistry and supersonic civil aviation have recently disclosed a host of even more disquieting possibilities—perhaps only the first of many—ranging some from 'greenhouse' action by halocarbons (Ramanathan, 1975) to coupled climatic and photochemical effects, including stratospheric temperatures affecting reaction rates and thence ozone chemistry (and perhaps climate). The above-mentioned possible interaction between denitrification and the integrity of the ozone shield illustrates the sort of unpleasant surprise that can remain invisible so long as soil chemists do not talk to stratospheric photochemists; and though the biological significance of ozone depletion is obvious, its climatic significance is speculative.

Attempts to develop sound theories of climate and of its variations (Schneider & Dennett, 1975) have tended to concentrate on global changes of state persisting for decades or centuries. Such changes could be induced, for example, by the melting of the thin and short-lived arctic pack-ice—a probably irreversible change that could be fairly easily accomplished (Lovins, 1973*a*; Manabe & Wetherald, 1975; Schneider & Dennett, 1975; Schneider, in press) and would have profound implications for human life. Likewise, recent geological, palaeoecological, geophysical, and archaeological, evidence shows that rapid areal extensions of the antarctic continental ice-sheet at intervals of the order of ten thousand years can raise sea-levels 10–20 m and reduce average global surface temperature 5–6°C in less than a hundred years (Hermann Flohn, pers comm. 1973). Such a surge may occur at an unknown (and currently unforeseeable) time in the next five thousand years or so, and constitutes a small risk whose serious consequences need study.

Yet the precariousness of the world's food supply (Eckholm, 1976; Schneider, in press) requires that more immediate attention be directed towards short-term regional instabilities in climate—periods of persistent aberrations from the mean on a time-scale of seasons or years, bringing repeated droughts—or, in some areas, grossly excessive rainfall. The environmental manager, who must plan on the basis of the extreme rather than the mean, must know whether bad years tend to coincide in different regions by mere coincidence or by causality ('teleconnection'); hence, how often will disastrous years such as 1972 recur? This is a fairly new subject of intensive study, both empirical and theoretical, and is fully as difficult as it is important.

Ironically, although it is short-term regional instabilities that pose the major immediate threat to world food production and to such activities as the navigation of arctic waters, it is often long-term global instabilities that these and other human enterprises might most readily induce. For example, although the biological effect of arctic oil-spills has long been a subject of concern, the possibility that a large spill might have major effects on global climate has only recently been recognized (Campbell & Martin, 1973; Aagaard & Coachman, 1975) and is now receiving (as it deserves) earnest attention. The suggested sequence is fairly simple: oil can allegedly emulsify into small persistent droplets which could be distributed by currents along the underside of the arctic pack-ice; the ice melts seasonally on top and freezes on the bottom, so bringing the oil to the surface in a few years; the oil

would then reduce the albedo (reflectivity) of the ice during the spring period of intense insolation (illumination and heating by the sun), thus encouraging an irreversible melting which could drastically alter zonal circulation throughout at least the Northern Hemisphere (Wilson & Matthews, 1971). Unfortunately, the arctic pack-ice is already subject to a number of present or planned attacks (such as high-latitude heating from industrial energy conversion, or altered salinity through the diversion of arctic rivers) which would tend to act in the same direction as the oil (Wilson & Matthews, 19'71; Lovins, 1973*a*; Manabe & Wetherald, 1975; Schneider, in press), just as most identified attacks on the ozone shield probably tend to deplete rather than to replenish it.

ENERGY

The climatic effects of Man's energy conversion are already observable locally and regionally, and could become globally important during the first half of the next century (Mitchell, 1975). Until a detailed and exact understanding of climatic change—if attainable—has refined calculations, present schemes for evading resource scarcities through large injections of energy capital are premature: regardless of the technology used, the climatic effects of the inevitable heat release may be intolerable (Lovins, 1973*a*). Other outer limits on energy conversion may arise through:

- The economic impact of shortages, of rising production costs, and of sectoral capital intensity that has recently increased by about an order of magnitude (Lovins, 1975*a*, 1975*b*).
- Socio-political instabilities (such as alienation, high-technology violence, and centrifugal political stresses) resulting both from deployment of centralized, complex, high-technology (hence vulnerable and unforgiving) energy systems and from gross inequities in the distribution of fuel resources and of energy conversion.
- The tendency of krypton-85 emissions from nuclear facilities to increase the electrical conductivity of the troposphere (Boeck *et al.*, 1975).
- The biological side-effects of producing such fuels as offshore oil, surface-mined coal, and transuranic isotopes.

Some energy resources may be simply too dangerous to use (Edsall, 1974, 1975) Some potentially intractable hazards, such as actinide aerosols (Lovins & Patterson; 1975), submicron particulates and sulphate particles, and liquefied natural-gas spills (Lovins, 1975*a*), are only just starting to receive serious attention. Although less harmful energy technologies—especially for living on energy income rather than on energy capital—are technically feasible and can be economically attractive, the formidable rate-and-magnitude problems of change in a massive energy economy (Lovins, 1975*a*, 1975*c*), as in other major sectors, ensure that no voluntary change will be rapid in rich countries, and hence that the oil/gas economy will persist long enough to cause serious political and fiscal dislocations.

The socio-political, environmental, and economic, problems of energy conversion, and the difficulty of rapidly deploying complex new energy technologies with their enormous requirements of capital (Lovins, 1975*b*), materials, and skilled labour, will together enforce a slowing of rates of growth in energy conversion, and now cast serious doubt on our ability to deploy, for example, widespread desalination, synthesis of nitrogen fertilizer, mining of very dilute mineral deposits, and other highly energy-intensive technologies (Lovins, 1975*a*). Indeed, energy conversion technologies are themselves so energy-intensive that the ability of some under any circumstances, and of many during periods of rapid growth (Price, 1975), to yield net energy is in serious doubt (Lovins, 1975*a*, 1975*b*).

It is hard to see how the meagre energy rations of poor countries (many of them already dependent on petroleum-based agriculture) can be much increased so long as the rich countries fail to realize that they themselves will have to conserve energy whether they like to or not. Waste will be greatly reduced by disruptive compulsory changes in life-styles brought about by shortages—if not by a deliberate strategy of increased efficiency (Over & Sjoerdsma, 1974; Armstrong & Harman, 1975; Ross & Williams, 1975; Schipper, 1975) and of more careful distinction between demand and need (Lovins, 1975*a*, 1975*b*, 1975*c*). Such a strategy cannot be devised until a wide range of energy futures and implications of choice has been explored in public, for people cannot choose options that they do not perceive Research to this end is only now beginning in a few countries (Energy Policy Project of the Ford Foundation, 1974; Chapman, 1975; Lovins, 1975*c*; Sørensen, 1975)

There seems no question that future energy decisions to be made by both producers and consumers will have profound, and so far unassessed, effects in practically every sector—especially in foreign policy and trade, agriculture, architecture, transport, economic planning, settlement patterns, and social organization This pervasive influence of energy, however, is not confined to those countries which are now using it most liberally and wastefully: developing countries, hardest hit by scarcity and high prices, will have to make special efforts to find, and to encourage reluctant industrial countries to help them to find, locally appropriate energy technologies and development paths that are not energy-intensive (or at least that are not intensive users of

eneigy capital), as in the long iun no other approach can succeed either for them oi foi anyone else. Noi aie eneigy problems in rich countries likely to be properly addressed until it is widely appreciated, firstly, that most of the impoitant energy issues aie not technical and economic but rather social and ethical, and secondly, that increases in energy supply tend to be slow, costly, risky, and temporary, whereas decreases in energy demand tend to be comparatively quick, cheap, safe, and peimanent

A possible outer limit on eneigy conversion thiough nuclear fission—a young technology whose rapid pioliferation (and potential foi nuclear violence and coercion by criminal lunatics) raises difficult ethical questions of transcendent importance (Edsall, 1974, 1975; Lovins, 197%)—is posed by its production of laige quantities of extremely toxic radioisotopes, some with half-lives of the order of thousands to millions of years. Plutonium-239, a biochemically active 24,400-years hard alpha emitter that is toxic in sub-microgiam quantities and can form respirable aerosols (Lovins & Patterson, 1975), is a prominent example. Such substances require infallible and perpetual isolation from the biosphere, and it is hard to imagine how this can be done. Plans to manufacture laige amounts of transuranic isotopes must therefoie be urgently re-examined. (Even the mobilization of thorium-230 in the mining of its parent, uranium, can result in a semipermanent release of veiy uncertain but potentially laige amounts of iadon-222 and its highly active daughters (Comey, 1975).)* More generally, the inherent risks of fission technology are so gieat that operating safety, waste containment, and the security of strategic materials, may be ultimately limited not by cost, ingenuity, oi diligence, but by the impact of human fallibility and malice on highly engineered systems (Lovins, 1975*c*). A rapidly glowing body of competent technical opinion suggests that this is the case, and that deployment of the technology should therefore be suspended until enough infallible people have been found and trained to operate it within a sufficiently placid social context foi the veiy long periods required

HAZARDOUS SUBSTANCES

Many classes of substances can now be identified which may be too hazardous for Man to trust himself to take caie of (examples include some classes of peisistent organic carcinogens). Some otheı peisistent substances can also be identified which, though not a *priori* candidates foi producing outer limits by jeopardizing human health oi the stability of life-suppoit systems ovei laige aieas, nonetheless appeai to carry enough risk to require special scrutiny. Identifying such a risk is a technical pioblem; deciding whether to incui it in the pursuit of some benefit is a political and ethical pioblem (Green, 1975).

Identifying and regulating toxic, mutagenic, teratogenic, carcinogenic, oi otherwise hazardous substances, well in advance of their distiibution—which, despite the best efforts at containment, may be world-wide and permanent—grows steadily more urgent as Man manufactures each year moie than a thousand substances that did not exist before. Our experience of these new substances is generally one of discovering unforeseen risks For example, though the persistence and toxicity of many halogenated aiomatic compounds are well known, some research workers aie only now beginning to suspect that low-molecular-weight halogenated hydrocarbons (such as aerosol-pi opellant chlorofluorocarbons, dry-cleaning fluids, and some other solvents) may inhibit fermentation The possible impact of some of these halocarbons on stratospheric chemistry is another recent and unwelcome surprise (cf. Report IMOS, 1975).

Likewise, a synthetic analogue of insect juvenile hormone is said to have been found recently to have substantial and perhaps irreversible biological effects on people in certain ciicumstances—in quantities of one oi two molecules*. Very many surprises of this sort suggest certain conclusions:

- No system is truly closed.
- Toxicity may be hard to determine, even with years of tests (especially foi genetic effects, as the introduction time of new substances is far shorteı than the generation time of Man)
- The primary (especially the long-term subclinical) effects of man-made substances are virtually as unknown as the rates, routes, and reservoirs, of their natural distribution, the ways in which they may be concentrated or altered in natural systems, and the ways in which they may interact with one another.,
- We shall never be able to predict the effects of all random combinations (synergistic or antagonistic) of man-made substances in *vivo*.
- We must therefoie face ethical questions about the risks and benefits of new substances, the rate (if any) at which future risks should be discounted, and the burden of proving risk.
- Monitoring of the entire biosphere—including the human genetic pool—is an impoitant, though belated, line of defence in detecting risks which we have failed to detect thiough earlier screening We must recognize, however, the defects of all monitoring systems: notably that, if a peisistent sub-

* *See* also *E* A Martell in *Am Scient*, July *1975*

* On requesting the Author to supply reliable references to this hair-raising new conceivable panecodisaster we received the response that none could as yet be given We consequently retain it as the *merest* ***suggestion,*** while warning that it should be treated with the utmost caution —Ed

stance is slow to propagate through the biosphere, its concentrations in relevant systems may continue to increase long after the case for regulating its distribution has been recognized, accepted, and acted upon. Therefore, admirable and necessary schemes for global monitoring must not be relied upon to relieve us of the responsibility of striving to avoid making mistakes earlier

NON-FUEL MINERALS

Outer limits to the availability of metals and similar materials might be posed by environmental, geopolitical, or economic, side-effects of extraction and processing, and perhaps in some cases by the inventories physically present in the lithosphere. Unfortunately, the basic data needed to assess these limits do not now exist. In particular, the detailed lithospheric distribution statistics (especially the degree of continuity of grade-tonnage distributions) are not now known for most metals (Lovering, 1969); hence neither the geopolitical nor the entropic significance of depletion of high-grade sources can now be assessed with sufficient accuracy for sound policy (Lovins, 1973*b*).

Likewise, nobody seems to have used the power of modern metallurgical theory and experience to assess in detail the likely scope, cost, rate, and difficulty, of substitution either in major alloy families or in specialized single-metal applications Despite some early work on the conceptual structure of this problem, no thorough study of material substitutions throughout the range of modern industry has been attempted or is yet proposed

Technical change in extractive industry will include extension to new areas with unique and largely unknown environmental problems (such as the Arctic, the sea-bed, and tropical rain-forests), and to regimes of polymetallic extraction based on elaborate multi-stream beneficiation and extractive metallurgy. Both the novel criteria (such as mineral grain-size) and the market structures that are characteristic of such future extractive economies deserve study, as the resulting political and market instabilities may be pronounced Little work has been done, too, on possible ways to buffer against future tensions and instabilities resulting from the exceptionally skewed geographic distribution of certain mineral reserves: it may be possible, by working far in advance, to distribute more equitably the economic and social benefits of such reserves.

HUMAN STRESS AND SOCIETAL TENSION

Little is known of human response to stresses as diverse as noise, boredom, changing age-structure, and urban crowding Indeed, some authorities accept 'stress' as a legitimate concept and identify as pathological states—i e. clinical entities resulting from 'stress' —patterns of behaviour which others construe as mere adaptation. Adaptation and adaptability are not necessarily good, however, and it is generally accepted that the survival of Man as a species may be less threatened by stress than is the survival of those qualities which distinguish Man as human. There are thus dangers as well as difficulties in devising social mechanisms and structures which are intended, in widely varying societies throughout the world, to counteract societal trends that conflict with biophysical constraints Such social engineering will require the most thoughtful consideration by a wide range of both scientists and humanists.

On a more pragmatic level, one must recognise that war and similar societal conflicts, aggravated by the continuing and needless proliferation of nuclear fission technology, are still the gravest threat to the survival both of humanity and of humane values. Unevenly distributed resources of many kinds have enormous conflict potential and can be defused only with the greatest difficulty Poverty and social inequities, too, can be immensely destructive—perhaps more directly than had been imagined. Thus certain direct links have recently been found, for example, between nutrition (of which relatively little is yet known) and the proper functioning of some of the body's mechanisms of immunity. It is possible that many more surprising connections with other forms of stress may in time be found

DIVERSITY AND RESILIENCE OF ECOSYSTEMS

Important and largely ignored insights are now emerging from work on the relationship of stability or resilience to diversity in natural communities, and on the dynamic behaviour of such systems under stress,, At the same time, more data are becoming available on the loss of genetic diversity through extinction of populations and species, through modification of habitats, and through decay of variability in gene-pools. (The human genetic pool may be altered not only by spontaneous mutation, chemical mutagens, and ionizing radiation, but also by various patterns of population growth or control: the genetic implications of demographic policies demand careful study but have received almost none,) All these discoveries give cause for grave concern at Man's abuse of both marine and terrestrial life-support systems whose stability and productivity are essential to our own (Polunin, 1974). We know very little about the dynamics of creeping and widespread ecological destabilization, nor about—to choose a specific example—the ability of marine and coastal ecosystems to withstand the various 'insults' (including ~1 cu km/yr of artificial materials) of which they are the final recipients (Wilson & Matthews, 1970).

Even if understanding of the dynamics of stressed biological systems is much improved, an important gap will remain in the perceptions of decision-makers who, conditioned by everyday experience of purely physical systems, expect linear and reversible behaviour—not the non-linearity, irreversibility, threshold responses, and long delays, of which natural systems are capable Until the mental models or paradigms of linear economics are replaced by appreciation of the intricacies of an animate world—and of the importance of preserving several thousand million years' worth of design experience—research alone cannot have the needed effect on indifference towards ecological and genetic degradation.

MANAGEMENT

More urgent than most biophysical outer limits are the limits of our abilities to manage large interconnected systems, and so to penetrate even the innermost of the inner limits. The task is to build management systems in accordance with the realities of biophysical cause and effect, in order to extend the limits of social capacity to cope with environmental problems. Lack of properly educated people—generalists with the integrative grasp, broad technical base, systems training, and international orientation needed to understand complex transdisciplinary problems—will be the main constraint. At present, nearly every element of the systems of rewards and penalties in both the public and the private sectors discourages the evolution of a class of environmental managers with these skills and qualities.

Meanwhile, the world's economic managers face some extremely difficult tasks for which they are not well prepared. They will have to deal increasingly with disruptive short-term capital flows having destabilizing effects on the world monetary and trade structure; they will have to begin to adopt a holistic view as it becomes clear that there is not enough capital (nor land, energy, time, etc) to devote separately to each competing problem in each sector; and they will have to devise, in highly industrialized countries, means for an orderly transition to a micro-variable but macro-stable economy of stock (Daly, 1973), with incentives for longevity and low-entropy design of manufactures, for stimulating recycling and repair, and for adopting low-impact life-styles Moreover, they will have to simplify economic structures which are now becoming so complex that their transaction costs may exceed their productivity No adequate theory exists that might guide any of these efforts Perhaps most difficult will be the need to face the issue of distribution rather than following the 'let them eat growth' theory: physical stabilization will entail much moral growth, together with the recycling of such nearly-extinct societal values as thrift, neighbourliness, craftsmanship, humility, diversity, and simplicity (Illich, 1973).

Economists now in service will find themselves compelled by circumstance to overhaul their toolchests at short notice. Discounted-cash-flow decision-making will quickly be seen to rely on a pernicious assumption of infinite substitutability of equally worthy investments (for example, forms of resource exploitation) Current discount rates will lose their relevance as they are seen to make the present value of practically any common resource—from whales to newborn children—virtually zero. The discounting of future risks as though they were real costs will seem more and more a way of masking social irresponsibility. Rapidly changing conditions will subordinate marginal-cost analysis to economic sensitivity analysis, and forecasting based on correlation will foreseeably give way to forecasting based on causality. Whole new sciences, such as energy analysis, are starting to emerge (IFIAS, 1975) and may substantially alter the basis of decision-making (Slesser, 1975). And as new tools evolve, so will new problems: an obvious category of limits to human activity — one of which, unfortunately, no examples can be given—is limits we haven't thought of yet Present research and development, being governed overwhelmingly by short-term market incentives and therefore largely responsive rather than anticipatory, are unlikely to identify such limits far enough in advance for convenient avoidance—especially as only a minute fraction (perhaps 2%) of all 'Research & Development' is devoted to the world's real problems rather than to military, prestige, and luxury or other projects

As rates of change increase, decision-makers will become more acutely aware of a central weakness of the conventional economic paradigm: its failure to recognize the effects of possible delays This leads to an inability to construct the anticipatory or growth-slowing policies that a lagged system requires. One can show, for example, that a feedback system using free, instantly available, and 100% efficient, technologies to abate perceived pollution in an exponentially growing industrial system will not be able to prevent exponentially rising pollution—simply because of the perceptual delay in recognizing the need to deploy abatement technologies. Yet an economist who perceives the world through a delay-free paradigm will not expect this result and will be unable to cope with it Not until delays and non-linearities in the world are systematically recognized in all sectors—in natural processes, in political perception, in social action, and in technical innovation—can the environmental problems of a dynamic world be successfully addressed.

Finally, as Eckholm (1976) emphasizes, incisive analysis, well-communicated to a wide range of people, is not enough to solve problems. For example, other-

wise sound proposals for land conservation cannot work without a widely-shared conservation ethic that impels ordinary people to demand and support government initiatives; nor without offering ways to meet basic human needs while avoiding environmental degradation; nor without reform of land tenure, social inequities, cultural patterns, and economic and political practice so that those people who are to do the conserving have strong personal incentives to forego apparent short-term benefits.

GLOBAL ORGANIZATION

In agriculture, industry, trade, or technological transfer—indeed, in any sector that one cares to examine—nearly all present development efforts are tending to produce an increasingly interdependent world. In the process, some sustainable social structures and cultural values, traditional and indigenous, are being submerged by others that are less appropriate and perhaps more ephemeral. Integrity is yielding to homogeneity, appropriate independence perhaps to short-sighted interdependence. There is no doubt that this is commonly done with the best intentions; but before it proceeds much further, should we not assess whether it is wise? Its drawback is that an interdependent world is extremely vulnerable to disruption of small parts (Brown, 1972). The possibility that, in building the sort of world which our liberal instincts demand, we may be destroying its natural defenses against instability, should give us reason to pause*.

If the world were under perfect management and had ample safety margins to guard against local wars, droughts, and other misfortunes, there would be little cause to worry about present trends—save, of course, concern at the social and humanistic implications of losing cultural diversity. But the world is under manifestly imperfect management, is torn by sectoral interests, and shows every sign of an increasing frequency of local and regional collapses. This being the sad situation, as a prudent contingency plan we should examine the appropriateness of each new link that makes the world more interdependent, and the possibility of sufficiently decoupling the world, under definite political and economic arrangements, to reduce the likelihood that local disasters might propagate more widely. In so doing, we might be laying the groundwork for a sustainable global society; for one need not allow economic decoupling to degenerate into the moral decoupling of which we have seen far too much lately.

It is hard to be specific about the forms that regional instabilities might take. Industrial societies are in many ways as vulnerable to external or internal dislocation as less industrial, more agricultural, societies; even though the latter may be far less able to buy their way out of trouble, their less centralized social organization and their greater adaptability may well serve them better to resist misfortune But in an interdependent world, local instabilities may rapidly spread. To make this less likely, we should consider the logistic details of possible regional instabilities, the mechanisms of propagation (for all we know, our customary means of intervention might make matters worse), and—most important—the epidemiological implications of regional disaster In this connection we must study the plausible patterns of predation on dense human monocultures, the analogy between broad-spectrum antibiotics in such monocultures and broad-spectrum pesticides in agricultural monocultures, possible trends and hazards in the selection and mutation of pathogens, and the implications of world-wide air travel. Such matters are not nice to think about; but not thinking about them is one way to ensure that the consequences of regional instabilities will be not merely regional, and will do much harm that could have been prevented

Examining what degree of regional integrity or global interdependence is appropriate (rather than taking it for granted) will require equal measures of dispassion and compassion Most important, it will require world-wide reflection on how best to further Man's highest gifts and goals. Such intellectual interdependence—the gathering and blending of Man's best ideas—differs from physical and economic interdependence by assuredly increasing, rather than potentially jeopardizing, our common security in an uncertain world.

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* The conflict between liberal instincts and cold assessment of long-term consequences raises unpalatable ethical issues that may be felt perhaps most acutely by those who advised in vain, shortly after World War II, that the nascent United Nations discourage the distribution of antibiotics to countries which were unwilling to reduce their fertility in proportion to their mortality. Such people argued then, and argue today, that it is morally piefeiable for a small rathei than a large number of people to starve—a proposition which is unlikely to commend itself to modern policy-makers who prefer to think that nobody needs to starve Similar issues are raised by 'triage'—the practice, in military medicine or foreign aid, of concentiating one's limited iesouices on those who need and can benefit fiom help, and neglecting those who will survive without it or die despite it The difficulty of thinking about such issues is not lessened by most people's unwillingness to discuss them

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SUMMARY

Biophysical and other 'outer limits' of food, land, water, climatic change, stratospheric chemistry, energy, hazardous substances, non-fuel minerals, human stress, and social and ecological stability, raise fundamental questions about present trends in management methods and in global organization. The diverse outer limits surveyed in this papei reflect complex, poorly perceived, and often unsuspected, interconnections between numeious biological and geophysical processes, many of which are obscure or still unknown. Our lack of predictive power, let alone of quantitative understanding, implies a need to treat essential life-support systems with great caution and forbearance, lest we erode safety margins whose importance we do not yet appreciate.

Even those outer limits which now seem remote are relevant to present policy, as their timely avoidance may require us to discard otherwise attractive short-term policies in favour of others that offer less immediate advantage but that retain options which may be needed later. Such alternative policies may have to rely more on social than on technical innovation in order to address underlying disequilibria rather than merely palliating their symptoms Moreover, some outer limits are sufficiently imminent, or require such long lead-times to avoid, that fundamental changes in policy, in institutions, and in the degree of global interdependence, seem necessary if we are to live to enjoy some of the later and moie interesting limits to human activity.

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A Multilingual Systematic Glossary of Environmental Terms

Neaily eveiy woid of the great woild languages has seveial possible meanings, but in each given context only one of these meanings is used It is accoidingly the ***context*** which tiansfoims the potential meaning of a teim into its conciete meaning

The fundamental erroi in the field of tianslation consists in thinking that the isolated woid, i e the lexicological unit, is also the conceptual unit, and that, consequently, it is sufficient to replace in a given text the words of language A by those of language B in ordei to expiess the meaning of the original in the language into which it is being translated It may seem strange that such an elementaiy erroi should be so widespread: however, this is the case It deiives directly from another mistaken conception—that the human being thinks in teims of words It is, of couise, undeniable that the lattei are needed to foimulate thoughts, but thoughts belong to a much earlier stage of intellectual activity What is needed now is an effort to decipher the thought of the foieign authoi that is hidden behind the veil of words which are only veiy imperfect means of communication between human beings. Thus it is the specific context in which a given teim is used that one has to know in oidei to appreciate fully the meaning of the teim The aggregate of such specific contexts peitaining to a given subject foims a genuine specialized language

Basing itself on these ideas and concomitant ideals of clear and piecise teiminology, 'Inteicentie' (the International Centie foi Terminology of Social Sciences) has prepared, within the last dozen years or so, seveial multilingual systematic glossaiies in which the most important teims peitaining to a given discipline appear within a continuous 'iunning' text forming a logical backgiound of these teims Accordingly these glossaries have the appearance of multilingual manuals, with the texts in the vaiious languages piinted in parallel columns The layout is such that the ieadei can see at a glance the equivalents, in all the languages used, of the key terms that aie piinted in heavy black type and numbeied consecutively within each entiy

If the ieadei is inteiested in the teiminology of a given aspect of the subject undei consideiation, he tuins to the detailed table of contents; if, howevei, he is looking foi an individual term, he finds it in the alphabetical indexes (one foi each language) appealing at the end of each glossary These indexes aie the only part of the glossaries that aie based on the alphabetical principle, which is veiy suitable foi the ***retrieval*** of infoimation, but—having nothing to do with logic—does not lend itself to the ***presentation*** of this information

Two systematic comprehensive glossaries founded on these principles and dealing, respectively, with economic terminology and statistical teiminology, have been published by Peigamon Piess, Ltd, Oxfoid—the fiist-named in 1964, the other in 1971 A ***Multilingual Systematic Glossary of Environmental Terms*** was piepaied by Inteicentie foi the United Nations Conference on the Human Environment, held in Stockholm in 1972 It was published as a UN document (UNCHE/72/misc.1) A Slovene veision of this Glossary is now being compiled

A second edition of this last Glossary (the first edition has long been exhausted) has now been planned and only awaits the finding of sufficient funds foi realization Undei the general aegis of the Foundation foi Environmental Conservation, these plans call foi full updating with an appioximate doubling of the number of teims (1,400) in the fast edition, and the addition of a new section on the law of the enviionment The piepaiation of this largely new Glossary should take 1½–2 years, but could be accelerated if sufficient financial suppoit weie foithcoming to pay foi specialist assistance.

The present headquaiteis addiess of Inteicentie is 3/3 Neue Weltgasse, 1130 Vienna, Austiia, whereto its diiector, the undersigned, moved fiom Geneva in 1974 He would be happy to supply on iequest moie ample information about this pioject

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