

The Sustainable Development Challenge for Technology: *will it work in time?*

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Abstract

Sustainable development is a three-pronged attack on the future. It is shorthand for a world in which economic progress, social equity and environmental quality are being integrated to provide fulfilling lifestyles for the planet's inhabitants, both now and in the future. Technology will have to play an important role in the transition towards sustainable development, and technological changes call for supportive changes in production and distribution systems and consumption patterns.

The role technology can play in achieving sustainable development is focussed on with special consideration for the opportunities to force technology to develop in support of sustainability. Objectives for sustainable technology – often referred to as factor X innovations – are reviewed and examples given of initiatives to initiate and/or accelerate the development of more sustainable technologies.

Introduction

This paper is about technology, as a short-hand for industrial production and consumption systems, and the global environment, which provides the natural resources and services that support those production and consumption systems. It deals in particular with the question whether, and possibly how, innovation in technology can solve the tremendous global development challenges ahead, without endangering the continued provision of natural resources and services by the global ecosystem. In 2040, the world population will have doubled or tripled with respect to 1990. Also, the less developed countries will continue to develop their production and consumption levels and will at least aim to be at equity with the developed world in this 50-year period. The developed world also will increase its production and consumption, but at a slower rate. The developed countries themselves are probably able to manage their environmental problems at home, but the global development and global environmental challenges will neutralise all end-of-pipe and process-integrated measures that are developed and implemented now. In order to counter these developments, technology must play an important role. Not all problems can however be solved by technical means, and in some cases changes in lifestyle will prove to be necessary. Profound changes in technology will prove to be necessary, which will not be achieved without profound changes in culture and structure (e.g. Vergragt et al, 1994).

To understand how technology can - or will need to - change to be able to fulfil the needs of future generations in the developed and developing world, three questions are discussed in this paper:

1. How big is the eco-efficiency¹ challenge that the sustainable development paradigm poses for technology? In short, what are the likely limits to the earth's carrying capacity, and is the ecological capacity available within these limits sufficient to sustain current resource consumption rates and deal with the expected growth of the world population and of production and consumption levels?
2. How can technology change and innovation contribute to meeting this challenge? It is most appropriate to think of technological fixes for the near, middle and far future, and it will be questioned whether or not the preparation for far future solutions, or sustainable technologies, can still be postponed.
3. What can be done to facilitate sustainable technology development? Technology forcing is gaining ground as concept for accelerating socially desirable technology innovation, and an example from The Netherlands is used to explain how this can work in support of sustainable development by means of innovations in the innovation processes.

The New Industrial Paradigm: Sustainable Development

We are in the midst of a paradigm shift with respect to how society views the environmental, social and economic implications of the industrialised world (Rowledge et al, 1999: p. 21). The shift is away from an industrial model in which environmental activity is viewed as a cost, resources are viewed as a free good, and the social implications of industrial policy are an afterthought. Leading decision-makers and thought leaders in academia, industry, government and non-governmental organisations are now embracing a new model in which economic, environmental and social considerations are highly integrated. In this model, industrial environmental activity is viewed as an opportunity for cost reduction, product innovation and increased shareholder value; understanding the social implications of decision-making is seen as a platform for the long-term prosperity of organisations. Rather than being an add-on, the economic viability of a national economy or an organisation is predicated on understanding and integrating environmental and social considerations into core decision making processes.

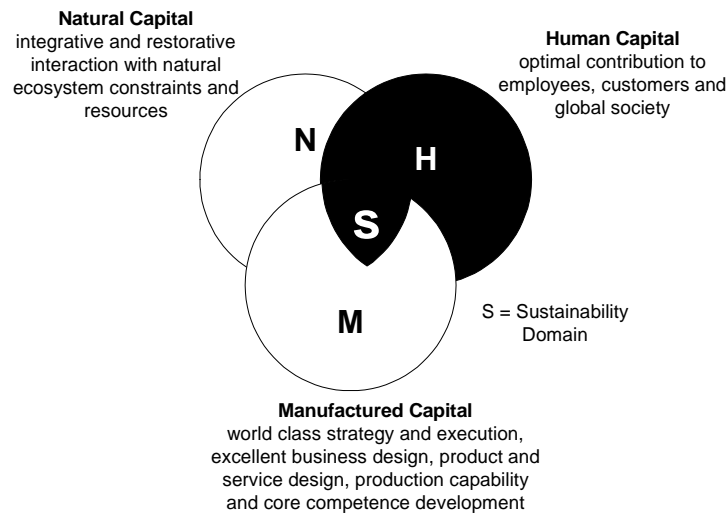
This new industrial paradigm is most often described as 'sustainable development'². This term is rooted in the 1987 Report of the World Commission on Environment and Development (commonly known as the Brundtland Report). Since the 1992 United Nations Conference on Environment and Development (UNCED) in Rio, sustainable development has been progressively embraced by leading industries, national governments, international organisations and financial institutions. There is, however, no uncontested operational definition of 'sustainability', although there is widespread agreement on the general, non-operational definition adopted by the Brundtland Commission: sustainable development is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). Sustainable development *will* be a defining element of the future global economy and society: a central element of value creation and prosperity. The break through paradigm is seeing the goal as *integrating*, rather than trading off or balancing, the three goals of: economic development; environmental protection and restoration; and social equity and well being. Visually and conceptually, progress toward

¹ The World Business Council has defined eco-Efficiency in detail for Sustainable Development. It is reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's carrying capacity (WBCSD, 1996). In the framework of this paper Eco-Efficiency is used as a short hand for the natural resource efficiency of production and consumption systems; i.e. the amount of natural resources consumed per unit of wealth created.

² It is remarkable that Australia is among the very few countries that continue to use the term 'Ecologically Sustainable Development' (e.g. Productivity Commission, 1999) and thereby limit the ramifications of the global quest for more sustainable development to the environmental arena.

'sustainability' is optimally attained through strategies and actions at the intersection of three converging circles (see Figure 1). This illustrates graphically that sustainability is achieved at the nexus of excellent managerial and production systems, in alignment with - and restorative to - natural systems, in optimal service of human prosperity and development (Rowledge et al, 1999: p 29).

Figure 1: A Model for Sustainability: the nexus of economic/manufacturing, natural and human systems (from Rowledge et al, 1999).



In many aspects sustainable development disentangles economic growth or progress from material resource use. It replaces the economic norm of quantitative expansion ('*growth*') with that of qualitative improvement ('*development*') as the path for future progress. 'Growth' is an increase in size through material accretion while 'development' is the realisation of a fuller and greater potential – so sustainable development is progressive social betterment without growing beyond the ecological carrying capacity (Dally, 1996, op cit. Rowledge et al, 1999, p. 22). The German Centre for Technology Assessment (CTA) postulates that there are three stages of such qualitative development (Ren et al, 1996, op cit. Rowledge et al, 1999; p193-194):

Stage 1: Continuous decrease in resource use per unit of GDP

Stage 2: Continuous decrease in resource use per capita

Stage 3: Continuous decrease in resource use per national economy

Much of the industrialised world has achieved Stage 1, where qualitative development implies that products use fewer resources for the same functionality. Stage 2 means development could occur wherever there is more added value than there is increase in production or consumption of materials and energy. Very few products, let alone sectors or countries, have reached this stage. Stage 3 only differs from Stage 2 in that it assumes increased value per national economy while the population of that economy continues to increase, with a decrease in absolute resource consumption. This stage will be difficult to achieve and is likely to require consideration of the ever-increasing population in addition to vastly increased resource productivity.

Progressing the implementation of sustainable development calls for a further understanding of the operational principles critical to sustainable development. Through its efforts to develop a sustainable vision for the highly industrialised German Baden-Wurttemberg

Region, CTA identified four such critical operational principles (Ren et al, 1996, op cit. Rowledge et al, 1999; p192-193):

1. *Acknowledge absolute limits to the carrying capacity of the earth.* This will require increases in human-made capital and dramatic increases in resource productivity.
2. *Acknowledge limits of substitution between natural and artificial capital, and ensure natural cycles necessary for human survival are identified and appropriately protected by political measures.* For many natural-system services and natural-system cycles it is difficult to determine true cost or value, although it is clear those externalities are extremely high, and imposing the externalities is impractical. Thus, developing sophisticated understandings of the natural cycles that are critical for survival, and consequently for sustainable development, and protecting those cycles through political interventions, seems essential.
3. *Focus on the resilience of anthropogenic ecosystems.* Although renewable resources are theoretically available indefinitely, that is only true if the ecosystems that support those resources are resilient enough to sustain their productivity under dynamic conditions. Thus, for example, if humans manage their ecosystems for renewable materials and energy too intensively, or force them to be too monocultural, they undermine the resilience of those ecosystems and jeopardise their sustainability. From a practical perspective, achieving sustainable development will require a commitment to economic and societal decision making that ensure resilient ecosystems.
4. *Incorporate social and cultural values into society's relationship to environment and nature.* Different societies (regions) will have different cultural and social perspectives on the intrinsic value of nature. To ensure sustainable development, those values will have to have a voice consistent with local preferences.

From an economic perspective, Hawken et al (1999) arrive at similar conclusions. In their view, the next industrial revolution is being created that will lead society to a new form of capitalism. The full valuation of all forms of capital, including human and natural capital, is critical for this new '*Natural Capitalism*'. It is argued that ensuring a perpetual annuity of valuable social and natural processes to serve a growing population is not just a prudent investment but a critical need in the coming decades. Doing so can avert scarcity, perpetuate abundance, and provide a solid basis for social development; it is the basis of responsible stewardship and prosperity in the 21st century and beyond. Box 1 summarises the four central strategies of natural capitalism: radical resource productivity; biomimicry; service and flow economy; and investing in natural capital.

The different perspectives on sustainable development have in common the realisation that the earth has a finite carrying capacity, or that the availability of resources and services from the global ecosystem is limited. Moreover they share the perception that overall global prosperity, well being and stability are served by a more equitable division of wealth among the global citizens. This automatically leads to the next question: what are the ecological limits to resource consumption? .

Ecological Carrying Capacity: Factor X and Beyond

The concept of 'carrying capacity' originates from biology where it means the maximum population of a given species that can be supported indefinitely by a defined habit. The notion of limits is fundamental to carrying capacity: when the maximum population level is exceeded, the resource base declines and – at some later date – so will the population. In

Box 1: Central Strategies of Natural Capitalism (Hawken et al, 1999).

The following four strategies are central for attaining 'Natural Capitalism'. All four are interrelated and interdependent; all four generate numerous benefits and opportunities in markets, finance, material, distribution, and employment. Together, they can reduce environmental harm, create economic development and increase meaningful employment.

1. *Radical Resource Productivity.* Radically increased resource productivity is the cornerstone of natural capitalism because using resources more effectively has three significant benefits: it slows resource depletion at one end of the value chain, lowers pollution at the other end, and provides a basis to increase world-wide employment with meaningful jobs.
2. *Biomimicry.* Reducing the wasteful throughput of materials – indeed, eliminating the very idea of waste – can be accomplished by redesigning industrial systems on biological lines that change the nature of industrial processes and materials, enabling the constant reuse of materials in continuous closed cycles, and often the elimination of toxicity.
3. *Service and Flow Economy.* This calls for a fundamental change in the relationship between producer and consumer, a shift from an economy of goods and purchases to one of service and flow. In essence, an economy that is based on a flow of economic services can better protect the ecosystem services upon which it depends. This will entail a new perception of value, a shift from the acquisition of goods as a measure of affluence to an economy where the continuous receipt of quality, utility and performance promotes well being.
4. *Investing in Natural Capital.* This works toward reversing world-wide planetary destruction through reinvestments in sustaining, restoring, and expanding stocks of natural capital, so that the biosphere can produce more abundant ecosystem services and natural resources.

principle carrying capacity can be applied to industrial ecosystems resulting in estimates of the maximum human population a given region can support. However, the carrying capacity then becomes dependent on level of technical development, and aspects of import and export of resources between regions would be neglected. Two different interpretations for the carrying capacity concept have therefore emerged; ecological footprints and rucksacks, and eco-space (environmental utilisation space) (OECD, 1995).

The concepts of *ecological footprints* and *ecological rucksacks* have been developed in an attempt to estimate the environmental capital requirements of an economy, based on an interpretation of carrying capacity that takes into account the impacts of technological advance and trade.

- The concept of *ecological footprints* redefines the carrying capacity as the area of productive land and water required to support a defined economy or population at a specified standard of living, wherever that land may be located. In the context of industrialised economies, thriving on imported energy, materials, food and animals feedstocks, a large part of their ecological footprint is remote, i.e. felt in other countries. As population numbers, and/or standards of living in rich countries increase, the remote land area required to support their economies rises. This phenomenon is described as 'appropriated' carrying capacity.
- *Ecological rucksacks* are concerned with the total weight of material flows involved in the production of a particular good. Thus, the real ecological weight of e.g. a motor car includes the weight of its constituent materials (metals, glass, plastic, etc.) plus the weight of soil, rock and wastes removed or created during the extraction and processing of those materials. This materials extraction phase often occurs outside the consuming country; ecological rucksacks, like footprints, are concerned with displaced environmental impacts.

While the ecological footprint concept is principally concerned with the psychological distancing and environmentally damaging effects of trade, ecological rucksacks take a more technical standpoint, focusing on the need to monitor and reduce the volume of materials flows by means of eco-efficient measures (particularly dematerialisation and materials reuse) and lifestyle change (OECD, 1995).

Simpson et al (2000) present the results of a recent ecological footprint analysis for Australia. The data used are from 1991-1992, and since only a few key materials were considered (excluding for instance sea products), the analysis should be regarded as a conservative proxy measurement. The results indicate that the average Australian appropriates 5.96 hectares of ecologically productive land in his/her consumption of goods and natural resources. The consumption and transport of food compromises the largest portion (45 per cent) of Australia's ecological footprint, due mainly to the area of pasture required to support the consumption of meat products. The consumer goods category compromises 22 per cent of the total, with significant contributions from the pastureland use category (through consumption of wool products), forests (wood furniture and paper and cardboard) and energy embodied in the goods consumed. For comparison purposes, Australia shares the third place in terms of largest ecological footprint with Canada (at 6.03 hectare/person), behind New Zealand (at 6.82 ha/person) and USA (at 7.44 ha/person). The current ecological footprint of an average Australian is 3.4 times higher than of the average global citizen and even 4.6 times higher than what is regarded as a fair earth share. Moreover, it is about 10 times higher than the ecological footprint of the Indian subcontinent.

Environmental utilisation involves the use of resources from and discharge of wastes into the environment. The environment responds by regenerating (renewable) resources and absorbing wastes: this capacity is the available 'eco-space', the boundaries of which are determined by the patterns and levels of economic activity (utilisation). As environmental degradation increases, reducing regenerative and absorptive capacity, the environmental utilisation space decreases (OECD, 1995).

Defining the sustainable level of use of natural resources calls for sustainability criteria. 'The Natural Step' is a well-known set of sustainability criteria. It specifies that in order for a society to be sustainable, nature's functions and diversity are not systematically (Natrass et al, 1999; p 23):

1. Subject to increasing concentrations of substances extracted from the Earth's crusts
2. Subject to increasing concentrations of substances produced by society, or
3. Impoverished by overharvesting or other forms of ecosystem manipulation, and
4. Resources are used fairly and efficiently in order to meet basic human needs world-wide.

The Natural Step has been a very effective strategy tool for a number of large corporations to develop and implement innovative environmental management strategies, such as the carpet lease approach from Interface and product recovery and down-cycling by Nike (Natrass et al, 1999).

Another emergent idea from the 1990's pertaining to carrying capacity, is the Factor X reduction in resource use, with X being between 4 and 50 (Reijnders, 1998). This factor X is qualitatively similar to the concepts of dematerialisation and eco-efficiency, but has a quantitative edge. The factor X may refer to a product (such as an automobile), a service (e.g. transport over a certain distance at a certain speed), an area of need (e.g. clothing), sector of the economy (e.g. energy supply and demand) or the economy as a whole. The lower value

proposed for X – a multiple of four – refers to near-term possibilities for improvement; the higher values indicate longer-term improvement potential. Factor 4 is symbolised as doubling wealth while halving resource consumption. A factor 10, reflecting a tenfold reduction of the material flow per unit of service to be realised over a period of 30-50 years, stems from the scenario of halving environmental impacts while achieving equity of access to resources. Factors in the range of 20 to 50 are used in sustainable technology development programs.

Others have attempted to quantify the eco-space in detail. A study commissioned by the Advisory Council for Nature and Environment (The Netherlands) provided leapfrog for the quantitative understanding of eco-space (Weterings et al, 1992). The quantification of the ecospace commences with the observation that there are three dimensions of environmental impact – depletion, pollution and encroachment. From there on a hierarchy of sustainability criteria was developed, ranging from the general to the specific. For *depletion*, the general sustainability criterion is that there should be no absolute exhaustion. For *pollution*, it is that there should be no accumulation of polluting substances or any lasting effects for coming generations. For *encroachment*, the general condition is that the rates of loss must not exceed rates of restoration or replenishment by natural or artificial means. In each case, more specific criteria can be worked out only for illustrative resources, pollutants or damages, and in respect to the relevant scale of the impacts – global, continental or national. In case of depletion of mineral resources, the basic reference is the proven or economically recoverable global stock of specific minerals. For renewable resources, the relevant reference is the rate of natural regeneration. For pollution and encroachment, reference evidence comes from studies or natural loadings, buffering capacities, substance concentrations and variability in these. For each selected resource-, pollutant- and damage-indicator, reference data were collected and projections made for the future impact level in The Netherlands in 2040 (50 years after the 1990 baseline). Comparing these projected impact levels with the estimated sustainable level of use, results in necessary reduction levels. These are summarised in Table 1. Clearly, Table 1 shows that, in the event of trends and policies remaining as now, the level of environmental impact in 2040 will exceed in many respects. In case of most indicators, the level of impact is of the order of several times the sustainable level and reductions of 50 to 95 per cent are desirable. Further analysis shows that three technology clusters account today for much of the total environmental stress: energy services, industrial materials supply and human nutrition.

Despite the many uncertainties in assessing the carrying capacity of the global ecosystem, different studies appear to convene on the need for quantum improvements of the eco-efficiency of our industrial society. It appears attractive to express those quantum improvements in terms of a factor X ; with X having a value of 1.5 to 2 for the short term (within 5 years), a value of 2 to 5 for the medium term (within 5 to 20 years) and a value between 20 and 50 for the long term (within 20 to 50 years). The factor X lacks precision as yet, and it is not yet widely considered that achievable values for X may vary widely among economic activities given technological constraints (Reijnders, 1998).

Technological Trajectories: The Case for Technology Forcing

Technology must play an important role to achieve the quantum improvements in eco-efficiency of current production and consumption systems. The spectrum of conceivable technology options can be mapped on three complimentary innovation tracks: *environmental care*; *eco-products and services*; and *sustainable technologies*, respectively for the near, middle and far future (Weaver et al, 2000). These three innovation tracks have different time-horizons and objectives (see also Table 2). The near future track is mostly concerned with issues of care and good housekeeping, in industry this corresponds to the fine-tuning of operations through mechanisms such as quality management, auditing and efficiency drives, which typically have a time horizon of up to five years. The near future track can deliver environmental outcomes from increased process efficiencies, complemented with the

Table 1: Projected versus sustainable claims on eco-capacity (for The Netherlands) (Weterings et al, 1992).

Indicator	Sustainable Level	Expected Level (2040)	Reduction Required (%)	Scale
Depletion				
Fossil fuels				
• Oil	50-year criterion	Stock exhausted	85	Global
• Gas	50-year criterion	Stock exhausted	70	Global
• Coal	50-year criterion	Stock exhausted	20	Global
Metals				
• Aluminium	50-year criterion	Stock > 50 years	None	Global
• Copper	50-year criterion	Stock exhausted	80	Global
• Uranium	50-year criterion	??	NQ	Global
Renewable resources				
• Primary productivity	20 % of total	50% of total	60	Global
• Animal biomass	20 % of total	50% of total	60	Global
• Biodiversity	5 species lost per annum	> 365 species per annum	99	Global
Pollution				
Macro-pollutants				Global
• Carbon emissions	2.6 gigatonnes per year	13 gigatonnes per year	80	Continental
• Acid deposition	400 acid eq/ha/yr	2400-3600 eq/ha/yr	85	National
• Phosphor deposition	30 kg/ha/yr	??	NQ	National
• Nitrogen deposition	267 kg/ha/yr	??	NQ	National
Metal deposition				National
• Cadmium	2 tonnes per annum	50 tonnes per annum	95	National
• Copper	70 tonnes per annum	830 tonnes per annum	90	National
• Lead	58 tonnes per annum	700 tonnes per annum	90	National
• Zinc	215 tonnes per annum	5190 tonnes per annum	95	National
Encroachment				
Dehydration	Reference year 1950	??	NQ	National
Soil loss	9.3 billion tpa	45-60 billion tpa	85	National

Table 2: Characteristics of Three Environmental Innovation Tracks (modified from Weaver et al, 2000).

Characteristics	Innovation Trajectories		
	Environmental Care	Eco Products and Services	Sustainable Production & Consumption
Time horizon	0-5 years	5-20 years	20-50 years
Characteristic of innovation	Process Control End of pipe	Integrated in process, equipment and/or product	New products and services
Means of improvement	Optimisation (care)	Process and Product Improvement	Systems Innovation and Technology Renewal
Burden reduction potential	Factor 1.5 (30 %)	Factor 5 (80 %)	Factor 10-50 (90-98 %)
Driving forces	Compliance Cost reduction Risk reduction	Product performance Public image Shareholder value	Belief in long term developments and shared prospects
	Cleaner Production		Sustainable Technology

application of end-of-pipe, pollution-control technologies. The middle future track is concerned with process- or product-integrated technological improvement, innovation and reorganisation. Nonetheless, it is confined with improvement within the framework of existing infrastructures and technologies. The typical time-scale is five to twenty years. Medium term innovation can reduce environmental stress by delivering cleaner products, services and technologies. The third - far future - track is concerned with fundamental renewal of technologies and organisational arrangements. By breaking with past practice, it can deliver leaps in performance. Innovation for technology renewal involves redefining existing technology development trajectories and provoking new ones. The time scale is 20 years or more. In principle, renewal can deliver sustainable technologies; ones designed from the outset to be intrinsically compatible with eco-capacity constraints.

The near and middle term future technological trajectories are often combined under the umbrella of Cleaner Production³ and/or eco-efficiency. In many industry sectors in the developed world, Cleaner Production is apparently well on steam (e.g. Freeman, 1995; Van Berkel, 1996; DeSimone, 1997), although this certainly does not imply that it is already fully accepted and implemented by industry. Van Berkel et al (1997) explored whether or not Cleaner Production practices were currently incorporated in key industrial development trends, i.e. production optimisation; process innovation; and product innovation. It turned out that current Cleaner Production practices do not yet encompass all major industrial development trends. In general, current Cleaner Production practices prove to be powerful in production optimisation and in the final stages of product and process innovation. Paradoxically, although Cleaner Production is based on a preventive mind-set, it is still added on to the final stages of industrial development instead of being designed in right from the start. In other words, Cleaner Production is moving industrial development from the end-of-the-*production*-pipe to the end-of-the-*innovation* pipe, but it has not yet been integrated into the *innovation* cycle as required for sustainable development.

Usual innovation practice appears not to be capable of delivering technologies and business plans compatible with sustainability, and even the promotion of Cleaner Production appears runs the risk of ending up in incrementalism and short-termism (e.g. Cramer et al, 1990; Hirshorn, 1997; De Bruijn, et al, 2000). The limitations of usual innovation practices are due mostly to a preoccupation with existing technologies and with making incremental improvements to these. Incrementalism is deep-rooted in usual innovation processes, especially in defining aspects such as the specification of technological problems and challenges, the specification of search domains and the specification of the relevant actors to be included in the social networks searching for solutions (Weaver et al, 2000). Generally, specifications surrounding the innovation process are too restrictive and compartmentalised to enable path-breaking solutions to be identified, explored and implemented. Search tends to be confined to existing definitions of both problems and solutions and is carried out by members of existing networks of actors whose foundations are generally rooted in established technologies and whose interests are vested in them. In turn, this characteristic narrowing of definitions and domains owes partly to the nature of the external and internal incentives that innovators face. Financial criteria and short-termism⁴ dominate usual innovation practice and are institutionalised within enterprises, which are the chief custodians of R&D resources and play the leading role in technological innovation.

This however does not imply that path-breaking innovations are impossible; these do occur as a result of concerted efforts as developments in for instance biotechnology, information

³ Cleaner Production refers to the continuous application of integrated preventive environmental strategies to increase eco-efficiency and reduce risks to humans and the environment. It can be applied to products, services and processes (i.e. ANZECC, 1998).

⁴ Short-termism is related to a number of factors. One is the required payback period that is usually short. Another is related to risk reduction. Known technologies are intrinsically less risky than unknown technologies (Weaver et al, 2000).

technology and new materials applications proved over the last decennia. Developing and implementing sustainable technologies is thus not *a priori* impossible. However, this calls for a substantial effort - ‘*technology forcing*’ - to try to influence long-term research, technology development and innovation practices in the direction of sustainability. The social network theory and Constructive Technology Assessment provide starting points for ‘*technology forcing*’. Possible elements are for instance (Weaver et al, 2000; Cramer et al, 1990):

- Establishment of new cross sectoral social networks – shared problem definitions constituted on a ‘first principles’ basis (starting with a redefinition of the ‘*need*’ to be fulfilled) are potentially key elements in the creation of new innovation networks and new technological trajectories (see also Hirshorn, 1997).
- Use of challenging eco-efficiency targets – creativity can be stimulated by proposing challenging eco-efficiency targets and drastic discontinuity.
- Backcasting⁵ is a possible tool for establishing shared visions of desirable future system states and for securing a ‘systems’ perspective on the transition process. It can also help in defining feasible short-term actions that can lead to trend-breaking change.
- Sustainable technologies will need to meet multiple criteria pertaining to future acceptability and viability. Constructive Technology Assessment can offer opportunity for participatory development of sustainable technologies and improve the chances of securing co-evolutionary developments in technology, policies, markets, attitudes and behaviour.

An operational model for technology forcing has been developed and pilot tested in the Netherlands Sustainable Technology Development Program (see Box 2 for a program summary). The model has been applied between 1992 and 1998 on five areas of projected future need in 2040, respectively: nutrition; transport/mobility; buildings/urban spaces; services provided by water; and services provided by chemicals and materials. The results and experiences for the nutrition case study are focused upon in the following section, to illustrate the technology forcing process and the nature of the results and the range of possible implications for society.

Sustainable Technology Development: Experience from The Netherlands

The Sustainable Technology Development Research Program commenced with planning a scheme of activities conducive to technology forcing for environmental sustainability. This was largely based on combination of theoretical and practical insights. Next this scheme was used as guidance for undertaking the case studies. The generalised scheme has three main phases of activity (see Figure 2). The first phase is designed to develop a long-term vision based on a strategic review of how a ‘*need*’ might be met in the future. The second phase is designed to clarify the near-term actions that are needed to realise this future. The third and final phase is concerned with realising the action plan. Although the scheme might give the appearance of a linear working approach, in practice it is meant to be an iterative process at least within each of the three key stages.

⁵ Backcasting begins with an attempt to envision an acceptable future system state, which takes into account the status of as many important defining constraints and criteria as possible, including the requirement to meet ‘needs’. This system state is then used as reference: for tracing pathways back to the present, for placing milestones along those pathways and for identifying short-term challenges and obstacles that will have to be overcome en route.

Box 2: The Netherlands Sustainable Technology Development (STD) Program (STD, 1997a).

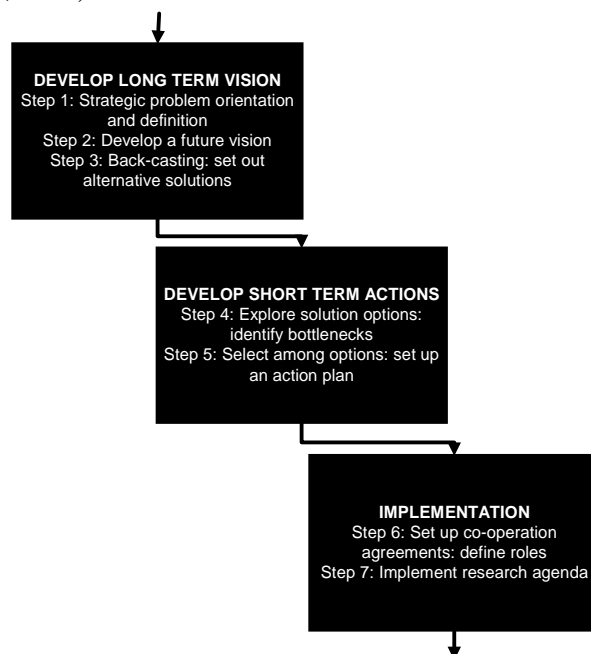
The Netherlands Interdepartmental Sustainable Technology Development Research Program was established to explore the prospects for integrating sustainability and technology policies. Its particular focus was on assessing whether and how sustainable technologies can be developed and implemented for achieving the long term eco-efficiency targets (for this program fixed as a factor 20 reduction in 50 years compared to 1990 baseline). The program aims were to:

- Develop, demonstrate and evaluate methodologies for influencing innovation processes in the direction of sustainable technologies.
- Initiate new technological trajectories related to key areas of need.
- Engage and involve stakeholders in innovation processes.
- Demonstrate that sustainable technologies are possible, in principle, if research, development and innovation processes are appropriately oriented and resourced,
- Disseminate and communicate program results, nationally and internationally, among innovators, policy makers, opinion leaders and partners in implementing sustainability.

The development of a methodology and establishment of a series of case studies were at the core of the research program. The five case studies conducted, along with illustrative, path breaking innovations these focused on, were:

1. Nutrition – with illustrations from novel protein foods, high-technology-closed-system horticulture; integral crop conversion, and mixed land use systems.
2. Transport/Mobility – with illustrations on urban underground freight transport; information technology for transport systems management; demand-responsive public transport and mobile hydrogen fuel cell.
3. Buildings and Urban Spaces – the illustrations in this case study targeted: sustainable public housing; sustainable offices; and urban restructuring.
4. Services provided by water – with a particular focus on differentiation in the municipal water chain.
5. Services provided by materials/chemical – the illustrations in this case study were: C1-chemistry; new chemical engineering approaches in fine chemistry; cascade use of biomass; structural materials from natural fibre composites.

Figure 2: The Sustainable Technology Development Schedule (STD, 1997a; Weaver et al, 2000).



In the case of nutrition⁶, the orientation analysis (step 1) commenced with a breakdown of current nutritional patterns, which in the case of the Netherlands showed that ten product categories constitute more than per cent of the total diet (i.e. meat, fish, sugar, potatoes, cereals, vegetables, fruit, oil and fats, dairy/cheese, drinks and other). Protein and fats tend to be over-represented in the current Dutch diet relative to the recommendations of major health organisations about the ideal dietary balance, whereas carbohydrates are under-represented. The current eco-capacity requirements associated with the production and consumption of each of the major food product groups were analysed and products were ranked according to their absolute and relative unsustainability. Environmental concern is particularly high for meat, dairy, glasshouse vegetables and potato production. The major unsustainabilities from meat production arise because of the intensive rearing of livestock, which leads to problems in disposing of animal wastes. The use and run-off of macronutrients in open-field agriculture is also an environmental problem, as is toxicity caused by the use of herbicides and pesticides. In addition, land use emerged as a crosscutting concern because it is implicated in all current food-producing activities. Although this might seem inevitable, this is related to current technologies for food production, which are mostly soil- and land-based. Finally, also consumer trends were analysed to complete the orientation analysis. There is a gradual shift away from carbohydrates, especially potatoes, largely caused by the diversification of eating habits and oriental influences. Moreover, the 'snacking' habit means that consumers eat more pre-cooked meals. This trend analysis suggests the need for reinterpretation of the environmental issues. Problems associated with potatoes will for example probably diminish owing to reductions in potato consumption.

The second step, development of a future vision, was largely organised around a multi-stakeholder scoping workshop, to which food producers, researchers, consumers and government agencies contributed. Major sources of environmental unsustainability in nutrition were identified, and ways depicted to address those. These possibilities were arranged around several broad themes:

- *Improved management and use of solar energy*: for example, to ensure that more light is fixed as biomass and that, in controlled production environments, such as glasshouses, systems are in place to even out the variation in solar energy supply.
- *Closed loop production*: for example, in open-land farming systems to ensure that wastes from plants are used as fodder for animals and wastes from animals are used to supply nutrients for plants, and in controlled environments to ensure that losses of pesticides and nutrients to the environment are minimised.
- *Reduced use of artificial inputs*: for example, by targeting nutrient, pesticide and herbicide application in relations to needs at the level of the individual plant and by genetically modifying plants so that nutrient, pesticide and other requirements (including for solar energy) are lower.
- *Better integration of agricultural activities into natural ecosystems*.
- *Better use of plant biomass so that less primary production is wasted*: for example, to reduce production of inedible materials, losses during storage and transport, and losses during animal conversion.
- *Better integration of demand and supply*: for example, to ensure that production takes place nearer consumption and is better matched to market demand.

⁶ The case study on nutrition has been summarised from STD 1997 b and Weaver et al, 2000.

- Development of *alternative or unconventional forms of foods* that can supplement or substitute for inefficiently produced conventional meat proteins: for example, protein products based on fermentation products or materials obtained from waste biomass.

The development of short-term action plans (Phase 2 in Figure 2) was organised around five innovation tracks toward radically more sustainable ways of meeting nutritional needs. These were:

1. *Sustainable multifunctional land use*. A multifunctional form of land use would aim at integrating several different forms of economic exploitation at the level of each land-holding enterprise. These could include crop and livestock provision, timber and biomass production, energy production, water management, provision of leisure and recreational opportunities, habitat and landscape protection, wildlife and biodiversity protection, etc.. This requires a switch to decision-making at the level of a natural ecosystem (such as catchment area), greater integration of decision-making and activities among constituent farms and enterprises within the ecosystem and more ecologically based criteria for designing systems of economic exploitation.
2. *High-technology closed-cycle horticulture*. The aim would be to enhance the benefits of existing glasshouse cultivation (not soil bound, production in close vicinity of consumer markets and efficient control over growth cycles), while reducing the disbenefits (in particular the energy consumption, and reliance on pesticides). The key is to use the available solar energy more efficiently, which involves: evening out diurnal and seasonal peaks and troughs in solar energy supply so that plant growth can occur evenly and continuously irrespective of the time of the day or season of the year; and increasing the utilisation rate of solar energy by plants, e.g. by converting a larger share of solar energy into wavelengths that plants can use for photosynthesis. Cycling water and nutrients can further enhance the environmental benefits.
3. *Integrated crop/biomass conversion*. The concept of integral conversion of plants and biomass is that of complete extraction of all useful ingredients contained within the molecular structures of plants formed during photosynthesis. The technological challenge is partly to increase the fraction and quality of useful molecular structure contained within the plant and partly to improve the separability of high-value components of the plant biomass from other material residues that might go on to be valorised in non-nutritional application fields, such as industrial materials or power generation.
4. *Novel protein foods*. Opportunities exist to develop a wide range of novel protein foods based on plant and non-plant proteins, such as genetically modified peas, beans, lupines, Lucerne and bacteria and combinations of those that have so far not been exploited. More than 50 promising sources of materials are already known. Many of these enable protein to be produced with factor 20 to factor 30 improvements in resource productivity and at substantially lower economic cost.
5. *Sensor technology*. A crosscutting technological need is for better information about growing conditions at the level of the individual plant. Real-time information on the status of both the plant and its surrounding environment is needed to minimise waste and reduce all forms of intervention in the plant growth cycle.

The leading R&D needs on each of these innovation tracks are summarised in Table 3. Environmental assessments have been conducted for key innovations on each track to assess whether or not the targeted Factor 20 reduction would appear feasible with the innovations identified. Examples of these environmental assessments are illustrated in Figure 3, for integral biomass conversion and high technology controlled closed cycle horticulture. In the case of pasta and cheese, unconventional production routes based on integral conversion from

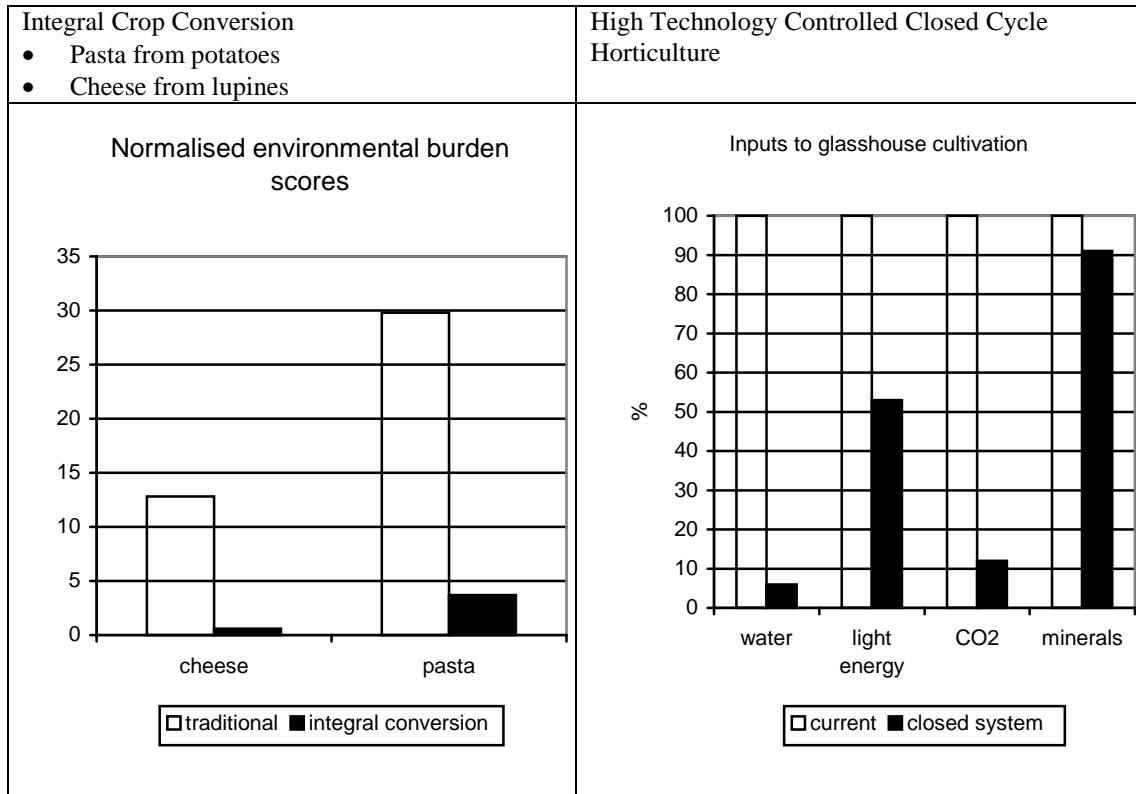
respectively potato waste and lupines, have the potential for factor improvements in the range between 8 and 21. For closed cycle horticulture, the improvement factors differ sharply per environmental impact category, with higher values for water conservation (factor 18) and CO₂ emission reduction (factor 8) and lower values for light energy (factor 2) and minerals consumption (factor 1.1). Each innovation track has been further elaborated into distinct action plans, and alliances are being negotiated between research institutions, agriculture, government and supply and processing industries to progress those action plans.

Table 3: Leading R&D needs for sustainable innovations for meeting nutritional needs in The Netherlands (modified from STD, 1997b and Weaver et al, 2000).

Innovation Tracks	Leading R&D Needs
1. Sustainable Multi Functional Land Use	<ul style="list-style-type: none"> • Consequences for agriculture of having higher water tables. • Rotation systems for enabling a wider variety of useful plant species to be grown, including energy and material crops in addition to food crops. • Technologies for capturing and transforming solar, wind and water energy, and use of groundwater for energy storage. • Technologies for enhancing efficiencies of material and energy recovery.
2. High Technology Controlled Cycle Horticulture	<p>Technological breakthroughs are needed in respect to:</p> <ul style="list-style-type: none"> • Plant physiology • Conversion of light to electricity • Transport of sunlight • Storage of energy • Conversion of energy • Process steering and management
3. Integral Crop/Biomass Conversion	<p>Calls for co-ordinated programme to develop plant varieties and related conversion technologies, including the physical equipment (such as bio-refineries), supporting materials (such as bio-catalysts) and logistics systems aimed at valorising biomass waste in situ through complete and integral crop conversions.</p>
4. Novel Protein Foods	<p>Major bottlenecks are social, cultural and economic, rather than technological. Communications and stakeholder involvement are especially important in building an acceptable palette of technological options and a platform of support for progressing these toward implementation.</p>
5. Sensor Technologies	<ul style="list-style-type: none"> • Electrical sensors, bio-sensors, optical chemical sensors and microanalysis systems for obtaining information on chemical composition of soils, manure, water and biomass, and the presence of specific compounds. • High energetic and nuclear techniques, spectroscopy, dielectric, radar and ultrasound techniques for measuring plant and animal conditions. • Light sensors, optical and electronic gas sensors for monitoring local microclimate, CO₂ concentrations and light conditions. • Remote sensing and imaging for information on precise position, form and structure of plants in relation to their surrounding environment.

The case on nutrition in the Netherlands Sustainable Technology Development Program exemplifies the significant outcomes from concerted technology-forcing initiatives. These include one or more strategic visions of a sustainable future, a set of alternative innovation trajectories, a set of near future challenges, networks of innovators interested in pursuing the required R&D and platforms of support for promising ideas from stakeholders. The work clearly demonstrates that although sustainability may depend on breakthroughs to overcome

Figure 3: Potential environmental improvements from sustainable ways for meeting nutritional needs in The Netherlands (adapted from STD, 1997 b and Weaver et al, 2000).



key technological bottlenecks, no single technological breakthrough in its own right will prove decisive. Clusters of related technological breakthroughs that operate synergistically to support entirely new ways of meeting needs are likely to be needed in most cases. These technology clusters will, in their turn, depend for their effectiveness and acceptability on a related set of structural and cultural innovations. There is little point in producing foods in artificial settings from unusual ingredients or from genetically modified plants unless these are acceptable to consumers.

Concluding Remarks

The sustainable development paradigm is changing the way society can produce and consume. The keys to sustainable development are that environmental, social and environmental objectives are being integrated, rather than balanced, the earth's carrying capacity is being respected and access to resources is being equally divided among and within generations. This will also require better and more transparent governance systems and structures both in the public and private sectors.

The current lifestyle of an average Australian appropriates already at least three times as much as the global average of the areas of ecologically productive land, and almost five times her/his fair earth's share. And this ecological footprint is under continuous upward pressure, reflecting the desire to grow by producing and consuming more material wealth. Strictly from an environmental point of view, sustainability is likely to require factor improvements in the range between 10 and 50, reflecting reductions in average resource consumption and wastage by 90 to 98 %, by the mid of this century. Technology innovation should play a prominent role in achieving those factor improvements. The near and middle term future technological innovations, in particular Cleaner Production technologies and practices, are considered

capable of delivering up to factor 5 improvements, through incremental changes in existing products, services and processes. Current innovation practice however appears not to be capable of delivering path-breaking innovations that offer prospect for factor 10 to 50 improvements. Preliminary evidence from technology forcing initiatives indicates however that path-breaking innovations are possible and that it is plausible that these can deliver the factor 10-50 improvements necessary for truly sustainable technologies.

The quest for more sustainable development influences the scope within which Australia's future can develop. Ignoring the sustainable development imperatives will sooner or later turn out to be a collision course as environmental disasters, such as for instance changes in global climate system, shrinking supplies of fresh and clean air and water or major industrial accidents, will necessitate expensive mid course correction and environmental restoration (e.g. WBCSD, 1997). Risks and costs to the society as a whole are certainly better managed by taking a proactive approach and creating better conditions to force technology innovation in the direction of sustainable development. The time has arrived that also Australia invests in such technology forcing initiatives in particular for key sectors in Australian economy and society (such as minerals and energy production, agriculture and transportation).

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