

# **SUSTAINABILITY**

## **The Corporate Challenge of the 21st Century**

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Chapter 9  
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# The technology strategy of the sustainable corporation

Hardin Tibbs

## Introduction and overview

Corporate sustainability, the long term social and environmental viability of business activity, will be achieved in the context of crucial large scale changes occurring in society over the next few decades. These changes will reshape business by fundamentally altering the rules of the game for commerce and defining a new overall technology strategy business will need to adopt.

The nature of the future sustainable corporation can only be fully understood in the context of developments happening at a global scale. The basic dynamic which shapes the agenda of sustainability is the exponential growth of both the human population and the flow of materials through the industrial economy. When both nature and industry are analysed in terms of flows of materials, it becomes clear that industry is now approaching (and even exceeding) the scale of the natural environment, setting the stage for accelerating large scale environmental pollution and degradation.

Nevertheless, there is reason to believe that human population growth will decelerate and stabilise during the next thirty years. This deceleration will accompany and invoke changes in social values and will, in any optimistic scenario, be accompanied by a deceleration of linear (non-cyclic) flows of materials through the industrial economy.

A deceleration of materials flows will be achieved by recasting the basic architecture of industry, converting it to a system of cyclic flows. As this happens, the mass intensity of industrial production can be expected

to decline (dematerialisation) and the carbon intensity of energy supply will complete its long run historical decline (decarbonisation). These developments will be guided by industrial ecology, an emerging field of applied research aimed at adapting industry to the unique bio-geochemical systems of planet earth.

As these developments occur there will be parallel shifts in business logic. Business thinking will shift from the concept of the value chain, based on the traditional model of linear materials flows, to the concept of the value loop, based on the sustainable model of cyclic materials flows. Value will be created and recreated endlessly as the same materials flow in a continuous loop, from manufacturing to consumption, then to reprocessing and back to manufacture. As firms become sustainable, they will have to relocate from the value chain to the value loop and many will have to redefine themselves in the process.

This sequence of changes, described in detail in the rest of the chapter, can be expected to determine the overall use of technology in the sustainable corporation after the whole socio-economic system achieves sustainability and increasingly during the transitional phase we are now entering.

## **A technology meta-strategy for the sustainable corporation**

It is useful to think of the sustainable corporation as having a generic sustainable technology strategy, as distinct from the detailed sustainable technology strategy of a specific corporation. This 'meta-strategy' for technology is an overall framing of technology itself by the sustainable corporation and by a future sustainable society. It relates the detailed commercial goals of a corporation to the larger social and environmental goals of society. It sits beyond or behind the strategies of individual firms, shaping their individual strategies and being expressed by them through their detailed technological programs, product development, manufacturing systems and support infrastructure.

The traditional corporation also has a technology meta-strategy, although it almost always remains implicit and is seldom consciously acknowledged. It is useful to compare the prospective sustainable meta-strategy with the largely unconscious prevailing technology meta-strategy of society and its institutions.

The modern limited liability company—in which the liability of the owners is limited to the capital they invest no matter what losses the company incurs—came into being in Europe in the eighteenth century at the

beginning of the industrial revolution. Their purpose was to limit the risk of investors in long and hazardous sea voyages that were nevertheless seen to benefit indirectly the whole community. In the nineteenth century, after the introduction of the joint stock company in the US, additional legal developments defined the company as a legal person with an indefinite lifespan, thus opening the way for enormous concentration of wealth and technological power by corporations. The modern corporation is thus a key socio-economic innovation of global industrial development, intended to achieve maximum economic output and growth by offering the dual incentive of maximising personal gain while limiting personal risk.

The technology meta-strategy of the conventional corporation is an expression of the wider social program of maximum industrial growth. Essentially it holds that any feasible technology that can be devised is available to any company to exploit how and where it likes without restriction. The social role of the firm is to maximise the use of any given technology and the supply of resources needed to operate it. As an incentive to develop the maximum range of possible applications as well as fundamental new technologies, the company can be granted a legal monopoly during the first couple of decades of exploitation of a new technology. Should the technology turn out to be physically harmful to people or the environment, provided this can be established on the basis of avoiding a Type I error of proof (discussed later), use of the technology may after some period of time be limited or legislated. If the technology simply causes social dislocation or personal stress, this is tolerated. The overall aim of this meta-strategy is straightforward: to maximise the development and growth of industry, a socially acceptable objective during the exponential expansion phase following the industrial revolution.

By contrast, the sustainable corporation<sup>1</sup> is the prospective future form of the corporation after the physical expansion phase of industrialisation decelerates, and the material throughput of the global economy levels out. The technology meta-strategy of the sustainable corporation brings a new set of values to the application and development of technology. The new perspective accepts the existence of highly advanced technology, and assumes that there is a high level of technological capability and scientific literacy in society. The meta-strategy favours technologies that enable the reuse of materials, cooperatively creating and maintaining a cyclic materials economy. It also favours the use of materials that exist abundantly in nature, and that are readily reprocessed and regenerated in nature. And in general it favours technologies that slow and reduce materials flows in the cyclic loop, particularly toxic elements and chemicals.

The sustainable corporation will therefore ensure that its use of materials contributes to an overall cyclic flow through the economy. It will also use energy technologies that have minimum, preferably zero, bio-geochemi-

cally active collateral materials flows or accumulations (such as CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub>, radioactive waste, etc.). It will avoid technologies and practices that degrade the informational integrity and genetic diversity of the biosphere. Since the overall technology program of society is no longer maximum physical growth, the products and services of the firm tend to relate to the creation and maintenance of complex physical systems. When there is a potential for technologies to cause physical harm to people or the environment, the sustainable corporation will adopt a precautionary approach, endeavouring to avoid Type II errors (discussed later) in establishing reasonable proof. The definition of harm is likely to expand, leading to avoidance and minimisation of technology that contributes to personal and social stress.

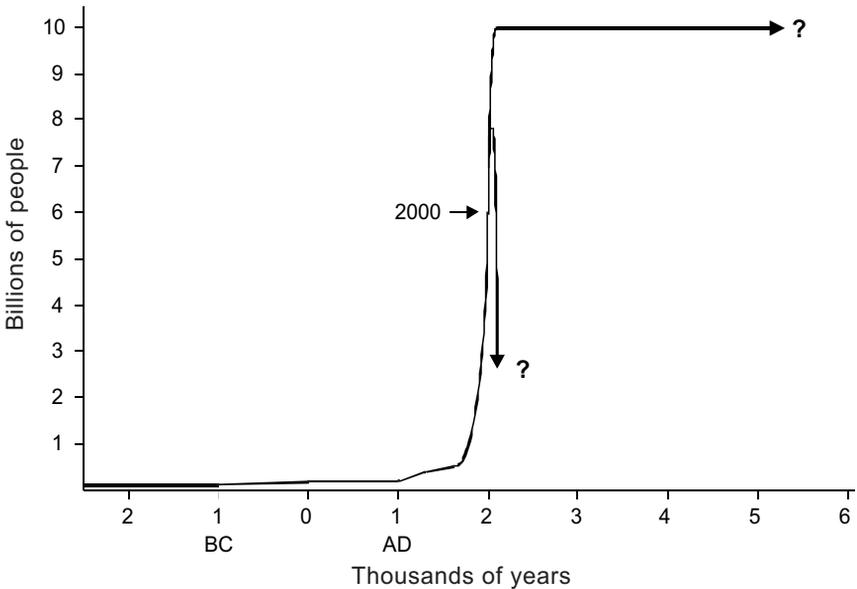
The thesis of this chapter is that this technology meta-strategy for sustainability will emerge from the sequence of future developments described here. Other outcomes are of course also possible: this account is in that sense only a scenario, (Schwartz, 1991) but it is a particularly important one because an optimistic outcome is difficult to project without it.<sup>2</sup> Put another way, the optimistic scenario—in which the worldwide challenges of unsustainability<sup>3</sup> are overcome—appears to depend on major changes of the kind described here.

## Materials flows

A basic assumption of the sustainable technology meta-strategy is that advanced technology need not be harmful to society and the environment, but that specific uses and applications of technology certainly can be. One of the main unsustainable impacts of technology is its ability to support an exponential increase in the linear throughput of materials through industry and the human economy.

Human population growth is the context for the exponential rise in materials throughputs, and the basis of the technology meta-strategy of the conventional firm. The growth to today's global population level of 6 billion was sudden and historically anomalous. Sometime around 1750, at the onset of the industrial revolution, the population began to grow at an unprecedented exponential rate. Exponential growth is growth that results in a doubling of size with each given unit of passing time.

Exponential growth in a finite system is extremely deceptive psychologically, as it appears to be reassuringly slow at the outset, but later accelerates suddenly to use up remaining space or resources with surprising speed. This is particularly dangerous for political and other decision-making, as it is notoriously difficult to take exponential change seriously until it is too late.

**Figure 9.1** Global population growth

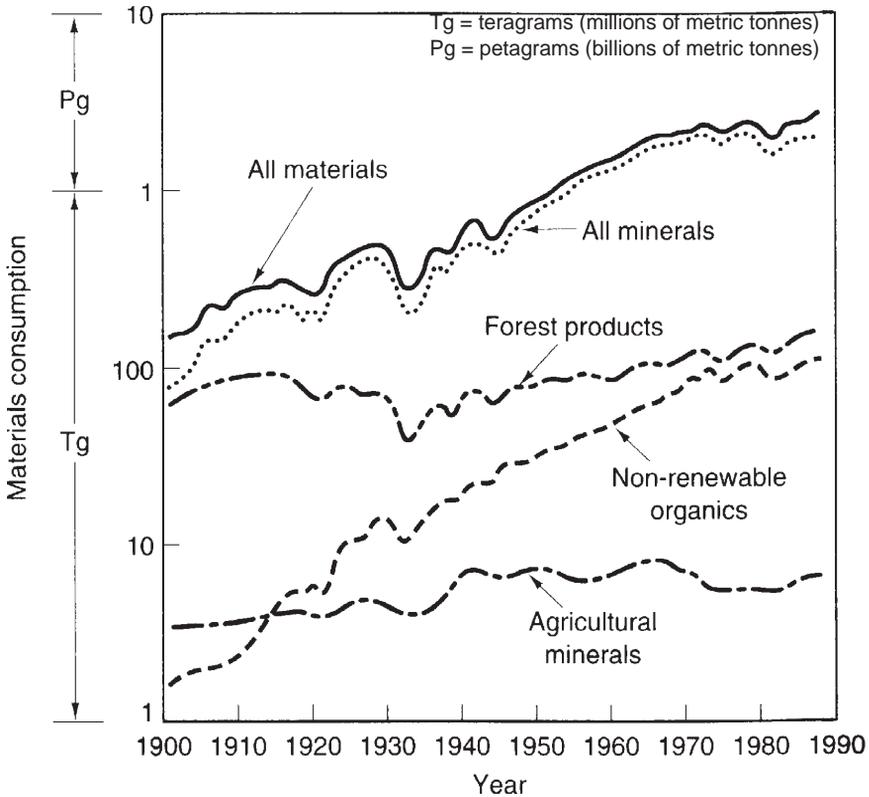
Source: Historical data based on Cohen, 1995

Figure 9.1 shows a simplified view of world population for the past several thousand years. It also shows the extraordinary jump that has taken place in the last 250 years. For thousands of years, the human population bumped along at a few hundred million people worldwide, growing slowly. In fact the increase was not steady during this period—there were alternating surges and contractions—and there was no consistent exponential growth towards present levels as many people assume. The average growth rate from 1650 to 1950 was about 12 times greater than during the previous 10,000 years, and it more than doubled again after 1950.

Today, the world population is still growing extremely fast, even though the growth rate is slowing slightly. More people have been *added* to the world population in the 1990s than existed in the entire world in 1750. The world population has doubled during the life time of anyone now over 40, and if present rates of growth are maintained, the total population will double again within the next 40 to 50 years.

The overall graph for the flow of materials through the industrial system over the same timeframe looks similar to Figure 9.1, except that growth is twice as fast—during the last few decades it has been doubling every 20 years. Figure 9.2 shows the expansion of materials consumption in the US during the last hundred years (the vertical scale is logarithmic, so the

**Figure 9.2 Consumption of materials in the US, 1900–89**



*Note:* On average, overall consumption of materials in the United States has doubled every 20 years during the twentieth century.

*Source:* Graedel and Allenby, 1995: 147

upward sweeping curve of increase appears as a roughly straight line). Total materials use in the United States has ballooned from 140 million metric tonnes a year in 1900 to 2.8 billion metric tonnes a year in 1990, up from about 1.6 tonnes per person to 10.6 tonnes per person. Environmental impact is determined by industrial throughput, so, for example, the amount of carbon dioxide released into the atmosphere every year has also doubled twice over since 1950.

The result of exponential growth is that the industrial production system has now reached planetary scale. The volume of materials flowing through the industrial system into the human economy worldwide is now at roughly the same scale as the flow of materials occurring naturally through global biogeochemical processes.

In the case of some materials, industry is already larger than nature.

**Table 9.1 Worldwide emissions to the atmosphere  
(thousands of tonnes per year)**

	Artificial flows	Natural flows	Ratio
Lead	332.0	28.0	11.9:1
Zinc	132.0	45.0	2.9:1
Copper	35.0	6.1	5.7:1
Arsenic	19.0	12.0	1.6:1
Antimony	3.5	2.6	1.3:1
Cadmium	7.6	1.4	5.4:1

Source: Nriagu, 1990

The global industrial flow of almost all toxic heavy metals is much greater than the natural background flows (natural flows occur because of geological processes such as the weathering of rock). The anthropogenic (human-caused) flow of lead into the atmosphere is 11.9 times greater than the amount of lead naturally mobilised through the biosphere. This is because internationally lead is still used in petrol (gasoline) as an anti-knock additive. For almost all the other toxic heavy metals, such as cadmium (5.4 times) and arsenic (1.6 times) the industrial flows into the atmosphere are greater than the natural flows (see Table 9.1). The metals are then dispersed into the biosphere—for example 13 million pounds of mercury (a neurotoxin) falls in rain every year.

Another well-publicised example is the release of carbon dioxide into the atmosphere from burning fossil fuels. In this case, the natural flow is very large because carbon is one of the major nutrient substances (one of the so-called 'grand cycle' elements) in the biosphere. By the early 1990s the burning of fossil fuel and deforestation were releasing roughly eight billion tonnes of carbon into the atmosphere every year (in the form of 30 billion tonnes of carbon dioxide). This anthropogenic flow of carbon is equal to about a sixth of the natural background flow, and is increasing the total atmospheric 'reservoir' of 750 billion tonnes by some four billion tonnes a year (only half of the excess carbon is being successfully absorbed by the biosphere and ocean every year).

Why are these global-scale flows a problem? One concern is that industrial flows of materials are now so large that they can destabilise natural global systems because of their sheer scale compared to natural flows. Climatologists believe that the increasing (but non-toxic) level of atmospheric carbon dioxide is changing the world's climate. Another concern is that global-scale flows of pollution will lead to chronic toxification of the entire biosphere. Finally, the flows and their effects are not only large but they are growing exponentially.

The exponential growth of industry is now reaching levels that risk a

global ecosystem breakdown. According to an estimate in 1986 (Vitousek, 1986), the human economy was then using 40 percent of the entire annual growth of land-surface biomass. If this percentage is increasing in line with growth in the use of materials—which is doubling every 20 years—it could reach the 80 percent level by 2006. Increasing the human share this much is inherently risky as it means that much less than half of the total natural ecological processes and habitat will remain, which may compromise their viability as a planetary life-support system (Baskin, 1997). The so-called ‘ecosystem services’ provided by the natural environment include water and air purification, and a recent study by Stanford University researcher Gretchen Daily (Daily, 1997) has valued their contribution to the world economy at over US\$33 trillion a year.

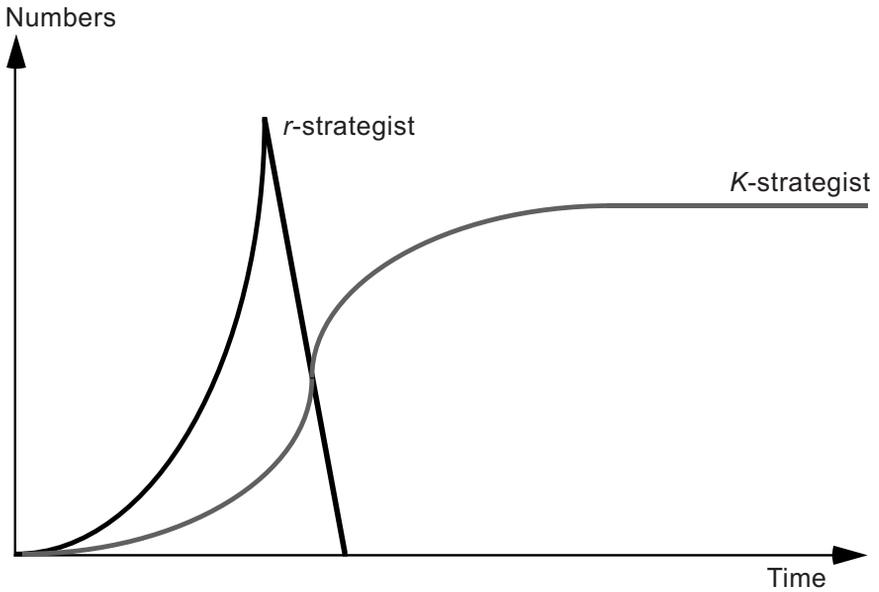
## **An inevitable deceleration**

In any optimistic global scenario, it is inevitable that population and materials flows will decelerate in the relatively near future. In part this is because population growth is now decelerating as an underlying driver. Although the population is still rising rapidly, the underlying exponential growth rate has been falling since its peak at 2.2 per cent per year in 1963. It may double once more during the first half of the 21st century, but is officially expected to have levelled off at around 10 billion people worldwide by around 2050. The other cause of deceleration is the unsustainability of exponentially rising materials consumption. In any optimistic outcome, a combination of technological and social change would lead to a reduction in materials flows. (The alternative pessimistic outlook is that the exponential growth of materials flows leads to a global level ecosystem crisis and breakdown.)

This double deceleration—of population and materials flows—marks the end of the physical growth stage of industrialisation. For the first time since the onset of the industrial revolution there will be a net per-capita dematerialisation of economic output internationally. This ‘turning of the corner’ from the historical growth phase of the planetary industrialisation process to the ‘sustained development’ phase will involve very significant social, technological and economic change. This may happen through voluntary policy change, spontaneous change induced by the market, or possibly be triggered by a crisis of unsustainability—or by a combination of all three.

The outcome of this transformative change will be a completely new kind of economy. It will be able to deliver prosperity equitably around the world, in balance with the natural environment, without depending on exponentially-growing materials flows. It would simultaneously cope

**Table 9.3 Ecological succession from J-curve to S-curve population growth**



Source: Lawlor, 1994

with the slowing and stabilising of population growth.

The overall concept of a transformation, or 'transition to sustainability,' itself has an analogue in a simple model of ecological development known as ecological succession. It is broadly equivalent to the shift that occurs as an ecosystem matures—as say forest regrows on cleared land—and makes the transition from a 'pioneer' to a 'mature' ecosystem (see Figure 9.3). 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 emphasise 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 stabilise 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 (Odum, 1989).

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 unlimited environment, such as cleared land being colonised by weeds, or a large planet with only a handful of industrialised 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*-organisations and *K*-industrialisation would replace older *r*-organisations and *r*-industrialisation (Lawlor, 1994).

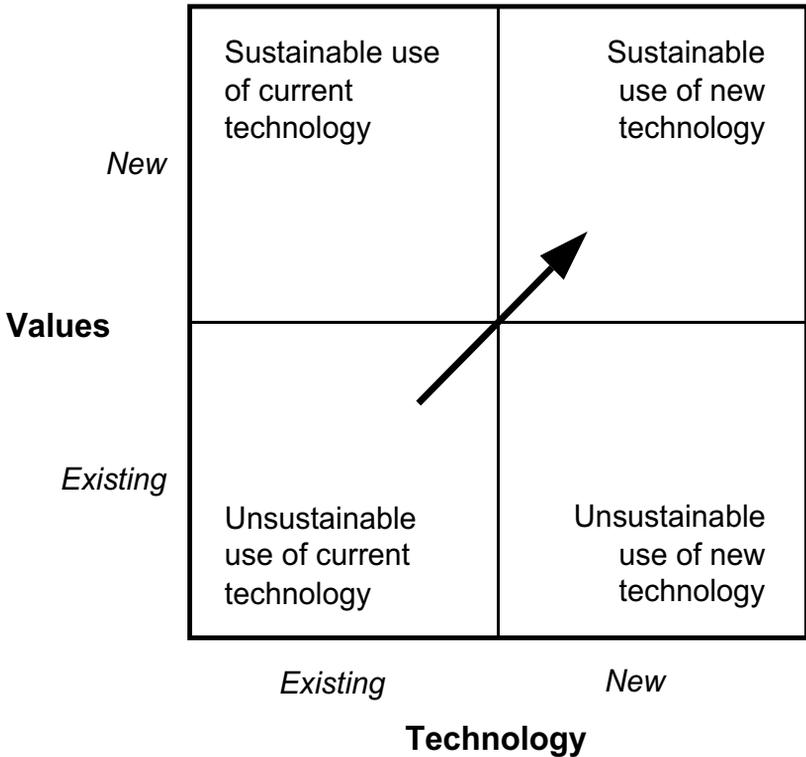
By analogy, we could argue that human society has been behaving like a pioneer species, but unlike other pioneer species, our frontier has now been pushed out to include the entire biosphere and we have nowhere else to go. The hope is that we will use our unique self-awareness to adapt and consciously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

The overall message is that any optimistic view of the future must contain very significant transformational change, as materials flows and population growth decelerate. Whether we view these changes defensively or proactively, it is apparent that most industries and activities will experience a deep shift of perspective and values, and a parallel shift to a new legislative, economic and technological base. Put simply, either there will be a system-wide crisis, or a solution will emerge. But the solution will not be an incremental modification of the way we do things now—it will be an entirely new kind of economy.

## The role of technology

How can this outcome be achieved? We will have to learn new ways of doing things, and this implies new attitudes and ways of behaving, new

**Table 9.4 Sustainability requires changes in both values and technology**



laws, and new technology. Technology is a particularly important source of change, because it most directly determines the scale of materials flows through industry, but it is not the whole story.

Figure 9.4 shows the contribution technology can make. The path of viable future development in any optimistic scenario is from the bottom left quadrant of the matrix towards the top right, as the arrow indicates. Change in either values or in technology alone is not enough: the two must happen in conjunction. One of the reasons for this is that technology—and new technology in particular because it is more powerful—can either help provide solutions or make the situation worse. What makes the crucial difference is human intention.

Technology and scientific knowledge are advancing extremely rapidly and are now providing the capabilities we need to create an economy that does not depend on ever-increasing physical growth. If underlying social beliefs shift—with a growing interest in less materialistic personal values and deeper meaning—this can be expected to lead to greater concern about

global issues and the environment, leading in turn to new priorities in technological design. In this way, new technological potentials can be directed along a path of development that is part of the solution rather than part of the problem.

For example, if biotechnology in agriculture is applied in a narrow reductionist way (bottom right quadrant), it could contribute to ecosystem destabilisation. Yet exactly the same technology applied within an ecosystemic paradigm (top right quadrant) could result in increased food production and improved ecosystem health. (Another way of expressing this would be to say that just because biotechnology is biological, that does not mean it is also ecological.)

Equally, expressing new social values using only today's technology is likely to mean unnecessary austerity. For example, a sustainability outlook might lead people to choose to give up heating and air conditioning and shiver or swelter in conventional houses (top left quadrant). But by expressing their new intent in terms of technology they could choose instead to be comfortable in houses with passive heating and cooling (top right quadrant). Behaving less wastefully is praiseworthy, but why ignore the potential of new technology?<sup>4</sup>

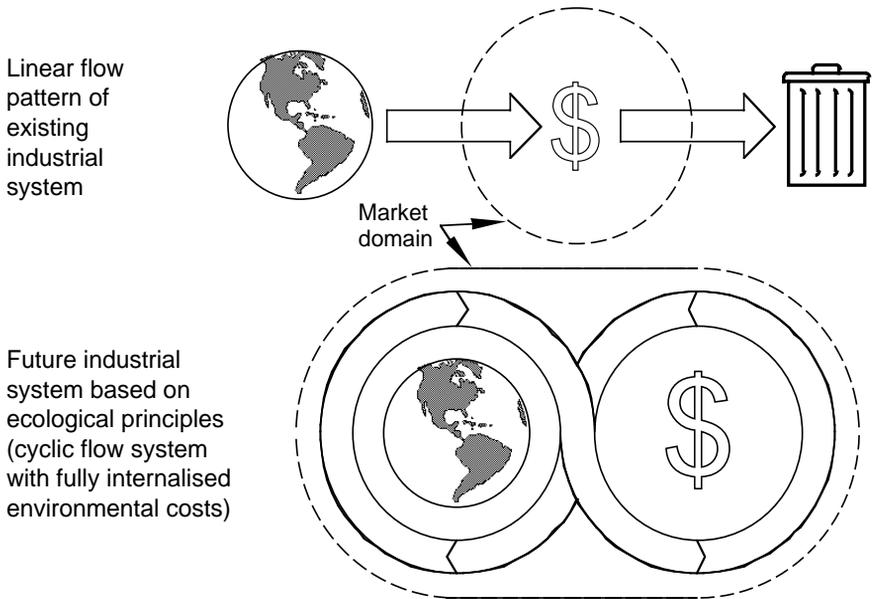
The matrix in Figure 9.4 does not tell the whole story of the technology meta-strategy—but it does illustrate why we cannot simply rely on the emergence of new technology on its own to enable the safe deceleration of exponential growth. Technology must be actively managed and designed to achieve this outcome, which is the purpose of the meta-strategy.

## **Technology to reduce the impact of materials flows**

The global scale of industry implies that the existing architecture of the industrial system is obsolete, as it will not be able to support environmentally sustainable development into the future. Industrial ecology is the emerging response to this challenge (Frosch, 1992; Tibbs, 1992; Graedel & Allenby, 1995). It sets out systemic design principles for harmonious co-existence of the industrial system and the natural system. Two of the most important foundation concepts are the 'cyclic economy' and the 'industrial ecosystem'.

At the moment, the industrial 'system' is less a system than a collection of linear flows. Industry draws materials from the Earth's crust and the biosphere, processes them with fossil energy to derive transient economic value, and dumps the residue back into nature (see Figure 9.5). For every 1 kilogram of finished goods we buy, about 20 kilograms of waste

**Table 9.5 From linear to cyclic economy**



have been created during production, and within six months 0.5 kilograms of our average purchase is already waste. This 'extract and dump' pattern is at the root of our current environmental difficulties.

The biosphere works very differently. From its early non-cyclic origins, it has evolved into a truly cyclic system, endlessly circulating and transforming materials, and managing to run almost entirely on solar energy (Lovelock, 1979). There is no reason why the international economy could not be redesigned along these lines as a continuous cyclic flow of materials. Such a 'cyclic economy' (see Box 9.1) would not be limited in terms of the economic activity and prosperity it could generate, but it

**Box 9.1 Characteristics of a cyclic economy**

- Industrial system seen as a dependent subsystem of the biosphere
- Economic flows decoupled from materials flows
- Environmental costs fully internalised into the market domain
- Cyclic flow of materials
- Virgin materials use minimised
- Information substitutes for mass
- System entropy kept as low as possible

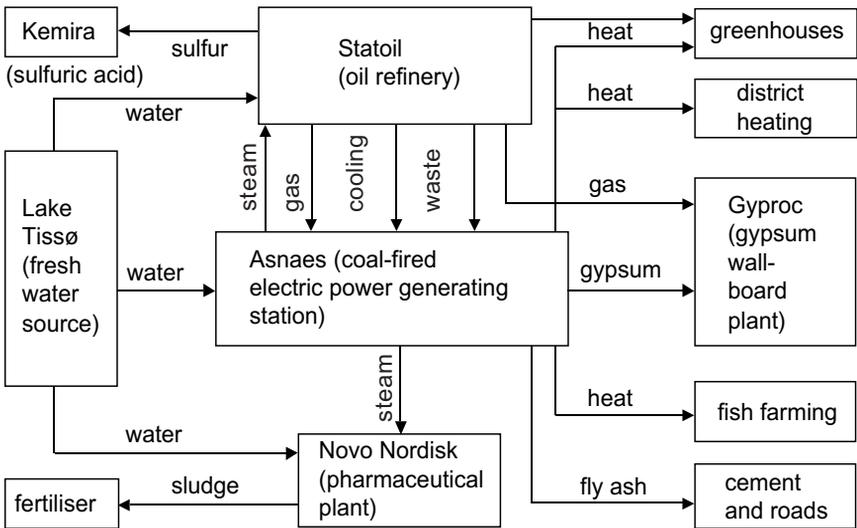
**Box 9.2 Characteristics of natural ecosystems**

There are many features of natural ecosystems that can be emulated by industry:

- In natural systems there is no such thing as ‘waste’ in the sense of something that cannot be absorbed constructively somewhere else in the system.
- Nutrients for one species are derived from the death and decay of another.
- Concentrated toxins are not stored or transported in bulk at the systems level, but are synthesised and used as needed only by individual species.
- Materials and energy are continually circulated and transformed in extremely elegant ways. The system runs entirely on ambient solar energy, and over time has actually managed to store energy in the form of fossil fuel.
- The natural system is dynamic and information-driven, and the identity of ecosystem players is defined in terms of processes.
- The system permits independent activity on the part of each individual of a species, yet cooperatively meshes the activity patterns of all species. Cooperation and competition are interlinked, held in balance.

would be limited in terms of the input of new materials and energy it required. Pollution would be reduced close to zero. At the time of writing, Germany is the first country to begin seriously experimenting with the legislation needed to create a cyclic economy.

At a finer-grained level, the design principles embedded in natural ecosystems (see Box 9.2) have given rise to the idea of the ‘industrial ecosystem’. This involves more than simple recycling of a single material or product. In effect, industrial ecosystems are complex ‘food webs’ between companies and industries to optimise the use of materials and embedded energy. They involve ‘closing loops’ by recycling, making maximum use of recycled materials in new production, optimising use of materials and embedded energy, minimising waste generation, and reevaluating ‘wastes’ as raw material for other processes. They also imply more than simple ‘one-dimensional’ recycling of a single material or product—as with, for example, aluminium beverage can recycling. In effect, they represent ‘multi-dimensional’ recycling, or the creation of ‘food webs’ between companies

**Table 9.6 The industrial ecosystem at Kalundborg**

and industries. A complex of industrial producers applying these principles has been referred to as an 'eco-industrial park'.

The best-known example of an eco-industrial park is in Denmark (Tibbs, 1992). A network of independent companies in the town of Kalundborg have created a permanent waste exchange system in an area about 16 kilometres across (see Figure 9.6). The waste transfers are across industries, so that the by-product of one company becomes the raw material for another. The cooperation involves an electric power generating plant, an oil refinery, a biotechnology production plant, a plasterboard factory, a sulfuric acid producer, cement producers, local agriculture and horticulture, and district heating. Among the 'wastes' that are traded, some by direct pipeline, are water at various levels of heat and purity, sulfur, natural gas, industrial gypsum and fly ash.

This cooperation was not required by regulation; the earliest deals were purely economic. Recent initiatives have been made for environmental reasons, yet have also paid off financially. In some cases mandated cleanliness levels, such as the requirement for reduced nitrogen in waste water, or the removal of sulfur from flue gas, have permitted or stimulated the reuse of wastes, and helped make such cooperation feasible. Most of the exchanges are between geographically close participants since the cost of infrastructure, such as pipelines, is a factor. But proximity is not essential; the sulfur and fly ash are supplied to distant buyers. Ultimately,

this kind of industrial ecosystem could be extended into a large-scale network that might include the entire industrial system (Frosch & Gallopoulos, 1989).

## **Dematerialisation, decarbonisation and industrial metabolism**

If large-scale industrial ecosystems are established, resulting in a continuous cyclic flow and re-use of materials, this would largely eliminate the direct environmental impact of industry. But to be fully effective, additional steps would be needed.

### **Dematerialisation**

The amount of materials in the closed loop, or web, can either be increased over time, kept stable, or decreased. Keeping it the same would avoid use of virgin non-renewable resources. But the system needs energy to run and leaks are possible (see below), and minimising these means reducing the volume of material in the loop over time.

If the global population doubles and becomes more affluent during the time the closed loop is established (within the next twenty to forty years), reducing or just holding the amount of material steady will require accelerated dematerialization.

Dematerialisation refers to a decline in the materials- and energy-intensity of industrial production—an existing trend in industrially developed economies. Both materials and energy use (measured as quantity per constant dollar of gross national product (GNP) have been falling since the 1970s (Larsen, Ross & Williams, 1986). This is because the market for basic products has saturated, while the weight and size of many other products has fallen. Information technology increasingly allows embedded information to reduce product bulk. New technologies such as nanotechnology—assembling materials atom by atom—promise to accelerate dematerialisation.

Industrial ecology would aim for miniaturised, lower-mass products with longer life. This would decouple economic growth from growth in materials use, enabling a fixed flow of materials in the cyclic loop to provide goods for many more people.

### **Industrial metabolism**

The efficiency of materials use is a key focus of industrial ecology. Industrial metabolism refers to the type and pattern of chemical reactions and

materials flows in the industrial system. Potential improvements could yield significant environmental benefits. Compared with the elegance and economy of biological metabolic processes, such as photosynthesis and the citric acid cycle, most industrial processes are far from their potential ultimate efficiency in terms of basic chemical and energy pathways.

Similarly, the cyclic flow of materials, like any engineered system, would suffer from leaks. But the most serious 'leaks' come from design, not accident. Many materials are 'dissipated' or dispersed into the environment as they are used, with no hope of recovery for recycling. This problem can be overcome by designing differently. For instance, car brake pads leave a finely distributed powder on our highways as they wear down. This can be avoided with frictionless electrically-regenerative braking, as in the latest hybrid-electric cars like the 1998 Toyota Prius.

### **Decarbonisation**

Energy would be required to move materials through the cyclic loop and periodically reprocess them for reuse. To minimise its environmental impact, this energy will need to be progressively decarbonised—contain less carbon over time. Energy sources have been decarbonising for more than 150 years, as industrialised countries move away from high carbon fuel sources such as firewood and coal, to oil and low carbon sources such as natural gas (Ausubel, 1989). Because carbon dioxide from industry is a major dissipative flow of material, industrial ecology would aim for decarbonisation of energy. A completely carbon-free energy supply could be provided using pure hydrogen gas produced from renewable energy sources. A possible future hydrogen-electric economy would combine hydrogen (the lightest element) to provide a clean, low-mass carbon-free store of renewable energy, and electricity to provide precision and control in energy delivery.

### **Planetary physiology**

The overarching concept behind industrial ecology is the need to place the whole global industrial system in the context of planetary physiology. The ultimate aim of industrial ecology is to create a planetary order of technology for the long haul—a deployment of technology planet-wide that is suited to the special characteristics of planet earth. Put another way, this means the emergence of a technological infrastructure that can harmonise with the unique bio-geochemical processes and cycles of this planet. One of the main reasons for thinking on such a large scale is precisely that industry itself has now reached planetary scale—its through-

puts and waste flows are so large that they are disturbing the large-scale planetary life-support systems on which we all depend.

This means that industrial ecology is focused not only on the structure of industry, but also on the systems and structures of planetary physiology. The appropriate long-term structure of industry cannot be determined until we have a good understanding of the way the planet works, at both large and small scales, both in time and space. Since the whole concept of looking at the physiology of the Earth itself is relatively new, industrial ecology has important contributions to make in this area, focusing study to provide the insights needed for the design of industry.

The British scientist James Lovelock coined the term Gaia (Lovelock, 1979) (the name of the ancient Greek goddess of the earth) to express the idea of the entire planet as a single living super-organism, with homeostatic feedback loops that create a physiology comparable to that of a regular organism. Lovelock pioneered the study of planetary physiology, or geophysiology as he calls it. Geophysiology can be understood as including geological processes, climatic and hydrological cycles, and ecology, all of which are responsible for materials flows in the natural environment. As we begin to uncover the intricately interlocked workings of geophysiology, the implications for industry become clear. We contain within our bodies biochemical processes that not only serve our own life, but also enable the bio-geochemical processes of Gaia. In a very literal sense, we are a functional part of the planet. Industry needs to be structured the same way—to serve human needs as well as planetary needs. Industry must become a cooperative part of the planet, of the life of Gaia.

Needless to say, it is far from that today. So how do we make a bridge between geophysiology and the design of industry? The keys to geophysiology are to understand the cycles of matter, the way feedback loops regulate the cycles, the key stocks and flows in the system, and the way living and non-living elements in the entire system interact. We can study how industry works on the large scale by mapping it in much the same way. The study of industrial metabolism, pioneered by scientist Robert Ayres, is a natural complement to geophysiology—indeed, given the scale on which we are doing things, it is rapidly making a significant impact on it. Industrial metabolism involves looking at the way elements flow from the environment into and through industry, and back out into the environment. The elements or molecules of most interest are those that flow in the greatest volume, and those that are the most toxic—either to organisms or to Gaia—carbon, sulfur, nitrogen, heavy metals such as cadmium and mercury, CFCs, etc.

Once we have understood better how Gaia works, and once we have a good grasp of today's industrial metabolism, we will be in a position to

devise a new form of industry. At that point, we may find we have to redefine the concept of industry itself. The trouble with the word ‘industry’ is the image it typically evokes of gloomy grey buildings with saw-tooth roofs and tall stacks belching grimy smoke. We need a different conception of industry.

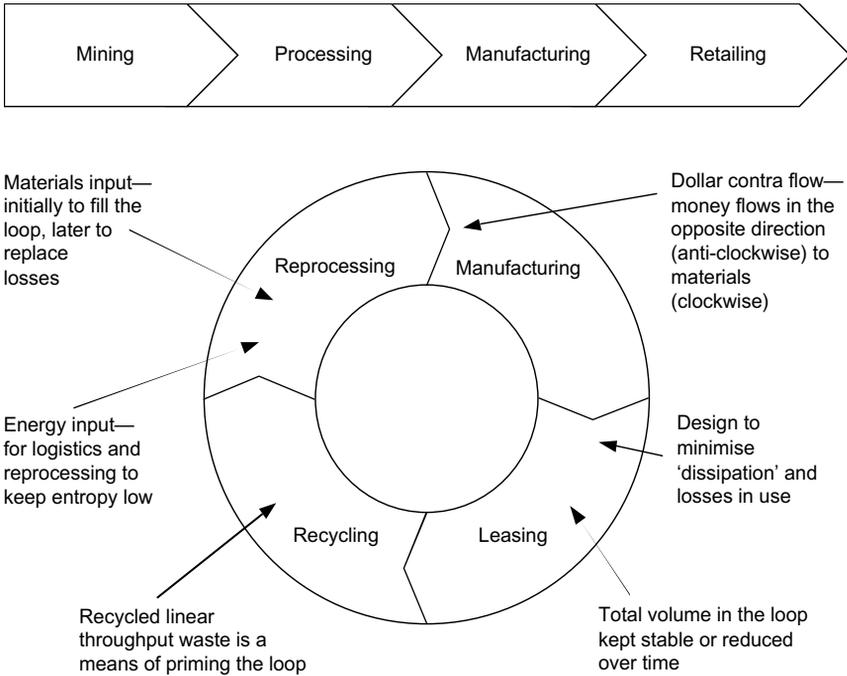
This is why the idea of industrial ecosystems, and eco-industrial parks, like the one at Kalundborg in Denmark, although vital, are not enough on their own. The heart of the industrial ecosystem at Kalundborg is a large—1500 megawatt—coal-burning electricity generating station called Asnaes. While it is true that many valuable savings in the use of materials and water have been achieved by linking Asnaes to other industrial facilities in the surrounding area, it seems unlikely that burning coal for energy production can be acceptable for very much longer.

In short, industrial ecology is more than simply a combination of best practice environmental management tools, such as life cycle analysis (LCA) and design for environment (DFE). Defining it in these terms fails to grasp the larger intent of industrial ecology. It is not just another tool, nor is it even another environmental management system (EMS). Industrial ecology is—or at least aspires to be—the emerging field of knowledge that interrelates the various environmental tools and management systems that have been devised so far. It generates an overall context and gives the whole set of tools and systems a coherent objective—aligning industry with geophysiology.

## From value chain to value loop

Business analysis focuses on the concept of the value chain, which represents the ‘idealised form’ of the linear-materials-throughput economy. Industrial players define themselves according to their roles and interactions in the value chain. The technology meta-strategy of sustainability requires this conceptual map to be revised. Instead of a value chain, sustainable corporations must come to see themselves as part of a cyclic value loop (see Figure 9.7). This will require a strategic redefinition for firms in many industries—particularly those at the beginning and end of the traditional value chain. Mining companies, for example, will no longer be able to view themselves as a one-way source point for materials in the industrial economy. They will need to re-perceive themselves as being in the materials management business, responsible for the post-use reclamation and reprocessing of the materials they specialise in. As today, they will supply concentrated, purified materials in specified physical forms to manufacturers who will convert these materials into finished goods. But

**Table 9.7 Relocating from the value chain to the value loop**



the new materials-managers will source the raw materials they need not from the earth's crust, but from the urban industrial ecosystems in the materials catchment areas where their plants are located. This is not such an outlandish concept, since it is essentially how steel mini-mills already source materials from urban catchment areas, reclaiming scrap steel from old automobiles and reprocessing it.

Seeing the cyclic economy from a business perspective as a value loop, highlights a number of important points about the detailed operation of cyclic materials flows.

An important question for industrial players committing to component infrastructure for the cyclic economy is the resilience of the resulting system. If an industrial ecosystem is created to reduce materials use and waste, what happens if or when one of its component processes becomes obsolete? Does the whole industrial ecosystem then become unviable? Or can structures of interlock be designed which allow for

change, such as cleaner future technology, without creating increased dependence on such things as coal-fired power plants? Put differently, can interlock be achieved without unwanted lock-in?

The answer is likely to depend on working through a sequence of steps. One approach would be first to identify a set of materials that have long-term geophysiological compatibility. A fairly small set of acceptable materials could probably be used to supply 80 percent or more of all production needs. The next step would be to devise clusters of production processes that use some or all these materials, and which can be interlocked ecosystem-style.

Once this is done, the resulting industrial clusters or industrial ecosystems should stand a reasonable chance of being stable over time. Gunter Pauli of the Zero Emissions Research Initiative (ZERI) at the United Nations University in Japan, has shown that focused industrial clusters of this sort, based on biomass inputs and zero waste, can make very good sense in business, social and environmental terms.

Once closed loops of materials flows are established, the next question is whether the volume of materials flowing in the loops can be allowed to grow or not. Linear throughput growth (in which materials flow through the economy as if through a straight pipe) places a double burden on the environment—once during the production of virgin materials, and again when wastes are ultimately dumped—and about 95 percent of all the materials we use end up as waste before the finished product is even purchased. But if all materials flow in a loop, does the volume in the loop matter? At first sight, it would appear not, but on closer examination, it is an issue.

The first concern is the exponentially growing demand for materials as global population and relative affluence increase. If all materials flowed in a closed loop and demand continued to grow exponentially, ever more virgin materials would need to be poured into the loop to meet this growing demand. Suppose this growth was offset by dramatic dematerialisation of the useful products created, to the point where the volume of materials in the loop could at least be kept stable. Would this be enough? The answer depends on the level of leaks from the loop, and the characteristics of the energy used to keep materials moving round the loop. Even in a loop, materials need to be transported and processed repeatedly to keep them useful, and this requires energy. If energy production still has a high environmental cost—for example because it still results in high carbon dioxide emissions—then the volume of materials in the loop would have to be reduced over time to lower the energy consumption. Simply folding linear flows into webs and loops is not enough.

## Avoiding harm

The emphasis in the meta-strategy for sustainability shifts from avoiding Type I to avoiding Type II errors when dealing with the possible negative impacts of technology (Lee, 1993).

During the growth phase of industrial development, the emphasis was squarely on the development of new scientific knowledge as a basis for acquiring technological capability. The scientific method calls for caution in advancing ideas as new knowledge unless they are well grounded in empirical evidence. The emphasis in science is to avoid what are called ‘Type I errors’—the error of affirming propositions as true that later turn out to be false. Over time this bias in science and engineering has become the predominant influence in environmental policy making and strategy setting.

In a world which now has a high level of scientific knowledge and which is saturated with technology, another kind of error becomes more important, but is less well recognised. This is the ‘Type II error’—the error of rejecting propositions as false that later turn out to be true. This is the kind of error that fire brigades try to avoid—which is why firefighters always respond to what may be false alarms.

When the concern is merely the development of abstract knowledge, society can afford to emphasise the avoidance of Type I errors. But when new technologies with potentially harmful effects are about to be commercially introduced, or when technologies with suspected harmful effects are proliferating rapidly, it can be dangerous to be obsessed only with Type I errors. The time it takes for definitive proof may be precisely the time during which critical harm is done. Far better, in these circumstances, to be much more concerned with avoiding Type II errors.

By emphasising Type II errors, the technology meta-strategy takes a precautionary approach. In this respect it is similar in intention to other sets of systems principles for sustainability. One well-known set of such principles was created by Dr. Karl-Henrik Robèrt, a 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 (for example, minerals, oil, etc.)
- 2 nature cannot withstand a systematic build-up of persistent compounds made by humans (for example, polychlorinated biphenyls (PCBs))

- 3 nature cannot tolerate a systematic deterioration of its capacity for renewal (for example, 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 (for example, the rain forest).

The Natural Step has been criticised because it does not address the full range of possible unsustainability. For example, it may not preclude possible negative impacts of biotechnology—probably because the four principles were developed before biotechnology emerged as a major commercial force. The technology meta-strategy for sustainability would address such gaps—in this case by explicitly calling for the protection and preservation of the informational integrity of the biosphere and ecosphere.

## The sustainable corporation

The sustainable corporation needs a clear framework for its strategic thinking. This chapter has attempted to show that the necessary framework can be rooted in an understanding of the sources of unsustainability, the technological responses necessary, and the business translation of these responses. However, the sustainable corporation cannot be considered as an isolated phenomenon—it must be closely related to changes in society as a whole.

Sustainability of corporations cannot be achieved independently of the socio-economic system as a whole, but their level of unsustainability can be reduced and this is an important near-term and transitional goal for corporate strategy. True sustainability can become a goal for corporations only as the whole socio-economic system moves towards sustainability.

The true future 'sustainable corporation' will emerge from this larger process of change. This can be expected to include a revision of international company law, redefining the goals of the private company and introducing a 'multiple bottom line': accountability to a wide range of present and future stakeholders, and a commitment to avoiding negative environmental and social externalities and maintaining social and natural capital stocks. These changes would no doubt be supported by changes in tax legislation, probably along the lines currently being discussed as 'ecological tax reform', in which the tax burden is shifted away from payroll to the

consumption of virgin materials (Weizsäcker, Lovins & Lovins, 1987). This would accelerate the shift away from intensive materials use and tend to reduce unemployment—in the terminology of strategist Michael Porter the emphasis in the search for productivity would shift from labour productivity to resource productivity (Porter, 1995).

A significant new paradigm of personal belief and social values would also be needed to accompany and enable the changes envisaged in the socio-economic system, since they will not be accomplished by technology advance alone. It can be anticipated that the result would be the emergence of a less materialistic, and hence less materials-intensive way of living. Such a shift may well be catalysed by major disruptions or crises, whether social, economic, ecological or climatic.

## Conclusion

The meta-strategy for the sustainable corporation addresses our total use of technology around the world and our ability to make it serve both society and individuals. It includes our need to work within geophysiology on both the large and small scales, the need to do this equitably, and the ability to keep doing it over time. The meta-strategy aims at ensuring that human application of technology can meet the needs of all peoples and exist in harmony indefinitely with natural bio-geochemical systems, based on the creation of large-scale technology ecosystems specifically adapted to this planet we call home.

As it happens, the ecosystems metaphor is already becoming influential in corporate strategic planning. Strategists are increasingly talking about 'business ecosystems,' about 'value webs' rather than value chains, and about 'co-opetition' a balance between competition and cooperation as is found in nature. This amounts to a realisation that business is more successful when it adopts a 'live and let live' orientation rather than when it attempts to destroy all competition, and that the 'survival of the fittest' is best understood in terms of the 'survival of those that fit best.' This shift of outlook is an ideal grounding for the next step, which is to relate business strategy and survival not only to adaptive fit with other businesses, but also to adaptive fit with the natural environment. If strategic ideas and an ecosystemic technology perspective flow together—a convergence whose time may be just about to arrive—it could well open the way for industry, and indeed all human technology, to become truly sustainable.

## Endnotes

- 1 The term 'sustainable corporation' can be understood in a 'strong' sense, as a future form of the corporation reframed by new company law and new tax and other legislation that refocuses its fundamental motivation, or in a 'weak' sense, as a transitional form of today's conventional corporation which is seeking voluntarily to reduce its contribution to unsustainability.
- 2 For a global sustainability scenario framework see Tibbs, 1998.
- 3 For a discussion of unsustainability see Tibbs, 1999.
- 4 Strictly speaking, the example given is not new technology, but since it is not mainstream its widespread adoption would be a major new development.

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