Pathways to Sustainability: Evolution or Revolution?*

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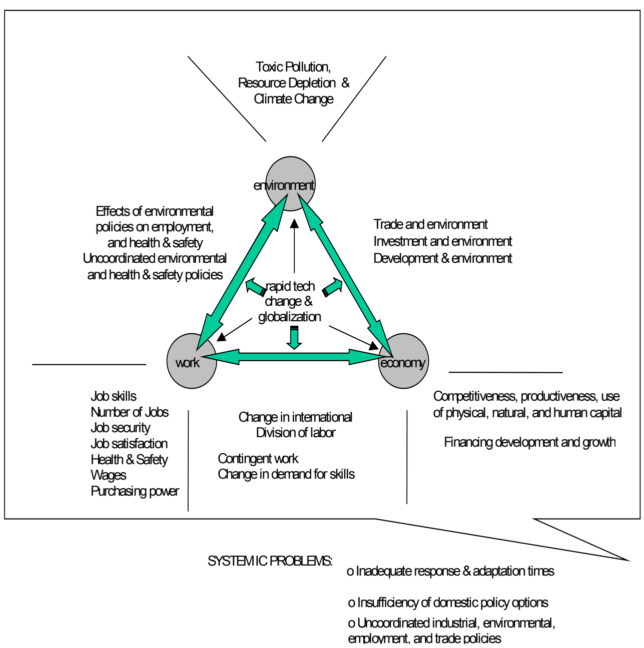
Introduction

The purposes of this chapter is to delve more deeply into the *processes and determinants* of technological, organisational, and social innovation and to discuss their implications for selecting *instruments and policies* to stimulate the *kinds* of innovation necessary for the transformation of industrial societies into sustainable ones. Sustainable development must be seen as a broad concept, incorporating concerns for the economy, the environment, and employment. All three are driven/affected by both technological innovation [Schumpeter, 1939] and globalised trade [Ekins et al., 1994; Diwan et al., 1997]. They are also in a fragile balance, are inter-related, and need to be addressed together in a coherent and mutually reinforcing way [Ashford, 2001]. Here we will argue for the attainment of 'triple sustainability' – improvements in competitiveness (or productiveness) and long-term dynamic efficiency, social cohesion (work/employment), and environment (including resource productivity, environmental pollution, and climate disruption)[1]. The figure below depicts the salient features and determinates of sustainability. They are, in turn, influenced by both public and private-sector initiatives and policies.



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[1] Elsewhere (Ashford et al., 1985), the author has coined the term "co-optimisation" to describe the simultaneous achievement of a number of societal goals, rather than trading one off for another. In popular parlance, this is known as a "win-win" or multi-dividend strategy.

This chapter also challenges certain tenets of the theories of reflexive law [Teubner, 1983] and ecological modernization [Mol, 1995][2]. While far-sighted prevention-oriented and structural changes are needed, some proponents of these theories argue that the very industries and firms that create environmental problems can, through continuous institutional learning; the application of life cycle analysis; dialogue and networks with suppliers, customers, environmentalists, and workers; and the commitment to implement 'environmental management systems,' be transformed into sustainable industries and firms. It will be argued here that while useful, these reforms are insufficient. It is not marginal or incremental changes that are needed for sustainability, but rather major product, process, and system transformations – often beyond the capacity of the dominant industries and firms.

The Importance of Innovation

In this chapter, we distinguish technological, organisational, and social innovation, although these distinctions may not always be very sharp [Rennings, 1998]. They are, in any event, related to one another and are necessary for transformations of the industrial state to a sustainable one.

Technological Innovation

Technological change is a general -- and imprecise -- term that encompasses invention, innovation, diffusion, and technology transfer. *Technological innovation* is the first commercially successful application of a new technical idea. It should be distinguished from *invention,* which is the development of a new technical idea, and from *diffusion*, which is the subsequent widespread adoption of an innovation beyond those who developed it[3]. Sometimes the innovation is embodied in hardware, devices, inputs/materials, and process technology. Sometimes it is embodied in the skills of labour and/or the organisation of production and work, and sometimes in all these factors.

Innovation can be driven by scientific discovery (an invention) searching for application (technology push innovation) or by a market need or opportunity (market pull innovation). Both are important [Pavitt, 1984]. However, the evolution from discovery (invention) to innovation to diffusion is not a linear process, but is a complex, dynamic, interactive, iterative one involving many factors and actors[4]. In 1989, Mowery and Rosenberg wrote:

> [M]any of the primary sources of innovation are located "downstream" without any initial dependence on or stimulus from frontier scientific research. These sources involve the perception of new possibilities or options for efficiency improvements that originate with working participants of all sorts at, or adjacent to, the factory level. The participants include professional staff such as engineers and those who have responsibilities for new

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[2] See Ashford, 2002b.

[3] The distinction between innovation and diffusion is sometimes hard to draw, however, because innovations can rarely be adopted by new users without some modification. When modifications are extensive, i.e., when adoption requires significant *adaptation*, the result may be a new innovation.

[4] For an extensive discussion of the dynamics of the innovation process, see "Chapter 1: Technological Innovation: Some Definitions and Building Blocks" in OECD, 1992, pp. 24-29. Also see Mowery and Rosenberg, 1989.

> product design or product improvement, and may include customers as well…
>
> The process of technological innovation has to be conceived of as an ongoing search activity that is shaped and structured not only by economic forces that reflect cost considerations and resource endowments but also by the present state of technological knowledge, and by consumer demand for different categories of products and services [Mowery and Rosenberg, 1989, p 8].

The implication of this dynamism is that there may be a variety of instruments and policies that need to be implemented to influence technological innovation in a particular direction. In particular, more than supporting R&D or creating markets is required. (See the discussion below.)

Like the term technological change, the term *technology transfer* is also somewhat imprecise, sometimes referring to the diffusion of technology from government to industry, or from one industry or country to another. Sometimes government transfers a technology (from national laboratories or research centers, for example) that is not much more developed than the invention stage, in which case the transfer to industry can actually result in innovation.

A technological innovation can be characterised by its *type*, by its *significance*, or by its *motivating force*. Technological innovation can be process-oriented or product-oriented[5]. It can be modest and incremental, or radical and revolutionary in nature[6]. Technological innovation can be the result of an industry's main business activities or can evolve from the industry's efforts to comply with or respond to health, safety, or environmental regulations and pressures

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[5] In acknowledging the importance of technological innovation to both environment and to employment in hopes of attaining triple sustainability, it may be useful to consider the *differential* effects that product versus process innovation may have on environment and employment. Cleff and Rennings (1999) argue that the benefits of *product* innovation may be more readily recognised and therefore pursued by industrial firms. It has been suggested that product innovations for new markets can result in new net employment, partly because of their greater reliance on demand-pull forces (Matzner et al., 1990; Brouwer and Kleinknecht, 1996), but that this is not true for all product innovations (Charles and Lehner, 1998). This, of course, does not justify neglecting policies that promote process change. In fact, product innovation that is more closely linked to process innovation and in which there is more reliance on a learning-based mode than on a scientific breakthrough, is argued to be more employment creating (Charles and Lehner, 1998).

In the context of environmental dividends, Cleff and Rennings (1999) argue that *environmentally friendly* products are more likely to emerge from market demands and consequently be pursed by firms, than technology pushed by regulation. However, see the later discussion of regulation and innovation which emphasises the very important fact that environmental degradation traceable to inputs or process technology is not necessarily amenable to solution by a focus on so-called environmentally friendly products.

[6] Christensen (1997), in a provocative book entitled, <u>The Innovator's Dilemma: Why New Technologies Cause Great Firms to Fail</u>, argues that a *product* innovation can also be classified either as 'sustaining' [not to be confused with sustainable] or as 'disrupting'. This dichotomy is independent of the incremental versus radical distinction for innovation, because it is based on 'value networks' (networks of customers with well-defined demands) that reflect whether or not changes in product attributes that require innovation are demanded.

[Ashford et al., 1979]. Regulation, market signals, and anticipated worker or consumer demand can affect any of the characteristics of innovation.

Finally, distinguishing between different kinds of technological change is essential for policy design, since the determinants and consequences of each -- and the incentives for, and barriers to, the success of each are different.

Organisational Innovation

Often, the term *organisational innovation* is used to refer to larger organisational features of the firm, beyond the organisational features of a specific product line, and is concerned with changes in and among various organisational aspects of *functions* of the firm such as R&D/product development, marketing, environmental and governmental affairs, industrial relations, worker health and safety, and customer and community relations. Discussions of 'innovation networks' focus on the importance of mutual learning among the members of the 'production chain' and have spawned a whole new area of attention to product change management [Georg et al., 1992]. It has recently been increasingly argued that organisational innovation within the firm, rather than technological innovation *per se*, is the area most in need of exploitation, especially in Europe [Coriat et al., 1995][7]. Certainly, changes in management attitudes, capabilities, and incentives are important determinants of the ability of the firm to change, and the idea of networks -- involving actors inside and outside the company -- is important. The firm participates in perhaps several networks in which mutual learning occurs involving suppliers, consultants, trade associations, geographically-close industries, consumers, workers, government, and others [Ashford and Meima, 1994]. The counterpart of organisational innovation in government – what might be called institutional innovation – is also a crucial and needed factor.

Social Innovation

In this chapter, *social innovation* is defined to mean both changes in the *preferences* of consumers, citizens, and workers for the types of products, services, environmental quality, leisure activities, and work they want – and changes in the *processes* by which they influence those changes. Social innovation can alter both the demand for and the supply of what the industrial state might offer. Obviously social innovation should not be confused with the term 'social engineering', since the former rests on information, education, communication, and enlightened self-interest, rather than values and conditioning imposed from outside the individual. A valid interface between social and organisational/institutional innovation is the increasingly important role of both labour and public participation in both private-sector and governmental decisions.

We treat the acquisition of employment skills as a supply-side concern, and thus arguably within the ambit of *technological* innovation, since physical capital, labour, and knowledge are currently considered the most important factors in production and service. Labour skills and know-how can have a profound impact on the innovativeness of the firm and a particular industrial sector[8]. However, while there are great promises for the so-called "knowledge-based

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[7] The type of organisational innovations that is needed for sustaining innovations may be different than those for disrupting innovations (see later discussion).

[8] See "Chapter 7: Human Resources and New Technologies in the Production System" in OECD 1992, pp. 149-166. See also OECD, 1996.

economy" and there are certain sectors and firms for which high returns might be expected for investment in worker education and training, it is not at all clear that unfocused and large programs will be any more successful than a large increase of financial or physical capital across the board. More targeted policies may be needed[9]. Finally, note that changing the capabilities and skills of workers will also alter their *demands* from the market both because it changes what workers may want and because it may augment the purchasing power of workers.

Commentary

The distinction between incremental and radical innovations – be they technological, organisational, institutional, or social – is not simply line drawing along points on a continuum. Incremental innovation generally involves continuous improvements, while radical innovations are discontinuous [Freeman, 1992], possibly involving displacement of dominant firms and institutions, rather than evolutionary transformations [Ashford, 1994][10]. [Christensen (1997) distinguishes the former as 'sustaining innovation' and uses the term 'disrupting innovation' rather than radical innovation, arguing that both sustaining and disrupting innovations can be either incremental or radical]. In contrast, Kemp (1994 and 1997) argues that 'technological regime shifts' brought about by 'strategic niche management' can result in radical [i.e., disrupting] innovation through a stepwise evolution in learning and experimentation by dominant firms. It is argued there that more radical, rather than incremental innovation, is needed to achieve Factor 10 (or better) improvements in both resource productivity and pollution reduction [Schmidt-Bleek, 1998]. Similarly, radical interventions in employment policy may be needed to offset increasing unemployment (e.g., in some European countries) and underemployment in the United States. This may require instruments, policies, and targets that are very different than those to foster incremental improvements.

Further, a preoccupation with product and process innovation, to the neglect of organisational and social innovation, may short-change the potential for advancing triple sustainability. The benefits of organisational innovation seem to be under-appreciated [Andreasen et al., 1995] and organisational changes that ignore the potential benefits of anthropogenic or human-centered production may not achieve their intended results. For example, a focus on limited organisational change -- for example in the concept of 'lean production' emphasising the organisation and selective automation of tasks – maximises the technological and minimises the human aspects of production, especially the extent to which problem-solving is actually a significant part of the worker's involvement[11], and repetitive, stressful work and burnout continues to prevail [Jürgens, 1995].

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[9] Work and the workplace are essential elements of industrial and industrialising economies. Work is combined with physical and natural capital to produce goods and services. The workplace is the place where the comparative advantages of workers and owners/managers create a market for exchange of talents and assets. Beyond markets, work provides both a means of engagement of people in the society, and an important social environment and mechanism for enhancing self-esteem. Finally, work is the main means of distributing wealth and generating purchasing power in dynamic national economic systems.

[10] Christensen (1997) would use the term 'disrupting innovation' rather than radical innovation, arguing that both sustaining and disrupting innovations can be either incremental or radical. See the discussion below.

[11] See Charles and Lehner (1995) for a discussion of lean production and why it imposes considerable limitations on a company's propensity to innovate.

Finally, a simplistic call for more worker training to upgrade skills, without corresponding changes in both technological and organisation innovation, may not be particularly helpful [Reich, 1991]. Not all firms and sectors are in a position to utilise these skills.

It should be obvious that all three kinds of innovation need to receive attention in a coordinated fashion in the design of policies to promote triple sustainability. Moreover, there is an increasing belief that 'new growth theory', asserting that it is the *combination* of technological, organisational and social factors, more adequately explains growth (and the Solow residual), rather than R&D, capital, or human investment alone,[12] because greater investment in both physical and human capital may create positive externalities and aggregate economies-of-scale effects, rather than simply augment the productivity of labour. Further, it is alleged to lead to more rapid diffusion and adoption of new production methods and techniques.

In 1992, the OECD was cautious about the conclusiveness of the evidence for new growth theory (OECD 1992, Chapter 8). By 1996, the OECD was enthusiastic about on the importance and revolutionary promise of the 'knowledge-based economy', arguing that, unlike capital investment, the rates of return to investment in education and training seem to increase over time and further, that industrial networks facilitate the ability of firms to share and combine elements of know-how to even greater advantage [OECD 1996]. Thus, through the lens of the 'knowledge-based' work, the importance of 'networks' took on new significance and seemed to provide support for new growth theory. These networks promote inter-firm interactive learning and are regarded as important components of 'national innovation systems' (also see the discussion below). Whether 'knowledge networks' are important across the board, or are useful in a narrower context is an important question to be answered.

The Importance of Globalisation

The globalising economy presents new challenges and opportunities for both technology and work in industrialised and industrialising countries. 'Globalisation' has at least three distinct meanings [Gordon, 1995], with different implications for production, workers and working life. 'Internationalisation' is the expansion of product/service markets abroad, facilitated by information and communication technology (ICT) and e-commerce, with the locus of production remaining within the parent country. Both developed and developing countries engage in this type of globalisation, but the nature of the exports may differ as to raw materials and semi-finished goods. 'Multi-nationalisation' is where a (multi-national) company establishes production/service facilities abroad, to be nearer to foreign markets and/or to take advantage of more industry-friendly labour, environmental, and tax policies, while maintaining research-and-development (R&D) and innovation-centered activities in the parent country. The third meaning is the creation of strategic alliances, what some call 'transnationalisation,' in which two different foreign enterprises merge/share their R&D and other capabilities to create a new entity or product line. Those concerned with enhancing trade are especially worried about barriers to internationalisation, while those concerned with possible erosion of labour/environmental standards bemoan the consequences of multinationalisation. Transnationalisation may lead to industrial restructuring with unpredictable consequences for national economies. All three kinds of globalisation raise questions of excessive market power, and hence political power, where concerns for profits overwhelm democratic and ethical values.

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[12] See the discussion of new growth theory in "Chapter 8: Technology and Economic Growth" in OECD, 1992, pp. 167-174. Also see Baldwin. 1989; Easterly and Wetzel, 1989; Grossman and Helpman, 1994; Lucas, 1988; Scott 1989; and Romer 1987, 1989, and 1994.

Globalisation raises new challenges for governance, especially vis-à-vis the roles of government, workers, and citizens in the new economic order. Within nation-states, the extent to which the 'externalities' of production – adverse health, safety, and environmental effects – are internalised differ according to the differential success of regulation/compensation regimes and the extent to which economies incorporate the ethics of fair play in their practices. There has been a constant struggle to establish good labour and environmental standards/practices within nations. With the advent of globalised, competition-driven markets, attention has now shifted to the harmonisation of standards through ILO conventions and multi-lateral environmental agreements, with only a modicum of success. Countries are slow to give up national autonomy, and only where there is a trend toward significant economic integration (as in the EU) are there successes at harmonisation. But globalisation has brought an even more complex set of challenges through the creation of trade regimes – such as the WTO, ASEAN, and NAFTA – where the term 'fair trade' means the elimination (or equalisation) of tariffs and so-called non-tariff trade barriers, which place labour and environmental standards at odds with trade objectives.

The trade regimes promote international laissez faire commerce; and rights-based law/protections and market economics have become competing paradigms for public policy and governance. Government plays very different roles when is acts as a facilitator or arbitrator to resolve competing interests, than when it acts as a trustee of worker and citizen interests to ensure a fair outcome of industrial transformations [Ashford, 2002]. The differences are pronounced when stakeholders have largely disparate power – or when some are not represented in the political process, as in the case of emerging or new technology-based firms.

Technological innovation and trade drive national economies in different ways [Charles and Lehner, 1998]. The former exploits a nation's innovative potential, the latter its excess production capacity. Innovation-based performance is enhanced by technological innovation and changing product markets, characterised by fluid, competitive production. Cost-reduction strategies are enhanced by increased scales of production and/or automation, usually characterised by rigid, mature monopolistic production. Economies seeking to exploit new international markets may enjoy short-term benefits from revenues gained as a result of production using existing excess capacity, but they may ultimately find themselves behind the technological curve. Performance-driven markets may be slower to gain profits, but may outlast markets driven by cost-reduction strategies. The consequences for workers may differ as well.

Increasing labour productivity, defined as output per unit of labour input, is a concern in nations pursuing either strategy. But labour productivity can be improved in different ways: (1) by utilizing better tools, hardware, software, and manufacturing systems, (2) by increasing workers' skills, and (3) by a better matching of labour with physical/natural capital and with information and communication technologies (ICT). Theoretically, increasing worker productivity lowers the costs of goods and services, thereby lowering prices -- and ultimately increasing the demand and sale of goods and services. Depending on the markets, more workers may be subsequently hired, than displaced as a consequence of needing fewer worker to produce a given quantity of goods and services. This optimistic scenario assumes a continual throughput society with increasing consumption. However, the drive toward increased consumption may have dire consequences for the environment [Daly, 1991]. In addition, questions arise as to whether, in practice, (1) labour is valued, and paid, more or less after productivity improvements, (2) there are positive or negative effects on job tenure and security, and (3) more workers are hired than displaced. The answers depend on the sources of the increases in worker productivity and the basis of a nation's competitiveness.

Innovation-based performance competitiveness presents opportunities for skill enhancement and building optimal human-technology interfaces, while cost-reduction strategies focus on lean production (with worker displacement), flexible labour markets, and knowledge increasingly embodied in hardware and software rather than in human capital. The consequences for workers are different for these two strategies. The former strategy rewards and encourages skill acquisition for many, with appropriate financial benefits for those workers. The latter creates a division between workers, some of whom are necessarily upskilled and many whose job content is reduced. Different national strategies might be pursued, reflecting different domestic preferences and culture, but there are further implications, depending on the extent to which trade drives the economy. Interestingly, the US is globalising and focusing on expanding markets abroad, while the EU is selling a smaller amount and percentage of goods and services outside its borders, focusing instead on integrating its internal markets in which its various members compete on performance. In the US, wage disparities are large and increasing, while in some parts of the EU – notably the Netherlands – wage disparities are much smaller and decreasing.

The changing global economy, however, presents challenges for all nations as concerns for the number of jobs, job security, wages, and occupational health and safety increase. In the private sector, labour needs a role in choosing and implementing information-based technologies; in the public sector there is a need for integrating industrial development policies with those of employment, occupational health and safety, and environment.

At the core of justice in the globalised economy is the right of working people and citizens to benefit from industrial transformations. The ultimate governance challenge is to achieve a fair division of the fruits of the industrial or industrializing state -- and a safe and healthful environment and workplace. This translates into environmental sustainability, but also sufficient job opportunities, job security, and purchasing power, as well as rewarding, meaningful, and safe employment. This can not be left to chance or serendipitous job creation. In formulating policies for *environmental* sustainability, economic growth and environmental quality are simultaneously optimised, rather than having environmental interventions occur after harmful technologies are in place. Instead, we seek to design and implement cleaner and inherently safer production. Employment concerns deserves no less a place in center stage; growth, environment *and* employment must be co-optimised. Systemic changes must be pursued and selected that intentionally benefit employment. Even with better prospects for employment, in an industrial system that continues to replace labour with physical capital, increasing worker capital ownership and access to credit [Ashford, 1998] that turns workers into owners may be an additional necessary long-term option if disparities of wealth and income prevail.

New Technology and Sustainability

Historically, advances in technology (1) were often concentrated in specific sectors, for example the use of fertilisers and pesticides in agriculture, or mass production in manufacturing, and (2) were sometimes deployed in many sectors, such as the harnessing of steam power, or the development of new materials such as plastics and ceramics. In the post-war years, there seemed no end to technological advancements, along with the jobs that they created. However in the 1970's, the overall rate of growth began to slow down and continued to slow down in the subsequent two decades. In the 90's, industries associated with the so-called knowledge-based economy began to grow and were responsible for an increasingly large share of employment growth[13].

It is argued that knowledge-based, information and communication technologies (ICT) have the potential to transform virtually every facet of production and consumption [OECD, 1996]. The microchip has doubled its information-processing capacity every 18 months [Mazurek, 1998] and other dramatic changes occur with unprecedented speed. Beyond ICT technologies *per se*, it is argued that a 'knowledge-based' economy allows smarter production, products, and ways of working and doing -- and further, allows new ways of integrating heretofore segregated human activities. According to this view, knowledge-driven innovation will be the next engine of economic growth [Castells, 1996; OECD, 1996].

A somewhat contrarian view has recently been expressed by Drucker (1999). He argues that new technologies will indeed emerge, but they will have little to do with the 'knowledge-based economy'. He muses that e-commerce (electronic commerce), which will change the *mental* geography of commerce, will have the more profound effect by eliminating distance; there will be "only one economy and only one market." Competition will know no boundaries, but the products and sectors that are affected will be eclectic and unexpected. "New distribution channels [will] change not only how customers behave, but also what they buy." And more to the point:

> The one thing…that is highly probable, if not nearly certain, is that the next twenty years will see the emergence of a number of new industries. At the same time, it is nearly certain that few of them will come out of information technology, the computer, data processing, or the Internet." [Drucker, 1999, page 54]

Drucker draws on both historical precedent for his predictions and on the observation that biotechnology and fish farming are already here. He opines that probably about a dozen technologies are now at the stage that biotechnology was 25 years ago. He reminds us that "the new industries that emerged after the railroad owed little technologically to the steam engine or to the Industrial Revolution in general," and that they were the product of a mindset that eagerly welcomed invention and innovation. Finally, he observes that

> "software is the reorganization of traditional work, based on centuries of experience, through the application of knowledge and especially of systematic , logical analysis. The key is not electronics; it is cognitive science. This means that the key to maintaining leadership in the economy and the technology that are about to emerge is likely to be the social position of knowledge professionals and social acceptance of their values." [Drucker, 1999, page 57][14]

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[13] This must be viewed in proper perspective. Employment growth associated with gearing up to the "information age" is a *transitional* phenomenon. It says little about the expected level of employment at equilibrium, when things level off – if they do. Relatedly, the earlier exuberance of the U.S. stock market performance is now being viewed more cautiously in light of the fact that most mutual fund stocks have decreased in value, with the market no longer being buoyed up by the high technology, computer-related investments.

[14] Drucker is not focused on innovation in ICT, but rather those innovations necessary for other new technologies to emerge. Since, according to his thesis, it is not generally known what these technologies will be, it is a reminder that investment in deliberate, applied areas for development could short-change the future.

Drucker also argues that this may require a radical change in the position of knowledge workers vis-à-vis their rewards and autonomy – and in industrial relations and labour policies.

Like ICT, biotechnology -- which, of course, is not a single technology -- has the potential for transforming agriculture, chemicals, pharmaceuticals, heath care, environmental cleanup, energy production, and even human reproduction itself [Krimsky, 1982]. New production methods and sources of food, chemicals, pharmaceuticals, and health care products are under development. Repair of undesirable genetic characteristics related to disease, the slowing of aging processes, the restoration of sight and hearing, and human reproduction are already the focus of research activity. The transformation of unwanted byproducts of industrial production and waste, and creation of new sources of energy are already under development. Although many developments in biotechnologies have not advanced to the same extent as ICT, a revolution is in the making. In a way, biotechnology, too, should be seen as an important part of the expansion of a knowledge-based society -- since it is based on molecular biology rather than traditional chemistry -- although this is not what is traditionally meant by the term. In addition, initiatives such as the mapping of the human genome would not be possible without the prior revolution in information technologies.

New materials and 'nanotechnologies' are also already the focus of new research, and the interface between materials research and the life sciences has taken on renewed attention. These are some of the new technologies meeting the expectations of Drucker.

As industrial societies mature, the nature and patterns of innovation changes [Abernathy and Clark, 1985; Utterback, 1987]. New technologies become old technologies. Many product lines (e.g., washing machines or lead batteries) become increasingly rigid, and innovation, if there is any, becomes more difficult and incremental rather than radical. In these product lines/sectors, changes are focused on cost-reducing production methods -- including increasing the scale of production, displacing labour with technology, and exercising more control over workers -- rather than on significant changes in products. Gradually, process innovation also declines. A useful concept related to individual product lines is that of 'technological regimes', which are defined by certain boundaries for technological progress and by directions or trajectories in which progress is possible and worth doing [Nelson and Winter, 1977].

Sometimes, the dominant technologies (such as the vacuum tube and mechanical calculator) are challenged and rather abruptly displaced by significant radical innovations (such as the transistor and electronic calculator), but this is relatively rare, although very important [Christensen, 1997; Kemp, 1994]. As industrial economies mature, innovation in many sectors may become more and more difficult and incremental, regulatory and governmental policies are increasingly influenced, if not captured, by the purveyors of the dominant technology [regime] which becomes more resistant to change. However, occasionally, traditional sectors can revitalise themselves, such as in the case of cotton textiles.

Other sectors, notably those based on emerging technologies, may experience increased innovation. The overall economic health and employment potential of a nation as a whole is the sum of these diverging trends, and is increasingly a function of international trade (see the discussion below). Whether nations seek to increase revenues based on competition in technological performance or alternatively on cost-driven strategies can have an enormous impact on employment [Charles and Lehner, 1998].

As will be discussed below, health, safety, and environmental regulation, structured appropriately, as well as new societal demands can also stimulate significant technological changes that might not otherwise have occurred at the time [Ashford et al., 1985]. Within countries, we speak of 'national innovation systems' to denote the institutions, actors, and practices which influence innovation in general [Nelson and Rosenberg, 1993; Nelson 1996]. These include not only support for R&D; the training and education of scientists, engineers, entrepreneurs, and managers of technology; tax treatment of investment; regulations; and support of exports, but also networks involving trade associations, suppliers and other firms, customers, and workers. In the context of new growth theory, these networks are said to effectively compound accumulated knowledge and provide new energy for both growth and employment. To the extent that innovation in the firm involves the increased participation of workers, and those responsible for innovation see workers as more than factors of production, worker know-how and creativity may yield unexpected benefits[15].

In addition to forces acting directly on the capacity to of a localised firm to innovate, an increasingly important additional driving force for growth is the globalisation of production and finance[16], which creates pressures, changes, and opportunities different from, and sometimes in contrary directions to, those created by technological innovation alone [Charles and Lehner, 1998; Costanza et al., 1991; Gordon, 1995; OECD 1997]. In 1989, Mowery and Rosenberg argued that research and development, or more broadly, the accumulations of knowledge underlying technological innovation, appear increasingly to issue from global networks of enterprises and associated institutions. This observation, echoing an increasing globalisation of commerce coincides with, but is not identical with the beginnings of the ICT explosion. Gordon, building on the optimism of Castells (1996), argues that globalisation[17] enhanced by ICT "provides a basis for new forms of world-wide interaction and control, and liberates organizational structure from spatial constraints." His view of modern innovation is that it:

> tends to be neither radical exogenous invention (as in the linear model) not narrowly path-dependent incremental change (as in the evolutionary model). Far more frequently, innovation tends to occur in the unilluminated space between these options: that is, while proceeding substantially within existing frameworks of knowledge and practice rather than initiating or requiring breakthroughs in science and technology, innovation nonetheless commonly tends to push at the margins of established organizational, technical, and economic practice as opposed cooperating within a more restricted field of "normal problem-solving routines." [Gordon, 1995, pp. 180-181.]

Globalisation of production (multinationalisation) inevitably leads to a globalisation of the labour market, which in combination with a shift to a knowledge-based economy, raises concerns for wage fluctuations and employment [Freeman and Soete, 1994; OECD, 1996 and 1998].

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[15] For examples of workers assisting their firms in changing technology to meet environmental regulatory requirements, see Kaminski et al., 1996.

[16] It is beyond the scope of this chapter to deal with the globalisation of the financial system, although it should be noted that trade flows are increasingly subordinated to, and shaped by, investment flows.

[17] For an excellent treatment of globalisation, see Gordon, 1995. The reader is cautioned that his conceptual trichotomy discussed earlier in this text is not reflected in most of the literature on globalisation, although it would be useful if that were the case.

Effects on Environmental Sustainability

Along with increases in the standards of living in developed countries, the unprecedented use of natural resources and energy, transformation of raw materials into products, and new agriculture, manufacturing, and production technologies are now known to both increasingly deplete the stock of resources and energy sources and to degrade the environment to the point that current industrial, agricultural, and transport systems are becoming unsustainable [Schmidt-Bleek, 1998; Meadows et al., 1992]. We speak of undesirable 'negative externalities' in terms of the depletion of natural capital and compromises to environmental quality, harm to public health, and worker injury and disease.

The traditional ways of addressing pollution problems in terms of pollution control or so-called end-of-pipe approaches -- *after* technological systems are designed and implemented -- are no longer seen as adequate. Similarly, small advances in the efficiency of energy and resource use can no longer compensate for increased world demand and consumption of resource and energy-intensive technology. Even if we could somehow prevent traditional pollution and chemical accidents by the transformation to cleaner and inherently safer technologies, we would still be facing an increasingly unsustainable depletion of resources and the creation of greenhouse gases.

Energy, extraction, production, transportation and agricultural systems need to be inherently cleaner, safer, *and* resource conserving -- i.e., sustainable – in order to avoid or minimise depletion of resources and pollution. These systems need to be designed with the consideration of costs to the environment and consumer and worker health & safety in mind from the beginning[18], across every industrial sector, and in every function of the firm. Thus, rather than environmental technology, *environmentally-sound and resource-conserving* technology is needed, and this presents a challenge and opportunity for major technological innovation. But, as discussed earlier, more than incremental technological innovation is needed.

Radical and significant new approaches require that inputs and materials, final products, and processes be changed, but even more is needed. A shift to product-services with net significant dematerialisation is also needed, for example, through the leasing of carpets, washing machines, or automobiles with guaranteed maintenance or remanufacturing. Beyond product-services, entire systems may need to change, for example substituting transportation systems for individually operated automobiles or changing agricultural growing and distribution systems.

Technological development takes its cues from the market, and both societal/consumer demand and the regulatory environment shape the signals to which technology developers respond. This suggests that policies should be focused to influence consumers and technology providers to adopt sustainable practices. Dematerialisation, and shifts to product-services and beyond, requires technological, organisational, and social innovation to bring about the necessary physical and material changes, changes in infrastructure, and changes in social demands -- and to maintain flexible and learning institutions for continuous improvement.

Effects on Employment and Social Cohesion

[18] See McDonough and Braungart (1998) who argue that more than 'eco-efficiency' is required in the sense advocated by Schmidheiny (1992). Fundamental redesign is required.

A cleaner and less resource intensive environment is only one of several constituents of a sustainable society. Secure and meaningful employment, providing workers with adequate purchasing power, is an essential ingredient of a sustainable and socially cohesive economy. A growing economic system, one that increasingly satisfies human needs and wants (i.e., increases wealth), needs an adequate supply and quality of human capital. ICT and biotechnology are two technological newcomers that both challenge our conventional views of labour, production, and products -- and provide unanticipated opportunity for change. Whether these technologies as they are likely to develop will result in changes in the right direction remains to be seen.

As discussed earlier, the assertion that possible decreases in employment and/or wages brought about by labour-saving, productivity-enhancing technological change would be adequately compensated by lower prices, subsequent increased demand, and production volume is seriously being called into question [EC, 1994; Freeman and Soete, 1994; Head, 1996; OECD, 1996 and 1998]. Incremental labour-saving innovation which dominates the majority of changes occurring in mature industrial economies is said to be at the root of creeping unemployment and underemployment involving the deskilling of at least some labour. While new higher-skilled or newer-skilled challenging and rewarding work is being created in some firms or sectors, employment is being destroyed in others. It can not be said that the winners can compensate the losers in either the nature or the amount of employment. Thus, in this scenario, net job creation is not an adequate metric of satisfaction with technological change. But further, the dichotomy itself may be far too simple. Gordon (1995) argues that both deskilling and reskilling can occur with similar technologies, task structures, and occupations, and that far from determining a unique outcome, information technologies simply expand the work organisation options. The concern for impacts on social cohesion stemming from a ‘digital divide’ among workers [Freeman and Soete, 1994; Head, 1996] also extends to effects on elderly parents and single-parent families who may not have access to the newer technologies.

The nature and rewards, both monetary and psycho-social, of work are undergoing structural change and revolution. But these changes are being brought about by new production, transportation, energy, and agricultural technologies that are undergoing innovation *without concern or planning for their impact on the nature and level of employment*. While compensatory policies, related to education, retraining, and the reorganisation of work exist or are being planned, they are *reactive* to technological changes. Here we need to take a lesson from the environmental problems created by rapid and extensive technological change. It is not sufficient to consider the effects on the environment as an *afterthought*. Environment quality needs to be *built in*. Similarly, it is suggested that thinking about work *after* technologies are planned and disseminated may be far too late to address their possible adverse consequences effectively.

We argue that production, consumption, environment, and employment ought to be *co-optimized* and considered simultaneously. This means technological, organisational, and social innovations need to be *proactive and anticipatory*, rather than reactive. A knowledge-based economy potentially allows for more flexibility and new definitions of work, leisure, production, and consumption. The context established for innovations in all dimensions needs to reflect the realisation that the real wealth of the people lies in economic, environmental, and social sustainability.

Distinctions Between Sustaining and Disrupting Innovation[19]

We have already discussed the need for a paradigm shift from the linear model of the innovation process (invention to innovation to diffusion) – to an iterative, network-influenced model to explain the back-and-forth of scientific and engineering advances -- and the influences on innovation upstream and downstream in the supply chain. A further paradigm shift is needed to explain why product-oriented firms that listen closely to their customers can in some cases succeed impressively, and in other cases fail when a new entrant introduces a product that literally destroys their market. This is important to understand if we are to have any hopes of influencing private sector activities in the direction of sustainability.

For this purpose, a distinction needs to be made between the description of product innovations as incremental or radical, and product innovations as *sustaining* versus *disrupting*. Sustaining innovations occur by established firms pushing the envelope to continue to satisfy existing consumers with improved products. Those improvements may be incremental or radical, and come in successive waves by established firms in that product market[20]. Disrupting innovations cater to different, perhaps not yet well-defined, customers with product attributes different from those in the established producer-consumer networks[21]. Ultimately, they may displace the established technology and market.

Christensen's (1997) concept of a 'value network' is "the context within a firm identifies and responds to customers' needs, solves problems, procures input, reacts to competitors, and strives for profit". In principle, product attributes related to triple sustainability could be important to some customers, for example, resource intensiveness or the way the products are made. An emerging case in point is environmentally friendly packaging that appeal to a defined customer base.

Product attributes are valued differently by different value networks. Existing mainstream customers may demand different things than 'special customers' who are presently small in number, but who could eventually reflect future mainstream demand. Sometimes networks emerge that reject a product previously accepted. Producers of genetically-engineered foods were reinforced by their traditional consumer network that these foods would be acceptable, and they therefore ignored a small, but vocal and different group of consumers who ultimately became a serious force with which to contend. The industry was lulled into complacency because they surveyed and listened to their main customers and did not entertain the possibility that things would change.

Disrupting innovations are technologically straightforward, often consisting of off-the shelf components put together in a [new] product architecture that is often simpler than prior approaches. They could, but need not be, heavily R&D driven. They offer less of what customers in established markets want and hence can rarely be employed there.

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[19] This discussion is derived largely on Christensen (1997), although the author accepts sole responsibility for over-interpretations in the context of sustainability issues.

[20] The successive waves of innovation follow sigmoid or "s" curves with changing rates of innovation within each wave.

[21] The creation of new products in this case is not a wave built upon prior waves, but rather occurs in an entirely new market.

The firm's organisational structure and the way its groups learn to work together can then affect the way the firm can -- and cannot -- design new products. Managerial decisions that make sense for companies outside a value network make little sense for those within it, and vice versa.

In addition to shifting consumer demands, regulation can 'make a market' by providing directions for technological change and product attributes. Of course, regulatory requirements that are viewed as disruptive by the firm and its managers often require disrupting technological changes -- and that is why managers of established firms that pursue sustaining innovation resist regulation and will try to influence regulation that can be satisfied by sustaining innovations -- if not by diffusion of their existing technologies.

Christensen (1997) discusses what could characterize the [rare] successful management of disruptive innovation by the dominant technology firms, rather than give way to their displacement by new entrant firms.

- managers align the disruptive innovation with the 'right' customers.

- the development of those disrupting technologies are placed in an organizational context that is small enough to get excited about small opportunities and small wins, e.g., through 'spin-offs' or 'spin-outs'.

- managers plan to fail early, inexpensively, and perhaps often, in the search for the market for a disruptive technology.

- managers find new markets that value the [new] attributes of the disrupting technologies.

Since, this is rarely done in the commercial context of product competition, it is unlikely to occur for many sustainability goals without either strong social demand or as a result of regulation[22]. This reinforces the view that disrupting innovations are necessary and the policy instruments chosen to promote triple sustainability need to reflect these expectations.

<u>Requisites for Technological and Organisational Innovation</u>

In industrial economies, the firm is the most important locus of technological innovation, although, as mentioned above, the construct of 'innovation networks' involving suppliers, consumers, workers, trade associations, others firms, and government more accurately captures the dynamics of the innovation process. In addition, government itself historically has also had an important role to play as a direct source of innovation, especially in the area of 'big science' such as in the cases of the early development of computers, air transport, and cancer therapies. The term 'innovation systems' has be described as "a set of institutions whose interactions determine the innovative performance…of national firms" [Nelson and Rosenberg, 1993]. Sometimes science and understanding precedes application (engineering), as in the case of modern chemical technologies. Sometimes applications precede and understanding follows, as in the case of electrical equipment industries. As discussed earlier, a better description of the innovation process might be an iterative process where understanding and application provide dynamic feedback to one another, giving rise to stages of advancement.

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[22] For a more optimistic view that large firms in established product markets can sufficiently transform, see Hart and Milstein, 1999. For a further defense of evolutionary transitions, see Rotmans et al., 2001.

In order for innovation to occur, the firm (or government itself) must have the *willingness, opportunity*, and *capability* or *capacity* to innovate [Ashford, 1994 and 2000]. These three factors affect each other, of course, but each is determined by more fundamental factors.

Willingness is determined by both (1) *attitudes towards changes in production in general* and by (2) *knowledge about what changes are possible*. Improving the latter involves aspects of capacity building, while changing the former may be more idiosyncratic to a particular manager or alternatively a function of organisational structures and reward systems. The syndrome 'not in my term of office' describes the lack of enthusiasm of a particular manager (in the firm or government agency) to make changes whose benefit may accrue long after he has retired or moved on, and which may require expenditures in the short or near term.

In the context of disrupting innovation by firms representing the dominant technology, willingness is also shaped by the [rare] commitment of management to nurture new approaches that are at odds with its traditional value network. In instances where firms pursue a dual strategy, the new initiatives are often short-changed in terms of the allocation of resources and top-flight researchers [Christensen, 1997].

Opportunity involves both supply-side and demand-side factors. On the supply side, technological gaps can exist (1) between the technology used in a particular firm and the already-available technology that could be *adopted or adapted* (known as diffusion or incremental innovation, respectively), and (2) the technology used in a particular firm and technology that could be *developed* (i.e., major or radical innovation). On the demand side, four factors could push firms towards technological change -- whether diffusion, incremental innovation, or major innovation -- (1) regulatory requirements, (2) possible cost savings or expansion of profits, (3) public demand for more environmentally-sound, eco-efficient, and safer industry, and (4) worker demands and pressures arising from industrial relations concerns. These latter two factors could bring about changes in the value networks, and could stimulate change too late in the dominant technology firms, if new entrants have already seized the opportunity to engage in developing disrupting innovations.

Capacity or capability can be enhanced by (1) increases in knowledge or information about more sustainable opportunities, partly through deliberately undertaken Technology Options/Opportunity Analyses, and partly through deliberate or serendipitous transfer of knowledge from suppliers, customers, trade associations, unions, workers, and other firms, as well from available literature, (2) improving the skill base of the firm through educating and training its operators, workers, and managers, on both a formal and informal basis, and (3) by deliberate creation of networks and strategic alliances not necessarily confined to a geographical area or nation or technological regime. Capacity to change may also be influenced by the inherent innovativeness (or lack thereof) of the firm as determined by the maturity and technological rigidity of particular product or production lines [Ashford et al., 1985; Ashford, 1994 and 2000]. The heavy, basic industries, which are also sometimes the most polluting, unsafe, and resource intensive industries, change with great difficulty, especially when it comes to core processes. However, new industries, such as computer manufacturing, can also be polluting, unsafe (for workers), and resource and energy intensive, although conceivably they may find it easier to meet environmental demands.

It deserves re-emphasizing that it is not only hardware, materials, process, and product technologies that are rigid and resistant to change. Personal and organisational flexibility are also important. Technology, organisation, and people combine together to influence change.

The willingness, opportunity, and capability/capacity to change all three must be addressed in order to encourage sustainable development. Finally, it is important to realise that Factor 10 (or greater) improvements require radical shifts in production, use, and consumption patterns and are not tied to any particular technological fix. Shifts to product-services which shift the focus from the production of products to the delivery of functions and utility (services) are central to dematerialisation, energy de-intensification, and the creation of new employment.

Implications for Policy

Recalling that a sustainable future requires technological, managerial, and social/cultural changes, it is likely that an evolutionary pathway is insufficient for achieving factor ten or greater improvements in eco- and energy-efficiency [McDonough and Braungart, 1998], and reductions in the production and use of, and exposure to, toxic substances [Ashford, 2000]. Such improvements require more significant and revolutionary changes [Andersen and Massa, 2000; Reijnders, 1998]. The capacity to change can be the limiting factor -- this is often a crucial missing factor in optimistic scenarios.

Significant industrial transformations occur less often from dominant technology firms, or in the case of unsustainable practices, problem firms' capacity-enhancing strategies, than from new firms that displace existing products, processes and technologies. This can be seen in examples of significant technological innovations over the last fifty years including transistors, computers, and PCB replacements [Ashford, 1994 and 2000; Ashford & Heaton, 1983; Strasser, 1997].

Especially in industries that are ‘flexible’ and always changing their products, we may be justifiably enthusiastic about existing firms' ability to move towards sustainable production. In this case, closer relations with customers and NGOs may be particularly helpful. But where the product line is ‘rigid’ or mature -- as was the case of PCBs, and is the case with other unsustainable technologies -- change is not easy, and Schumpetarian revolutionary ‘waves of creative destruction’ replace the product via new entrants to the market – often necessitated by stringent regulation.

Rigid industries whose *processes* have remained stagnant also face considerable difficulties in becoming significantly more sustainable. Shifts from products to ‘product services’ rely on changes in the use, location, and ownership of products in which mature product manufacturers may participate, but this requires significant changes involving both managerial and social (customer) innovations. Changes in socio-technological ‘systems’, such as transportation or agriculture are even more difficult [Vellinga and Herb, 1999]. This suggests that the creative use of law is a more promising strategic instrument for achieving sustainable industrial environmental transformation, than the reliance of the more neo-liberal forms of ecological modernisation on firms' economic self-interest.

This is not to say that technical assistance by government; enhanced analytic and technical capabilities on the part of firms; cooperative efforts and improved communication with suppliers, customers, workers, other industries, and environmental/consumer/community groups are not valuable adjuncts in the transformation process. And that is of course the value that ecological modernisation scholars have brought into the discussion on major transformations in product, processes and socio-technical systems. But in most cases these means and strategies are unlikely to be sufficient by themselves for significant transformations, and they will not work without clear mandated targets to enhance environmental, safety, and health performance of the private sector. Nor will streamlining regulatory processes by itself be sufficient for the transformations that are needed.

Government has a role to play in providing the opportunity for technological transformation/sustainable development through the setting of clear standards and policy goals, while allowing flexible means for industry to achieve those goals – in the spirit of ‘backcasting’ (as opposed to ‘forecasting’ to assess future problems) used in the Netherlands for the Dutch National Environmental Policy Plans [Vergragt and van Grootveld, 1994]. This approach involves setting long-term goals – as much as 50 years ahead – and putting policies in place to encourage the needed transformations [Keijzers, 2002, 2000; Vollenbroek 2002][23]. Care must be taken to avoid dominant technological regimes from capturing or unduly influencing government regulation or negotiation processes (Ashford, et al., 2001]. New entrants and new technologies must be given a chance to evolve to address environmental problems. Direct support of research and development, tax incentives for investment in sustainable technologies, and other technical assistance initiatives that fall under the rubric of ‘industrial policy’ are other areas where government can make a difference [Nelson & Rosenberg, 1993]. Ideally, an ‘industrial policy for sustainability’ would include provisions relating to not only production and the environment, but also consumption, employment, and trade. Regulatory and other policy design and implementation are largely in the hands of government. The government has to do more than simply serve as a referee or arbiter of competing interests because neither future generations nor future technologies are adequately represented by the existing stakeholders.

[23] Some argue that these transformations or ‘transitions’ can be managed [Rotmans et al., 2001], through ‘strategic niche management,’ but others are skeptical about the adequacy of this evolutionary approach [Ashford et al., 2001].

References

Abernathy, W. J. and Clark, K. B. (1985) "Mapping the Winds of Creative Destruction" *Research Policy* 14: 3-22.

Andersen, Mickael Skou and Massa, Ilmo. (2000) Ecological Modernisation: Origins, Dilemmas, and Future Directions. *Journal of Environmental Policy and Planning* 2(4), 337-345.

Andreasen, Lars Erik , Coriat, Benjamin, den Hertog, Friso, and Kaplinsky, Raphael (Eds.) (1995) Europe's Next Step: Organisational Innovation, Competition and Employment, London: Frank Cass & Co., 332 pp.

Ashford, Nicholas A. (2002) "Government And Innovation in Environmental Transformations in Europe And North America", in Special Issue on Ecological Modernization, Sonnenfeld, David and Mol, Arthur, (Eds.) *American Behavioral Scientist*, Volume 45, No. 9, pp. 1417-1434.

Ashford, Nicholas A. (2001) "Innovation – The Pathway to Threefold Sustainability" in The Steilmann Report: The Wealth of People: An Intelligent Economy for the 21st Century Lehner, Franz, Charles, Anthony, Bieri, Stephan, and Paleocrassas, Yannis (eds.) Brainduct ® - digital edition, 2001 pp 233-274, based on Ashford, Nicholas A., "Technological, Organisational, and Social Innovation as Pathways to Sustainability," manuscript, 42 pages.

Ashford, Nicholas A. (2000). An Innovation-Based Strategy for a Sustainable Environment. In J. Hemmelskamp, K. Rennings, F. Leone (Eds.), *Innovation-Oriented Environmental Regulation: Theoretical Approach and Empirical Analysis*, ZEW Economic Studies. Heidelberg, New York: Springer Verlag, pp. 67-107.

Ashford, Nicholas A. (1994) "An Innovation-Based Strategy for the Environment," in Worst Things First? The Debate Over Risk-based National Environmental Priorities, A. M. Finical and D. Golding (eds.), Resources for the Future, Washington, DC, pp. 275-314.

Ashford, Nicholas A., Ayers, Christine and Stone, Robert F. (1985) "Using Regulation to Change the Market for Innovation," *Harvard Environmental Law Review*, 9(2):419-466.

Ashford, Nicholas, Hafkamp, Wim, Prakke, Frits, and Vergragt, Philip (2001) Pathways To Sustainable Industrial Transformations: Cooptimising Competitiveness, Employment, and Environment, Final Report to the Ministry of Environment and Spatial Planning, Government of the Netherlands (30 June 2001)

Ashford, Nicholas A. and Heaton, George R. (1983) "Regulation and Technological Innovation in the Chemical Industry" *Law and Contemporary Problems* 46 (3): 109-157.

Ashford, Nicholas A., Heaton, George R. and Priest, W. Curtiss (1979) "Environmental, Health and Safety Regulations and Technological Innovation," in Technological Innovation for a Dynamic Economy, C. T. Hill and J. M. Utterback (eds.), Pergamon Press, Inc., NY. pp. 161-221.

Ashford, Nicholas A. and Meima, Ralph (1994) Designing the Sustainable Enterprise: Research Needs and Policy Implications for a Sustainable Future, Summary Report of the Second International Research Conference of the Greening of Industry Network held November 1993, Tufts University, Supplement to *Business Strategy and the Environment*, Vol. 3, Part 2, 40 pp.

Ashford Robert A. (1998) “A New Market Paradigm for Sustainable Growth: Financing Broader Capital Ownership with Louis Kelso’s Binary Economics” *Praxis: The Fletcher Journal of Development Studies*.14:25-59.

Baldwin, R. (1989) “On the Growth Effects of 1992” *Economic Policy*, fall. 3(1):141-202.

Brouwer, Eric and Kleinknecht, Alfred (1996) “Firm Size, Small Business Presence and Sales of Innovative Products: A Micro-Econometric Analysis ”*Small Business Economics*, 8:189-201.

Castells, Manuel (1996) The Rise of the Network Society, Blackwell, Oxford.

Charles, Tony and Lehner, Franz (1998) “Competitiveness and Employment: A Strategic Dilemma for Economic Policy" *Competitiveness and Change* 3:207-236.

Christensen, Clayton (1997) The Innovator’s Dilemma: When New Technologies Cause Great Firms to Fail, Harvard Business School Press.

Cleff, Thomas and Rennings, Klaus (1999) “Determinants of Environmental Product and Process Innovation,” *European Environment* 9:191-201.

Coriat, Benjamin. (1995). Organizational Innovations: The Missing Link in European Competitiveness. In L. E. Andreasen, B. Coriat, F. de Hertog, and R Kaplinsky (Eds.) Europe's Next Step: Organizational Innovation, Competition and Employment London: Frank Cass & Co, pp. 3-32.

Costanza, Robert, Daly, Herman, and Bartholomew, Joy (1991) “Goals, Agenda and Policy Recommendations for Ecological Economics” In Robert Costanza (ed) *Ecological Economics* Columbia University Press Press: New York, pp. 1-20.

Daly, Herman. (1991) “Chap. 9: The Steady-State Economy: Alternative to Growthmania.” Steady-State Economics. Washington, DC, Island Press.

Diwan, Ishac and Walton, Michael (1997) “How International Exchange, Technology and Institutions Affect Workers: An Introduction” *World Bank Economic Review* 11(1):1-15.

Drucker, Peter (1999) “Beyond the Information Revolution,” *The Atlantic Monthly* October 1999, 284(4):47-57.

Easterly, W. R. and Wetzel, D. L. (1989) “Policy Determinants of Growth” *World Bank Working Papers*, WPS 343, December.

EC = European Commission (1994) Growth, Competitiveness, and Employment: The challenges and ways forward into the 21st century. Brussels: European Commission.

Ekins, Paul, Folke, Carl, and Costanza, Robert (1994) “Trade, environment, and development: the issues in perspective” *Ecological Economics* 9:1-12.

Freeman, Chris (1992) The Economics of Hope, Pinter, London.

Freeman, C. and Soete, L. (1994) Work for All or Mass Unemployment? Pinter, London.

Georg, S., Røpke, I. and Jørgensen, U. (1992) "Clean Technology: Innovation and Environmental Regulation" *Environmental and Resource Economics* 2(6):533-550.

Gordon, Richard (1995) "Globalization, New Production Systems, and the Spatial Division of Labor: Chapter 5" in Littek, Wolfgang and Charles, Tony (eds.) The New Division of Labour: Emerging Forms of Work Organisation in International Perspective, New York, Walter de Gruyter, 514 pages.

Grossman, G. M. and Helpman, E. (1994) "Endogenous Innovation in the Theory of Growth" *Journal of Economic Perspectives* 8(1):23-44.

Hart, Stuart and Milstein, Mark B. (1999) "Global Sustainability and the Creative Destruction of Industries" *Sloan Management Review* 41(1):23-33.

Head, Simon (1996) "The New, Ruthless Economy." *The New York Review of Books* Feb 29 1996: 47-52.

Jürgens, Ulrich (1995) "Chapter 11. Lean Production in Japan: Myth and Reality" in The New Division of Labour: Emerging Forms of Work Organisation in International Perspective Littek, Wolfgang and Charles, Tony (Eds.) New York: Walter de Gruyter, pp. 349-366.

Kaminski, Michelle, Bertelli, Domenick, Moye, Melissa, and Yudken, Joel. (1996) Making Change Happen: Six Cases of Companies and Unions Transforming Their Workplaces, Work and Technology Institute, Washington, DC

Keijzers, Gerard (2002) "The Transition to the Sustainable Enterprise" *Journal of Cleaner Production* 10(4):349-359.

Keijzers, Gerard (2000) "The Evolution of Dutch Environmental Policy: the Changing Ecological Arena from 1970-2000 and Beyond" *Journal of Cleaner Production* 8(3):179-200.

Kemp, René (1994) "Technology and Environmental Sustainability: The Problem of Technological Regime Shifts" *Futures* 26(10):1023-1046.

Kemp, René (1997) Environmental Policy and Technical Change: A Comparison of the Technological Impact of Policy Instruments, Edward Elgar, Cheltenham, UK.

Kleinknecht, Alfred (1998) "Is Labour Market Flexibility Harmful to Innovation?" *Cambridge Journal of Economics* 22:387-39.

Krimsky, Sheldon (1982) Genetic Alchemy: The Social History of the Recombinant DNA Controversy MIT Press, Cambridge, MA.

Littek, Wolfgang and Charles, Tony (Eds.) (1995) The New Division of Labour: Emerging Forms of Work Organisation in International Perspective New York: Walter de Gruyter, 514 pp.

Lucas, R. E. (1988) "On the Mechanics of Economic Development" *Journal of Monetary*

Economics 22(2):3-42.

Matzner, E., Schettkat, R. and Wagner (1990) “Labor Market Effect of New Technology” *Futures* 22:687-709.

Mazurek, Jan (1998), Making Microchips: Policy, Globalization, and Economic Restructuring in the Semiconductor Industry, J. Mazurek, MIT Press, Cambridge, MA.

McDonough, William and Braungart, Michael (1998). “The NEXT Industrial Revolution”. *The Atlantic Monthly*. October, 282(4): 82-90.

Meadows, Donella H, Dennis L Meadows, and Jorgen Randers (1992) Beyond the Limits: Confronting Global Collapse, Envisioning A Sustainable Future. Earthscan Publications, London.

Mol, A. P. J. (1995*). The Refinement of Production: Ecological Modernization Theory and the Chemical Industry*. Utrecht, The Netherlands: Van Arkel.

Mowery, David C. and Rosenberg, Nathan, (1989) Technology and the Pursuit of Economic Growth Cambridge University Press, Cambridge, 330 pp.

Nelson, Richard R. (1996) “Chapter 10: National Innovation Systems: A Retrospective on a Study” The Sources of Economic Growth. Cambridge, MA: Harvard University Press, pp 274-302.

Nelson, Richard R. and Rosenberg, Nathan (1993) National Innovation Systems: A Comparative Analysis, New York, Oxford University Press.

Nelson, Richard R. and Winter, Sidney G. (1977) “In Search of Useful Theory of Innovation” *Research Policy* 6:36-76.

OECD (1992) Technology and Economy: The Key Relationships, OECD (92 92 02 1) ISBN 92-64-113622-3, Organisation for Economic Cooperation and Development, Paris, 327 pp.

OECD (1996) The Knowledge-based Economy, Organisation for Economic Cooperation and Development, Paris, 57 pp.

OECD (1997) Economic Globalisation and the Environment. Paris: OECD.

OECD (1998) Technology, Productivity, and Jobs Creation: Best Policy Practices, OECD (92 98 05 1P) ISBN 92-64-16096-5, Organisation for Economic Cooperation and Development, Paris, 327 pp.

Pavitt, Keith (1984) “Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory,” *Research Policy* 13:343-373.

Reich, Robert (1991) The Work of Nations New York: Alfred A. Knopf.

Reijnders, L. (1998). The Factor X Debate: Setting Targets for Eco-Efficiency. *Journal of Industrial Ecology* 2(1):13-22.

Rennings, Klaus (1998) Towards a Theory and Policy of Eco-Innovation: Neoclassical and (Co-) Evolutionary Perspectives ZEW Discussion Paper 98-24 Centre for European Economic Research (ZEW), Mannheim.

Romer, P. (1987) “Crazy Explanations for the Productivity Slowdown” *Macroeconomics Annual* National Bureau of Economic Research, Washington, DC, pp. 307-8.

Romer, P. (1989) “What Determines the Rate of Growth and Technological Change?” *The World Bank Working Papers*, WPS 279, September.

Romer, P. (1994) “The Origins of Endogenous Growth” *Journal of Economic Perspectives* 8(1):3-22.

Rotmans, Jan, Kemp, René, and van Asselt, Marjolein (2001) ”More Evolution than Revolution: Transition Management in Public Policy” *Foresight* 3(1):015-031.

Schmidheiny, Stephen (1992) Changing Course: A Global Business Perspective on Development and the Environment MIT Press, Cambridge, MA, USA.

Schmidt-Bleek, F. (1998) Das MIPS-Koncept Droemer-Knaur-Verlag, Munich. See also, Statement to Government and Business Leaders: The Carnoules Statement 1997, The International Factor 10 Club.

Schumpeter, Joseph (1939) Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process New York, McGraw-Hill.

Scott, J. (1989) A New View of Economic Growth Oxford; Clarendon Press

Strasser, K. (1997). Cleaner Technology, Pollution Prevention, and Environmental Regulation. *Fordham Environmental Law Journal* 9(1):1-106.

Teubner, G. (1983). Substantive and Reflexive Elements in Modern Law*, Law and Society Review* 17:239-285.

Utterback, J. M. (1987) “Innovation and Industrial Evolution in Manufacturing Industries” in Technology and Global Industry: Companies & Nations in the World Economy, B. R. Guile and H. Brooks (eds.) National Academy of Engineering, National Academy Press, pp. 16-48.

Vellinga, P., & Herb, N. (1999). Industrial Transformation Science Plan, IHDP Report 12, Bonn, Germany. [Online September 3, 2000]. Available: <http://www.vu.nl/ivm/research/ihdp-it>.

Vergragt, Philip J. and van Grootveld, Geert (1994) Sustainable Technology Development in the Netherlands The first phase of the Dutch STD program, *Journal of Cleaner Production*, 2 (3-4):133-139.

Vollenbroek, Frans A. (2002) “Sustainable Development and the Challenge of Innovation”*Journal of Cleaner Production* 10(3):215-223.