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Sustainability

Could this be the future of our planet? If current environmental deterioration continues, Earth could become as inhospitable to human life as the barren planet Mars. This paper explores the risks, the scenarios, and the options.

by Hardin Tibbs

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Acknowledgements

Furthering technological and economic development in a socially and environmentally responsible manner is not only feasible, it is the great challenge we face as engineers, as engineering institutions, and as a society.

Paul E. Gray, President of the Massachusetts Institute of Technology, 1989.[1]

This paper is based on a GBN report prepared for the Electric Power Research Institute (EPRI) in 1994. It is an edited and recast version of the original report. EPRI is a GBN WorldView member organization and one of America's largest research organizations. Formed in 1973 by the electric utility industry to provide large-scale cooperative research and development, EPRI's work covers a wide range of technologies related to the generation, delivery, and use of electricity. Funded through annual membership dues from some 700 member utilities, more than 350 scientists at EPRI's headquarters in Palo Alto, California, currently manage some 1,600 ongoing projects throughout the world. The work is carried out by hundreds of individual research organizations, primarily commercial and industrial firms, universities, utilities, and government laboratories.

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The author, Hardin Tibbs, is a strategist who was a senior consultant with GBN when the original EPRI report was written. He is also the author of a related GBN publication, *Industrial Ecology: An Environmental Agenda for Industry.*

1. Why Sustainability?

The idea of sustainability—and the closely related concept of sustainable development—is inspired by the widespread belief that the current pattern of human activity cannot be sustained for very much longer. At its simplest, sustainability is a rallying cry for hope. It postulates that there can be a future design of society in which environmental degradation and extremes of social inequity are avoided on an ongoing basis. As an agenda, it implicitly calls for a sense of responsibility and action sincerely aimed at improving or changing our current way of living, and averting what many feel is a looming social, ecological, and economic crisis.

This potential crisis is not a scientifically proven proposition, and in a strict sense cannot be. Nevertheless, a number of serious studies and systemic models support the plausibility of this view. In consequence, since the late 1980s, following the initiative of the UN World Commission on Environment and Development—the "Brundtland Commission"—the objective of sustainability has been widely adopted by government policy makers and corporate boards.

To adopt sustainability as an organizational policy objective is one thing: to understand what it means in practice is not so straightforward. The concept of sustainability amounts to a call to deal with the entire complex of global problems as an interrelated whole. This is a challenge that goes well beyond the scope of issues individual organizations or governments have had to deal with before, and it demands new ways of thinking and acting. This paper aims to create an understanding of the new approaches that will be needed, by clarifying the meaning of sustainability and providing some insight into its strategic implications for individual organizations.

2. What Is Sustainability?

2.1 Introduction

Sustainability has very broad scope. It addresses almost all aspects of society and extends decades into the future. It is a process for finding solutions to global problems, and it is being put forward as an international strategic agenda. Precisely because of the breadth of these aspirations, sustainability is often regarded as a fuzzy concept—which hinders its implementation.

In an effort to clarify exactly what sustainability means for industry and government, a number of formal definitions and descriptions have been put forward. These range from formulations by the United Nations, to definitions from the perspective of specific academic disciplines, to indexes and lists of principles. So far, there is no universally agreed single definition. But sustainability is a multifaceted concern, so it may well be more productive to look for a defining framework with several dimensions, rather than for a single-point definition.

2.2 Definitions of Sustainability

This section describes four significant and frequently referenced definitions of sustainability. These are a political definition, a systems definition, an economic definition, and an ecological definition: taken together they represent the range of analytical approaches to sustainability.

A Political Definition: The Brundtland Report

Gro Harlem Brundtland, the prime minister of Norway, chaired the World Commission on Environment and Development, created by the United Nations in 1983. The Commission's landmark report *Our Common Future*[2] (often referred to as the "Brundtland report"), published in 1987, introduced the concept of sustainable development into public debate. The idea struck a chord, and dozens of books, articles, and academic papers followed.

Our Common Future defines sustainable development succinctly: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (p. 43). Arguably, this raises as many questions as it answers, but it does elegantly balance concerns about meeting immediate needs with the principle of intergenerational equity. The report identifies social and ecological problems as the primary areas of concern, and sees the way society is deploying industry and technology, and distributing their benefits, as both driving and defining these problems.

The report focuses these issues through two important sustainability principles which it identifies: needs and limits (p. 43). It regards meeting human needs as crucial: "Sustainable development requires meeting the basic needs of all and extending to all the opportunity to fulfill their aspirations for a better life" (p. 8). This clearly emphasizes the human dimension of sustainable development. The report sees limits as real but conditional: "The concept of sustainable development does imply limits—not absolute limits, but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities" (p. 8). This recognizes that the continuing availability and extent of natural, renewable resources and "ecosystem services" will be a function of social and technological developments.

Our Common Future does not see sustainable development as a static utopian objective: "Sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs" (p. 9). Nor is this expected to be simple: "We do not pretend that the process is easy or straightforward. Painful choices have to be made. Thus, in the final analysis, sustainable development must rest on political will."

Writing in the foreword, Gro Harlem Brundtland proposes a worldwide political agenda: "What is needed now is a new era of economic growth—growth that is forceful and at the same time socially and environmentally sustainable...it is possible to join forces, to identify common goals, and to agree on common action" (pp. xii–xiv).

A Systems-Based Definition

The book *Beyond the Limits*,[3] is a 1992 update and revision of the controversial *Limits to Growth*.[4] It describes a series of runs on a computer model originally developed at the Massachusetts Institute of Technology (MIT) called "World3," which shows in broad terms how the global system might react in the years ahead, based on a variety of different assumptions about resources and responses. The book also provides a definition of sustainability phrased in the language of systems theory:

> *From a systems point of view a sustainable society is one that has in place informational mechanisms to keep in check the positive feedback loops that cause exponential population and [physical] capital growth. That means that birth rates roughly equal death rates, and [physical] investment rates roughly equal [physical] depreciation rates, unless and until technical changes and social decisions justify a considered and controlled change in the levels of population or capital. In order to be socially sustainable the combination of population, capital, and technology in the society would have to be configured so that the material living standard is adequate and secure for everyone. In order to be physically sustainable the society's material and energy throughputs would have to meet economist Herman Daly's three conditions:*
>
> - *Its rates of use of renewable resources do not exceed their rates of regeneration.*

- *Its rates of use of unrenewable resources do not exceed the rate at which sustainable renewable substitutes are developed.*

- *Its rates of pollution emission do not exceed the assimilative capacity of the environment.*

*(*Beyond the Limits*, p. 209.)*

The authors of *Beyond the Limits* believe that achieving sustainability will mean changing the structure of the system: "In systems terms changing structure means changing the *information* links in a system: the content and timeliness of the data that the actors in the system have to work with, and the goals, incentives, costs, and feedbacks that motivate or constrain behavior" (p. 191).

The authors also agree with *Our Common Future* that sustainability is not a fixed state: "The word *equilibrium* in systems language means that the positive and negative loops are in balance and that the system's major stocks—in this case population, capital, land, land fertility, nonrenewable resources, and pollution—are held fairly steady. It does not necessarily mean that the population and economy are static or stagnant" (p. 200). (Italics in original.)

Economic Definitions

Economic definitions of sustainability focus on the issue of "economic growth" versus "development." The impact and acceptability of inexorable economic growth has been a vexed issue in environmental debate since the 1970s. In the 1990s it is being resolved rhetorically in terms of "green growth," but there are several commentators who claim that this term is contradictory and that this particular emperor has no clothes.

The economist Paul Ekins has offered a useful distinction between production growth (growth in GDP); environmental growth (growth in biomass); and utility or welfare growth ("true economic growth").[5] Thus it is possible to have production growth without welfare growth because of negative externalities (cost of impacts), and conversely, welfare growth without production growth. The latter allows a new definition of development as purely qualitative growth—hence the term "sustainable development."

Former World Bank economist Herman Daly, a leading theorist of sustainability, goes further. He says that development should mean "qualitative change of a physically nongrowing economic system in dynamic equilibrium with the environment." This is because any physical subsystem of a finite and physically nongrowing earth must itself eventually become nongrowing. Growth would therefore become unsustainable eventually and the term "sustainable growth" would then be self-contradictory. "But sustainable development does not become self-contradictory."[6]

Sustainable development is thus defined technically as a mode of "improvement" that preserves natural capital—growth in welfare without production or physical growth. Similarly, the aim of what has been termed "strong" sustainability would be that a society "lives within its means"—in other words it does not spend more than the natural resource "income" from its natural capital endowment. This corresponds to the standard economic concept of income as defined by the British economist

John Hicks in 1939: expenditure in any period that results in no net change in capital.

This reveals the close connection between "sustainable development" and "sustainability." Sustainable development is an ongoing pattern of economic activity that meets the sustainability criterion of not exceeding Hicksian income for either manufactured or natural capital. In contrast, the term "sustainable growth" is self-contradictory because it implies growing aggregate levels of physical output in industrialized countries[7]. Sustainable development in Daly's sense would need to occur in a physically nongrowing—in fact strongly "dematerializing" during the transitional phase—but transactionally buoyant economy.

The British environmental economist David Pearce has generated a list of "sustainable" and "unsustainable" national economies by applying a test for what he calls "weak" sustainability.[7] He tests for this by subtracting depreciation of natural and manufactured capital from gross savings or investment, thus allowing substitution of manufactured for natural capital—hence "weak" sustainability.[8] Even by this measure, only 11 of the 20 countries for which the necessary data were available are sustainable. When a "strong" sustainability measure is applied, in which substitution is not allowed, all countries fail, since they all show depreciation of natural capital. The Netherlands comes closest to being "strongly sustainable" with a depreciation of its natural capital equivalent to only one percent of GDP.

An Ecological Definition

The biologists Paul and Anne Ehrlich have put forward a widely used equation that analyzes the sources of unsustainability from an ecological perspective. The equation relates environmental impact to three variables—population, affluence (or consumption per capita)[9], and technology (ecological impact of technology):

I (impact) = P (population) x A (affluence) x T (technology)[10]

Of these three variables, the one most directly under the control of industry is technology. Applying the equation to determine the role of technology, if world population (P) is expected to increase, and the level of affluence or consumption (A) will inevitably increase as the Third World industrializes, then the ecological impact of technology per unit of consumption (T) must decrease substantially to hold environmental impact steady, let alone reduce it. Thus the equation holds the key to quantitative assessment of the ecological challenge for technology, given varying assumptions about population (P) and affluence (A).

A typical application of the I = PAT equation for assessing the demands on technology is given in a proposal for sustainable technological development submitted to the Dutch government, which is keen to promote sustainable technology.[11] The example given runs as follows:

If each variable is set for a 1990 baseline, the result is:

$$I = P \times A \times T$$

$$1 = 1 \times 1 \times 1$$

If we suppose that over the next 50 years the world population will double and that per capita affluence will increase fourfold, then in order for the total environmental impact to remain as it was in 1990, the environmental impact of technology must fall to one eighth:

$$1 = 2 \times 4 \times 1/8$$

But this is not a particularly demanding case, since it does not aim for any improvement in environmental impact. The Dutch report then considers the implications if the aim is for total environmental impact to fall to half its 1990 level, while population triples and world-wide consumption increases eight times. The demand for technological improvement is then much greater:

$$1/2 = 3 \times 8 \times 1/48$$

This reduction in environmental impact to almost a fiftieth of its present level is equivalent, among other things, to close to a 98 percent reduction in all sources of pollution. A reduction of such magnitude would require two or three successive waves of progressively more advanced technology, moving from "end of pipe" controls through what the authors call "process integrated" technology, and culminating in what they call a "fundamental renewal" of technology in order to reach the 96 percent target. The aim of the Dutch government research program defined in the proposal is to explore ways of leapfrogging directly to the fundamental renewal stage.

A similar conclusion can be reached using more plausible assumptions about population growth and a more ambitious environmental objective. If the aim is a reduction of environmental impact to a quarter, while population doubles and affluence increases four times, the pollution produced by technology must still decline by almost 97 percent:

$$1/4 = 2 \times 4 \times 1/32$$

The economist Paul Ekins has published a similar example showing a required reduction of 93 percent.[12]

2.3 Principles and Indexes

Sustainability can also be approached through two forms of framework for action—lists of principles, and progress measures or indexes.

Sustainability Principles

In the search for sustainable policy measures, lists of "sustainability principles" are frequently generated. These include official versions by governments, principles adopted by organizations, and principles proposed by individual authors. They usually consist of recommendations for specific changes that would be needed in order to achieve sustainability.

At the international level there is the Rio Declaration on Environment and Development, announced after the United Nations Conference on Environment and

Development (UNCED) meeting at Rio de Janeiro in June 1992. This document proposes 27 principles for sustainable development.

At the national level a handful of countries have established sustainability principles. For example, the Australian Government has a National Strategy for Ecologically Sustainable Development (ESD), which consists of a "goal," three "core objectives," and a list of seven "guiding principles." An example of a "guiding principle" is: "Cost effective and flexible policy instruments should be adopted, such as improved valuation, pricing, and incentive mechanisms." A paragraph that follows the list of principles is noteworthy: "These guiding principles and core objectives need to be considered as a package. No objective or principle should predominate over the others. A balanced approach is required that takes into account all these objectives and principles to pursue the goal of ESD." This is significant because the high degree of interdependence between sustainability principles means they cannot be pursued independently or selectively.

In the United States, the President's Council on Sustainable Development (PCSD) has drafted a similar set of 15 principles that support a vision of a sustainable United States of America.[13]

In September 1989, in the wake of the Exxon Valdez oil spill, a set of 10 principles for business environmental ethics was proposed by the Coalition for Environmentally Responsible Economies (CERES). Major corporations have begun to adopt this code, originally referred to as the Valdez Principles, and since renamed the CERES Principles. The business community has developed its own response to sustainability in the form of Stephan Schmidheiny's Business Council for Sustainable Development, based in Switzerland, and it too has made a declaration of business commitment to sustainable development on behalf of its international membership.

Individual authors have also put forward similar sets of principles. In an article in *Utne Reader*, Paul Hawken proposed a 12-step program to create a sustainable society.[14] His specific proposals for systemic change go somewhat deeper than the expressions of intent in the principles already mentioned. Edward Goldsmith has written a radical manifesto called *The Way: An Ecological World-View*. It is almost biblical in tone and weight, and sets forth an explicitly quasi-religious worldview centered around ecology.[15] One of the epigrammatic chapter headings is blunt: "Ecology is a Faith." While some of the principles being put forward by individual authors may seem extreme, most of the ideas now considered to be conventional business environmental practice started life as implausible, impractical notions—so even *The Way* may foreshadow more widespread social attitudes in the twenty-first century.

Sustainability Indexes

Explicitly multidimensional measures of sustainability are provided by various indexes and indicators intended to assess the degree of sustainability achieved by economies and communities. A few communities have created their own multiple-measure indicators, such as "Sustainable Seattle," which tracks a range of quality of life and environmental factors from year to year. The idea is that this mix of qualitative measures will give a better idea of the overall health of the community than the conventional measure of economic growth does, (i.e., simply counting the money value of all economic activity, desirable and undesirable, and adding it all together).

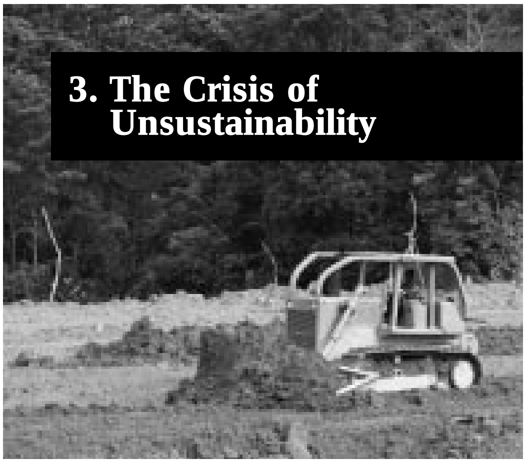
Similar alternatives to economic measures such as GDP have also been proposed at the national level. In fact, it is now a fairly well established idea that purely economic measures of national performance such as GDP and GNP do not accurately reflect true changes in economic welfare, let alone social welfare or ecological health. This is one cause of environmentalists' reservations about "economic growth." As a result, there have been a number of attempts to devise more sensitive indicators.

Among the alternative indexes proposed for economic assessment are: the Measure of Economic Welfare (MEW) put forward by economists Nordhaus and Tobin; the Net National Welfare (NNW) calculated by a team of leading Japanese economists; the Economic Aspects of Welfare (EAW Index) proposed by economist Xenophon Zolotas; and the Index of Sustainable Economic Welfare (ISEW) developed by economist Herman Daly at the World Bank.[16]

The EAW Index includes environmental factors, but not sustainability, whereas the MEW does not include environmental issues but does address sustainability—in the economic sense of "Hicksian income" (see Section 2.2, Economic Definitions). The ISEW, which is probably the best-known of the proposed economic indicators, builds on the strengths of the MEW and the EAW by including both environmental issues and income sustainability.

National indicators not primarily based on economic data include the United Nations Development Program's Human Development Index (HDI), and the Country Futures Indicators (CFI) suggested by social and environmental futurist Hazel Henderson.[17]

In April 1998, the British government announced its intention to adopt a comparable set of eight to ten "sustainability indicators" to reduce the focus on GDP. This and the growing public debate about the inadequacy of economic measures suggests that the concept of alternative measures of national and local performance is gradually gaining acceptance.



3. The Crisis of Unsustainability

3.1 Introduction

To understand how the concept of sustainability could shape the future strategic environment for organizations, it is helpful to assess how it could drive social and economic change. Strictly speaking, any change will not be caused by the future condition of sustainability as such but by the already existing conditions that are putting the idea of sustainability on the international agenda. This set of driving forces is referred to here as *unsustainability*—a complex of trends that cannot continue indefinitely.

What is significant in the concept of unsustainability is the idea that the risk we run is not a single crisis, but a crisis of crises: many breakdowns happening simultaneously throughout our entire environmental and socioeconomic system, and on a worldwide scale. Although there were isolated instances of ecological collapse in earlier eras, today our technological capability is powerful enough to endanger the entire biosphere. This is the looming "crisis of unsustainability."

3.2 Unsustainability

The History of Unsustainability

Twentieth-century unsustainability has its roots in the advent of modern science and applied technology. Starting in Europe during the Renaissance, the rise of science and the cultural outlook that accompanied it introduced two powerful new sources of change. These were the onset of mechanized industrial production, which increased the use of resources, and a simultaneous improvement in nutrition, healthcare, sanitation, and hygiene, which in turn sharply reduced the death rate. These developments gathered substantial momentum by the nineteenth century in industrial countries, leading to rapidly increasing and much wealthier populations which used ever larger amounts of materials and energy—both in absolute terms and per capita.

This increased throughput led to numerous stresses on the natural environment. The land area requisitioned for human activity steadily expanded, putting pressure on natural habitats and biodiversity. The spillover effects of fossil fuel combustion and chemicals manufacture began to degrade the quality of air, water, and land on a large scale, aggravated by the inputs of chemicals and energy to mechanized agriculture. The scale and rate of natural resource consumption raised concerns that the entire stocks of fossil fuels and key minerals would be exhausted within the foreseeable future. All these pressures influenced and entrained a growing set of social concerns. By the 1960s, the whole daunting complex of seemingly barely soluble world problems was being described by futurists as the "World Problématique" (Figure 1).

Objectively, the situation of human society in the late twentieth century is both extraordinary and unprecedented. We are witnessing unique conditions, which William C. Clark, at the Kennedy School of Government, Harvard University, has described in this way:

> *[The world] physical stage is rapidly changing. It holds twice as many people as it did in 1950: four times what it did in 1850. World trade has increased more than 20-fold over the last century; energy use more than 100-fold. This increasing magnitude of human activity has brought about an increasing scale and complexity of interactions among humans, their technologies and their environments. What were once local incidents of pollution shared throughout a common watershed or air basin now involve multiple nations—witness the concern for acid deposition in Europe and North America. What were once acute episodes of relatively reversible damage now affect multiple generations—witness debates over disposal of chemical and radioactive wastes. What were once straightforward questions of ecological preservation versus economic growth now reflect complex linkages—witness the feedbacks among energy and crop production, deforestation and climate change that are evident in studies of the atmospheric greenhouse effect. What once seemed a relatively well-behaved world of smooth and predictable trends increasingly reveals a propensity for abrupt and unexpected change—witness the surprise and consternation of scientists and policy people alike confronted with the appearance of the Antarctic ozone hole.*

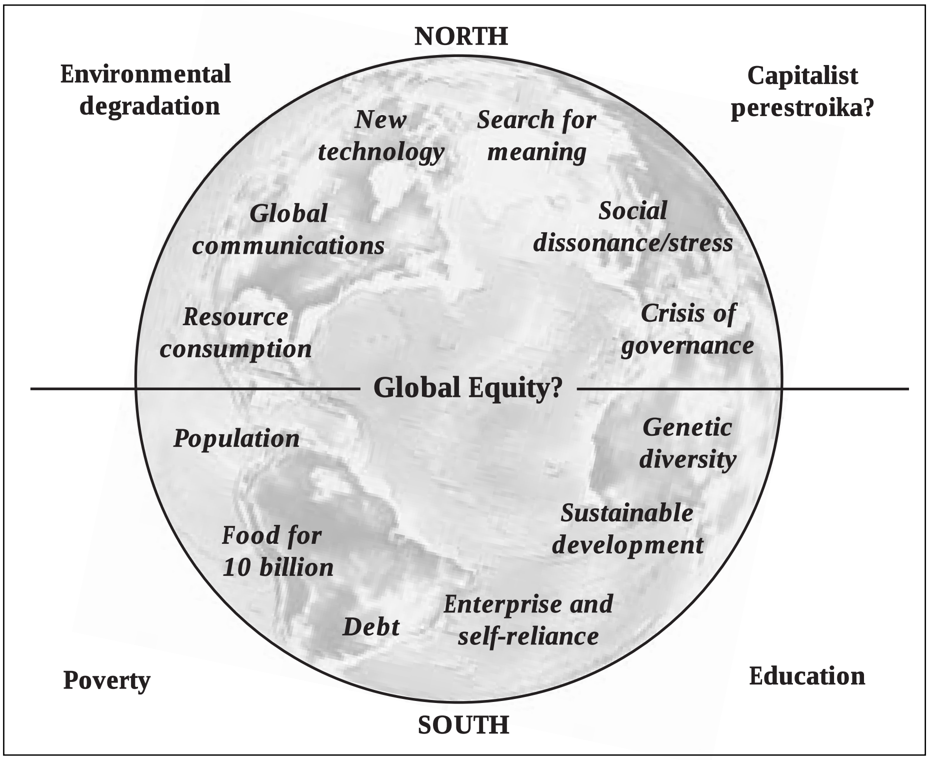


Figure 1, The "World Problématique"—the scope of unsustainability

Thus, as it approaches the twenty-first century, humanity is entering an era of chronic, large-scale, and extremely complex syndromes of global interdependence. Relative to earlier generations of problems, these emerging syndromes are characterized by profound scientific ignorance, enormous decision costs, and time and space scales that transcend those of most social institutions.[18]

It is perhaps not surprising that these problems should be slow in getting attention, given the deceptiveness of exponential growth. *Beyond the Limits* illustrates this by quoting a French riddle for children: "Suppose you own a pond on which a water lily is growing. The lily doubles in size each day. If the plant were allowed to grow unchecked, it would completely cover the pond in 30 days, choking off all other forms of life in the water. For a long time the lily plant seems small, so you decide not to worry about it until it covers half the pond. On what day will that be?"[19] The answer, surprising on first encounter, is on the 29th day. On the 30th day the lily doubles for the last time, taking the pond from half full to full. What is also worth noting is just how small the lily is for most of the month—as late as the 25th day it still covers only 1/32 of the pond.

Similarly, for a very long time it seemed preposterous that human activity could threaten planetary ecological integrity, but as exponential industrial growth began to approach worldwide scale, this prospect quickly became more plausible. And given the "surprise" aspect of exponential growth, it may intensify very suddenly.

3.3 The Seriousness of the Threat

An important element in judging the seriousness of unsustainability is the degree to which the problem is being balanced by the response. Although it is hard to find simple ways to measure the scale of the problem, the pressures on our environment caused by the rise of industry can be understood more clearly by analyzing them in terms of the broad classes of benefits or "goods" provided by the natural environment. These can be categorized as resource supply, ecosystem services, and social amenity. These categories each contain specific measures of the extent to which unsustainability threatens "environmental goods"—and the measures provide a basis for assessing the adequacy of the response being made.

Physical Resource Depletion

The first category of environmental good is relatively straightforward. Our physical environment supplies resources which include minerals, fossil fuels, and so on. Obviously, if a resource is close to running out, continued use of it, especially at high volumes, is by definition unsustainable. This kind of concern was first voiced in the late eighteenth century, and was revived as an issue in social debate in the early 1970s, when projections of rapidly rising industrial consumption—in studies such as *Limits to Growth*—raised an alarm.

Vaclav Smil provides an example of the situation today: "A China matching today's South Korean energy use would have to triple its per-capita energy consumption, requiring an equivalent of at least two billion tons of crude oil. China could never buy 80 or 90 percent of this fuel: it would be more than all the crude oil traded today on the world market."[20]

A specific measure is provided by the scale of human appropriation of the output of the whole biosphere. In 1986, when the world's population was five billion, the human consumption of food and biomass resources was calculated to have reached 40 percent of the entire annual land-based product of photosynthesis.[21] This growing percentage requires very large-scale clearance of wild habitat for agriculture and forestry and it is unlikely that the natural ecosystem can tolerate usage rates much beyond 60 or 70 percent. It is not clear if the percentage of net primary product (NPP) use is increasing linearly with population, but making that assumption, at the most rapid rate of population growth anticipated by the United Nations the 60 percent level could be reached as early as 2010. The projected world population would then be about 7.5 billion.[22]

It might seem that a sustainable approach to resources would be to call for the current generation to curb its use of resources specifically to allow a fair share for future generations. The problem with resource conservation is the expectation that advancing technology will increasingly replace the materials in use today with new or different materials—a process referred to as technological substitution. A well-known example is the substitution of telephone wires made of copper by fiber optic cable made from glass. And if technological substitution is assumed, it can be argued that using fewer resources today could have the perverse effect of leaving future generations worse off. There are two main reasons for this. First, restraint might slow the rate at which new technologies could be found or introduced. That would tend to prolong pollution from existing "dirty" technologies. However, this fear may be unfounded in practice, as demonstrated by the rapid appearance of innovative substitutes to CFCs following the Montreal Protocol. CFCs were a maturing commercial product with expiring patent protection, and the government-mandated opportunity to innovate provided a timely means of sidestepping the threat of new market entrants.

Secondly, the future pattern of resource use might be very different, which means it is not possible today to identify the most valuable resources for the future. This uncertainty makes it hard to introduce pro-sustainability policies that restrict resource consumption on grounds of scarcity alone. Policies that would indirectly reduce resource consumption, for instance by favoring recycled over virgin resources, seem more promising.

The argument for resource conservation would have the most force if technological progress was slowed or halted—as it might be in the wake of widespread ecological or economic crisis—since we would then have no alternative but to rely on the existing pattern of resource use into the future.

Erosion of Ecosystem Services

So-called "ecosystem services" comprise the next category of environmental good. Broadly, these are the biological life-support functions of the planet—services provided by the biogeochemical system acting as a whole. These include climate stabilization, food supply, and waste disposal and materials recycling by the biosphere. The biological and economic survival of human beings depends on the natural environment to continue providing these services, and today there is a great deal of evidence that these functions are under threat.

The mechanisms underlying these services—the biological nutrient cycles (of carbon, nitrogen, sulfur, etc.), the hydrological cycle, soil fertility, mature ecosystems, and biodiversity, cannot be replaced by technology at a planetary scale, indeed, at our current state of knowledge, they cannot even be repaired on that level.[23] This damage could become critical on a much shorter timescale than fossil and mineral resource depletion.

A particularly insidious problem is the way pollution above a certain level can saturate and actually erode the natural mechanisms of pollution absorption. This effect can lead to "erosion loops" of positive feedback—vicious circles which appear in times of stress and make bad situations worse, making them deteriorate at an ever increasing pace.[24]

The causes and symptoms of damage fall into three broad classes:[25]

- Atmospheric change—acid rain (with resulting acidification of soils and waterbodies); the greenhouse effect; and ozone depletion.

- Depletion or destruction of bio-resources—deforestation, desertification, water depletion, and species extinction.

- Persistent toxification—poisoning of land and water by pesticides, herbicides, and toxic wastes.

Ecosystem services are under threat as the scale of human activity grows relative to the natural system. This can be seen in the scale of materials mobilization—the extraction and movement of materials—through the industrial system as a whole, compared to the natural background rates of mobilization through the global ecosystem. Here the numbers are intimidating: for many toxic heavy metals artificial mobilization is running at several times the natural background volumes. Taking atmospheric releases alone (all of which are dispersed into the biosphere), artificial releases of arsenic are 1.6 times greater than natural releases, cadmium 5.4 times greater, and lead 11.9 times greater.[26] This means that the scale of industry, seen as a materials transport system, is already up to 10 times larger than the natural ecosystem. It is unlikely that the biosphere can tolerate such "overloading" of its inputs indefinitely.

A similar but better known instance is the release of carbon dioxide from carbon-based fuel combustion. Carbon dioxide is a gas, seemingly insubstantial, but the sheer mass involved is immense. By the early 1990s, the burning of fossil fuel and deforestation were releasing roughly eight billion tons of carbon into the atmosphere every year (the actual weight of carbon dioxide is 3.66 times greater than this). This means that artificial flows of carbon are increasing natural background flows by about a fifth, and increasing the total atmospheric "reservoir" of 750 billion tons by some four billion tons a year (some of the excess carbon is absorbed by the biosphere and ocean). The effect of this is directly measurable. The concentration of carbon dioxide in the atmosphere has increased from an estimated 280 parts per million (ppm) in 1750, to 315 ppm in 1958, and 357 ppm in 1993. It is widely feared that this continuing increase will be enough to trigger significant changes in the world's climate.

If the substitution of nature by technology is taken to its extreme—a hypothetical world in which there is no nature left—it is unlikely that viable human life could continue. This situation is rather like the inverse of the problem faced in colonizing a barren planet such as Mars. Scientists propose that the most effective way of making Mars habitable would be to "terraform" it—establish ecosystems that mimic conditions today on the Earth. The alternative would be to provide acceptable conditions using technological systems alone but—apart from establishing small enclosed colonies—it is doubtful whether technologists would want to ignore the tremendous effectiveness of using living organisms. Given this logic, it is odd that we would ever contemplate de-emphasizing the established biological life-support systems we already have on Earth.

In fact, using the example of Mars is misleading, since conditions on an abiotic Earth would be more like those on Venus,[27] with surface temperatures around 300°C and shallow acidic seas, making human survival as a lone species highly implausible. Popular humor suggests that we would not be completely alone—supposedly there would also be cockroaches (because of their extreme hardiness) and no doubt bacteria and viruses. But in any case, the resulting ecosystem would be far less conducive to health than the ecosystems that exist today, and sooner or later human beings would be unable to thrive biologically.

Most popular awareness of environmental issues falls into the category of threats to ecosystem services. In fact, the most immediate limits faced by industrial society involve the finite ability of the biosphere to withstand the destruction of habitat and to absorb the residues of industrial and economic activity. Dr. Karl-Henrik Robèrt, founder of The Natural Step (see Section 6.4, New Criteria for Design), has expressed this well:

> *In all essential respects, down to the tiniest molecule, we humans have the same structure as endangered birds of prey, seals, and otters. In a biological sense we are neither the masters of nature nor its stewards, but a piece of nature ourselves, just like seals and otters. And if these species have become threatened with extinction in the space of a few decades because of our environmental pollution, we too are threatened. We have enough knowledge to say that the only way of reversing this process is to avoid introducing substances into nature that it cannot process and to learn to live cyclically just like cells in nature.*

Threats to the Quality of Social Functioning

The final class of environmental good is the contribution the natural environment makes to stable, well functioning social structures. One aspect of this is what might be called the psychological, social, and cultural amenity value of the natural environment. This is a function of the intrinsic value of landscape and biodiversity, which is not amenable to substitution, technological or otherwise, and which has a direct influence on psychological well-being and the maintenance of social equity and stability. Since this quality is almost impossible to quantify, it is particularly at risk in a bottom-line market economy.

Ecological disruption also poses a direct threat to social stability. The tight coupling between ecological and social conditions has given rise to political concern about "eco-security" in recent years. Social stability is in large measure dependent on stable, reliable ecological conditions. When climate changes, and crops or water sources fail, the result is very often war or mass migration, or both. The last two decades have provided many instances of this, particularly in Africa. Widespread ecological disruption is not simply an issue of supply lines and climatic disruption—it could, in the extreme, spell the end of the orderly, well-educated and prosperous consumer markets in the industrialized countries, on which the planning assumptions of almost all companies depend.

Social stability also faces another related threat. Although industrialization releases tremendous cultural dynamism and vitality, the dislocations it brings also tend to undermine cultural integrity, leading to psychological disorientation and social disaffection. The success of industrialization depended in part on the existence of a coherent "moral orientation" in society, which business has long taken for granted. Ironically, it is the scientific rationalism on which industry depends that has undermined the idea of "morality" and rendered it "old-fashioned." Beliefs that uphold self-restraint, justice, and equity—the basis of social order and a long-term perspective—are now dangerously missing in Western industrial societies.

This does not imply that industrial technology is intrinsically harmful, but rather that its power amplifies underlying social dysfunctionality, forcing us to confront the need for change at a deep level. One way of summarizing the problem is in terms of the "social productivity of knowledge." Modern industrial society enjoys an unparalleled level of knowledge, yet it also experiences poverty, social polarization, and ecological destruction. Clearly we have not yet found the right formula or context for the deployment of our knowledge in order to solve these problems. The sustainability debate is ultimately a critique of the existing social and environmental productivity of knowledge, and it proposes that a new configuration of society and technology could avoid these shortcomings.

The Scale of Response

The balancing half of the "problem and response" equation is an assessment of the response being made. If the scale of the response already underway matches the scale of the problem, it implies that we are on a smooth path of incremental transition to sustainability. If, however, the scale of the problem is outstripping the scale of the response, it means that, effectively, we are deciding that the problem will look after itself. A review of the situation shows that there is no practical means in prospect for restraining human population growth worldwide; that industrial throughput volume continues to accelerate; and that almost no country—and only a tiny percentage of companies—have a truly proactive environmental philosophy: so it could well be inferred that the problem is indeed running ahead of the response.

In fact, estimates of the imminence of the supercrisis of unsustainability vary from about a decade to 50 years or more. If the nearer-term estimates are accurate, this implies that we must make profound changes in every aspect of our lives in the near future if we are to avoid severe system-wide disruption. It also implies that our collective decisions and actions over a period perhaps as short as the next 10 years or so may be critical in laying the foundation for conditions many decades into the future—placing a special responsibility on the current generation.

4. Facing a Transition

4.1 Introduction

In order for today's unsustainability to be replaced by a future condition of sustainability there will have to be a transitional period of some sort. In principle there are a number of possible ways a transition could happen. It could be a process of smooth and continuous change, or it could be abrupt. Equally, it could be the result of a deliberate program, or it could be spontaneous. Several possible modes of transition are explored here, all metaphors for what could happen—borrowed from ecology, systems theory, and genetics. Appreciating the possible dynamics is an important part of assessing the options for action by individual organizations, whether the aim is to contribute to a process of transition or simply to survive it.

4.2 The Concept of Transition

An Ecological Analogy of Transition

The overall concept of a "transition to sustainability" itself has an analogue in ecological development. It is broadly equivalent to the shift that occurs during the development of an ecosystem—say the regrowth of forest on cleared land—as it makes the transition from a "pioneer" to a "mature" ecosystem, a process known as ecological succession (Figure 2). The characteristic strategies of organisms that thrive in each of these two phases are particularly relevant.

The earliest plants to establish themselves on cleared land are called *r-strategists* because they emphasize high rates of reproduction (high r) and dispersal ability. Most of their biomass goes into reproductive structures, and they grow rapidly and produce large numbers of seeds. These pioneer species survive by their ability to find new open terrain and move on. Their populations increase rapidly and become locally extinct quite rapidly, a J-shaped curve of population that climbs steeply, hits a limit, and falls away. Many short-lived annual weeds are r-strategists.

The r-strategists are followed by *K-strategists*: species that are adapted to stabilize their populations at a steady level. K is the term used in the equations of population ecology to denote the upper carrying capacity—the maximum sustainable density in an established ecosystem. The K-strategists grow slowly, put most of their biomass into non-reproductive structures (stems, roots, and leaves), and produce few seeds. The K-strategists follow an S-shaped curve of population growth that smoothly levels out and extends on into the future at the carrying capacity. The trees in a mature forest are K-strategists.[28]

The industrially assisted population growth of human society has been the result of an r strategy, with an emphasis on rapid growth, high rates of reproduction and wide dispersal. The r strategy is well suited to an initially

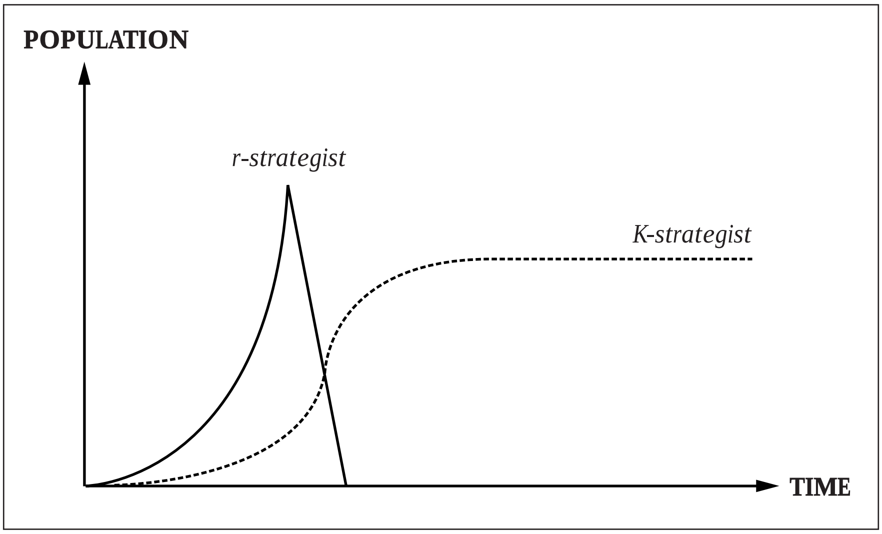


Figure 2, Ecological succession from J-curve growth to S-curve growth
Source: Lawlor, 1994

unlimited environment, such as cleared land being colonized by weeds, or a large planet with only a handful of industrialized countries. Our social institutions, just like the genes of the biological r-strategist, are adapted to this rapid growth mode. The challenge we now face as a society is to begin to adopt a K strategy—which in ecosystems is one better suited to a sustained role in a crowded environment and implies a greater energy investment in the maintenance and survival of the adult.

This is a substantial challenge. Put in another way, it would mean moving from our familiar, r form of capitalism, to an entirely new *K-capitalism*. In terms of the ecological analogy, this means completely reinventing the genetic makeup of our institutions, government and business. New *K-organizations* and *K-industrialization* would have to replace older *r-organizations* and *r-industrialization*.[29]

By analogy, we could argue that human society has been behaving like a pioneer species, but unlike other pioneer species, our frontier has now been pushed out to include the entire biosphere and we have nowhere else to go. The hope of sustainability is that we will use our unique self-awareness to adapt and consciously modify our behavior, so avoiding the fate of other pioneer species when their environment gets too crowded.

A Complex Systems Analogy of Transition

The actual dynamic of transition has a parallel in the concept of *bifurcation* in dynamic systems theory. When complex flow-dependent systems are exposed to high levels of constraint and stress they may suddenly and spontaneously move through a chaotic transition state to a completely new and unexpected form of order: this transition between states is known as bifurcation. High constraint and stress certainly characterize the current worldwide social and economic condition, and the collapse of the Soviet Union has demonstrated that there can be a sudden breakdown of prevailing conditions of order. And although conditions in Russia in the aftermath of breakdown are still fairly chaotic, a new form of order is slowly emerging.

The reason why bifurcation occurs can be explained using the "bumpy landscape" metaphor.[30] This sees the dynamic state of a complex system as a ball resting in a hollow in a bumpy surface. If nothing changes, the ball will remain still. But if an outside force builds up on the ball it may suddenly be forced up over the rim into a neighboring hollow—this is equivalent to increasing activity in the system. Or alternatively the bumpiness of the surface itself may change, forcing the ball to move—which is equivalent to a change in the parameters that shape the system. So although a system may be stable for a long time, it can change unexpectedly, and in fact this tendency is an intrinsic property of complex dynamic systems.

A bifurcation can take a variety of forms. It can be smooth and continuous, or it can be abrupt and discontinuous. These different types of bifurcation could well represent possible transition paths to sustainability.

A Genetic Analogy of Transition

The idea of bifurcation implies that a sudden shift in the system could be a positive or at least neutral event. How could this be so? The theory of "punctuated equilibrium" in biology provides, by analogy, a possible explanation. Some evolutionary biologists argue that evolution has not progressed by steady, incremental change, but by sudden jumps or leaps alternating with long periods of stasis.[31] This accounts for the sudden bursts of new species evident in the fossil record.

Danny Hillis, a pioneer of massively parallel computing, has demonstrated the phenomenon of punctuated equilibrium in simulations with "virtual" organisms. When he examined the genotypes of these organisms during what was assumed to be the quiescent phase between evolutionary jumps, he discovered that instead of being static, the underlying genetic makeup was actually seething with activity, preparing for the next jump.

The explanation was a gradual accumulation of "epistatic" genes—genes that were individually recessive, but which would interact synergistically when all were present to produce a completely new attribute for the organism as a whole. When the occurrence of the epistatic genes in the population as a whole reached a certain percentage—which turned out to be $1/e^2$—there was a phase transition, and the new trait would suddenly emerge in the population, as if from nowhere.[32]

By analogy, the evolution of social values could perhaps occur in a similar way, with the gradual buildup of an array of new values that are each "recessive"—meaning that any one is not overtly expressed by the individual—but which when present together "suddenly" give rise to a completely new mainstream outlook with a positive transformational effect on the socioeconomic system.

4.3 The Prospects for Transition

A Smooth Transition

One interpretation of smooth transition is that there will simply be continuous adaptive change in society. This would mainly be an unconscious response to unfolding conditions, much as the "invisible hand" of the marketplace is understood to act. In this view, there is no "crisis of unsustainability": we are merely witnessing, as at many other times in history, a dynamic disequilibrium which will spontaneously resolve itself. The symptoms of imbalance will be disturbing in any "snapshot" of prevailing conditions, but emergent solutions are always just around the corner.

An extreme *laissez-faire* version of this view would regard current concern about unsustainability to be a non-issue, on the basis that the present is never literally "sustainable"—it is always transforming into a new state. A more activist view would be that an orderly transition to sustainability is possible, but only if there is deliberate intervention to change the existing system. But for this to happen, there would need to be a clear consensus that a problem exists, as well as a willingness to take preemptive action. The danger is that political systems often respond only to crisis conditions, by which time there may be little maneuvering room left to implement an adequate policy response (Figure 3).

An Abrupt Transition

The idea of an abrupt transition to sustainability assumes that there could be a sudden shift in the socioeconomic system, following the onset of crisis conditions. In this case, the crisis might not be a mere breakdown of social order or ecological collapse—although it could be these—it could also represent the spontaneous emergence of a new kind of order, as dynamic systems theory suggests.

A physical demonstration of this form of bifurcation was discovered as early as 1927 by a Danish engineer, Balthasar van der Pol. Experimenting with a feedback loop to turn an

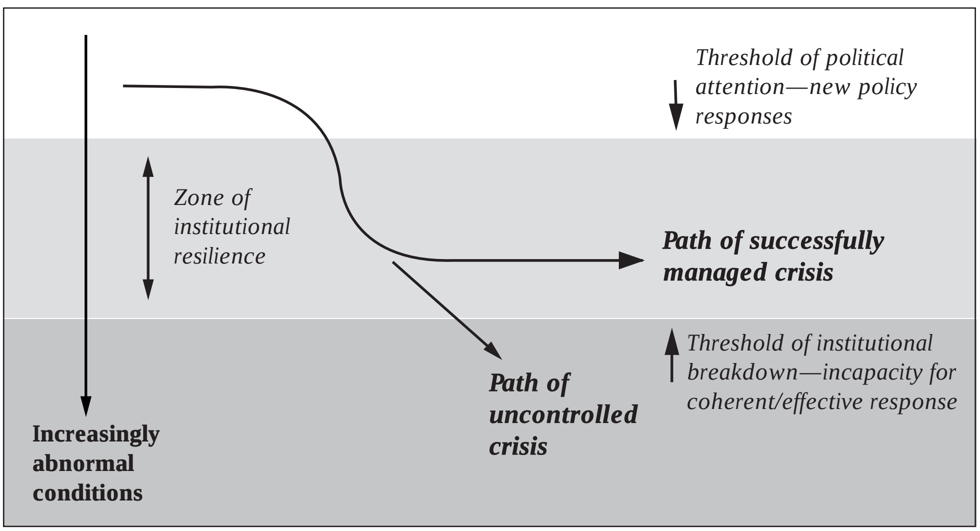


Figure 3, Two thresholds—response and capability

oscillating current into a tone on a telephone, he discovered that when the current in the loop was increased, the frequency of the tone jumped inexplicably to higher and higher multiples of the current's frequency. Between the jumps were bursts of noise—small regions of chaos. Although not understood at the time, the noise was created by conflicting attraction between regimes of higher and lower frequency.[33] By analogy, this phenomenon provides two important insights: that a positive shift is not necessarily going to be smooth, and an abrupt shift does not necessarily have to be negative.

Care is needed in drawing too close a parallel between systems theory and social behavior, but it does offer a highly illuminating metaphor. As a society we are indeed "increasing the current," almost literally. The energy flow through the industrial system is two orders of magnitude above its level 100 years ago, and is projected to increase. Global communications channels and message volume are increasing exponentially. Materials are being mobilized through the system at unprecedented levels.

Our socioeconomic system could, following the analogy of van der Pol's feedback loop, jump to a "higher frequency." In other words, the unsustainable conditions we now face could force a shift to, say, higher levels of social cooperation and more effective institutional design than have been possible historically. This, of course, is highly speculative, but it does suggest—and no more than suggest—that an abrupt change, possibly characterized by temporarily chaotic conditions, could turn out to be the prelude to a sustainable future. Unfortunately, it could also mean the collapse of the present system, so the positive possibility does not mean it is safe to wait for a crisis to develop.

4.4 The Dangers of Crisis

The Possibility of Ecological Collapse

A system-wide crisis could take society along a very different path. Many environmentalists fear that industrial society faces a very real prospect of ecological collapse and technological regression—perhaps even the extinction of the human species itself. In this case the bifurcation would not be to a new higher-level regime of order, but a drop back to a lower level, as sharply changed ecological conditions wrench the socioeconomic system from its existing state.

An analogy can be made with the distinction between chronic and acute medical conditions. In the case of arterial disease, a person may be living and eating in a way that slowly contributes to arterial thrombosis, and this condition may persist for years as a chronic disease condition without the sufferer having any decisive cause for alarm. Eventually, however, the body's resilience is exhausted, and the result is a heart attack—the disease has become acute. If the patient is lucky, this attack is not so severe that it is fatal, but sufficiently serious to prompt a reassessment of lifestyle and a change of diet.[34]

Ecological systems have similar characteristics to biological systems in this regard. They are capable of absorbing very considerable amounts of stress over extended periods without showing apparent harm—a condition of chronic unsustainability—but while this is happening, their buffering capacity is gradually being depleted. The moment comes when a critical threshold is suddenly crossed, followed by very rapid and "unexpected" breakdown in some aspect of the ecological system—a condition of acute unsustainability. If the stress is the result of human action, the sudden breakdown may then trigger changes in the human behavior that caused the problem—although if the effects are localized change is often resisted.

The recent history of Big Moose Lake in the Adirondack Mountains provides an excellent example of abrupt ecological breakdown (Figure 4).[35] The acidity of the lake water held steady for 200 years—as long as it had been measured—but between 1950 and 1980 it suddenly increased tenfold, from a pH of 5.5 to 4.5, causing many species of fish to die off. The origins of this abrupt jump in fact go back more than 70 years, to the industrialization of the American Midwest around 1880. Huge amounts of sulfur released by coal burnt several hundred miles away in the Ohio River valley were deposited as sulfuric acid in rain downwind. The burden of sulfur climbed steeply until 1920, when it stabilized at around 3.5 million tons a year. Yet it was not for another 30 years that the acidity of the lake began to change. The explanation turned out to be that the soils in the watershed of the lake had provided an enormous buffering capacity that was able to neutralize the acid rain for six decades. Finally, when the buffering capacity was exhausted, the acidity of the lake abruptly registered a change that had in fact been initiated 60 years earlier.

Ecological systems on both large and small scales exhibit this kind of nonlinearity—in other words instead of showing steady change, they appear to be unaffected for a long period and then suddenly change drastically, like the plot of acidity (pH) in Figure 4.

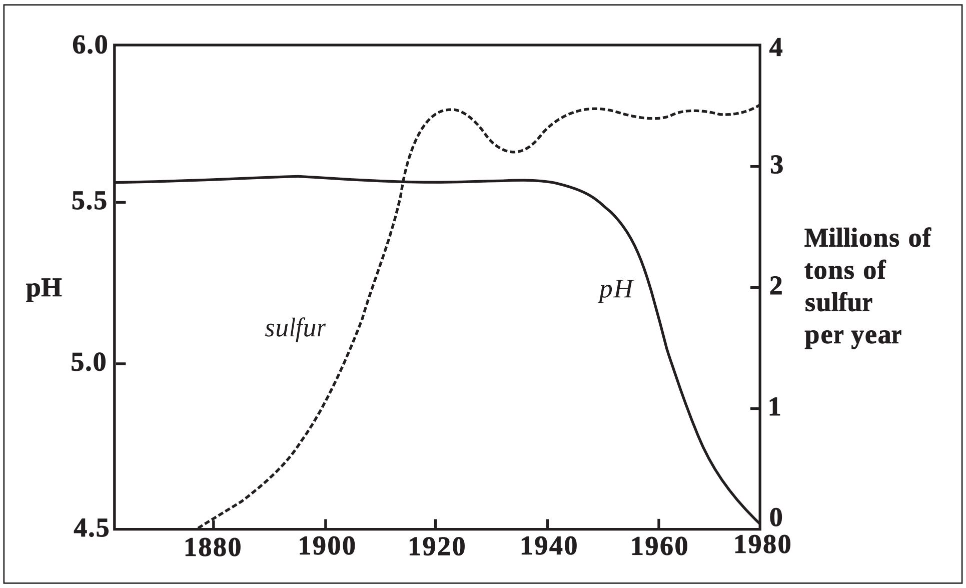


Figure 4, History of sulfur deposition and acidity at Big Moose Lake, Adirondacks
Source: Stigliani, 1993

This makes ecological nonlinearity a prime candidate for potential surprise or discontinuity, raising the question of where in the system these effects may be brewing, and on what scale.

The potential for nonlinear ecological collapse is by no means limited to the small scale—it could extend to breakdown in the large-scale ecological and biological systems we depend on for survival. This possibility is explored in *Beyond the Limits*.[36] When the World3 computer model is run to reflect continuing "business as usual," the result is a general collapse early in the next century (see Figure 7, section 5.2). This is acute unsustainability with a vengeance—the equivalent of a fatal heart attack. As the book says:

> *On a local scale, overshoot and collapse can be seen in the processes of desertification, mineral or groundwater depletion, poisoning of soils or forests by long-lived toxic wastes. Legions of failed civilizations, abandoned farms, busted boomtowns, and abandoned, toxic industrial lands testify to the "reality" of this system behavior. On a global scale, overshoot and collapse could mean the breakdown of the great supporting cycles of nature that regulate climate, purify air and water, regenerate biomass, preserve biodiversity, and turn wastes into nutrients. Twenty years ago few people would have thought ecological collapse on that scale possible. Now it is the topic of scientific meetings and international negotiations.*[37]

The Vulnerability of the Industrial System

Industry and environment can no longer be compartmentalized. The global environmental system and the socioeconomic system are now coupled—the fate of one is tied to the fate of the other. If conventional industrialization keeps growing, it risks bringing down the ecosystem; if the ecosystem crashes, it will drag down the economy.

The industrial system is highly vulnerable if there is serious ecological breakdown. Multinational companies are tuned like Grand Prix racing cars for better and better lap times, better and better quarterly results. They assume the racetrack will be perfectly smooth, without obstructions. Industrial installations, buildings, plant, energy transmission lines, are all designed for a narrow set of climatic and ecosystem assumptions—conservative maximum wind loading, moderate earthquake resistance, a steady flow of resources. But we now know, from studies of such things as Arctic ice cores, that nature is certainly capable of far more severe disturbances than the recent, relatively narrow range of climatic variation has led us to assume. This puts the operational basis of today's industrial society directly at risk from possible global ecological breakdown and accompanying widespread natural disasters.

5. Pathways into the Future

5.1 Introduction

The dynamic of transition explains how we might reach sustainability. But what would sustainability itself look like? We are more familiar with sustainable future worlds than we may think, thanks to popular fiction. In fact, the full range of possible future outcomes arising from unsustainability is surprisingly wide, although not all of them are plausible or desirable. Several works of fiction that illustrate this are discussed here, to give an expanded sense of what a future condition of sustainability could mean. These are followed by a specifically devised set of scenarios that try to capture the full range of possible outcomes, and as will be seen, they are by no means all equally convincing or attractive. This discussion sets the stage for exploring the means available to us for deliberately steering towards a more sustainable future.

5.2 Images of Sustainability

Purely technical definitions do not convey what sustainability might mean in the real world. But most of us are already familiar with detailed descriptions of both sustainable and unsustainable worlds. Although we may not have thought about it in this way, sustainability and its opposite, acute unsustainability, are recurring themes in popular culture, particularly in science fiction.

For instance, the worlds described or implied in two contemporary works of fiction, the novel *Ecotopia*[38] and the television series *Star Trek*,[39] might seem far apart. Yet they both depict societies in which the problems of technological imbalance with ecology, and associated social malaise, have been resolved. What is significant is the difference in the way these problems have been dealt with in the two worlds.

Back to Nature: Ecotopia

Ecotopia, a novel by Ernest Callenbach, is set in the near future and is probably the classic work of "eco-fiction." In it, Northern California, Oregon, and Washington have seceded from the United States and formed a new country called Ecotopia. The official ideology of *Ecotopia* is deep ecology, with a radically decentralized zero-growth economy; minimal and carefully considered use of "appropriate" technology; and an Earth-centered spiritual philosophy. It is a culture of material restraint, with contentment and deep personal satisfaction arising from community living and proximity to nature. As a scenario, it is well worth reading. As a book, *Ecotopia* has enjoyed a steady following in spite of its relative obscurity, and remains in print more than 20 years after its original publication in 1975.

Technology as Servant: Star Trek

By contrast, the immensely popular television series *Star Trek, The Next Generation*, devised by Gene Roddenberry, is set in the twenty-fourth century and most of the action takes place aboard a super-lightspeed military starship of the United Federation of Planets. Life aboard the Starship Enterprise reflects an undimmed spirit of adventure and expansionism, in which the frontier is no longer the American West, but the further reaches of the galaxy. The series only rarely visits planet Earth, but events and dialogue reveal the social character of the Federation. In this society, striving for material possessions has been eliminated through the effortless and equitable provision of material requirements for all, while the prowess of its technological capability is evident on board the Enterprise. Acceptance of social diversity and racial integration is taken for granted—and emphasized by the presence of alien humanoids on the crew of the Enterprise. Principles of justice, self-discipline, duty, and honor are expected and upheld. Personal striving focuses on self-development and cultural pursuits.

The series depicts a world in which the mainstream aspirations and hopes of the twentieth century United States have been accomplished, and the underlying assumptions of its idealism have not had to be questioned. Industrial production technology has been continued and perfected, culminating in something analogous to a waste-free "desktop factory." Biological science is far advanced—although it is not used for genetic "enhancement" or cloning of human beings, only for medical repair and health maintenance. Ecological science has reached a level that enables planetary ecosystem diagnosis and maintenance, and environmental difficulties on planet Earth are a thing of the past.

In view of the "back to nature" connotations sustainability is often felt to have, the world of *Star Trek* is probably not the first example of a sustainable world that would spring to mind—*Ecotopia* is more likely. But the *Star Trek* world evidently is sustainable, since life has carried on and disaster has been avoided, while problems of ecology and social justice have been resolved. This version of sustainability shows that it could be indistinguishable from a popular conception of the future in which progress is maintained.

Social Collapse: Riddley Walker

A global breakdown, the failure to achieve sustainability, is also a common theme in popular fiction. If the planetary ecosystem broke down badly enough to bring an end to industrial activity and advanced communications, but not badly enough to bring an end to human life, then the world might resemble some of the post-nuclear war fiction of the 1970s or early 1980s. An example would be *Riddley Walker*, a novel written in 1980 by Russell Hoban, and set some generations after a devastating nuclear war.[40] In the story, society has degenerated into a kind of medieval shadow world, littered with half-remembered and barely surviving fragments of twentieth century culture. The entire story is an imaginative tour-de-force told in the distorted remnants of the English language. With its isolated pockets of survivors and genetic mutations resulting from residual pollution, this could equally well be a world of post-ecological collapse.

A world like this might be sustainable in the narrow sense that it could continue to sustain a small population if enough foraged or farmed food were available, and if natural ecosystems recovered enough. But it would not have "solved" the problem of technology—in *Riddley Walker* the primitive culture is being torn apart by the rediscovery of gunpowder. Nor would it have resolved ecological or social problems, since basic survival would now dominate concerns for all. Advanced technological capability would have been lost outright. This would be a world in which what we are doing now has indeed proved unsustainable—where the environment has been pushed to the point of collapse, and has brought down the economic and cultural continuity of society with it. In short, the boundary that divides sustainability from unsustainability in this world is an involuntary loss of cultural and ecological continuity.

Technology as Tyrant: Blade Runner

A contrasting outcome that has been imagined in fiction is that the natural environment will not easily collapse, being much more robust than we imagine. Ecological degradation might continue as a chronic condition from generation to generation, without any sudden catastrophic disintegration. In this case, the existing pattern of industrial expansion and technological advance would continue, and many of the "ecosystem services" we now rely on would be progressively replaced by technological substitutes.

The limiting factor in a world like this might well turn out to be social. To some degree, this is already happening. In the advanced economies today, as well as on a worldwide scale, extremes of income disparity are growing, as is crime and intra-national warfare. Seemingly insoluble social stresses are created as we substitute technology for nature. When clean air and water are provided by nature, they are freely available to all, but when they are supplied or restored technologically they are provided through the market and people are forced to participate in a monetary economy to have access to them. The freedom to live a simple life close to nature has been lost, and the effects are, in economic terminology, highly "regressive." A world in which technological substitution of nature has been allowed to proceed very far, without any catastrophic general collapse of ecosystems, might resemble the world of the science-fiction film *Blade Runner*,[41] directed by Ridley Scott and based on a story by Philip K. Dick.

Blade Runner is set in the Los Angeles of the twenty-first century and depicts a nightmarish world of technology pushed to whatever limits the market can take it, with a resulting social experience of ruthlessness, danger, crime, alienation, distrust, and fear. The images of the film are dark, polluted, and technologically menacing, showing a society split between a mutant low-life street world, and a manipulative elite living in sleek high-technology fortresses. The film's striking opening sequences show the megastructures of an endless dark cityscape, below a sky thick with churning orange clouds, punctured by occasional spurts of flame from the structures below. Biological technology is well advanced, but used to distort nature, not to restore it. Industry is seen as ever more highly polluting, with no effective restraint.

The world of *Blade Runner* is sustaining itself in some narrow sense of the word—it continues to exist—but at what cost? The main casualties appear to be the loss of "civilized conditions"—democratic process, justice, personal safety, cultural expression—and the loss of experience of nature, which has powerful psychic and psychological significance. This amounts to an impoverishment of experience, a failure to sustain certain aspects of life necessary for the nurturing of a human being. Most people living in democratic industrial societies today would regard such a future as unacceptable, and as having failed the sustainability criterion by not maintaining crucial attributes of positive social experience. It might be better to substitute the term "persistent" as a way of describing a world like *Blade Runner* that is sustainable in the literal sense, but unacceptable.

These cultural images tell us that acceptable futures are popularly thought to lie in a band between ecological breakdown and social breakdown (Figure 5). The extreme beyond this in one direction is that nature overwhelms technology, and in the other direction that technology obliterates nature. And although the world we live in is clearly seen as having the potential to move toward one or other extreme, there is also the possibility that we can find a balance between these two tendencies.

5.2 Scenarios of Sustainability

If the present situation is unsustainable, and if the future outcome is not necessarily a smooth transition to sustainability, how much can we say about the alternative outcomes? Do the images of sustainability and unsustain-

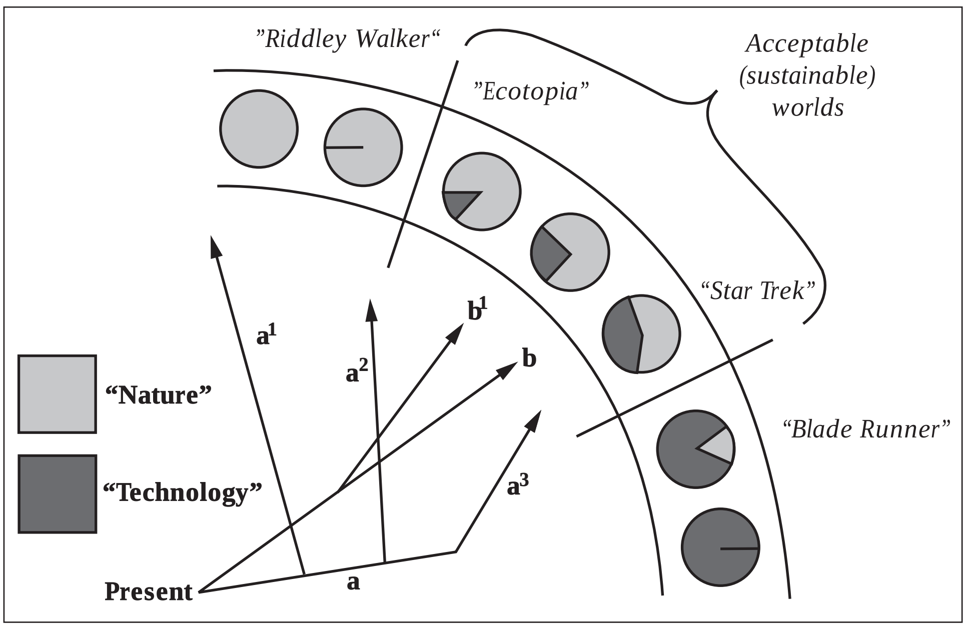


Figure 5, Pathways to sustainable future worlds
Path (a) is unsustainable, and may lead to ecological collapse (a1) , or it may be deflected towards sustainability (a2) and (a3). Path (b) is sustainable, but may be fine-tuned (b1).

ability expressed in popular fiction cover the whole range of possibility?

The following seven "thumbnail scenarios" are simple thought experiments that attempt to explore the full variety of possible future pathways. They have a long reach, both geographically and in time. They do not focus on an immediate decision-making horizon, but they do offer a large-scale backdrop or context for more focused planning scenarios.

The seven scenarios form a "scenario tree" (Figure 6), each branch of which is at least in principle possible, although, as the discussion will suggest, they are perhaps not all equally plausible. It is important to examine them because they all represent generic tendencies of the system that are usually not thought through to their logical conclusions. At one level, these scenarios can be regarded simply as alternative possible outcomes, useful for the light they bring to the question of sustainability. However, if the overall line of reasoning presented here is valid, the conclusion must be that *if* the assumption of unsustainability[42] is made, sooner or later there will be a more or less abrupt transition, which is likely to be a distinct watershed event in human history.

Technoworld: Silicon Switzerland

The top branch of the scenario tree shows two possible outcomes from increasing substitution of natural capital by technology. The intermediate step on the way to these worlds is characterized as *Technoworld*. Although it is unlikely that natural capital could indefinitely be replaced by artificial capital, one outcome, at least in principle, might be a "science fiction utopia" represented by the *Silicon Switzerland* scenario. In this world, all of soci-

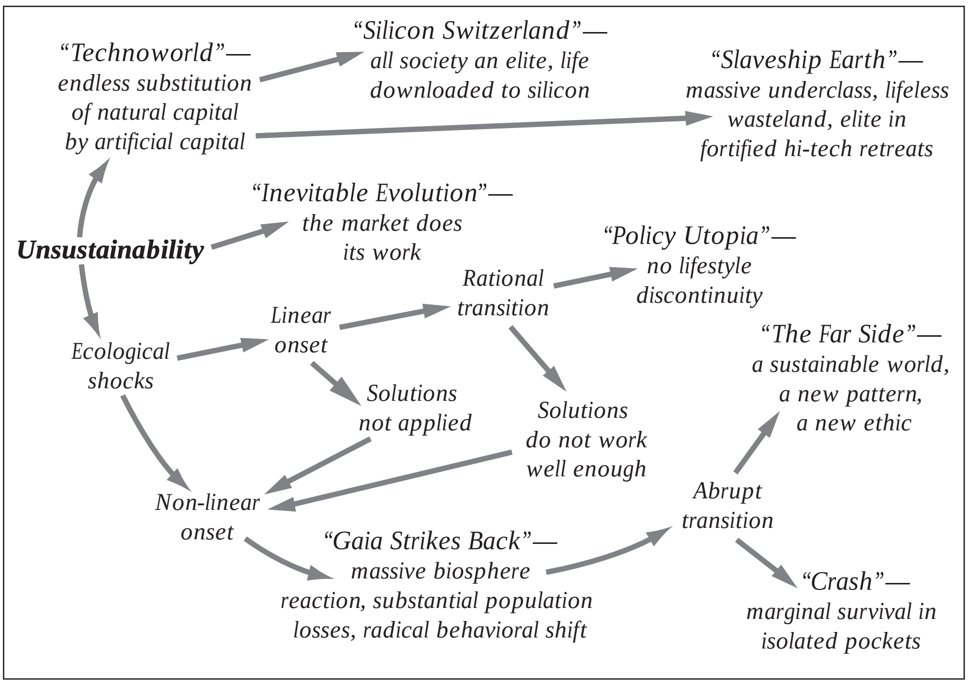


Figure 6, Scenario family tree: the outcomes of unsustainability

ety is an elite class and poverty is eliminated: ultimately everyone is "downloaded" to silicon and other robotic substitutes for biological life. Such a scenario depends on an intensely materialistic philosophy of existence, with many questionable assumptions—for instance that all of society could form an elite in an increasingly lifeless world, or that the true nature of human beings is such that we could successfully transfer ourselves into computers. The plausibility of this world would at best be a minority viewpoint.

Technoworld: Slaveship Earth

The alternative outcome from a *Technoworld* situation is a world in which the loss of natural capital precipitates social breakdown. In the scenario called *Slaveship Earth*[43] a small elite is entrenched in fortified, high-technology retreats or fortresses, while a massive underclass ekes out a miserable existence in an almost lifeless wasteland. Again, it is doubtful whether a world like this would have much staying power, but it does at least capture what appears to be the more likely outcome of unlimited substitution of natural capital. Since social stability and environmental quality are intertwined, in a world where there was environmental desolation without an actual environmental collapse (if such a thing is even possible) social breakdown would be highly likely.

Slaveship Earth would not necessarily require highly advanced technology. It could be the outcome of an extension of existing technologies—what Herman Kahn described as "superindustrialization," the rapid expansion of today's trends without any transition to "post-industrialization."[44] If technology does advance and becomes less energy- and materials-intensive this should be beneficial for the environment, yet an alternative and paradoxical outcome is also possible. Things could be "worse" with "better" technology. In a world without an established "green technology" paradigm, the early advent of nanotechnology, or an energy technology like cold fusion, could unleash environmental despoliation far worse than the existing abundance of cars and chain saws can achieve. Learning how to manage our existing technologies from an environmental perspective will be what "qualifies" us to deploy higher levels of technology safely while avoiding an outcome like *Slaveship Earth*.

Both *Silicon Switzerland* and *Slaveship Earth* are best considered "phantom" scenarios, important for "thinking through" all the possibilities. That is, they may be unlikely to represent real outcomes, but they do show what happens when a particular line of reasoning is carried through to its logical conclusion.

Inevitable Evolution

The next branch of the scenario tree is a world called *Inevitable Evolution*, in which the action of the market alone would bring about a condition of sustainability. In the view of many, such a world is at best a simplification since many instances of market failure have been identified—for example, the now well-recognized failure of existing markets to account for environmental externalities. Markets are the result of deliberate planning that allows trade in specific kinds of property, but the active redesign, but the active redesign of markets falls outside the scope of this scenario. For example, the deliberate use of market incentives to bring about sustainability would be the result of a conscious policy initiative, not purely the action of the "invisible hand" of the market in the sense intended in *Inevitable Evolution*.

A real example of the fortuitous action of the market in spontaneously bringing about an environmentally favorable outcome will explain the idea behind this scenario. In the electricity industry in the United States, the technology of choice for most new generating capacity is the Combined Cycle Gas Turbine (CCGT). This is because CCGT generators—in essence consisting of jet aircraft engines (aeroderivative turbines) bolted to a concrete platform—are relatively small scale, modular, and comparatively inexpensive, posing low financial risk. In addition, since natural gas is the lowest-carbon and cleanest-burning fossil fuel available in today's fuel market, and since CCGTs have the highest conversion efficiency of any current generating technology, there are real environmental benefits from the use of this new technology. But it is market forces that are ensuring very rapid adoption of this technology, because both gas and CCGTs are cheap. In other words, this is a prime example of the way the market can do better than public policy.

Whether this circumstance is more than a one-off fluke is an open question. Perhaps a better question is whether any policy maker can afford to rely on favorable coincidence as a basis for forward planning. If not, then there is hardly likely to be a world in which the pure action of the market is allowed to operate unfettered in all countries.

Policy Utopia

The next branch of the tree explores a chain of related scenarios in which policy initiatives are taken deliberately to bring about sustainable outcomes. Given the impediments to radical change that exist (discussed in Section 8), these policy initiatives do not happen out of the blue. They are stimulated by some degree of adverse environmental experience—as has already been the case with existing environmental regulation. The "mildest" case is the onset of chronic unsustainability—the incremental worsening of environmental degradation. In an ideal world there would be a rational decision to take broad-based precautionary action, and the outcome is *Policy Utopia*, in which a smooth transition to sustainability is accomplished without any discontinuity in lifestyle for the majority of people.

But would linear environmental degradation—which many argue we are experiencing already—be enough to trigger an adequate policy response? There would be no decisive events which would constitute "proof" of overriding environmental urgency as far as existing policy-making regimes are concerned. "Solutions" applied under these conditions would perhaps be no more likely to lead to radical reform than existing environmental legislation. Indeed, it may well be that we are already in a world of linear onset, with no convincing sign of *Policy Utopia* on the horizon. In any case, it is not clear that a radical move to sustainability could be accomplished without any perceived lifestyle discontinuity, or conversely that lifestyle discontinuity would be acceptable if there was no background of urgency or compelling need for change.

Gaia Strikes Back

Even if a "rational transition" is attempted, it might not succeed. The solutions applied might not work, either because they were not stringent enough, or because they were simply not effective. In this case, continued ecological degradation leads in the end to some form of nonlinear ecological collapse, perhaps in the form of multiple breakdown events. In other words, chronic unsustainability will ultimately lead to acute unsustainability—the heart disease leads to a heart attack. The same happens if "linear onset" is simply ignored by public policy and no solutions are applied.

The bottom branch of the scenario tree looks at what could happen if we are faced by nonlinear onset of ecological breakdown—the ecological heart attack. The actual occurrence of a breakdown, or a combination of events that could together be regarded as a breakdown, is represented by the *Gaia Strikes Back*[45] scenario. There are a number of environmental shocks that could signal a condition of overshoot and even some possible events that would not be terrestrial in origin (Table 1). In the worst case, a massive reaction to industrial activity by the biosphere could lead to possibly substantial population losses (the J-curve dynamic) and the shutdown of much economic activity, with a serious loss of institutional and organizational capability.

Crash

The aftermath of such an experience could itself go two ways. If we assume that the shocks were bad enough to cause severe dislocation of the existing order (anything less would only count as linear onset), then in the extreme case, the impact would be so bad that civilized life as we know it would be terminated, with no hope of recovery or reconstruction in the short term. *Crash* is the worst case scenario of the whole tree, in which there is only marginal survival in isolated pockets where a few people have managed to hang on to the vestiges of modern technology.

The Far Side

More hopefully, although the impact might be bad enough to interrupt the existing conduct of life, it would not be bad enough to prevent reconstruction in the short term—say, on the order of a decade. The scenario called *The Far Side* supposes that this interruption and

- **Abrupt climate change (≤5°C in a decade, as in the Arctic ice record)**
- **Ocean current shifts (e.g. sudden cooling of Europe by shift in Atlantic)**
- **Violent storms, flooding**
- **Prolonged drought (and wildfires)**
- **Volcanoes, earthquakes, tidal waves**
- **Rapid sea level rise (icemelt positive feedback)**
- **Worldwide ozone loss**
- **Loss or reduction of food production**
- **Rapid solar irradiance variation (≤0.7% per decade and/or major flares)**
- **Asteroid or comet impact**

Table 1. Possible environmental "shocks" and the results of overshoot

restart (almost like rebooting a computer) has turned everyone—consumers, corporations, and government—into convinced environmentalists, since they have experienced conclusive "proof" of the environmentalist position. In these circumstances, only a pattern for society and industry that is truly sustainable will be acceptable. This would indeed be a transition to sustainability, since new models for social organization and the use of technology would be applied everywhere, but it would be an abrupt transition, with lifestyle disruption for many people. In the very best case, the collective shock of looking over the ecological precipice—quite possibly with extensive loss of life—would usher in a golden age of international restraint, awareness, and cooperation, in which the promise of advanced technology to improve the lot of the human race would truly be realized. This vision might be considered utopian, but it does suggest that the storm cloud of ecological breakdown could have a silver—or in this case, golden—lining.

5.4 Scenarios from Beyond the Limits

As mentioned in Section 2, a series of scenarios are presented in *Beyond the Limits*[46] based on runs of the World3 computer model, exploring a variety of assumptions about the global system.

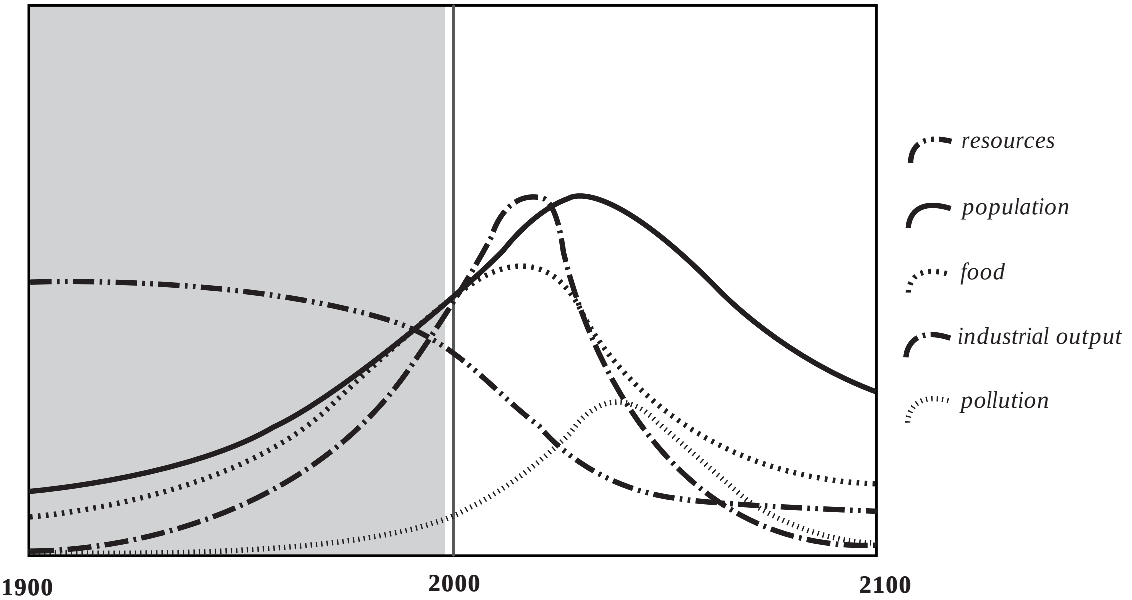
When the computer model is run "as is" (business as usual), "with no unusual technical or policy changes," the result is a general system-wide collapse early in the next century, perhaps around 2020 (Figure 7). Since this first scenario of the book ("scenario" here meaning simply a run of the model) corresponds to the controversial "standard run" in *Limits to Growth*, it is worth repeating a disclaimer from *Beyond the Limits*:

> *This scenario is not a prediction. It is not meant to forecast precise values of any of the model variables in the future, not the exact timing of events, nor, we believe, does it necessarily represent the most likely "real world" outcome....The strongest statement of certainty we can make about Scenario 1 is that it portrays the most likely general behavior mode of the system, if the policies that influence economic growth and population growth in the future are similar to those in the past, if technologies and value changes continue to evolve in the manner prevailing now, and if the uncertain numbers in the model are roughly correct. [*Beyond the Limits*, p. 134.]*

In other words this model has roughly the same status as our knowledge about the general behavior of a bouncing ball—we may not know enough to be able to predict exactly where a specific ball will land on a specific occasion, but we do know enough to be able to describe the general trajectory it will follow.

Beyond the Limits goes on to explore, through World3, what might happen when a wide variety of hypothetical changes are introduced in an attempt to stave off disaster. The potential for technological innovation alone is explored, but this only buys time—there is still a collapse, but it is delayed until the middle of the twenty-first century. Radical behavioral and attitudinal changes are explored too, but it turns out that these alone are not enough either—there is *still* a crash in the mid twenty-first century. In this model, it is only when both these kinds of changes are applied together that a crash is avoided, and this is the outcome described in Scenario 10 (Figure 8).

State of the world



Material standard of living

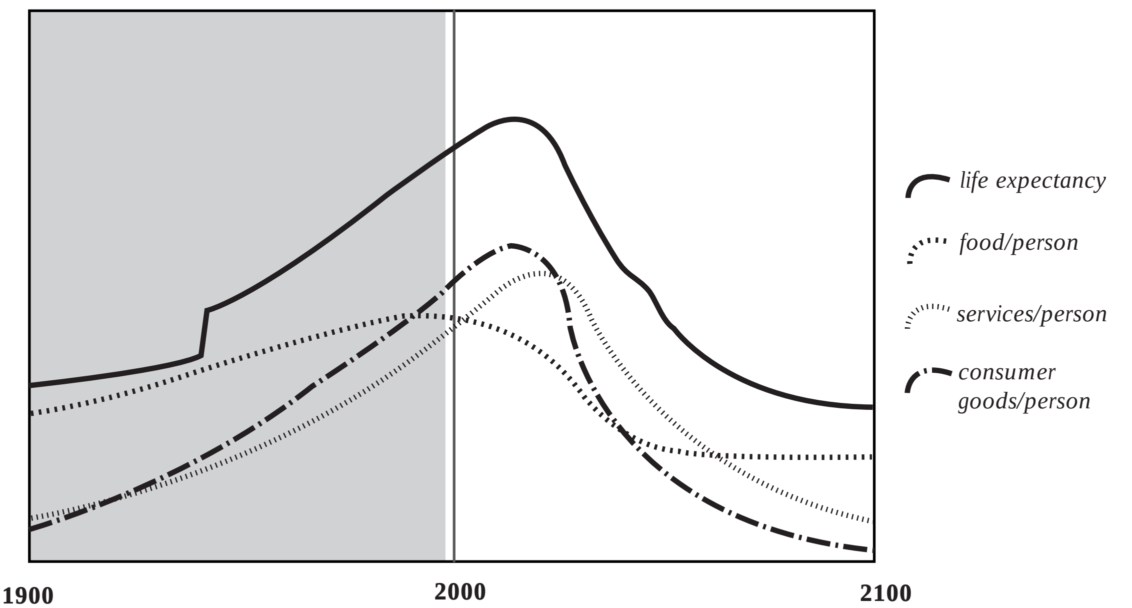
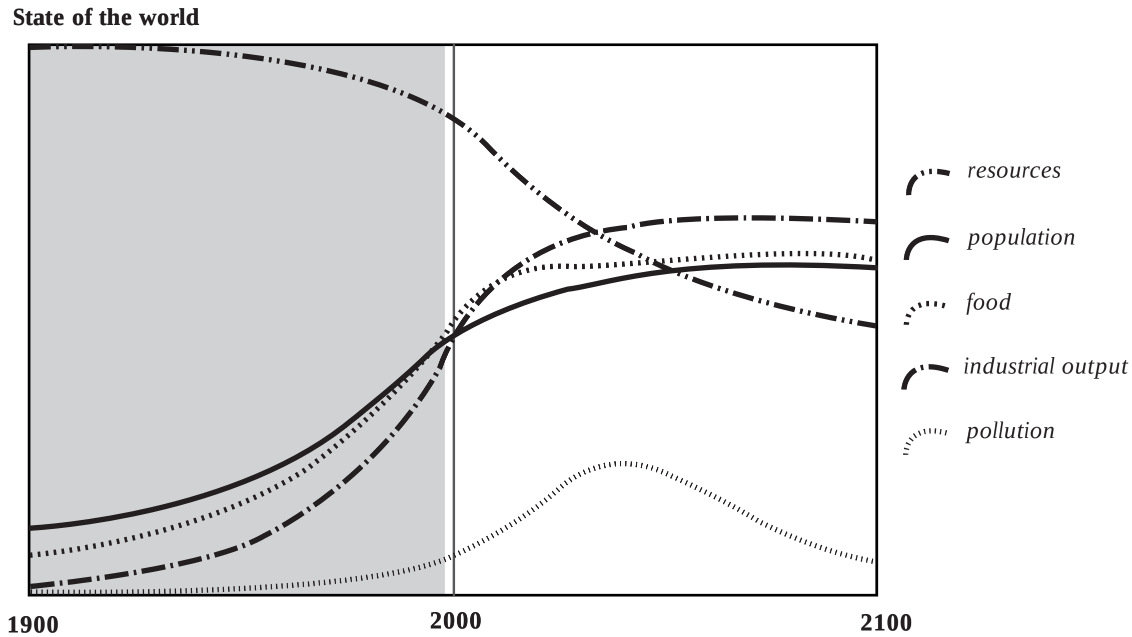


Figure 7, *Beyond the Limits* Scenario 1
Source: Meadows, 1992

THE STANDARD RUN FROM THE LIMITS OF GROWTH
The world society proceeds along its historical path as long as possible without major policy change. Population and industry output grow until a combination of environmental and natural resource constraints eliminate the capacity of the capital sector to sustain investment. Industrial capital begins to depreciate faster than the new investment can rebuild it. As it falls, food and health services also fall, decreasing life expectancy and raising the death rate.



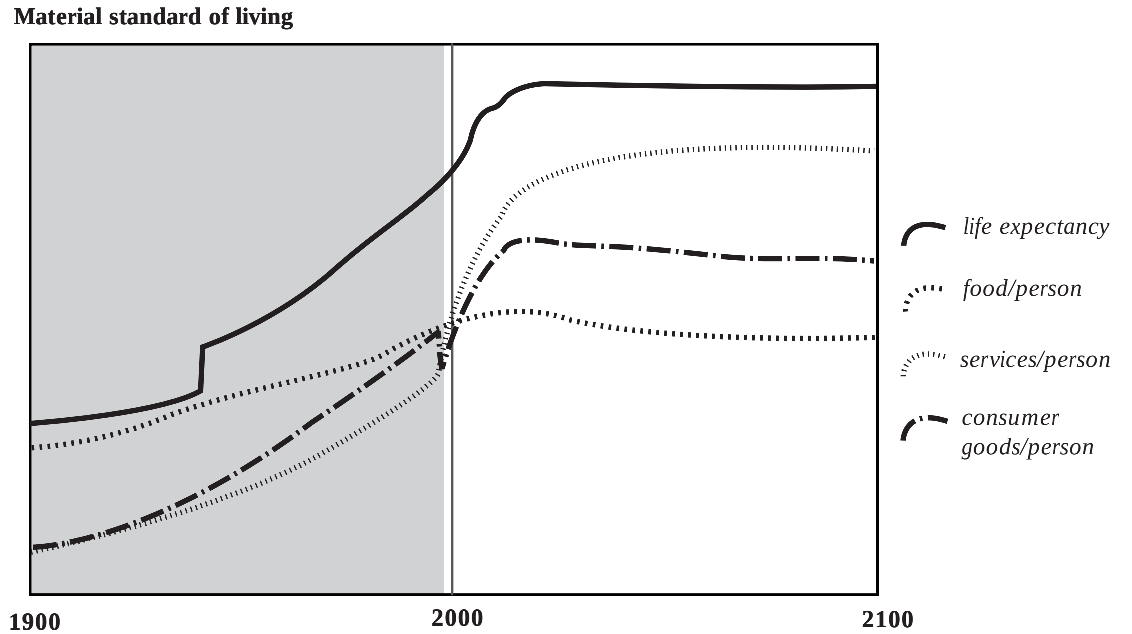


Figure 8, *Beyond the Limits* Scenario 10
Source: Meadows, 1992

STABILIZED POPULATION AND INDUSTRY WITH TECHNOLOGIES TO REDUCE EMISSIONS, EROSION, AND RESOURCE USE ADOPTED IN 1995

In this scenario population and industrial output per person are moderated as in the previous model run, and in addition technologies are developed to conserve resources, protect agricultural land, increase land yield, and abate pollution. The resulting society sustains 7.7 billion people at a comfortable standard of living with high life expectancy and declining pollution until at least the year 2100.

The book also explores the time sensitivity of the Scenario 10 "solution." How quickly would this miraculous combination of behavioral, policy, and technological changes need to be made? The last few scenarios in the book suggest that if the changes are made starting in 1995, we squeak by. But if we delay for 20 years, until 2015, it is too late and again there is a collapse by mid-century, although if the policies are grimly adhered to there is a recovery by the end of the century. So, the World3 model suggests that if we are to avoid an economic and ecological crash in the first half of the next century some very radical policy measures must be enacted very soon, within say the next 10 years at the latest.

The problem, of course, is that if there are no forcing events and things are left to the normal political decision-making process, it is very hard indeed to see how we would collectively summon up the determination and the capacity to initiate the necessary changes by 2005 or so.

Faced with projections of this enormity, there is an overwhelming temptation to dismiss them as unrealistic, yet this model is hard to argue away in its entirety. It does not aim to provide precise dates or quantities, but rather to illuminate the general mechanisms of unsustainability. It has benefited from significant international criticism, and has, in fact, shifted its argument from the original resource scarcity concern of *Limits to Growth* to a focus on the inability of the biosphere endlessly to absorb pollution and other damage. At the very least, its message provides an essential reference point for "scenario thinking" about unsustainability.

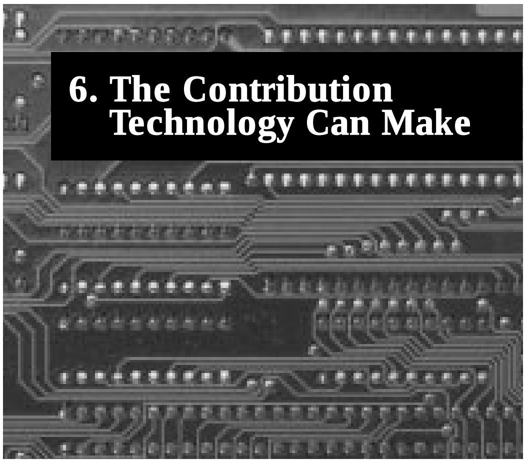
5.5 Learning from the Scenarios

Some important insights can be drawn from the scenarios presented in this section, plus the discussion in preceding sections.

Given the inherent inertia of the system to proactive change, a primary issue is whether or not the magnitude of the global environmental problem is matched by the magnitude of the aggregate response. Since, as noted in Section 3, only a tiny percentage of companies, and almost no countries, have a truly proactive environmental philosophy, it seems probable that the scale of the problem indeed continues to be larger than the scale of the response. This is a contentious issue, however, with no clearly agreed answer, and it remains an open question in the scenarios.

If the scale of the response either is or will be adequate, then the "transition to sustainability" will be smooth and incremental—indeed it may not seem to be a "transition" at all, it may simply look like the natural evolution of the system. If, however, the scale of the response neither is nor will be large enough, then by definition, given the fundamental dynamics of ecological systems, there will in due course be ecological "shocks."

Another key insight is there are two particularly important types of change involved in any shift toward greater sustainability—social change and technological change. If change is being introduced deliberately to reduce unsustainability, both social or behavioral and technological change need to occur together; one or the other alone will not be enough.



6. The Contribution Technology Can Make

6.1 Introduction

Technological change is potentially a crucial factor in reducing unsustainability. But it is sometimes argued that new technology is all we need to solve existing problems. This is paradoxical, because technology is also the direct cause of much unsustainability. Unravelling this dilemma means first appreciating the way technology is changing, then looking at the contribution technological efficiency can make, and finally understanding what is involved in deliberately reshaping technology.

6.2 Technological Advance

Technology is set to advance significantly. Raw computer power has the potential to increase by at least another two orders of magnitude, while hardware size shrinks. The rapidity of this progress can be estimated by plotting parameters such as the number of atoms representing one information bit (Figure 9), or the steadily falling amount of waste heat produced by each logic operation (Figure 10).[47]

Straightforward projection suggests that fundamentally new technological capabilities will be required in the 2010 to 2015 timeframe if current rates of miniaturization are to continue.

In this timeframe, for example, storage of one information bit using only 100 atoms, and thermal dissipation at the level of random molecular motion at room temperature (kT), should be achieved—both of which would require "nanotechnology," or molecular-scale engineering. Existing rates of technological advance thus suggest that nanotechnology will be emerging as a practical reality by approximately 2010.[48] Nanotechnology has such potentially far-reaching implications[49] that almost all bets are off when it comes to predicting specific implementations, but it appears likely that it will accelerate many of the broad technology trends already underway.

Energy technology is also expected to evolve significantly, with economically competitive photovoltaic (PV) technology for bulk utility power generation also projected in the 2010 to 2020 timeframe. Wildcard energy technologies such as cold fusion are looking increasingly plausible.[50] Technological capability in biotechnology (as opposed to laboratory science) is likely to mature in the same timeframe. Other wildcard technologies such as bioelectromagnetism[51] will probably achieve critical mass by 2010, although they are not yet blips on the radar screens of most corporations.

These estimates indicate that the period beyond 2010 will see some powerful new technologies coming online, with as much potential for social impact as any of the major technologies implemented in the early years of the

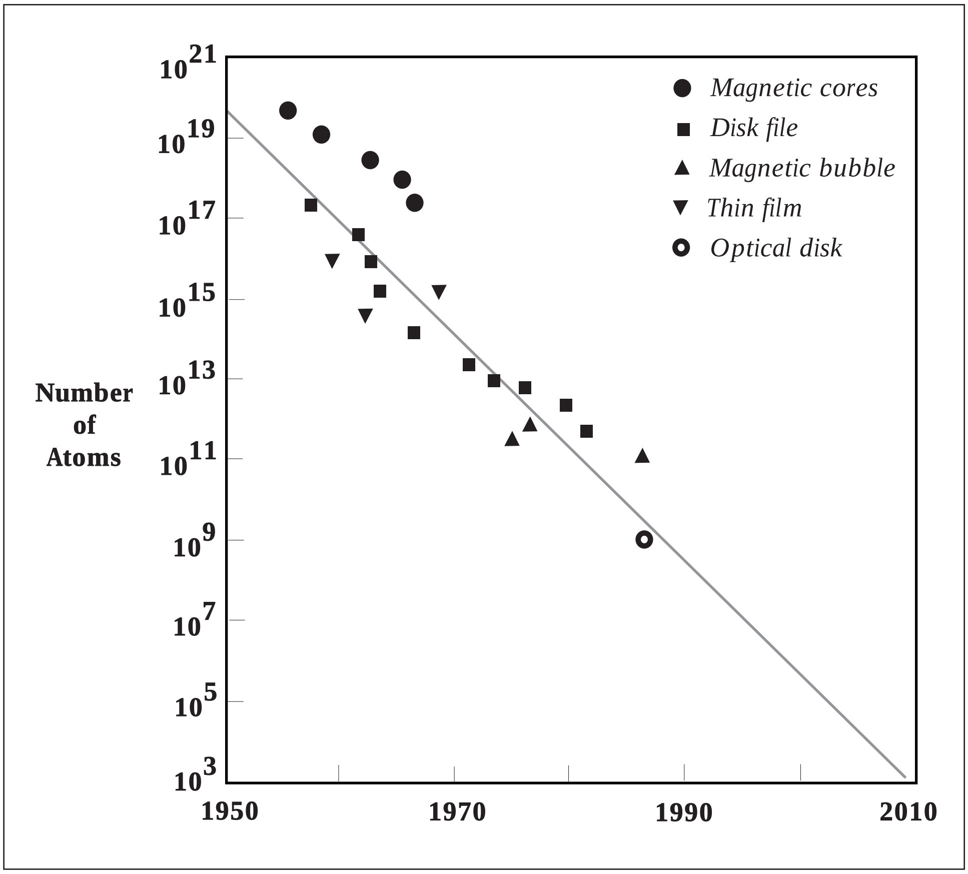


Figure 9, Number of atoms used to store one information bit in successive computer storage technologies
Source: Keyes, 1988

twentieth century—such as electric power, radio, automobiles, or aviation.

However, from the social and environmental point of view, these technologies are definitely two-edged. On the upside, they hold great promise for solving existing problems. Nanotechnology, for instance, promises ultra-clean manufacturing technology with zero waste, as in the concept of the "desktop factory" into which a little methane and a lot of software is fed, and from which come atomically precise components of, say, solid diamond (made from the carbon in the methane) and perhaps some surplus electricity.

On the downside, however, these same technologies could wreak havoc if we have not learned how to control them adequately. Nanotechnology could just as well create virus-sized, self-replicating, (and worse yet, maybe even randomly evolving) robotic devices (like the "nanites" of *Star Trek* fame) that might feed on some key component of the biosphere—say chlorophyll. Such a prospect could be as devastating as a nuclear world war.

It is also possible that the early onset of acute unsustainability could disrupt the stable social and economic conditions required to develop

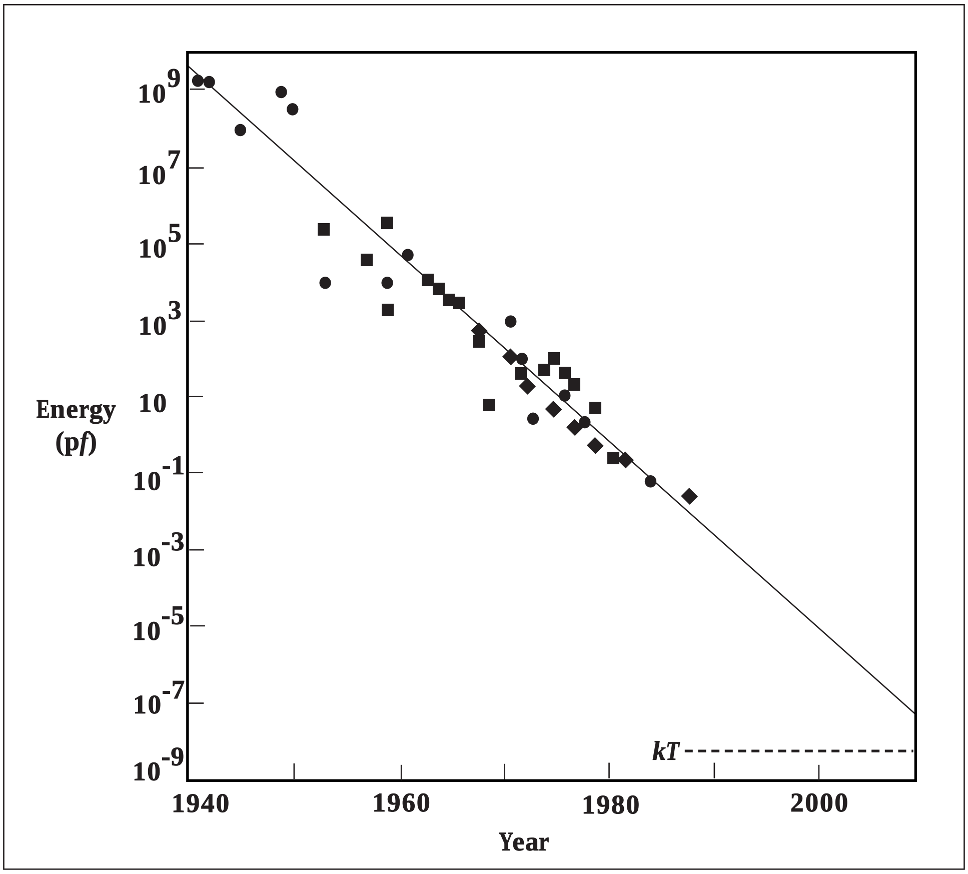


Figure 10, The decreasing energy dissipated per logic operation in successive generations of computer technology
Source: Keyes, 1988

and deploy new technologies. This risk and the potential danger from the power of new technology, places a special value on the effort to learn how to guarantee environmentally safe operation of both existing and future technology. It means that this discipline is a necessary social prelude to the safe development of these more advanced technologies—in effect it forms a critical doorway to higher levels of technological achievement for our culture as a whole.

Dematerialization

Some important overall trends in technology can be identified. One is dematerialization—a term which refers to the steadily declining mass and energy intensity of economic output in all highly industrialized economies.[52] Once the bulk of basic product demand is satisfied in society, the amount of materials and energy used per dollar of economic output begins to fall. As technology and materials become smarter, functions and structures that required high materials content and multiple components can be replaced by information stored explicitly and electronically, or implicitly in the form of advanced applied knowledge. Products become cheaper to manufacture, and can simultaneously be sold for more, since the knowledge content frequently makes them more effective. If the information is in the form of onboard electronics, then this can be exploited by designers to add features or improved user interfaces, further increasing market value.

Dematerialization also implies a shift from resource industry employment toward knowledge industry employment. Since less-industrialized countries tend to be the resource suppliers,[53] this will have significant social impact on them. The need for education in these countries will be a major challenge in the years ahead, and given the international reach of information technology it may be that computer-based learning will fill part of the requirement, just as computer-based employment may be able to provide new jobs.

The tendency toward dematerialization makes technology intrinsically lighter on the natural environment. If dematerialization is adopted as a deliberate design objective, the underlying trend could be significantly accelerated.

Decentralization

A further trend in technology is decentralization. Applied technology, in the form of products and processes, is increasingly being deployed in smaller, modular increments, and designed for decentralized rather than centralized operation. This trend is, at least in part, because optimal scale no longer coincides with maximal scale: experience has shown that there are social and other limits to large unit scale, both in the technology itself and in the institutions and organizations needed to control or manage it. Earlier patterns of organizational management were aimed at effective management of large scale, whereas the challenge is now effective management of complexity. Technology itself is accelerating this trend, as it either incorporates information technology or actually is information technology. As production technology is automated or "informated" by distributed intelligence, and networked using digital communications, it simultaneously increases complexity and demands new systems-oriented approaches for its management.

Consumers have consistently made choices that have amplified the move away from centralized technology—a move described as "demassification," a shift from the monolithic mass market toward mass customization. Consumers favor technologies that offer greater flexibility, personal control, and freedom of choice. The fax machine and the cellular telephone are examples, both made possible by miniaturized electronics, and both in turn making possible the decentralization of office work, as well as the interconnection and networking of dispersed groups.

These developments greatly enhance the capability, influence, and awareness of individuals and groups—for example, the students in China who were able to fax news about Tiananmen Square around the world. This tendency is likely to be enhanced by the extremely powerful new technologies that are moving toward industrial application in the early part of the next century. This presents a challenge of adaptation not only to individuals, but also to major social institutions.

Business will be faced with increasingly complex and rapidly changing market conditions, and changing social values in the workforce. Government will be challenged as traditional sources of political power become less effective. In an almost literal embodiment of the slogan "Think globally, act locally," the new technology will increase the ability for problem-solving at the supranational level, while at the same time facilitating demands for local or regional self-determination.[54]

6.3 Technological Efficiency

There is a prevailing belief that improving the efficiency of technology—for example by reducing energy consumption—will automatically reduce the overall environmental impact of industrial society. However, although increased efficiency can undoubtedly have environmental benefits, it does not always have the expected effect, and is often simply a way of buying time.

There are several reasons why improvements in efficiency cannot be relied on to yield an automatic reduction in unsustainability. Firstly, the overall growth in the use of a technology frequently outstrips gains in efficiency. If an efficiency is introduced it tends to have a stimulating economic effect since, if nothing else changes, it causes costs and prices to fall, which either expands the existing market or opens up new markets (Figure 11). Because of this, efficiency has been the principal dynamic of industrial growth since the onset of the industrial revolution. Second, efficiency gains are often deployed on the margin, in the form of additions to the existing capital stock, leaving the bulk of the existing stock in place. Third, an achievable efficiency gain, such as a saving in energy costs, may be too small a part of overall costs to justify capital expenditure and so may be postponed. The outcome of these factors is that although efficiency per unit of production has consistently improved, the aggregate environmental impact and use of resources has been steadily increasing.

In addition, technological efficiencies interact with consumer behavior in unexpected ways. This is illustrated by a 1980 study of the economics of house heating. Researcher Alex Scott proposed a model of house-heating fuel consumption[55] which was later confirmed in empirical studies, and can be generalized to other consumer technologies.[56]

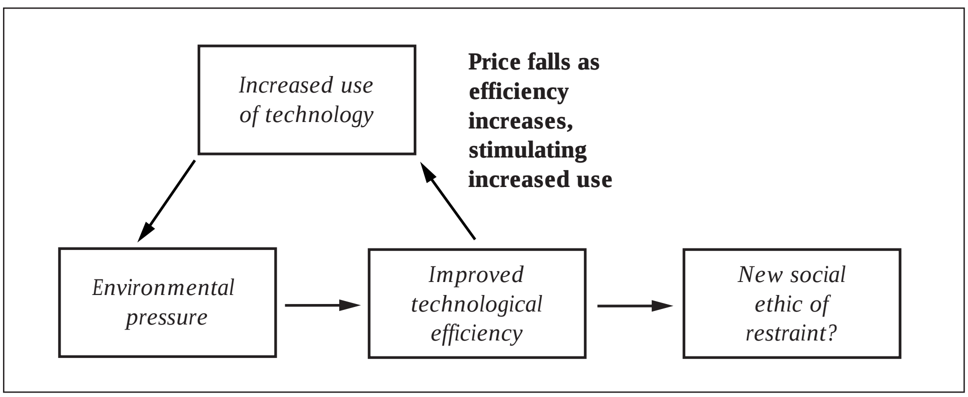


Figure 11, The "paradox of efficiency"

The model may be illustrated roughly as follows. Suppose an uninsulated house is so drafty that it is not worth spending more than a minimal amount on localized heating. Then the house is insulated enough for some heat to be retained, and it becomes worthwhile to pay for more fuel because of the greatly increased comfort that can be achieved. So, surprisingly, this means that a modest improvement in efficiency causes the fuel use to go up, not down, because it is now feasible to keep the whole house warm. If the insulation is improved further, the higher level of expenditure on fuel will be maintained because it becomes feasible to make the whole house even warmer. But people do not want even a well-insulated house to be kept at more than about 75°F, so once the improvement in insulation makes this temperature easy to attain, the expenditure on fuel finally begins to fall. As the insulation is improved beyond this point, the whole house can be kept at 75°F with progressively less fuel. The ultimate is a house so well insulated that it stays warm from solar heat, so that less would be spent for heat than in the original drafty house. (This ignores capital costs, since in a new house this outcome could be achieved by different design rather than by additional capital equipment.)

There is a "human scale" effect at work here. When no amount of expenditure will place people in the naturally desired comfort range, they will spend very little on the service or function. If technological improvements place the range just within reach, people will increase expenditure and consumption of related resources. Their expenditure will only fall if the technology improves so much that the comfort range is easily attainable with minimal resources.

Thus a move from a low- to an adequate-effectiveness technology—as in the early stages of industrialization—usually results in an increase in both per capita and overall consumption of input supplies. A deliberate move to more efficient technologies may result in an increase in consumption of inputs (or more accurately, throughputs) unless the efficiency is extremely high, or the technology has free inputs—as with, say, photovoltaic electricity. This shows that any attempt to develop ecologically neutral industrialization by leapfrogging to eco-efficient technology must meet a key performance criterion: that aggregate throughput consumption is less than with existing (possibly subsistence) technologies. This is a tough target, requiring major new advances in technological capability and application.

6.4 Reshaping Technology

The Product System Hierarchy Concept

How can these features of technology be related to the prospect for a transition from unsustainability to sustainability? Is there a way of linking the objectives of sustainability to the decisions that shape technology and guide the uses to which it is put? One potential approach can be derived from the concept of the product system hierarchy, which relates the broad context of technological change to specific technological developments.

Complex systems of applied technology can be understood as hierarchies consisting of large scale system elements, subsystems, individual products, component sub-assemblies, and components. This organization is particularly evident in large-scale engineered systems such as air or road transport systems (Figure 12).

As technology systems develop they tend at first to be constrained by limits at a low level in the product system hierarchy. As these are overcome by advances in technological performance, the constraints typically shift to higher levels in the hierarchy. This has enabled the performance of whole product systems to improve, resulting in increased intensity of application and use. This broad trend is evident in many technology systems that have developed during the course of this century. As an example, the speed of automobiles early this century was limited to walking speed by the performance of components, such as the poor strength-to-weight ratio of structural materials, but as technological advances were made in structural design, metallurgy, and so on, these limits were overcome. The speed of cars is now limited by factors such as the ability of drivers to control the vehicle, road conditions, traffic congestion, and so forth.[57]

This improvement has caused many technological systems to encounter limits not related to the technical performance of their components. Instead new limits have been set by the environment in which the technology system had to operate. In the case of automobiles, these include the ability of the driver; the cost of creating and maintaining a high speed road system; the geopolitical ramifications of oil supply; urban air pollution; and, most recently, the possible impact of increased carbon dioxide on the world's climate.

Two points about these high-level limits are worth making: first, these are all aspects or subsets of other high-level systems with which the automotive transport system intersects at its highest levels. Secondly, the high-level limits now being encountered are very often associated with ecological degradation or social impacts. The important point from the technology perspective is that these new limits

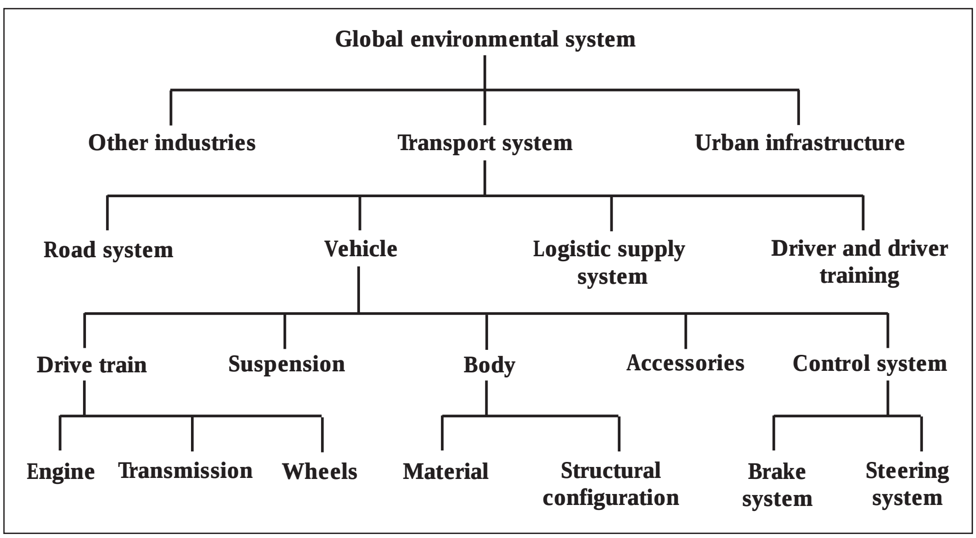


Figure 12, Product system hierarchy for automobile transportation
Source: Adapted from Steyn & De Wet, 1994

are being encountered precisely because the raw performance of technology has been improving. The performance of individual components can no doubt be pushed further by assiduous R&D, but unless the goals of this R&D can be related to the newly encountered higher-level limits in some systematic way, the R&D activity itself will have declining marginal relevance to real world problems.

What Should the Role of R&D Be?

Future technological development can be expected to benefit from conceptual advances in basic science, and to see consequent advances in the performance of individual technological components. But these advances will inevitably have the effect of increasing the effectiveness or power of product systems as a whole, putting even greater pressure on high-level limits. This means that the dynamic of conventional R&D has entered a self-limiting regime unless a way can be found explicitly to include high-level factors among the criteria for new technology development.

The objective of sustainable technology is to find a way to include social and environmental criteria in technological applications. At the same time, the internal dynamic of technology development has arrived at a very similar requirement. This is a very fortunate and potentially fruitful congruence as long as it is consciously recognized and reflected in R&D planning.

The challenge for sustainable technology development and for technology development in general has become the same: to find a conceptual framework that will relate or integrate criteria corresponding to different levels of the product system hierarchy. These criteria will step significantly beyond the design scope used in the past.

New Criteria for Design

An expanded conceptual framework might, for example, be provided by principles for sustainable application of technology. A candidate set of such principles has been provided by Dr. Karl-Henrik Robèrt, the leading Swedish cancer researcher, with his nationwide initiative in Sweden, *Det Naturaliga Steget* (The Natural Step). These principles were arrived at by a consultation process involving Swedish scientists and academics, with 22 rounds of drafts and corrections, so they represent a refined technical consensus.

The Natural Step consists of four principles:

1) Nature cannot withstand a systematic build-up of dispersed matter mined from the earth's crust (e.g. minerals, oil, etc.)
2) Nature cannot withstand a systematic build-up of persistent compounds made by humans (e.g. polychlorinated biphenyls (PCBs))
3) Nature cannot tolerate a systematic deterioration of its capacity for renewal (e.g. harvesting fish faster than they can replenish, converting fertile land to desert)
4) Therefore, if we want life to continue, we must (a) be efficient in our use of resources and (b) promote justice—because ignoring poverty will lead the poor, for short term survival, to destroy resources that we all need for long-term survival (e.g. the rain forest).

Although explicit principles such as these are not yet in widespread use, a wider systemic orientation is, in fact, gradually being absorbed into design thinking (not necessarily in a fully articulated form) and is being expressed as a new philosophy of design, sometimes referred to as "green design." The author David Wann has suggested the alternative terms "deep design" and "aikido engineering."[58]

Green design was defined by the U.S. Congressional Office of Technology Assessment (OTA) as a "design process in which environmental attributes are treated as *design objectives*, rather than as *constraints*. A key point is that green design incorporates environmental objectives[,] with minimum loss to product performance, useful life and functionality."[59] (Italics in original.)

The objective of green design is to relate engineering design to a knowledge of environmental consequences throughout the lifetime of a product. It aims to synthesize information about human needs and natural environmental functioning and seeks to provide end-use services with minimal technology and minimum use of mass and energy, and with the minimum environmental disruption. Amory Lovins has called this approach an "end-use, least-cost perspective" in which the end use is defined as closely as possible to the true human benefit provided, and least cost is assessed in terms of the entire system of which the design is a part.

A hallmark of green design would be fully closed product and materials cycles. For example, in a sustainable nuclear power system, if such a thing is possible, all the radioactive reaction products would have further uses in the industrial system—there would be no waste, even of irradiated components. Already, the design of industrial infrastructure is beginning to move toward systems solutions, an approach being explored by the emerging field of "industrial ecology."[60] Over time, green design would give rise to a new industrial architecture in which all products and technologies would be coupled into a comprehensive recycling "food web" or industrial ecosystem.[61]

6.5 Values and Vision for the Future of Technology

Social Values and Technology

The increasing power of technology is a two-edged sword as far as reducing unsustainability is concerned. As technology advances, it gives us an enhanced ability to solve existing problems. But this additional power could equally well create even worse problems if applied without environmental or social restraint.

This suggests that a shift in the social values governing applied technology is needed. Fortunately, social attitudes toward environmental and social issues related to technology do seem to be changing in response to unsustainability. Evidence of environmental damage is probably the most obvious of the motivating factors.

The history of technology demonstrates clearly that social values determine the form applied technology takes, although often unconsciously. We can therefore expect that new values will inevitably shape new technological solutions. The question is whether this will happen fast enough. Ideally, we will find ways of applying the new values consciously and promptly around the world to deliver sustainable technologies tailored to local conditions—cultural, economic, and environmental.

Technology and Environment

Reducing the environmental impact of technology means that ultimately we must come to see the engineering or technological system together with the natural system as a single design field or problem. With this perspective, the engineering system could only be said to work well if it works with or within the natural system without compromising its functioning. Better yet, with appropriate design, technology may also enhance the functioning of the natural system as well as be enhanced by it.

In other words, engineering systems have traditionally been looked on as effective if they *exploited* natural forces effectively as a means of functioning well. Now the need is for engineering systems to *cooperate* with natural forces in a way that benefits from them without impairing their function as part of the whole planetary system. This is a new order of design challenge calling for a new conceptual approach to technology.

The essential point about technology and the environment is that together they constitute a total system that we are increasingly being obliged to manage as a whole. We are also part of this total system biologically, so that things such as our health are at stake. As Lynn Margulis has said, "Nature is not other, nature is part of us." We have conveniently been able to ignore this big picture up to now, but as the scale and power of industrialization increases we cannot continue to do so indefinitely.

7. New Beliefs and Behavior

7.1 Introduction

We are now seeing, around the world, a collision between the values of the industrial revolution—unrestrained use of technology to exploit natural resources for rapid growth in production—and the limited capacities and resources of the biosphere. This collision is giving rise to an entirely new set of beliefs and values. This is an extremely powerful source of change, since our beliefs determine what we value, which in turn shapes our motivations and intentions and the way we behave.

The underlying philosophy and beliefs of industrial society shape both the acceptable uses of technology and the economic theories that now prevail. Neither the current form of technology nor economics is absolute, in spite of the commonly held view that both represent objective solutions. In fact, both represent an interaction between available knowledge and social attitudes. This makes both subject to change.

The intensifying crisis of unsustainability will steadily increase the pressure for a change of perspective, and that change will be a crucial element in enabling a move to sustainability. As beliefs change, technology and economics will be altered, in turn reshaping the context of social experience. Understanding these interconnections is therefore important for assessing policy and strategy options.

7.2 Changing Values

Environmental Values

Most preindustrial societies had strong ecological values because their limited technical capability and mobility quickly ran up against local environmental limits, and these cultures were constantly aware of the need to "live within their means."

As technology developed during the industrial revolution, local environmental constraints were lifted, permitting great increases in food production, population, and economic activity. As the world approaches full industrialization, environmental limits are once again being approached—this time on a planetary scale—and environmental values are reemerging.

The realization is slowly taking hold that the world economy is a subsystem of the world ecosystem, and that the health of the economy as well as the health of humans depends on the health of the environment. The truth of this has recently been brought home by graphic news coverage of environmental desolation in Eastern Europe. As an example, the towns of Osek, Mezibori, and Most, in the Bohemian Basin of the Czech Republic, experience some of the worst air pollution in the world—with SO_2 readings of up to 2,440 micrograms per cubic meter of air (compared with a typical reading of 13 for Los Angeles).

This is taking a terrible toll on the health of its inhabitants, who are experiencing serious respiratory disease, immunodeficiency, reduced life expectancy, premature births, and levels of lead in children at three times the level certified as neurotoxic in the United States.[62] There are many similar problems in the former Soviet Union, and there appears to be no prospect that they will be dealt with while the economies of these countries remain in disarray.

In the emerging view of an interdependent existence, the environment is coming to be seen not just as a big resource repository to be freely manipulated, but as a living, self-organizing system, somewhat like a living body. Interventions must be based on extensive knowledge of the whole system—which is tightly coupled, interdependent, and responds adaptively—and must be carefully limited in scope if they are to be even partly successful. The complexity and delicacy of the web of life is such that clumsy interventions will provoke unwanted side effects and ill-health. Efforts to alter an aspect of the environment because it is inconvenient from the perspective of current industrial practice are likely to trigger some other unanticipated dysfunction.

Social Values

Simultaneously, social attitudes have been shifting under the direct impact of technology. Much of the technology introduced during the twentieth century, and particularly since World War II, has had the effect of expanding personal freedom. The birth control pill, for instance, was midwife to sweeping change in the sexual mores of the Western world. And people have been eager to explore new freedoms in personal mobility, affluence, and styles of living.

But while the frontiers of personal freedom may have been pushed back, limits to personal behavior still exist. Personal experience has bumped up against frustrating reversals and contradictions. AIDS reversed many of the changes encouraged by the contaceptive pill. Drug-resistant strains of bacteria have undermined the sense that fatal disease is in retreat. Material accomplishments have been tarnished by family disharmony, stress, and lack of time. Regular surveys by the National Opinion Research Center in Chicago reveal that no more Americans report they are "very happy" now than in 1957, although per capita consumption has doubled since that time.[63] Belief in the inevitable progress of scientific materialism is being undermined by growing income polarization in democratic industrial countries, and the existence of starvation in a world where science is, in principle, capable of eliminating material need.

Yet as society changes, the principal drivers for a change of personal values and outlook are not necessarily only the rising levels of misery and poverty generated on the underside of industrial development, although these certainly heighten calls for reform. Affluence, or the promise of affluence as conveyed by film and television, together with the spread of education and democracy, are combining to create higher levels of social aspiration and motivation. They fuel an expectation and a demand for a progressively higher marginal quality of life—which includes improvements in social justice and environmental quality.

All these changes seem to be opening up a willingness to take another look at the way society deals with social and environmental issues, and in particular the way these are linked to incessant growth in consumption.

Shifts in Fundamental Belief

As social change accelerates, it is motivating intense questioning of basic principles and assumptions. As we move into the twenty-first century, there is evidence of a profound shift of outlook on basic questions of belief that could lead to major changes in society. One example of this is the increasing search for personal meaning and purpose that is fueling interest in things as diverse as Buddhism and New Age philosophy, indigenous cultural wisdom, the rediscovery of the sacred, and Deep Ecology.

In the closing years of the twentieth century, the prevailing intellectual view is that science ultimately determines our beliefs and that religion is outmoded as a source of knowledge. This is itself a belief, and one that is increasingly open to question. Science has been tremendously effective in elucidating the macrostructure of the universe, as well as the microstructure of matter. It has not, however, answered perennial questions about the meaning and purpose of "life, the universe and everything." It has not provided any substantive insights as to exactly *why* (for what purpose) the big bang occurred, or *why* life as a phenomenon is self-organizing and evolving, or who we are, or why we are here. These are obvious questions, the sort that children love asking. The sophisticated intellectual position is that such questions are naive: but this is perhaps because intellectual approaches have not been effective in finding answers.

However, people retain great interest in these questions, and the prevalent answers—or lack of answers—have a great deal to do with shaping socially acceptable behavior. They are at the root of the manageability of society and the mental well-being of individuals, who have to provide themselves with some kind of working hypothesis as to the answer in order to get on with the business of their lives and ordering their personal priorities.

Strictly speaking it should be enough to say simply that such questions have not been answered by science (or logical philosophy), and that the question of whether they *can* be answered by science or philosophy is still open. On questions of belief the only rationally justified scientific position is agnosticism, since absence of proof is not proof of absence. More often, though, the authoritative intellectual opinion that is expressed is that there simply is no meaning or purpose—life is considered to be nothing more than a biochemical accident on a lonely lump of rock in an empty universe. Such nihilism may seem to have no practical relevance, but indirectly it is proving inexorably corrosive.

The resulting social confusion and moral disorientation are undermining the fabric of inner cities, democratic institutions, and big business alike—and ethics are under threat even in the truth-seeking scientific enterprise itself. Social turmoil and uncertainty are powerful driving forces behind the search for more satisfying answers to basic "obvious" questions, and appear, in part, to account for the burgeoning popularity of New Age pursuits and for the longevity of bestsellers such as M. Scott Peck's *The Road Less Traveled* (more than 10 years on the *New York Times* non-fiction bestseller list).

The Validation of Personal Experience

Highly educated professional opinion does appear to be out of step with the rest of society. A recent paper in the *Journal of Nervous and Mental Disease* noted that while fewer than 5 percent of Americans call themselves atheists or agnostics, among American psychologists the figure is 57 percent.[64] Significantly, however, the outlook of psychologists and psychiatrists is changing. In May 1994 the American Psychiatric Association published revised guidelines about what is and is not mental disorder. One of the recommendations was that therapists stop assuming that "psychoreligious" and "psychospiritual" experiences or problems are necessarily indicative of mental illness.

Moves by the psychiatric profession to validate religious or spiritual experience coincide with a gradual change in the epistemological status of personal experience itself. As privileged professional viewpoints are undermined in a world of "postmodern" fracturing and multiplicities of knowings, it is becoming harder to dismiss the validity of the personal viewpoint. People are moving increasingly to "reclaim" their own experience from the limbo of its professionally defined status as merely an artefact of brain functioning. An aspect of this is the trend toward "personal" religious experience, and if this continues it is possible that the fundamental tenets of religious belief might be validated and "updated" in a rapprochement with science. The result might be a future form of "religious" understanding based on a fusion of personal spiritual experience and scientific knowledge.

Such speculation is not novel—it was, for example, eloquently expressed in the first half of the century by Teilhard de Chardin:

> *To outward appearance, the modern world was born of an anti-religious movement; man becoming self-sufficient and reason supplanting belief. Our generation and the two that preceded it have heard little but talk of the conflict between science and faith; indeed it seemed at one moment a foregone conclusion that the former was destined to take the place of the latter. But, as the tension is prolonged, the conflict visibly seems to need to be resolved in terms of an entirely different form of equilibrium—not in elimination, nor duality, but in synthesis.*
>
> *After close on two centuries of passionate struggles, neither science nor faith has succeeded in discrediting its adversary. On the contrary, it becomes obvious that neither can develop normally without the other. And the reason is simple: the same life animates both. Neither in its impetus nor its achievements can science go to its limits without becoming tinged with mysticism and charged with faith. Like the meridians as they approach the poles, science, philosophy, and religion are bound to converge as they draw nearer the whole.*[65]

A shift in "official beliefs" could trigger far-reaching reappraisal of values in almost every area of life. This could amount to a reversal of the two-centuries-long trend toward secularization, materialism, and reductionism in Western thought. Just as the biggest surprise of the last 25 years was the collapse of communism, the biggest surprise of the next

25 years might well be the collapse of materialism as the dominant cultural philosophy.

7.3 An Expansion of Values

Roderick Nash, Professor of History and Environmental Studies at the University of California–Santa Barbara, has proposed that emerging ecological values are only the latest stage in a progressive evolution of ethical concern in Western society, starting with the self and the tribe, expanding to other groups within society and finally to animals and nature itself (Figure 13).[66] Nash views this expansion of ethical horizons as being mirrored in the historical sequence of extending legal rights (Figure 14), stemming from the natural rights tradition (most clearly articulated by the philosopher John Locke) that goes back to the concept of natural rights in Greek and Roman judicial thinking.[67] Figure 14 does not imply that the minority referred to in a specific legislative act immediately attained full social rights in fact as well as in theory, but it is indicative of the way social ethics have expanded over time.

A very similar progression of concerns can be observed as the design of technology becomes more responsive to broader social issues.

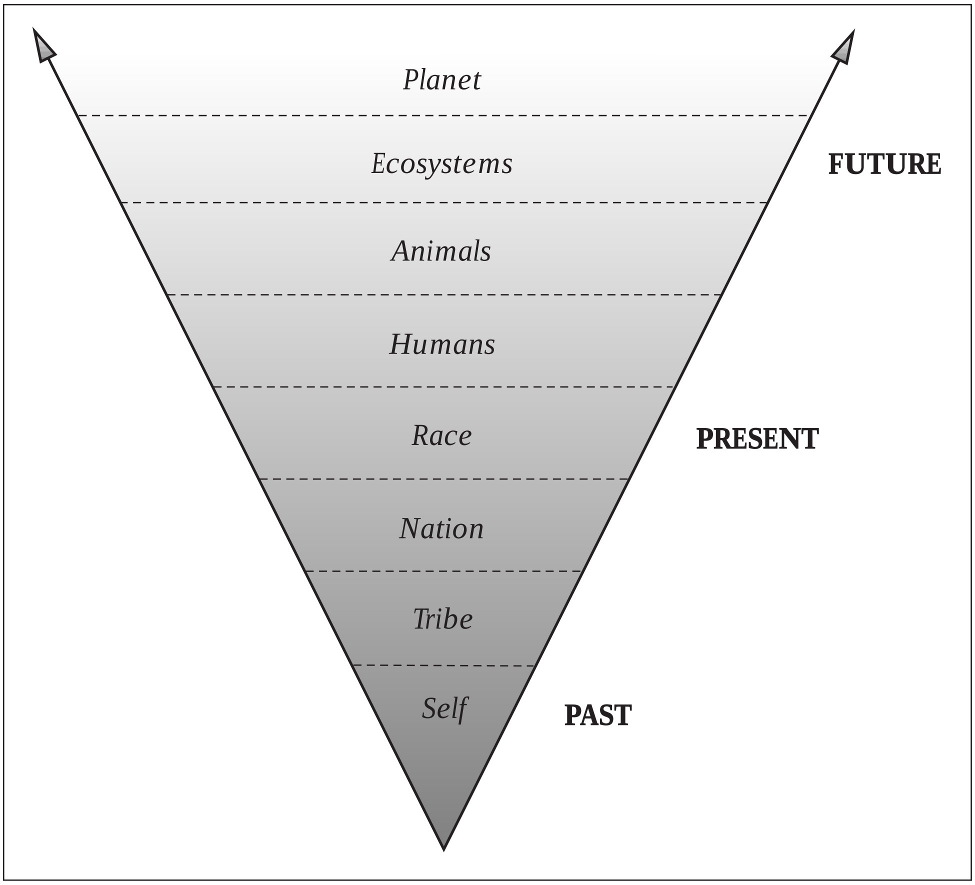


Figure 13, The evolution of ethical concern
Source: Adapted from Nash, 1989

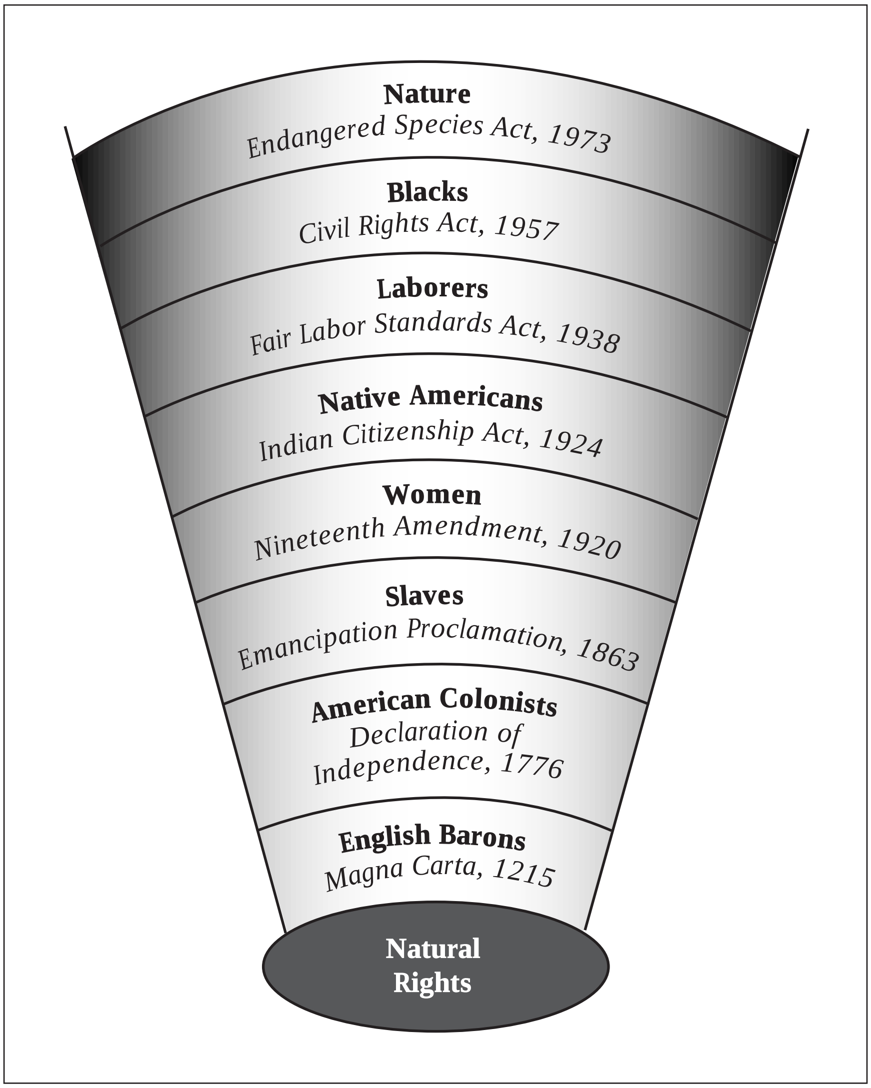


Figure 14, The expanding concept of legal rights
Source: Nash, 1989

Concern has been shifting from the most basic considerations of engineering requirements, through anthropometric and ergonomic concerns, to ecological constraints, to the progressively "softer" issues of social impacts and individual cognitive and psychological factors (Figure 15). Among other things, these progressive ethical and technical expansions appear to describe a "filling out" of the sequence of individual motivations described by Abraham Maslow in his influential "Hierarchy of Needs."[68] According to Maslow, each successively higher level in the needs pyramid becomes an important motivation only when lower-level needs have been met, suggesting that rising affluence is indeed an important element in the expansion of values described by Nash.

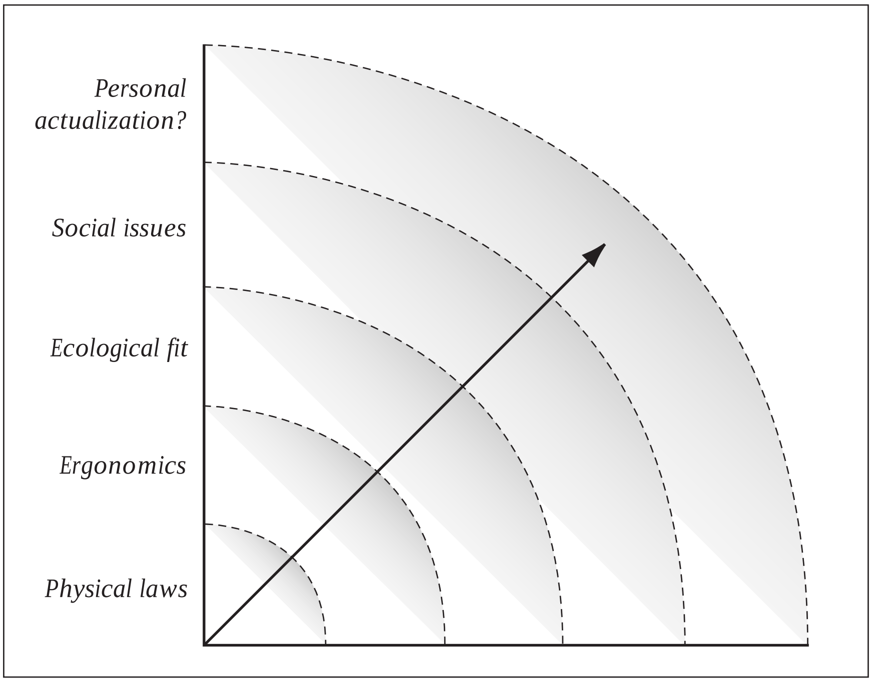


Figure 15, Progressively evolving concerns in technological design

7.4 New Values Will Reshape Economics

Economics is potentially a key enabling factor for sustainability because at present it is failing to provide a form of accounting that reflects unsustainability. Prices, for example, do not reflect all the social and environmental costs (externalities) involved in providing a product or a service in the marketplace, and in many cases actually include subsidies which reduce the perceived cost still further. This leads to overconsumption and misallocation of resources. If the prices were right, consumers would spontaneously make choices which have social and environmental benefits, and the marketplace would thus work for rather than against sustainability. But the political will for these and other economic changes must itself come from somewhere. Ultimately, the source will be a climate of new values that create the political mandate to account fully for unsustainability.

7.5 Unsustainability as a Crisis of Values

Unsustainability can be seen to be not an environmental or social crisis as such, but rather a values crisis with adverse ecological and social symptoms. The same set of beliefs and attitudes which has given rise to the problem is also impeding corrective innovation and policy responses. To achieve sustainability it is essential that we begin not only to think in new ways, but to believe new things. As Einstein is quoted as saying, "No problem can be solved from the same consciousness that created it."

Twentieth century society has been intoxicated by the accomplishments and sheer power of science and technology, preferring to deploy new ideas right away rather than worry about possible side-effects. Industrial culture is being forced to mature as its unintended effects cease to be purely hypothetical, and as society grows more technologically savvy. This maturing could be the basis for a "whole" culture in the twenty-first century that would be in sharp contrast with the contradictory, unbalanced, and fragmented culture of the twentieth century.

8. How Much Can One Organization Do?

8.1 Introduction

Given the scope of the problem of unsustainability, and the difficulties involved in achieving sustainability, how much can a single organization or corporation do? In particular, if the problem involves the entire system, how much can a single corporation do if it is only able to act unilaterally?

This section attempts to answer these questions by looking first at the constraints to decision making that confront organizations, and then at the options available for setting strategy and taking action.

8.2 Impediments to Decision Making

Organizations face significant impediments to taking precautionary action to avoid future environmental risks. These include the Precautionary Principle and the complementarity problem it involves, and the difficulty of "withdrawing from the commons."

Pascal's Dilemma and the Precautionary Principle

The first decision-making impediment resembles the classic philosophical theorem, Pascal's Wager. Pascal's Wager was proposed by the seventeenth century mathematician and philosopher Blaise Pascal. It argues for belief in God on the grounds that a believer loses nothing if it turns out that God does not exist, but that an unbeliever will face serious consequences if God does exist (Figure 16). The basic idea of this wager originated in the Islamic world, and is unique among the philosophical arguments concerning the existence of God in that it is based on an appeal to prag-

	God exists	*God does not exist*
Pascal believes in God	*No problem*	*No problem*
Pascal does not believe in God	*Serious trouble at the Pearly Gates*	*No problem*

Figure 16, Pascal's Wager

matism rather than on an attempt to develop logical arguments about whether or not God exists.

In a more general sense the wager addresses situations in which there is a decision that involves a large potential risk and that must be made on the basis of incomplete evidence.[69] This is clearly analogous to the situation companies face when they formulate environmental policy.

The environmental equivalent of Pascal's Wager is the "Precautionary Principle." It is an approach to environmental policy that has been adopted in principle by the European Commission and has the support of many environmental organizations. Essentially, it holds that the environment should not be left to show harm before action is taken to protect it, because by then irreparable damage may have been done—as a precaution, it's safer to behave as if the problem is real and serious from the outset. The concept is straightforward, but when any attempt is made to apply it within the context of "objective" decision-making criteria, it runs into a series of obstacles. This is demonstrated by the fictitious Pascal Corporation in the discussion that follows.

In the arena of financial investment management a precautionary approach is commended as fiduciary prudence. In the environmental arena, however, things are not so straightforward. If Pascal Corporation attempts to apply cost-benefit analysis and payback time to evaluate a precautionary approach, it emerges that there is a fundamental complementarity involved which acts as a logical trap for decision making (Figure 17).[70]

This complementarity turns on the fact that successful preventative action would preclude ever knowing what the cost of environmental degradation would have been, and so incurs costs today that cannot be weighed against a quantifiable future saving. Conversely, the cost today can be avoided, which means that the future cost of degradation will become known in due course, but this must be set against the unquantifiable risk that the future cost may be

	Current costs	*Future costs*
Take precautionary action today	*Possibly unnecessary cost incurred today*	*Cost avoided will never be known*
Wait for full extent of problem to become known	*Cost avoided today*	*Future cost may be very high and harm may be irreversible*

Figure 17, The complementarity of precaution

much greater than current costs for prevention. By then it may be too late to repair the damage, let alone take preventative action.

Pascal Corporation could sidestep this dilemma if it had rigorous scientific proof of the environmental damage. However, scientific research that would "prove" that a serious environmental problem exists faces a similar dilemma. The mere existence of generalized symptoms of ecological stress is not considered acceptable for a strictly reductionist approach to proof, which requires actual harm to be observed. Normal scientific research requires observation of cause and outcome, and replication—yet to let the global environmental "experiment" run its course risks the very outcome that such research is designed to avoid. Edward O. Wilson at Harvard University puts it succinctly: "One planet, one experiment."[71]

This dilemma throws us back squarely on the role of the values of the decision maker. If the decision makers in Pascal Corporation value the environment for its objective or "use" characteristics and apply money as a yardstick, complementarity is an obstacle. In contrast, if they value the environment for its intrinsic or "non-use" characteristics, the complementarity ceases to be an obstacle, since risk is assessed by a more holistic appraisal of scientific and other data, and precise quantification of the risk is not necessary to justify taking preventative action.

The Tragedy of the Commons

Even if Pascal Corporation does decide to anticipate environmental damage, it faces a further impediment. Although it wants to take significant steps toward fundamental environmental improvement, the effectiveness of its actions will be diluted or negated by the fact that the rest of its industry is not making the same changes (Figure 18). Not only this, but Pascal Corporation's competitiveness and market position may be harmed if it takes action unilaterally.

The difference between this situation and the classic form of Pascal's Wager is that in the latter, judgement is passed on individual behavior, while in the case of the environment it is the total sum of actions that is important. So even if Pascal Corporation has decided to apply corporate environmentalism, its actions may still be ineffective. The ultimate environmental "judgment" will depend on the actions of the whole industry, not of one player.

This situation amounts to a corollary of Garrett Hardin's well-known "Tragedy of the Commons."[72] Using the example of herdsmen putting livestock to graze on a common pasture, the Tragedy shows how each user of a common resource has an individual incentive to exploit the common resource up to and beyond the limit at which the entire commons is overloaded by shared use. Equally, there is no incentive for any one herdsman to alleviate this overcrowding by unilaterally removing livestock from the commons. In fact, such an action would not only harm the herdsman's own interest by reducing his flock, and would give a relative advantage to his neighbors, but it would leave open the possibility that his neighbors might add yet more livestock to the commons. In other words, there would not

	Environmental degradation is real, and urgent action is needed	Environmental degradation is exaggerated, business as usual can continue
Pascal Corporation adopts corporate environmentalism	Can Pascal Corp. save its own skin by unilateral action?	Pascal Corp. wastes its money
Pascal Corporation does nothing	Pascal Corp. goes down with the rest	Pascal Corp. is smart

Figure 18, Pascal Corporation's dilemma

only be an individual loss, but the ultimate collective tragedy would not be averted either.

This dilemma exists in a strong form for Pascal Corporation if its value-perspective treats the seriousness of environmental concerns as essentially unproven. Such an orientation is quite common, explaining in part why so many companies find difficulty in initiating radical action on the environment. Even with values that assert the seriousness of environmental problems, the dilemma still exists in the sense that individual organizations cannot directly influence the collective fate, and because the scope for individual actions is (at least initially) limited by the systemic context.

But there are ways for Pascal Corporation to sidestep the dilemma. One is a special case: Pascal Corporation may be the dominant player in a specific locality so that "withdrawing from the commons" (by, say, switching to a less polluting process) actually strengthens rather than weakens its position, because the local community continues to tolerate, say, a manufacturing facility. Alternatively, a "level playing field" can be imposed by regulation so that all players are obliged to withdraw equally from the commons and the cost is shared equally, without unfair advantage to those who would otherwise fail to withdraw. However, the political decision to impose such regulation would itself be a reflection of a new value orientation.

8.3 What Can Pascal Corporation Do?

In the face of these impediments to decisio n making, it might appear that there is little that Pascal Corporation can do to facilitate sustainability and reduce the threat of unsustainability. Yet a number of broad initiatives are possible. What follows is a list of seven elements of a strategic posture that Pascal Corporation (or any other company) could choose to adopt.

(i) Achieve Good Environmental and Social Practice

The starting point for the journey to sustainability is conventional best practice. This requires excellence in environmental and social issues management, going beyond basic regulatory compliance. What this means is being continuously defined and developed in the management literature by researchers and consultants, and in practice by leading corporations.

However, such actions alone will not be enough to ensure sustainability, since most existing regulations are not intended to achieve sustainability, but only to avoid extremes of environmental damage and social inequity. Best practice environmental and social issues management by Pascal Corporation is base camp for its climb to sustainability.

(ii) Stage Changes Over Time

In the journey toward sustainability, everything cannot be done at once. A transition to sustainability, or to sustainable operations by an individual corporation, will be a change that occurs progressively over a period of time. During this time, Pascal Corporation will have a foot in both worlds: it can continue to operate in the traditional way, while it is investing in and steadily introducing new, sustainable approaches to its operations.

It is important not to have a black and white view of the existing way of doing things as being either completely right or completely wrong. Nor is it two-faced to accept that the existing approach is no longer appropriate while continuing existing operations, as long as a genuine effort is being made to develop a new approach. Stakeholders know that change cannot be instantaneous. What they want to hear is that industry recognizes the issues and is applying its managerial and technical expertise to devising solutions. If Pascal Corporation's stakeholders sense sincerity they will certainly allow it time to make the transition.

(iii) Consciously Apply Values

It is important to recognize that logic is not enough. Deciding on the importance of sustainability is fundamentally not a question that can be resolved by analysis alone. It may look like a purely technical or rational issue, but ultimately it can only be addressed by a qualitative judgement on the part of the decision maker. This judgement will have to be based on a broad, holistic assessment of the available information, and a qualitative appreciation of the risk involved, because a neat logical proof will not be forthcoming.

Pascal Corporation needs to make a values-based, normative decision affirming that sustainability has intrinsic value. It must say what it wants to see happen, not just what it considers itself technically obliged to do. Not only will this cut through the complementarity of the Precautionary Principle, but it can also provide the raw material of an inspiring management vision for the future of the company, and a way of tapping into powerful personal motivations among its workforce. Consciously applying values—instead of always trying to avoid subjective positions in policy and strategy—is an essential enabling step for actions aimed at achieving sustainability.

(iv) Adopt a Systemic Perspective

Pascal Corporation should adopt a truly systemic perspective. This means seeing the company's activities in the context not just of the market for their products, but in the context of the whole environmental and socioeconomic system. This involves looking not only at the total lifecycle of its own products, but also at all the components and materials that they use, and at the environmental and social impacts involved. It means adopting the perspective that technology and the environment constitute a single design field, or problem, to be managed as a whole. And it means not deciding environmental and social issues on the basis of spot impacts, but in the context of a wider perspective and a long-term view.

This kind of thinking can be pushed even further, by asking if the product or service is compatible with a sustainable economy. Could the end-use benefit be delivered in a completely different way, with less social and environmental impact? This explicitly involves design and design thinking as a pivotal skill in finding better systemic solutions.

A systemic perspective quickly leads to the awareness that parallel change is needed in other parts of the larger system if Pascal Corporation is to make all the most effective changes it can. If the rest of the system does not change, there is a limit to the types and extent of changes that Pascal Corporation can make. This is a problem that itself calls for specific strategies and tactics. Two examples of such actions are: leading by example to encourage corresponding change by other industry participants; and lobbying government for system-focused legislation.

Leading change will involve actively networking and communicating among industry peers, as well as upstream and downstream in the value chain, for coordinated moves toward change across the system. These are exactly the kinds of actions that Volkswagen, for example, has been pursuing in the German car industry in the face of impending German product take-back legislation that will mandate full recyclability of cars.[73] Acting alone, Volkswagen would not be able to achieve all the changes needed to ensure that their cars will be easy to disassemble, and to put in place a logistics system to take back their cars from the marketplace for recycling.

In this example, the legislation is already in place. But if not, Pascal Corporation can lobby government for change at both the national and international level. Having a level legislative playing field nationally and internationally is one way to overcome the dilemma of withdrawing from the commons. But this will mean calling for stronger legislation which, from a purely self-interested perspective, is the opposite of what companies usually want.

Moreover, the legislation needed is not simply stronger, but significantly different in character. For instance, the bulk of existing environmental legislation is not system-oriented. Even in the case of an environmental problem as basic as pollution, existing legislation treats different media—air, water, land, etc.—separately.[74] This permits a company to reduce its air pollution at the expense of, say, increased sludge production, without there being any attempt to consider what would be the best outcome for the whole system, taking air, water, and land together. In addition, system-oriented legislation would also involve regulations that support, or at least don't hinder (as do some existing laws), systemic initiatives such as industrial ecology.[75]

Achieving a level international playing field of strong system-oriented environmental legislation would involve international agreements for management of the global commons: the air, the ocean, and the biosphere. Since such agreements are not likely to come quickly, are changes at the national level useful even without matching changes at the international level? Michael Porter at the Harvard Business School has argued persuasively that strong national environmental laws make a nation and its companies more competitive, not less.[76] This flows from a dynamic view of competition, in which conditions are not static but constantly changing and so demand continual innovation to stay competitive. This innovation is shaped by laws, and if these are defined appropriately, they allow companies to jump ahead of international competitors. From this, Porter derives what he calls a "resource productivity" perspective, in which innovation, and its supporting legislation, is focused on getting the most from the resources a company uses, which is not only good for the environment, but also good for profitability.

(v) Instill an Attitude of Innovation

Another element of the new thinking is the pervasive importance of innovation itself. As we have just seen, Michael Porter has highlighted the role of innovation in making strong environmental legislation effective. Continual innovation is essential for making the most of new technological capabilities, and it will also be required to reduce the environmental impact of technology to a fraction of its present level (see Section 2). Innovation is also important as another way of overcoming the decision-making dilemmas described earlier in this section.

Innovation can provide an alternative to withdrawing from the commons. Innovative, lateral thinking may offer a way to relieve pressure on a common resource by changing the way it is being used, or transforming the way things are done, rather than by simply retreating. Innovation is the key to finding solutions to apparently insoluble problems, of which many are posed by unsustainability. In general, solutions will not come from within the current practice or way of thinking. Innovation is a vital element in providing the substance of actions that organizations will take, based on a full understanding of what is needed conceptually to achieve sustainability.

(vi) Create New Models

Creating models or demonstrations of a sustainable mode of operation has great value, even though such models may not appear feasible in the existing business or political climate.

In a sense this is a form of insurance. If the magnitude of global unsustainability is already being matched by the magnitude of the aggregate incremental response, then these new models may not be needed. But if incremental change will not be enough, then new models and eco-climatic shockproofing (discussed next) will increase system resilience and adaptability.

The adaptive value of this approach is similar to the value of genes held in reserve in a healthy gene pool: they may not all be expressed in prevailing conditions, but if, say, the climatic regime of the ecosystem shifts, they can quickly become active and avert extinction under the new conditions.

In this way, any models created would provide an adaptive reserve available for rapid implementation if social values suddenly shifted in favor of radical sustainability. They would not necessarily aim to be implementable or cost effective in the existing business or political climate. They could explore possible conceptual or engineering applications of values and principles that might be feasible in a future sustainable context.

Preparatory experimentation and exploration is very important for increasing decision-making flexibility and the effectiveness of response to crises. A small crisis in the context of much preparation is likely to lead to a far more effective response than even a very large crisis which occurs in the absence of preparation, while lots of corrective action following small shocks will reduce the chance of big shocks later. Even debating and discussing sustainability themes may play a positive future role. One explanation for the much worse environmental pollution in the former Iron Curtain countries is the suppression of advocacy groups that in the West have played a key sensitizing and awareness-raising role of this kind.

Pascal Corporation and its industry need to undertake a deliberate program of "model making" R&D. Conceptual development, exploratory research, and pilot scale trials could lead to a "library" of innovative sustainable technology solutions and practices that would be available to Pascal Corporation and members of its industry.

While modeling technology solutions would be a matter of maximal application of the design principles for sustainability, anticipating the possible social and economic contexts for these solutions will be harder. The character of the economy as a whole is likely to shift if all capital goods are designed for zero or ultra-low throughput, and there will be accompanying social adjustments. For instance, many industries are sellers of throughput resources, which means that ways of introducing highly efficient technologies without major loss of employment will need to be found. There is much speculation as to what a sustainable economy would be like: it might not, for example, be dependent on physical growth like today's economy, which stalls if it is not accelerating. There is also likely to be an emerging interrelationship between eco-efficiency, a leaner consumer psychology, and equitable provision for social need.

Fortunately, model-making activity is more than simply another form of long-term insurance, since it has real learning value in the present. Even if there are no disasters, the exercise of systematically thinking through existing operations and technologies, and exploring "deep redesign" possibilities, is likely not only to yield lower-cost means of environmental compliance, but might well suggest new competitive positioning, novel products, or other ideas that can be applied to existing operations in the current business climate.

(vii) Shockproof Against Acute Unsustainability

Finally, steps can be taken to minimize the direct impact of any possible system-wide ecological or climatic shocks. These range from the large-scale collapse of ecosystems, to sudden climatic shifts (see Table 1, Section 5.2). Doing this means looking at the vulnerability of industrial installations and operations to system-wide rather than localized disaster. Weak links and leverage points can be identified, by analyzing operational and logistical systems and testing them for vulnerability against "event scenarios" based on possible environmental and climatic shocks.

Measures can then be taken for "eco-climatic shockproofing" of the organization. This might mean anything from decentralizing management control and record-keeping, to reducing the sensitivity of the organization to financial or market disruptions, or reducing dependence on single plants or installations, or even establishing ownership or direct control of vital logistic systems and supply lines currently operated by third parties.

As an example, infrastructure designed for autonomous, off-grid operation is likely to be more resilient than grid-based infrastructure. In September 1995, when Hurricane Marilyn hit the U.S. Virgin Islands, nearly every hotel was damaged, but a new eco-resort was left unscathed and operational. Its recycled building materials withstood 115 mile-per-hour winds, and its off-grid power systems never faltered.[77]

The assessment of risk to industrial facilities from localized disasters such as earthquakes is a fairly well-established activity, but shockproofing against system-wide shocks would be different in several ways. Eco-climatic shocks might be more severe, might involve several types of events simultaneously, might last longer, and have effects over a much wider area. These possibilities change the usual assumptions about the scale of impact and reliance on other parts of the industrial system and other geographical areas to be functioning normally. Restarting industrial operations would be very much slower if the normal supplier and infrastructure services were missing, or if there were major disruptions in customer operations.

Given the potential for the insurance industry to be among the first to fail if the frequency of natural disasters continues to increase,[78] and for the Federal Emergency Management Agency (FEMA) to be overstretched or even inoperative if too many strike at once, eco-climatic shockproofing could be a very valuable form of "real insurance."

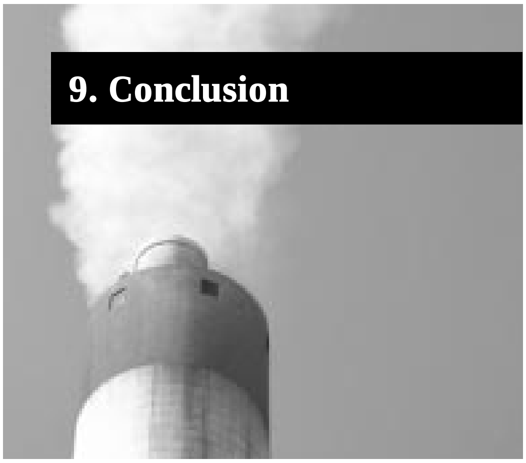
Even if acute ecological breakdown never occurs, eco-climatic shockproofing measures will make Pascal Corporation much more resilient in the face of routine shocks and disasters. As with making models of sustainable operation, the exercise of systematically thinking through vulnerabilities is likely to yield ideas that can be applied to existing operations.

8.4 Summary

In spite of the impediments encountered when an organization faces the issue of sustainability from a purely logical perspective, a coherent strategic posture can be based on a set of generic policies and strategies. As described here, they include:

- Achieving best practice environmental and social issues management as a first step
- Working with the assumption that change will be staged over time
- Consciously adopting a values-based approach
- Adopting a systemic perspective
- Establishing an ingrained attitude of innovation
- Creating and experimenting with models of new sustainable approaches
- Hedging against possible crisis conditions

This list is not comprehensive, nor does it include the many possibilities that would be specific to a given organization. These can be discovered by applying the principles of sustainability to the unique situation and strategic context of the organization.



9. Conclusion

Sustainability is a desired condition that lies in the future. In the present is its opposite: a condition of unsustainability. Unsustainability is not primarily an issue of resource depletion and limits, but more immediately of rising threats to the biosphere from the increasing scale and impact of industrialization and population growth. Shifting from unsustainability to sustainability will involve a transitional period that could be smooth, but may equally well involve a multiple crisis and abrupt change.

Technological solutions are an extremely important means of averting acute unsustainability, particularly innovations that improve the efficiency of resource use. Technology is advancing increasingly rapidly and will confer greater ability to solve existing environmental problems, but also the potential to make them much worse if future technology is used without social and ecological discipline. As a result, we will need a new framework of social and ecological criteria to guide technology development. Our collective ability to introduce and apply this discipline will depend on new social values—and there are signs that these values are emerging.

Organizations intending to take action on the issue of sustainability face decision-making paradoxes which preclude a clear logical rationale for taking action. Sustainability therefore confronts organizations with the need to determine what they think *should* be done, rather than only what can be analytically justified. Assessing the seriousness of unsustainability requires organizational decision makers to make a judgement, based on their beliefs and values and a holistic assessment of risk. Such an uncomfortable but unavoidable position will involve organizations in the wider social process of exploring new values.

Society is rapidly approaching a bottleneck: a collision between the increasing power of technology and the limited capacity of the biosphere. At issue also is our ability to make technology serve society. We must develop the social discipline to master this dual challenge over the next decade or so. If we can do this, we will be able create a just and sustainable society in the early years of the twenty-first century, fulfilling the promise of both technology and democracy—a promise that has remained just beyond our grasp in the twentieth century.

References

1 Paul E. Gray, writing in *Technology and Environment* (Washington: National Academy Press, 1989).
2 World Commission on Environment and Development (WCED), *Our Common Future* (Oxford University Press, 1987).
3 Donella H. Meadows, et al., *Beyond the Limits* (Post Mills, Vermont: Chelsea Green Publishing, 1992)
4 Donella H. Meadows, et al., *The Limits to Growth* (New York: Universe Books, 1972).
5 Paul Ekins, "Making Development Sustainable" in *Global Ecology*, Ed., Wolfgang Sachs (London: Zed Books, 1993).
6 Herman E. Daly and John B. Cobb, Jr., *For the Common Good* (Boston: Beacon Press, 1989).
7 Nevertheless, the term "green growth" is still useful in the medium term as a way of referring to production growth of "green" technologies and products. The ultimate aim of "green" products is to displace enough other products to result in an aggregate contraction of throughput demand by manufactured capital—at which point the term "green ungrowth" might become more apt.
8 David Pearce, "Measuring Sustainable Development" *Quarterly Bulletin of The Center for Our Common Future* (Geneva: June 1993). The idea of "weak" and "strong" sustainability appears in almost identical form in Herman Daly's *For the Common Good* (op. cit.) on p. 72.
9 This use of the term "affluence" does not imply behavior related to different individual income levels, but simply specifies the prevailing consumption level of a given population.
10 P. R. Ehrlich, et al, *Ecoscience: Population, Resources, Environment* (San Francisco: W. H. Freeman, 1977).
11 J. L. A. Jansen and Ph. J. Vergragt, *Sustainable Development: A Challenge to Technology* (The Hague, Netherlands: Ministry of Housing, June 1992).
12 Paul Ekins, "The Sustainable Consumer Society, A Contradiction in Terms?" *International Environmental Affairs* (Vol. 3, No. 4, Fall 1991).
13 http://www.whitehouse.gov/PCSD
14 Paul Hawken, "A Declaration of Sustainability" (*Utne Reader*, September/October, 1993).
15 Edward Goldsmith, *The Way: An Ecological World-view* (Boston: Shambala, 1993).
16 Herman E. Daly and John B. Cobb, Jr., op.cit.
17 Hazel Henderson, *Paradigms in Progress* (Indianapolis: Knowledge Systems Inc., 1991).
18 William C. Clark, *Visions of the 21st Century: Conventional Wisdom and Other Surprises in the Global Interactions of Population, Technology and Environment*. Discussion Paper 89-09 (Cambridge: John F. Kennedy School of Government, Harvard University, June 1989) pp. 1-2.
19 Donella H. Meadows, et al., op. cit., p. 18.
20 Vaclav Smil, "Asia's Stumbling Giant" *The Independent Monthly* (Surry Hills, Australia: May 1994.)
21 Peter M. Vitousek, et al., "Human Appropriation of the Products of Photosynthesis" *Bioscience* (Vol. 36, June 1986) pp. 368–373.
22 United Nations estimates published by the World Resources Institute, *World Resources: 1994-95* (New York: Oxford University Press, 1994).

Assuming linearity, and assuming that 40 percent is the 1986 value, if 4.94 billion people consumed 40 percent of NPP, 100 percent would require (100/40) x 4.94 = 12.35 billion and 7.37 billion in 2010 would therefore consume (100/12.35) x 7.37 = 59.68 percent (based on USDA and UN world population figures).

23 Robert U. Ayres, "Industrial Metabolism—Closing the Materials Cycle" in *Clean Production Strategies* ed. Tim Jackson (Boca Raton, USA: Lewis Publishers, for the Stockholm Environment Institute, 1993).

24 Donella H. Meadows, et al., *Beyond the Limits* op. cit., p. 128. "Positive feedback" is the systems term for a system response that amplifies the original phenomenon—making it either better or worse, depending on whether it was good or bad in the first place.

25 Classification from Paul Ekins, "The Sustainable Consumer Society, A Contradiction in Terms?" *International Environmental Affairs* (Vol. 3, No. 4, Fall 1991), p. 246.

26 J.O. Nriagu, "Global Metal Pollution" *Environment*, 32 (7) (1990) pp. 7–32.

27 James E. Lovelock, *Gaia: A New Look at Life on Earth* (Oxford: Oxford University Press, 1979).

28 Eugene P. Odum, *Ecology and Our Endangered Life-Support Systems* (Sunderland, Massachusetts: Sinauer Associates, Inc., 1989).

29 Lawrence R. Lawlor, *The Ecology of Corporate Re-Engineering: Is Business Leading Us to a Sustainable Future?* (Unpublished paper, March 1994); and personal communication, 1994.

30 C. S. Holling, "The Resilience of Terrestrial Ecosystems: Local Surprise and Global Change" in *Sustainable Development of the Biosphere* ed. W. C. Clark et al., (Cambridge: Cambridge University Press, 1986), pp. 292–317.

31 Niles Eldredge and Stephen Jay Gould, "Punctuated Equilibria: An Alternative Approach to Phyletic Gradualism" in *Models in Paleobiology* ed. T.J.M. Schopf (San Francisco: Freeman, Cooper & Co., 1972).

32 A description of Hillis' work can be found in Steven Levy, *Artificial Life: The Quest for a New Creation* (New York: Random House, 1992).

33 John Briggs and F. David Peat, *Turbulent Mirror* (New York: Harper & Row, 1989) p. 84.

34 As an aside on this point, it is worth noting that the knowledge of the availability of high-technology intervention such as surgery may well be unhelpful to the patient's long run health, since behavioral and dietary changes may be deferred in the belief that the problem can be fixed by surgery later, when it reaches crisis level.

35 William Stigliani and Wim Salomons, "Our fathers' toxic sins" *New Scientist* (11 December 1993).

36 Donella H. Meadows, et al., op. cit.

37 Ibid., p. 130.

38 Ernest Callenbach, *Ecotopia* (Berkeley: Banyan Tree Books, 1975).

39 Gene Roddenberry was the originator of this television series.

40 Russell Hoban, *Riddley Walker* (New York: Simon & Schuster, 1980).

41 *Blade Runner* was directed by Ridley Scott and based on *Do Androids Dream of Electric Sheep?* and *Total Recall*, by Philip K. Dick. It was first released in 1982, followed by a director's cut in 1992. In the film, set in Los Angeles in 2019, a retired police "blade run-

ner" is rehired to track down and "retire" four off-world renegade bioengineered androids.

42 The "assumption of unsustainability" implies taking the condition of unsustainability seriously.

43 This title is not original: it has been used by James Garbarino, who attributes it to Paarlberg (no reference given). James Garbarino, *Toward a Sustainable Society* (Chicago: Noble Press, 1992), p. 40.

44 Herman Kahn, *World Economic Development 1979 and Beyond* (Boulder, Colorado: Westview Press, 1979).

45 Gaia here is a direct reference to James Lovelock's Gaia Theory.

46 Donella H. Meadows, et al., op. cit.

47 R. W. Keyes, "Miniaturization of Electronics and its Limits" *IBM Journal of Research and Development* (Volume 32, Number 1, January 1988).

48 Ralph Merkle at Xerox Parc in Palo Alto provided this insight (personal communication).

49 K. Eric Drexler et al, *Unbounding the Future: The Nanotechnology Revolution* (New York: William Morrow, 1991).

50 Edmund Storms, "Warming Up to Cold Fusion," *Technology Review* (May/June 1994) p.19.

51 Robert O. Becker & Gary Selden, *The Body Electric: Electromagnetism and the Foundation of Life* (New York: William Morrow, 1985).

52 Robert Herman et al, "Dematerialization" in *Technology and Environment*, eds. Jesse H. Ausubel and Hedy E. Sladovich (Washington, D.C.: National Academy Press, 1989) pp. 50–69.

Also Eric D. Larson, Marc H. Ross and Robert H. Williams, "Beyond the Era of Materials" *Scientific American* (June 1986) pp. 24–31.

53 Stephen G. Bunker, "Modes of Extraction, Unequal Exchange, and the Progressive Underdevelopment of an Extreme Periphery: The Brazilian Amazon, 1600–1980" *American Journal of Sociology* (Volume 89 Number 5).

54 Alvin & Heidi Toffler, "21st Century Democracy: An Idea Whose Time Has Come" *New Perspectives Quarterly* (Volume 9, Number 4, Fall 1992) pp. 13–21 (see also other relevant articles in this issue).

55 Alex Scott, "The Economics of Househeating" *Energy Economics* (June 1980).

56 Graham Capper and Alex Scott, "The Economics of Househeating: Further Findings" *Energy Economics* (April 1982).

57 Herman de V. Steyn et al, "Technological Limits and the Hierarchy of Product Systems" *Technological Forecasting and Social Change* (46, 1994), pp. 11-15.

58 David Wann, *Deep Design* (Washington D.C.: Island Press, 1996).

59 U.S. Congress, Office of Technology Assessment, *Green Products by Design: Choices for a Cleaner Environment OTA-E-541* (Washington D.C.: U.S. Government Printing Office, October 1992), p. 7.

60 Hardin Tibbs, "Industrial Ecology: An Environmental Agenda for Industry" *Whole Earth Review* (Number 77, Winter 1992) pp. 8–10.

61 Robert A. Frosch, "Industrial Ecology: A Philosophical Introduction" *Proceedings of the National Academy of Sciences* (Volume 89, February 1992) pp. 800–803.

62 Dennis Hayes, "Ravaged Republics" *Discover* (March 1993) pp. 66–75.

63 Alan B. Durning, "Asking How Much is Enough" in *The State of the World 1990* ed. Lester R. Brown et al., (New York: Norton, 1986) p. 156, note 17.

64 David Lukoff, Francis Lu, and Robert Turner, "Toward a more culturally sensitive DSM-IV. Psychoreligious and psychospiritual problems" *Journal of Nervous and Mental Disease* (Vol. 180, No. 11, November 1992) pp. 673-682.
65 Pierre Teilhard de Chardin, *The Phenomenon of Man* (New York: Harper and Row, 1959) pp. 283–284.
66 Roderick Frazier Nash, *The Rights of Nature: A History of Environmental Ethics* (Madison, Wisconsin: University of Wisconsin Press, 1989) p. 5.
67 Ibid. p. 7.
68 Abraham H. Maslow, *Motivation and Personality* (New York: Harper, 1954).
69 Pascal also developed the basic concept underlying what is now called decision theory.
70 Carlo C. Jeager, "Theoretical Perspectives on the Consequences of Climate Change." Paper presented at the 88th Annual Meeting of the American Sociology Association, (Miami: August 1993). This paper presents a discussion of complementarity in environmental decision making. The complementarity is analogous to Heisenberg's Uncertainty Principle in quantum physics, which holds that either the momentum of a particle or its location can be measured, but that knowing either one of these renders the other fundamentally indeterminate.
71 Edward O. Wilson, *The Diversity of Life* (Boston: Belknap, Harvard University Press, 1992) p. 182. The context of the quote is: "If enough species are extinguished, will the ecosystem collapse, and will the extinction of most other species follow soon afterward? The only answer anyone can give is: possibly. By the time we find out, however, it might be too late—one planet, one experiment."
72 Garrett Hardin, "The Tragedy of the Commons," *Science* 162, 1968. pp 1243-1248.
73 Georges Haour et al, "How New Requirements on Car Recycling will Jolt the Automotive Industry" *Greener Management International* (Issue 9, January 1995) pp. 52–61.
74 U.S. Congress, Office of Technology Assessment, Industry, *Technology and the Environment: Competitive Challenges and Business Opportunities, OTA-ITE-586* (Washington, DC: U.S. Government Printing Office, January 1994) p. 263-289.
75 Robert A. Frosch, "The Industrial Ecology of the 21st Century" *Scientific American* (September 1995), pp. 144–147.
76 Michael E. Porter et al, "Green and Competitive: Ending the Stalemate" *Harvard Business Review* (September-October 1995), pp. 120–134.
77 From GreenClips, an Internet news service (San Francisco: GreenClips@aol.com, 8 December 1995).
78 Jeremy Leggett, "Who will underwrite the hurricane?" *New Scientist* (7 August 1993), pp. 29–33. Also, William K. Stevens, Violent Weather Battering Globe in Last 2 Years Baffles Experts" *New York Times* (May 24, 1994), pp. B5–B6.