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SUSTAINABLE MANUFACTURING AND ECO-INNOVATION

First steps in building a common analytical framework

This CIIE has tasked the Secretariat to work on sustainable production and eco-innovation (DSTI/IND(2007)24). This document is part of the first progress report on this project. It has been revised following the International Conference on Sustainable Manufacturing and the second Advisory Expert Group meeting held on 23-25 September 2008 in Rochester, NY, United States. It is submitted for discussion under item 9 of the CIIE meeting to be held on 30-31 October 2008.

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Summary

Over the last decades, manufacturing industries have taken several steps to reduce their environmental impacts, responding to tightening regulations and increasing pressure from various stakeholders. Industry initiatives towards sustainable manufacturing have evolved from end-of-pipe pollution control through cleaner production to much more systematic and integrated strategies such as green supply chain management and industrial ecology.

The predominant focus of such initiatives has been the employment of technological innovations, typically by modifying existing products and processes to increase eco-efficiency or to minimise toxic materials and pollutions. While this approach has led to incremental environmental improvements, it is widely recognised that more progressive action is also needed to tackle continuous environmental degradation.

To meet the growing environmental challenges, much attention has recently been paid to innovation as a way of developing sustainable solutions, also known as eco-innovation. As argued over general innovation, non-technological innovation, such as changes in organisational structures, marketing methods and business models, are of growing importance for companies to achieve significant environmental improvements. Consumer behaviour, social norms, cultural values and formal institutional arrangements are increasingly seen as intricate parts of developing high-impact eco-innovative solutions.

This paper presents a framework developed as a first attempt to combine the notions of sustainable manufacturing and eco-innovation with an aim to facilitate analysis of sustainability initiatives in manufacturing companies. While the application of the eco-innovation concept in sustainable manufacturing would offer a promising way for moving industrial production towards a truly sustainable direction, it requires companies to undertake a deliberate re-examination of all phases of the production system. Eco-innovation solutions can hardly be identified and implemented by a single company. This would entail the development of new institutional arrangements such as knowledge network and partnerships that can function as co-creative processes.

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1. Introduction

1. The primary goals of a sustainable society concern three areas, namely *i)* the creation of material wealth and prosperity; *ii)* the preservation of nature; and *iii)* the development of beneficial social conditions for all human beings. Interest in building a sustainable society has been significantly increasing among politicians, business leaders and the general public alike. This is particularly evident when considering the current debate on climate change and the level to which the issue has risen on the global political agenda.

2. Manufacturing industries account for a significant part of the world's consumption of resources and generation of waste. On a global scale, for example, the energy consumption of manufacturing industries has grown by 61% from 1971 to 2004 and accounts for nearly a third of today's global energy usage. Likewise, they are responsible for 36% of global carbon dioxide (CO_2) emissions (IEA, 2007). These figures do not include raw material extraction and use of manufactured products, which, if included, would imply a far greater impact. To date, manufacturing industries have taken several steps to reduce their environmental and social impacts, largely driven by stricter regulations and growing pressures on industry to take more responsibility for their operations. However, the trend for companies to voluntarily improve their social and environmental performance based on motives related to higher profitability, increased efficiency and stronger competitiveness is growing. As such, industries are gradually moving from pollution control and treatment measures to more integrated and effective solutions.

3. Despite such improvements, it is widely recognised that further action must be taken urgently to avoid continuous environmental degradation. Considering the current trajectory, for example, the world population is expected to grow by 1.8 billion over the next 20 years. Nearly 97% of this increase is projected to occur in less developed nations (UN-DESA, 2006), *i.e.* with China and India alone accounting for more than 500 million people. Meanwhile, the number of people living on less than USD 1 a day is projected to be halved over the same time period (World Bank, 2007). The International Energy Agency (IEA) predicts that the global energy-related CO_2 emissions will increase by 25% by 2030 even under the current best policy scenario (IEA, 2007). This illustrates the high relevance of altering patterns of production and consumption in ways that do not put further pressure on the planet.

4. Manufacturing industries are of major significance in this regard, and the pressure for them to reduce their environmental and social impacts is bound to increase further. However, they also have the potential of becoming a driving force for the creation of a sustainable society by designing and implementing integrated sustainable practices that will allow manufacturing companies to eliminate or drastically reduce their own environmental and social impacts, as well as by developing products that can contribute to better environmental performance in other sectors. Such development calls for a shift in the perception of industrial production to one where manufacturing is understood as an interdependent part of a greater system instead of an independent process (Maxwell et al., 2006), and the adoption of a more holistic business approach that integrates environmental and social aspects on an equal footing with economic concerns.

5. Aiming to move the above agenda forward with reference to the OECD/CIIE project proposal on sustainable manufacturing and eco-innovation outlined in DSTI/IND(2007)24, this paper investigates the concepts of *sustainable manufacturing* and *eco-innovation* and the possibility of considering the two concepts within a common analytical framework. The OECD hopes that this exercise will facilitate a better understanding of current sustainability initiatives in industry and provide guidance on how to encourage future industry action in this direction.

6. The paper firstly categorises different notions of sustainable production initiatives that have been promoted and applied in manufacturing industries over the last few decades. Secondly, it gives a conceptual overview of eco-innovation and outlines how this concept could help manufacturing sectors to improve their sustainable production initiatives. Lastly, the paper explores conceptual relationships between sustainable manufacturing and eco-innovation and proposes a common framework for analysing the current initiatives from a broader perspective as well as spreading good practices in the sectors, especially among supply chain companies and small and medium-sized enterprises (SMEs) that tend to lack the knowledge and resources for such purposes. At the first stage of the project, the main focus of this paper concerns only environmental aspects of sustainable development.

2. Sustainable production in manufacturing sectors

7. The idea of *sustainable development* emerged in the early 1980s primarily triggered by growing concerns over a rising number of environmental damages associated with economic growth (IUCN, 1980). Since then, the concept's coverage has expanded to include other aspects, and today it is typically associated with development that ensures *i)* environmental protection; *ii)* economic wealth; and *iii)* social equity – also known as the three pillars of sustainable development – in a context where the needs of present generations can be met without compromising the ability of future generations to meet their own needs (WCED, 1987). The use of "sustainability" in more specific areas such as production, manufacturing, innovation, etc. tend to follow the above definition, albeit within a more confined context.

8. There appears to be no general definition of *sustainable manufacturing* but the concept fits well with the broader idea of *sustainable production*. The concept of sustainable production emerged from the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992 as a vital part of realising sustainable development (Veleva and Ellenbecker, 2001). The Lowell Center for Sustainable Production at the University of Massachusetts, Lowell, defines sustainable production as "the creation of goods and services using processes and systems that are: non-polluting, conserving of energy and natural resources, economically viable, safe and healthful for workers, communities, and consumers, and socially and creatively rewarding for all working people" (Nasr and Thurston, 2006). With specific reference to "production in manufacturing sectors", this provides a good starting point for defining sustainable manufacturing and is used as a baseline in this paper, though the paper focuses mainly on environmental aspects. Below, this section provides a conceptual overview of sustainable manufacturing initiatives and how these have evolved over time.

Pollution control and treatment

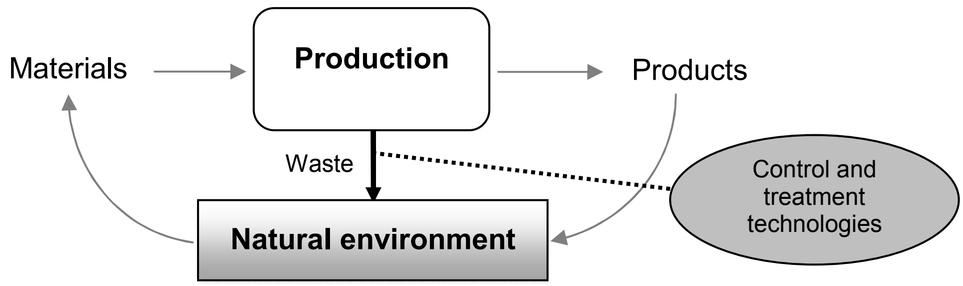
9. Historically, the environmental harm caused by industrial production was typically dealt with according to the doctrine "solution to pollution is dilution" with dispersing pollution in less harmful or less apparent ways (UNEP and UNIDO, 2004). In more recent years, driven by stricter environmental regulations, industry has mostly dealt with environmental harm by attempts to control and reduce the amount of emissions and effluents discharged into the environment by using various treatment measures.

10. Pollution control is characterised by the application of technological measures that act as non-essential parts of already existing manufacturing processes at the final stage of these processes. For this reason, they are often referred as "end-of-pipe" technologies (see Figure 1). In general, the alleviation of environmental harm from pollution control stems from reducing or removing contaminants to air, soil, and water that have already been formed in the production process.

11. Since pollution control does not restructure the existing production systems in any major way, the only benefit of their application is better environmental performance, and investment in such measures has traditionally been perceived as a costly burden by manufacturing companies. As such, the view has

typically been that industrial competitiveness will suffer from higher costs of environmental protection and clean-ups, and that environmental performance constitutes a trade-off with business profitability and economic growth (Porter and van der Linde, 1995).

Figure 1. Pollution control and treatment



12. When dealing with environmental harm, curative solutions to improve performance are still essential for most manufacturing industries and their potential impact is far from insignificant. Examples of such solutions include biological and chemical components for the treatment of wastewater, air filtration systems, and acoustic enclosures for noise reduction. In the context of climate change, the latest technologies designed to capture CO_2 emissions, which then can be stored in deep geological formations or ocean masses (also referred to as carbon capture and storage, CCS), are also highly relevant. Yet, there is a growing trend towards investigating more preventive options.

Preventive solutions and cleaner production

13. In the effort to shift industrial environmental management from conventional pollution control to a more proactive approach, the United Nations Environment Programme (UNEP) introduced a Cleaner Production Programme in 1989. The concept of *cleaner production* builds on the precautionary principle, a philosophy of "anticipate and prevent", through an integrated environmental strategy. Since 1994, UNEP has worked with the United Nations Industrial Development Organization (UNIDO) for setting up National Cleaner Production Centres (NCPCs) worldwide to spread the industrial application of this philosophy. By 2007, 37 NCPCs have been established.

14. The major factor that distinguishes cleaner production from pollution control and treatment is the fact that the environmental focus is directed towards the earliest possible stage in the industrial process, *i.e.* at the source of pollution. A shift towards cleaner production from pollution control, therefore, entails the investigation of all aspects of the existing production process and its organisational arrangements aiming to identify areas that can be targeted to reduce or eliminate environmental harm. The areas for implementation are often categorised into five main areas:

i) Housekeeping, which refers to improvements in work practices and maintenance;

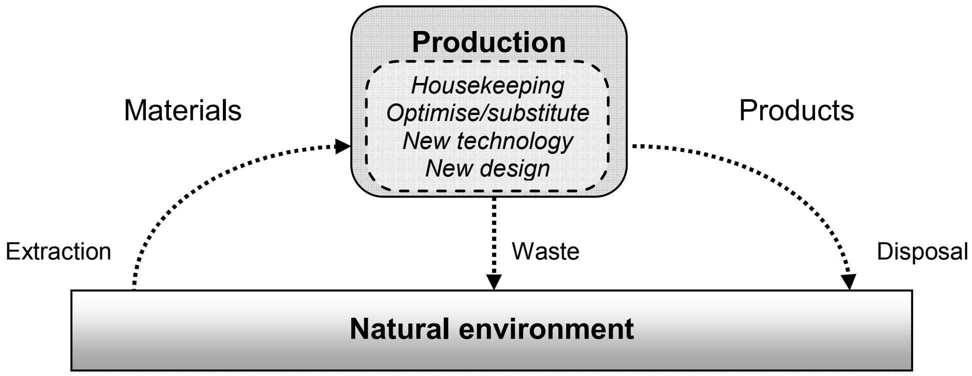
ii) Process optimisation, which leads to the conservation of raw materials and energy;

iii) Raw material substitution, which eliminates toxic materials by shifting to more environmentally sound resources;

iv) New technologies, which enable reductions in resource consumption, waste generation and emissions of pollutants; and *v)* New product design, which aims to address and minimise environmental impacts throughout the product lifecycle (Ashford, 1994).

15. The concept of cleaner production embraces the notion of efficient resource consumption while avoiding unnecessary waste generation (see Figure 2). Improvements in environmental performance based on lower pollution from sources rather than output require changes to the existing manufacturing processes, products/services, and/or organisational structures and procedures. Even though the implementation scope of cleaner production stay within the boundary of the manufacturing company, as is the case with pollution control, this leads to a more integrated environmental approach and is considered key for moving towards eco-efficient production (see next section). The potential economic and environmental benefits of cleaner production are therefore also often superior to those of end-of-pipe solutions.

Figure 2. Cleaner production



Note: The perspective of the natural environment is broadened compared to pollution control and treatment (Figure 1) as the concept of cleaner production takes the whole range of the production process into account.

16. The implementation of cleaner production initiatives nevertheless constitutes a larger and more challenging task. The development of cleaner production may be hampered particularly by barriers within companies that arise from organisational co-ordination problems as well as insufficient managerial support. Additional obstacles may arise from regulatory environments such as in Germany where specific technology standards imposed by regulations favour end-of-pipe abatement measures rather than cleaner production options (Frondel, *et al.*, 2007). For these reasons, and because little empirical analysis has been conducted regarding investment in specific types of environmental technologies, there is a widespread assumption that end-of-pipe technologies still dominate environmental investment decisions in many companies.

17. However, recent evidence based on the results from a survey of more than 4 000 manufacturing facilities located in Canada, France, Germany, Hungary, Japan, Norway and the United States does not support this assumption (Frondel, *et al.*, 2007). Although significant differences were observed between facilities and countries, more than 75% of the respondents reported predominant investments in cleaner production technologies. The data also supported the argument that end-of-pipe technologies are typically introduced to cope with regulatory compliance, while the implementation of cleaner production technologies is driven by the potential for increasing manufacturing efficiency and reducing costs of operations. This was indicated by a positive correlation between corporate investments in end-of-pipe

technologies and respondents' assessment and perception of stringency of regulatory measures and environmental policies, while cost saving motives and the responding companies' use of specific environmental management tools (*e.g.* environmental policies, accounting, audits, etc.) were correlated with investments in cleaner production.

18. Other evidence of benefits related to cleaner production is offered by a large number of case studies, although most of these are anecdotal. Frequently mentioned benefits are improvements to products and processes, savings on raw materials and energy, and increased competitiveness through new and improved technologies. Other benefits include lower risk of non-compliance with environmental legislation and reduced liabilities associated with treatment, storage and disposal of wastes, which limits the need for expensive end-of-pipe technologies. Cleaner production is also often associated with improved health, safety and morale of employees (Hui, *et al.*, 2001; ISO, 2007).

Eco-efficiency and managerial approaches

19. With the shift from pollution control to pollution prevention, environmental considerations and improvement of environmental performance in manufacturing industries are also increasingly regarded from a perspective of business interests rather than one of regulatory compliance. In many cases, companies have come to find that doing good for the environment does not necessarily result in bad business. In fact, it may lead to gaining a competitive edge through better general management, optimisation of production processes, reductions in resource consumption, and the like (see Box 1). "Going green" is progressively being seen as a potential profitable enterprise, and voluntary as well as pre-emptive sustainability initiatives have become increasingly common in recent years.

Box 1. Savings through better environmental performance

The Green Suppliers Network co-ordinated by the US Environment Protection Agency (EPA) seeks to help SMEs in the manufacturing sectors through programmes that help companies to identify strategies for implementing cleaner production techniques. A review of the results of 60 such programmes shows strong evidence of improved environmental performance as well as large savings for the companies (www.greensuppliers.gov). Experiences from European initiatives also show that a considerable number of SMEs are becoming increasingly interested in implementing cleaner production to improve their economic and environmental performance (Kurzinger, 2004).

20. A range of developments in the global economy are strengthening the demand for increasing efficiency. The internationalisation of manufacturing production and its value chain, for example, is strengthening competitive pressures and the need for manufacturing companies to improve their cost-effectiveness is ever increasing. Combined with growing resource constraints, which has led to higher costs of core manufacturing activities, the incentive for improving resource efficiency is ever-growing.

21. To help companies step up the contribution to the creation of a sustainable society while remaining competitive in the global market, the World Business Council for Sustainable Development (WBCSD) introduced the concept of *eco-efficiency*. This concept was put forth as one of industry's key contributions to sustainable development at the time of the UNCED in 1992 (Schmidheiny, 1992)[1].

22. The WBCSD defines eco-efficiency as a state that can be reached through "the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while

1 In 1992, the UNCED concluded that "the major cause of the continued deterioration of the global environment is the unsustainable patterns of consumption and production, particularly in industrialized countries, which is a matter of grave concern, aggravating poverty and imbalances". This statement was put forward, particularly to Western countries, as a challenge to change the current consumption and production patterns, backed by a global plan for action known as Agenda 21.

progressively reducing environmental impacts of goods and resource intensity throughout the entire lifecycle to a level at least in line with the earth's estimated carrying capacity" (WBCSD, 1996). The goal of eco-efficiency points towards the adoption of production methods that go hand in hand with an ecologically sustainable society and overarches a range of other important concepts surrounding sustainable production and manufacturing.

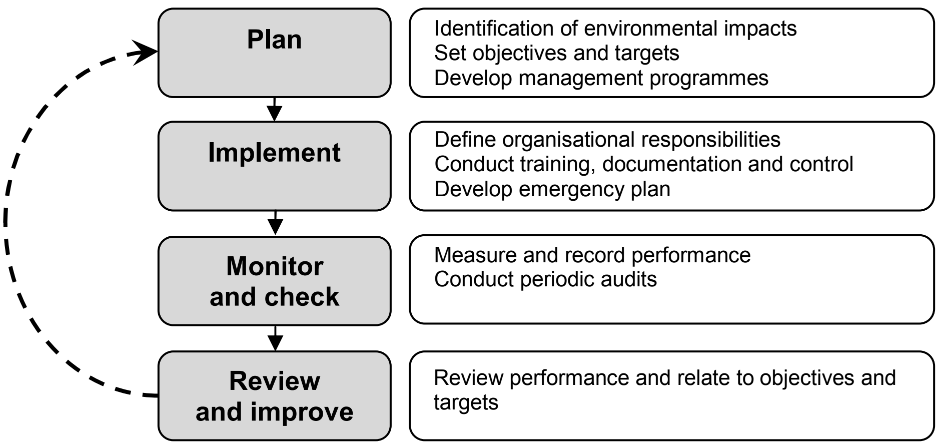
23. Over the last decade, the original idea and importance of eco-efficiency as a guiding principle for industrial production and business decisions has gained much broader attention and has been promoted with a simpler catchphrase "doing more with less", *i.e.* producing more goods and services while using fewer resources and creating less waste and pollution (*e.g.* EC, 2005). This movement has led to the evolution of a diverse range of conceptual and methodological approaches such as environmental monitoring and auditing, and environmental strategies (Maxwell, *et al.*, 2006) which companies can use to better implement the eco-efficiency principles in their production.

24. Such tasks are not trivial to manufacturing companies and place great emphasis on their organisational management capability. The development of environmental management systems (EMSs) has tied many of the environmental monitoring and management principles together, providing a framework by which companies can move towards eco-efficient production (Johnstone, *et al.*, 2007).

25. An EMS is meant to provide companies with a comprehensive and systematic management system for the continual improvement of its environmental performance. Once implemented, the system relies on a specific and documented structure that can typically be characterised by four cyclic and action-oriented steps: *i)* plan; *ii)* implementation; *iii)* monitor and check; and *iv)* review and improve *(Perotto, et al.*, 2008) (see Figure 3). These steps are applied across all elements of the company's activities, products and services that interact with the environment (ISO, 2004), and may include the restructuring of processes and responsibilities throughout the company.

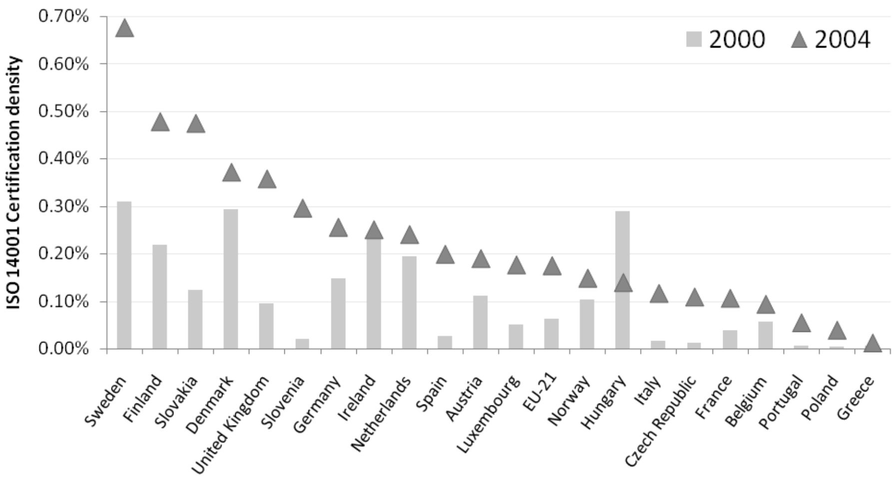
26. There are many ways in which EMSs can be implemented due to organisational and industry diversities. Standards nevertheless exist for guiding and securing the coherence of main principles. The two main standards, for which a certification also can be obtained, are ISO 14001, developed by the International Organization for Standardization (ISO), and the Eco-Management and Audit Scheme (EMAS), developed by the European Commission. These schemes aim to ensure that companies adopt an environmental policy, that environmental responsibilities are clearly designated throughout the organisation, and that they undergo external audits of the system.

Figure 3. A typical cycle of environmental management systems



27. EMS implementation can be useful not only for improving the environmental performance of manufacturing processes (Johnstone, *et al.*, 2007) but also for meeting increasing pressure from stakeholders, improving the corporate image, as well as reducing risks of environmental liabilities and non-compliance (Perotto, *et al.*, 2008). Much evidence, albeit mostly from case studies of individual companies, also points to the fact that the introduction of EMSs lead to better financial performance. The number of EMS certifications has grown substantially in some countries, though the proportion of certified companies is still very low (see Figure 4 in case of Europe).

Figure 4. Percentage of company population with ISO 14001 certifications in EU Member States



Source: Eurostat.

28. The measurement of environmental performance lies at the heart of any EMS as it provides the information that is essential for managing and reducing environmental impacts. Assessing environmental performance, however, is not a marginal task and is subject to methodological debates.[2] Environmental performance is typically monitored through process measurements, and managed by the help of various indicator sets that aim to summarise and simplify relevant information from the production system (Indicator issues are extensively discussed in DSTI/IND(2008)17).

Lifecycle thinking and green supply chain management

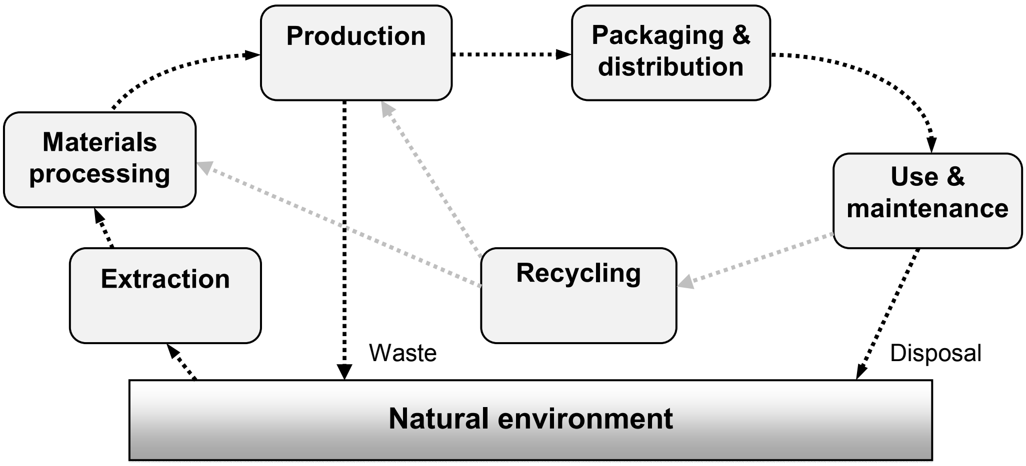
29. One of the most widely used tools for measuring environmental impacts and assisting decision-making over the development of new products/services and processes is lifecycle assessment (LCA). As its name stands, this tool is based on a particular way of thinking that aims to reduce the use of resources and environmental impacts throughout the entire life-span of products and services. Lifecycle thinking goes beyond cleaner production as it emphasises the need for companies to look beyond their conventional boundaries when considering environmental impacts of their activities. This involves taking into account environmental impacts and responsibilities that arise from the extraction of materials through the design of products/services and production processes to the consumption and the final disposal of products/services. For this reason, LCA is also referred to as "cradle-to-grave" analysis.

2 To address the difficulties in environmental performance measurement, the ISO published the ISO 14031 standard in 1999 which contains guidance on the design and use of environmental performance evaluation in alignment with the ISO 14001 EMS standard. This issue is still under discussion (Perotto, 2008).

30. The lifecycle philosophy and management approaches have laid the foundation for a range of relatively new and proactive environmental initiatives and business models, in which environmental considerations expand beyond the manufacturing facility and into the entire value chain. On the policy level, this trend has been reflected by Extended Producer Responsibility (EPR) initiatives and the European Union's Integrated Product Policy (IPP) that seek to extend the responsibility of producers throughout the product lifecycle.

31. One of the focus areas that emerged from the lifecycle thinking and its application is the concept of *green* (or sustainable) *supply chain management* (GSCM) (Seuring and Muller, 2007). The main idea of GSCM basically follows the structure in Figure 5 as it includes environmental considerations into the total chain of exchange from original source of raw materials, through the various companies involved in extracting and processing, manufacturing, distributing, and to consumption and disposal (Saunders, 1997).

Figure 5. Lifecycle thinking



32. The adoption of GSCM is far more demanding as it, in addition to various elements of cleaner production and implementation of EMS, requires the development and maintenance of close co-operative relationships with external entities such as suppliers and retailers. This can constitute a significant challenge for any company to adopt GSCM, especially for large companies that rely on thousands of suppliers and sub-contractors.

33. The pressure for companies to be accountable for their environmental and social responsibilities is, nevertheless, rising. This has led to the practice of *corporate social responsibility* (CSR) whereby companies, on an ethical and voluntary basis, declare their commitment to consider the consequences of their business activities and to take responsibilities for them beyond legal requirements.

34. In recent years, CSR has emerged as a mainstream business issue, mostly due to a growing attention to social and environmental issues and a rising demand for improved business ethics from governments, activists, the media, investors, and the like (Porter and Kramer, 2006). CSR is principally a voluntary approach but some governments are adding pressures onto companies to improve their accountability by, for example, requiring the disclosure of ethical, social and environmental risks in annual corporate reporting (*e.g.* France).

35. Yet, even though CSR constitutes an important element of industry's move towards sustainable development, a company's adoption of CSR does not automatically guarantee that the company will subscribe to sustainable manufacturing practices. Also, while a growing number of companies are now

addressing issues related to CSR, not many of them are clear on what exactly this involves and which concrete actions to take (Porter and Kramer, 2006). Sustainability reports themselves tend to offer a compilation of uncoordinated efforts of social and environmental activities. Provisions of coherent frameworks and strategies on how the company is addressing, or plans to address, its social and environmental responsibilities, and how these are linked to the company's core business strategy, have not been widely addressed (GRI and KPMG, 2008).

36. Also, a recent study indicates that a majority of 45 European companies which were asked about their understanding of CSR emphasised the importance of compliance with mandatory legal requirements as opposed to going beyond such regulations (Öko-Institut, *et al.*, 2008). One of the major reasons for this lies in the difficulty in understanding how benefits of CSR activities, which usually occur in the medium to long term, can be quantified and related to the associated investments. This naturally leads to disincentives for engaging in sustainable practices and makes such efforts even more vulnerable in times of high economic uncertainty.

Box 2. Corporate sustainability reporting and socially responsible investment (SRI)

Public sustainability reporting regarding environmental and social activities of companies and their supply chain provides a mechanism for companies to inform stakeholders about their accomplishments and targets for the future towards sustainable development. Reporting typically happens on a voluntary basis, and therefore without stringent requirements, but can to some extent be considered as a company's non-financial equivalent to its financial report.

Even though sustainability reporting has been mostly used as a communication tool, the activity is nevertheless widely recognised as an important mechanism for improving corporate environmental and social performance. Some reporting schemes offer guidance and examples on how sustainability risks and opportunities are measured and reported and can often assist companies in identifying areas for improvements and value creation. A growing number of companies have also been engaged in sustainability reporting as mainstream investment managers increasingly look at what lies beyond the balance sheet in addition to those involved in socially responsible investment (SRI). Moreover, international initiatives such as the UN Global Compact and the UN Principles for Responsible Investment (PRI) are adding the pressure onto companies to report on their sustainability performance.

Today, several frameworks and guidelines on how and what to report exist – among them, the Global Reporting Initiative (GRI)'s Sustainability Reporting Guidelines are becoming an internationally accepted standard (For more details, see DSTI/IND(2008)17).

A new industrial revolution

37. To meet the global environmental challenges caused by the consumption and production patterns that have been established since the Industrial Revolution, there is a need for shifting perceptions and finding ways by which the ideas and concepts that traditionally have been viewed as trade-offs can be integrated. In essence, there is a need for a "New Industrial Revolution" where economic wealth goes hand-in-hand with environmental and social sustainability. The increasingly blurred demarcation of manufacturing and services (Mont, 2002), or goods and services, could be seen as an early example of developments in this direction. Switching towards better environmental performance through material flow reduction has led to a more integrated approach of sustainable manufacturing, often referred to as *product-service systems* (PSS). PSS encourages companies to increase the re-use and re-manufacturing of products. Taking this further, the need for virgin materials can be drastically reduced by adopting a *closed-loop production* where the re-sourcing of materials that currently exist in the production system is maximised. Advanced solutions adopt an even more holistic view of manufacturing, such as the idea of *industrial ecology*, where the effluents of one producer's operations are used in another producer's production.

a) Product-service systems (PSS)

38. Whereas traditional manufacturing focuses on the production and supply of goods to consumers, a PSS focuses on the delivery of consumer utility and product functionality. For example, when producing and supplying photocopiers to their consumers, a company based on the PSS model retains product ownership by supplying the photocopier as a function such that consumers only purchase the copying service and not the product itself.

39. The PSS concept is widely used in the sustainability-related articles but rarely in the mainstream business literature (Tukker, *et al.*, 2006). In the business literature, however, concepts such as “offerings”, “value propositions”, “functional sales”, “experiences” and “servicising” are used for similar meanings.

40. The PSS approach in fact has been applied in business-to-business contexts for years. When applied to consumer products, however, PSS can have far reaching implications with respect to business management, production strategies and environmental benefits. They are derived from the fact that product ownership never be transferred from the producer to the consumer, and therefore that the costs of product maintenance, retirement, and replacement are internalised for the producer’s profit maximisation objectives. As such, because the entire stock of manufactured goods is essentially “stored” by consumers, companies need not sell more products to maximise profits. Instead, profits can also be made by minimising material consumption and increasing product re-use, recycling and re-manufacturing. In effect, this could bring far-reaching environmental benefits.

41. Another environmental benefit of PSS could be gained from increasing product-use intensity, by sharing the same products among many consumers. Today, a car is parked most of its lifetime rather than being driven, and an electric drill is typically used only a few times a year. The application of PSS, therefore, may lead to a radical reduction in the production of physical goods and thus less material consumption and waste generation. PSS also offers the opportunity to alleviate the pressure of realising profits in markets characterised by rapid changes in consumer preferences and fast technological developments (Behrendt, *et al.*, 2003).

42. The adoption and financial viability of PSS depends on a number of changes with respect to economic, social and technological infrastructures as well as business models (Mont, 2002). From the perspective of manufacturing companies, for instance, PSS could imply a shift from the traditional point-of-sale business model to one centred on long-term service contracts which affects the organisational management and marketing of products. The major issue from consumers’ point of view relates to product ownership. They need to change their perception of products from “own” to “lease” and from “use” to “share” in order for the PSS model to function, but ownership of certain products is strongly entangled with their own identity and status (*e.g.* cars, luxury goods, housing). An indication of this difficulty can be seen from the car leasing and sharing schemes which, despite their success, have remained a tiny fraction of the entire car market (see Box 3).

Box 3. Application of product-service systems: Electrolux and InterfaceFLOR

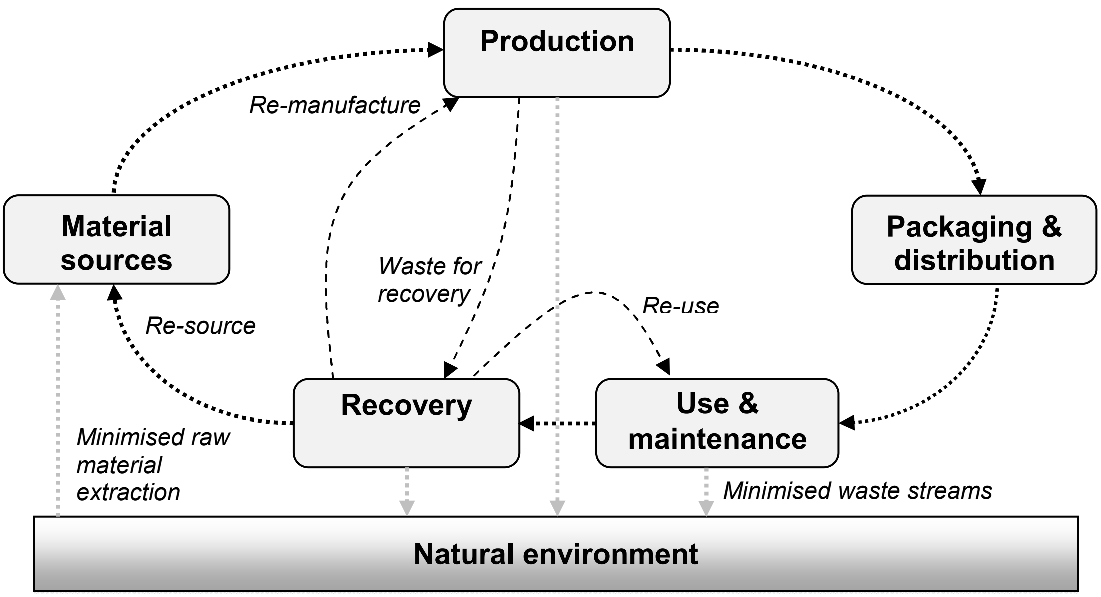
Electrolux, a Swedish producer of domestic appliances, has been investigating the idea of selling cleaning services instead of washing machines. Based on a pilot project engaging 50 households, Electrolux implemented a PSS based on pay-per-wash cleaning services, an automatic replacement programme that replaces the washing machine after 1,000 washes (4-5 years), and an intelligent central data facility that monitor and automate the service (Mont, 2001). Electrolux is also engaged in the establishment of community-based washing centres by supplying appliances, installation of the equipment, training of service personnel, assistance with environmental permits, contracts for the maintenance of the appliances and take-back options (Mont, 2006).

Similarly, InterfaceFLOR, an American producer of carpets, is offering carpet rotation and replacement services instead of selling carpets. This product-service system is part of a broader initiative called "Mission Zero" through which the company aims to eliminate all forms of waste from its facilities by 2020, including carpets that are sent to landfill after end usage. InterfaceFLOR is using the rotation and replacement service as a model to take back old carpets for what they call "re-entry" – recycling for materials that can be used for new carpets to decrease the use of virgin petroleum-based raw materials (www.interfaceflor.com).

b) Closed-loop production

43. Closed-loop production is similar to the lifecycle thinking but distinguishes itself by "closing" the material resource cycle, implying that all components that currently exist in the system are re-used, re-manufactured or re-sourced in some way. This entails a shift from traditional linear production methods to a circular and more systemic perspective – where products and processes are designed with "re-incarnation" in mind. The need for virgin materials is eliminated, or drastically reduced, and waste is re-sourced into the system. Closed-loop production, therefore, constitutes advancement of the "cradle-to-grave" thinking towards "cradle to cradle" (McDonough and Braungart, 2002).

Figure 6. Closed-loop production system



44. The development of closed-loop manufacturing requires a strong focus on the product design process. In addition to minimising the material and energy usage needed for making products and their distribution as well as the impacts from product use and disposal, the design process must also take into account how products and wastes can be best recovered. For heavy machinery, for instance, vehicle designs can be optimised not only by using the fewest possible harmful materials and aiming the highest

fuel efficiency, but by designing the vehicles for disassembly/separation, cleaning, inspecting, repairing, replacing, long lifetime duration, and for reassembling and "rebirth". By tapping into the large resource potentials that exist in the current waste flow, the need for virgin materials and waste disposal could be significantly reduced. The idea of PSS discussed above can facilitate business conditions for realising closed-loop production as an important building block for sustainable manufacturing (Behrendt, *et al.*, 2003) (see Box 4).

Box 4. Product design, re-manufacturing and PSS

Re-manufacturing is a practice that can reduce environmental impacts while increasing revenues. Xerox (photocopying machines) and Caterpillar (construction and mining equipment) are two companies that have embraced this idea as an integral part of their business models and have improved their environmental conduct by doing so.

For commercial reasons, Xerox was an early adopter of leasing instead of selling its products. In the 1980s, however, Xerox set the goal of becoming a "Waste Free Company" and introduced several environmental measures including toxic waste management, cleaner production techniques, and eco-friendly design for higher energy efficiency and ease of disassembly for remanufacturing and recycling (Roy, 2000). A range of photocopiers containing remanufactured components were introduced in 1993 with guarantees to be of equal quality and performance to "new" copiers. Today, Xerox sells "printing and document services" including provision and maintenance of copiers, and collection, copying and delivery of documents. Some of their products can have up to 7 lives (Gray and Charter, 2006); www.xerox.com).

Caterpillar has, like Xerox, established ongoing revenue opportunities for several generations of their product lines through clever design strategies and collection mechanisms that maximise remanufacturing possibilities. Using financial incentives for customers to return equipment after their lives, Caterpillar is able to remanufacture components for a fraction of the original cost while keeping attractive profit margins even if the remanufactured products are sold at discount prices with the same warranties as new products (Gray and Charter, 2006). Besides having a positive financial impact, there is an environment benefit as the consumption of materials, energy and water is reduced (America.gov, 2008).

c) Industrial ecology

45. The extensive application of closed-loop production thinking and techniques across industries and society at large beyond a single company boundary is named *industrial ecology*. Industrial ecology, which stems from systems theory, is broader and more holistic in its view of industrial production system compared to closed-loop production. The name derives from the concept's focus on seeing industrial society as an analogy to environmental ecology and its use of natural eco-systems as a metaphor and model to better organise industrial production (Frosch and Gallopoulos, 1989). Following the metaphor, industrial ecology distinguishes itself by considering the industrial production system as an interdependent part of the environmental system (Garner and Keoleian, 1995). That is, industrial society must be viewed not in isolation from its surrounding systems but in concert with them (Jelinski, *et al.*, 1992).

46. In relation to closed-loop production, industrial ecology could be viewed as "a system of systems", which ties several closed-loop production systems together by a circular flow of resources such that one system's effluents are used as another system's input, while also operating in harmony as a part of the greater environmental system. This means that industrial ecology not only relies on materials that can be re-sourced in the industrial production system, such as aluminium which can be re-used, but also materials that are reusable in the natural environmental system, such as textile that can be re-used as biodegradable garden mulch after its life as an upholstery fabric. Mimicking ecosystem terminology, this distinction between materials can be referred to as technical and biological nutrients (McDonough and Braungart, 2002). The development and implementation of such a system necessitates a multi-disciplinary and multi-organisational approach where stakeholders from various industrial sectors and societal areas and disciplines are engaged in intelligent and co-operative partnerships. This highlights that no single company can become sustainable on its own.

47. At the present stage, there is a considerable gap between the theoretical approaches and visions for industrial ecology, and what is actually being implemented in society under the circumstance where the value chain of manufacturing companies is increasingly being globalised. However, some industrial applications of industrial ecology have been attempted through the establishment of "eco-industrial parks". These parks are comprised by a cluster of companies that seek to harness industrial symbioses through close co-operation with each other, and with the local community, by mutually sharing resources to improve economic performance while minimising waste and pollution (see Box 5). This idea is also promoted by the United Nations University (UNU) Zero Emissions Forum, which is establishing pilot eco-park projects as well as researching industrial synergies and sustainable transactions (Kuehr, 2007).

Box 5. An eco-industrial park in Denmark

One of the earliest and most well-known eco-industrial parks is located in Kalundborg, Denmark. Rather than being the result of a carefully planned process, the eco-park has developed gradually through the co-operation between a number of neighbouring industrial companies. The main participating companies comprise a coal-fired power plant (Asnæsværket), a refinery (Statoil), a pharmaceutical and industrial enzyme plant (Novo Nordisk and Novozymes), a plasterboard factory (Gyproc), a soil remediation company (AS Bioteknisk Jordrens), and the municipality of Kalundborg through the town's heating facility.

The evolution of the eco-park was initiated when Gyproc located its facility in Kalundborg in 1970 to take advantage of the butane gas available from the Statoil refinery and at the same time enabling Statoil to stop flaring this gas. Since then, the network has grown and today the participating companies are highly integrated. For instance, surplus heat from the power plant is used to heat about 4,500 private homes and water for fish farming, and fly ash is supplied for production of cement. Process sludge from fish farming and Novo Nordisk is supplied to nearby farms as fertiliser. Novo Nordisk also supplies farms with surplus yeast from insulin production for pig food. The Statoil refinery supplies pure liquid sulphur from its de-sulphurisation operations to a sulphuric acid producer (Kemira).

The exchanges above only describe a part of the material flow of the Kalundborg eco-park, which in total has been estimated to be around 2.9 million tonnes per year including fuel gases, sludge, fly ash, steam, water, sulphur and gypsum (Gibbs, 2008). This industrial symbiosis has served to reduce the environmental impacts from industrial production and led to significant economic savings. The participating companies are constantly co-operating on finding new ways of improving the industrial symbiosis based on economic and environmental consciousness (For more information, see www.symbiosis.dk).

48. Industrial ecology is also closely linked to the concept of *biomimicry* which was derived from "life" (bios) and "imitation" (mimesis). Coined by Janine Benyus in 1997, this concept advocates that industrial production can learn from nature to establish sustainable consumption and production patterns (Benyus, 1997). Biomimicry essentially seeks to draw inspiration from nature in the creation of new industrial products/services and processes. In contrast to industrial ecology, which is more concerned with the industrial production system's structural arrangements, this concept promotes a process-oriented view on production.

A summary on the evolution of sustainable manufacturing

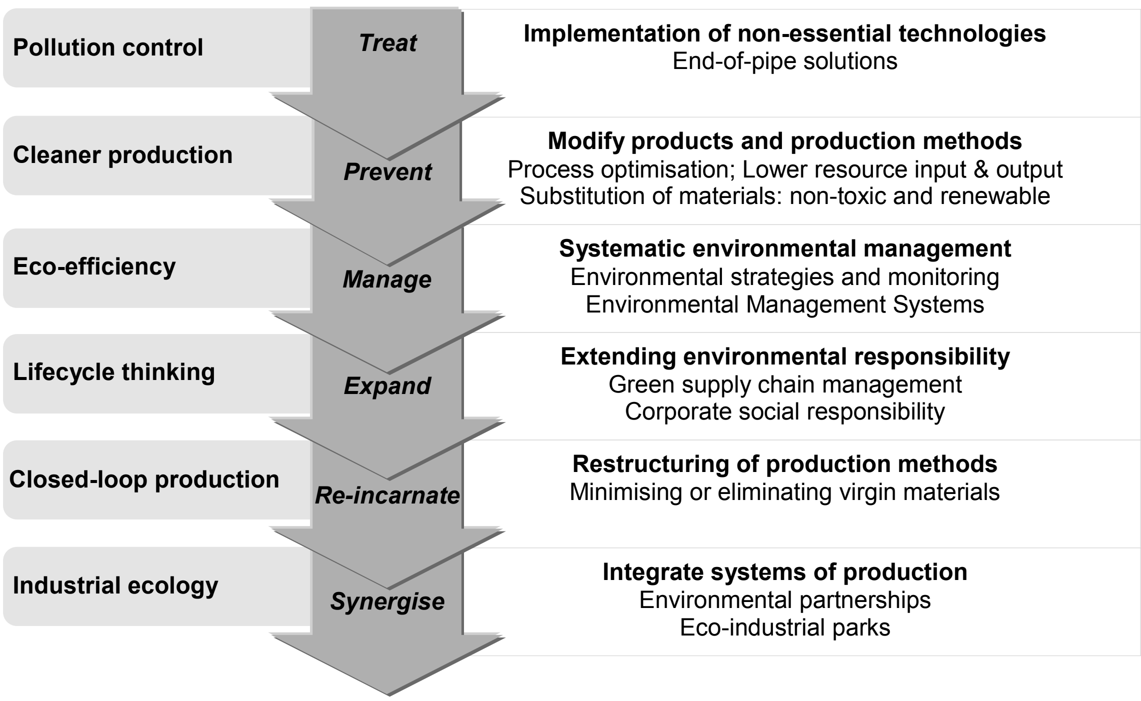
49. To sum up, the thinking and practices for sustainable manufacturing have evolved in several ways in the last decades – from the application of technology for the control and treatment of pollution at the end of the pipe through the prevention of pollution to minimising inputs and outputs and substituting toxic materials. Recently, manufacturing companies have focused on solutions that employ more integral methods to minimise material and energy flows by changing products/services and production methods and re-incarnating disposed output as new resources for production.

50. Advancements towards sustainable manufacturing have also been achieved through better management practices. Environmental strategies and management systems have allowed companies to better identify and monitor their environmental impacts and have facilitated improvements in

environmental performance. Although such measures were initially limited to the application in plant-specific production systems they have evolved into the support for better environmental management throughout the value chain of companies.

51. More integrated and systematic methods to improve sustainability performance in manufacturing industries have laid the foundation for the introduction of new business models such as product-service systems which could lead to significant environmental benefits. Furthermore, although still few in numbers, more efficient and intelligent ways of structuring production systems are being established, such as eco-industrial parks where economic and environmental synergies between traditionally unrelated industrial producers are harnessed (see Figure 7).

Figure 7. The evolution of sustainable manufacturing concepts and practices



3. Eco-innovation

52. In the last few years, many companies and consulting firms have started using *eco-innovation* or similar terminologies to present positive business contributions to sustainable development through innovation and improvements in production processes and products/services. Even a few governments and the European Union are now promoting the concept as a way to fulfil sustainable development targets while keeping industry and the economy competitive.

53. In the European Union (EU), eco-innovation has been considered to support the wider objectives of its Lisbon Strategy for competitiveness and economic growth. In 2004, the Environmental Technology Action Plan (ETAP) was introduced to promote the development and implementation of eco-innovation[3].

3 The ETAP is actively seeking to consolidate an EU-wide market for environmental technologies. One of the core areas in this regard is the development of an Environmental Technology Verification (ETV) system that can help to accelerate market acceptance of key innovative technologies by providing accurate and verified information on technology performance. The European Commission is working closely with the United States and Canada where ETV systems have already been implemented.

The ETAP defines eco-innovation as "the production, assimilation or exploitation of a novelty in products, production processes, services or in management and business methods, which aims, throughout its life cycle, to prevent or substantially reduce environmental risk, pollution and other negative impacts of resource use (including energy)". The action plan provides a general roadmap for promoting environmental technologies and business competitiveness by focusing on: *i)* bridging the gap between research and markets; *ii)* improving market conditions for environmental technologies; and *iii)* acting globally. Eco-innovation now forms part of the EU's Competitiveness and Innovation Framework Programme running from 2007 to 2013, which offers EUR 28 million funding in 2008 to stimulate the uptake of environmental products, processes and services especially among SMEs.

54. In the United States, environmental technologies are also seen as a promising potential for improving environmental conditions without impeding economic growth, and are being promoted through various public-private partnership programmes and tax credits (OECD, 2008). In 2002, the Environment Protection Agency (EPA) laid out a strategy for achieving better environmental results through innovation (EPA, 2002). Based on this strategy, the EPA set up the National Center for Environmental Innovation and is promoting the research, development, and demonstration of technologies that contribute to sustainable development in partnership with state governments, businesses and communities.

55. While the promotion of eco-innovation so far has focused mainly on the development and application of environmental technologies, there is an increasing emphasis to go beyond these areas. This not only reflects the growing understanding of and research in the non-technological aspects of innovation, such as *organisational innovation* and *marketing innovation* that are defined in the latest version of the OECD Oslo Manual (OECD, 2005), but also eco-innovation's focus on sustainable development that demands broad structural changes in society.

56. In Japan, the government's Industrial Science Technology Policy Committee introduced the term eco-innovation in 2007 as a more overarching concept that provides the direction and visions for societal changes – as well as technological changes – needed to achieve sustainable development. The committee considers that the current pattern of economic growth achieved through "functionality-oriented, supplier-led mass consumption" is approaching its limit due to constraints of the environment, resources and energy. Under the circumstances that people in the country have been highly satisfied in material terms, it argues that the economic growth in the twenty-first century can be pursued from the demand side through appealing to people's *kansei* (sensitivity). In order to bring this into reality, it adds that the establishment of a new socio-industrial structure where environmental conservation and economic growth fuse together would be necessary. In short, the committee defines eco-innovation as "a new field of techno-social innovations [that] focuses less on products' functions and more on [the] environment and people". In more concrete terms, the committee proposes to promote the construction of "zero emission-based" infrastructures in energy supply, transport and town development, as well as sustainable lifestyles through selling services instead of products and visualising environmental and *kansei* values (METI, 2007).

57. As such, there is some diversity in the scope of applying the concept of eco-innovation, while overall aims for promoting this term seem to be common in the direction of pursuing economic and environmental sustainability in parallel. With the aim to unify the conceptual understanding of eco-innovation, and to facilitate the construction of an analytical framework that combines eco-innovation with sustainable manufacturing dealt with in Section 4, this section attempts to draw a conceptual and typological overview of eco-innovation and the different areas to which the concept can generally be applied for diverse types of businesses.

A conceptual overview of eco-innovation

58. The term eco-innovation first appeared, among others, in the book *Driving Eco-innovation* written by Claude Fussler and Peter James in 1996. The authors defined the concept as "new products and processes that provide customer and business value while significantly decreasing environmental impacts". Following the overarching concept of sustainable development the broader meaning of eco-innovation has come to include social and institutional aspects. Although some strands in the literature attempt to discern and highlight differences between concepts such as "eco-innovation", "environmental innovation", "innovation for sustainable development", and "sustainable innovation", they are mostly used interchangeably (Charter and Clark, 2007). This paper primarily uses the eco-innovation terminology, but it makes no distinction with the related concepts.[4]

59. Eco-innovation is closely related to the conventional understanding of innovation which, following the OECD Oslo Manual, can be described as the creation and application of new, or significantly improved, products (goods or services), or processes, marketing methods, or organisational methods in business practices, workplace organisation or external relations (OECD, 2005). This interpretation is distinct from invention, which refers to the phase in which the idea behind the innovation is conceived. It is also distinct from the dissemination process of the innovation. Combined, however, *invention*, *innovation* and *dissemination* constitute what is referred to as the *innovation process*. This process should also be applicable to eco-innovation.

60. Eco-innovation may, however, be distinguished from conventional innovation in two significant ways. Firstly, eco-innovation is not an open-ended concept as it represents innovation with a specific direction. This direction reflects the concept's explicit emphasis on resulting in a reduction of environmental impact whether such an effect is intended or not. Secondly, eco-innovation is not limited to innovation in products, processes, marketing methods and organisational methods, but also includes innovation in social and institutional structures (Rennings, 2000). This reflects the fact that the eco-innovation's scope could go beyond the conventional organisational boundaries of the innovating company and into the broader societal sphere through changes in social norms, cultural values and institutional structures – in partnership with stakeholders such as competitors, companies in the supply chain, those from other sectors, governments, retailers and consumers – to realise or leverage more environmental benefits from the innovation.

61. Based on the Oslo Manual (OECD, 2005) and drawing from other sources (*e.g.* METI, 2007; Reid and Miedzinski, 2008; UM-MERIT, *et al.*, 2008)[5], eco-innovation can be described as "the creation of new, or significantly improved, products (goods and services), processes, marketing methods, organisational structures and institutional arrangements which, with or without intent, lead to environmental improvements compared to relevant alternatives". Following this interpretation, "innovation" and "eco-innovation" are distinguished solely by their environmental effects compared to relevant alternatives; the definition therefore only provides a weak conceptual demarcation of innovation and eco-innovation and should only be seen as a starting point for eco-innovation analysis. Thus, to

4 The Japan's eco-innovation concept aims at higher satisfaction of human needs and higher quality of life as well as environmental protection. As the first stage of this project, the concept of eco-innovation is described as the one covering only environmental aspects. However, the inclusion of social aspects in this concept can be considered by simple extension of the application areas and impacts of eco-innovation.

5 For example, the EU-funded Measuring Eco-innovation (MEI) project proposes that eco-innovation be defined as "the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives"(UM-MERIT, *et al.*, 2008).

facilitate the comparison and analysis of different business activities aimed at eco-innovation, the concept, and its typology, is further elaborated below.

Typology of eco-innovation

62. Inspired by existing innovation and eco-innovation literature (*e.g.* OECD, 2005; Charter and Clark, 2007; Reid and Miedzinski, 2008), it is proposed that eco-innovation can be analysed according to three key axes; referring to the innovation's *1)* target; *2)* mechanism; and *3)* impact:

1) **Target** refers to the basic focus area of eco-innovation. Following the typology defined in the Oslo Manual, the target of an eco-innovation can be categorised into: *i) products* (both goods and services); *ii) processes*, such as a production method or procedure; *iii) marketing methods*, referring to the promotion and pricing of products, and other market oriented strategies; *iv) organisations*, such as the structure of management and the distribution of responsibilities; and *v) institutions*, which include broader societal areas beyond a single company's control such as broader institutional arrangements as well as social norms and cultural values.

2) **Mechanism** relates to the method by which the change in the eco-innovation target takes place or is introduced. It is also associated with the underlying nature of the eco-innovation – whether the change is of technological or non-technological character. Four basic mechanisms are identified: *i) modification*, such as small, progressive product and process adjustments; *ii) redesign*, referring to significant changes in existing products, processes, organisational structures, etc.; *iii) alternatives*, such as the introduction of goods and services that can fulfil the same functional needs and operate as substitutes for other products; and *iv) creation*, comprising the design and introduction of entirely new products, processes, procedures, organisations and institutions.

3) **Impact** refers to the eco-innovation's effect on the environment conditions, across its lifecycle or some other focus area. The impact depends on the combination of the innovation's target and mechanism, which here is referred to as the innovation's *design*, and can be illustrated across a continuous range starting from incremental environmental improvements to the complete elimination of environmental harm. For particularly well-defined areas, it can be related to the concept of "factor" which is used to describe technological performance with respect to energy and resource efficiency. A factor 2 improvement in CO_2 emissions, for example, denotes a 50% reduction, everything else being equal.

63. Based on the typology above, eco-innovation can be approached from three axes which enable companies to design and analyse their eco-innovative initiatives and strategies with respect to specific areas (targets), the type of progress that is being made (mechanisms), and the resulting effects (impacts). While this approach can be applied to eco-innovative initiatives across all targets and mechanisms, it is generally possible to draw a distinguishing feature of the underlying nature of change with respect to eco-innovation in products and processes compared to marketing methods, organisations and institutions. Eco-innovation in products and processes, for instance, are typically considered more closely related to technological advancements regardless of the eco-innovation's basic mechanism described above. With regards to marketing methods and organisational structures, on the other hand, the eco-innovative mechanisms tend to be more associated with non-technological changes (OECD, 2007). This notion extends to changes in institutional arrangements. These differences, along with the impact of eco-innovation, are further illustrated below.

Eco-innovation in products and processes

64. Advancements in products and processes, which tend to rely on technological advances, cover a broad range of tangible objects that can improve environmental conditions and could therefore also be referred to as technological eco-innovations. Among examples are computer chips that are faster while consuming less energy, cars that are more fuel efficient, and production methods that use fewer resources. Generally, they are also characterised by their curative or preventive nature.

65. Curative eco-innovative technologies are equivalent to end-of-pipe technologies as described in Section 2, because they are aimed at reducing or eliminating contaminants that have already been produced. Preventive eco-innovative technologies, on the other hand, aim to reduce or eliminate the source which produces the pollutants. These technologies are thus related to cleaner production techniques but they could be unintended results of efforts to improve general business profitability.

66. Both curative and preventive eco-innovative products and processes can offer large potential for tackling environmental challenges. Yet, from a broader sustainability perspective, they should only be seen as part of the solution (Brown, *et al.*, 2000). Furthermore, if promising solutions are not tested with a view to their potential adverse effects, some may even lead to the creation of new environmental hazards and problems (Reid and Miedzinski, 2008) (see Box 6). See the Annex for an overview of selected work in the OECD with relevance to eco-innovation in products and processes.

Box 6. The rise and fall of CFC gases

Chlorofluorocarbon (CFC) gases were developed in the 1930s to replace hazardous materials such as sulphur dioxide and ammonia. Due to their non-toxic, non-flammable and non-corrosive properties, and being both inexpensive and efficient, they were long considered to be an ideal refrigerant. The use of CFCs increased rapidly after their market introduction not only in air conditioning and refrigeration equipment but also throughout a large range of industrial applications.

In the 1970s, however, it was found that CFC gases have an ozone depletion effect. Large reductions in the ozone layer, particularly over the Antarctica, were reported in the mid-1980s and concerns about an increased likelihoods of skin cancer rose. This eventually led to the ban of CFC gases through an international agreement when the Montreal Protocol on Substances that Deplete the Ozone Layer entered into force in 1989 (WMO and UNEP, 1998; 2006).

Eco-innovation in marketing, organisations and institutions

67. Contrary to products and processes, eco-innovation in marketing methods, organisational structures and institutional arrangements tends to follow mechanisms of a non-technological nature. Such changes constitute a relatively new area in the innovation literature and were only adopted by the third and latest revision of the Oslo Manual in 2005 with the introduction of innovation in marketing methods and organisational structures.

68. Eco-innovation in marketing includes new ways by which environmental aspects are integrated into communication and sales strategies. Eco-innovative marketing concerns the company's orientation towards customers and can play a significant role in leveraging environmental benefits through influencing them. This can be achieved, for instance, by improving general product and company appeal in connection with the development and/or sale of eco-efficient products through better market research, direct contact with consumers, and marketing practices that appeal to environmentally aware consumers. Eco-innovation in marketing may also include new business models that change the way products are priced, offered and promoted such as the adoption of product-service systems (PSS).

69. Organisational eco-innovation includes the introduction of new management methods such as environmental management systems (EMSs) and corporate environmental strategies. While these areas concern general environmental business practices, organisational eco-innovation can also take form through changes to the company workplace such as by centralising or decentralising environmental responsibilities and decision-making powers, and by establishing training programmes for employees designed to improve environmental awareness and performance. Organisational eco-innovation also includes changes in how companies organise their relations with other firms and public institutions such as the adoption of green supply chain management and the participation in public-private partnerships for environmental research and projects.

70. Although institutional innovation is not covered by the Oslo Manual, the literature on conventional innovation emphasises the importance of co-evolving social and institutional changes in connection with, but as a separate part of, the innovation process (Grubb, 2004; Reid and Miedzinski, 2008). In the context of sustainability, however, a small but growing body of literature argues that changes in social norms, cultural values and institutional structures can be considered eco-innovative solutions in themselves or constitute intricate parts hereof (Rennings, 2000). This view is gaining ground from a policy perspective where, in Japan for instance, eco-innovation increasingly is viewed as a field of techno-social innovations that not only can improve environmental conditions but also satisfy subjective valuations linked to higher-order human senses and intuition, also known as *kansei* (METI, 2007).

71. The concept of institutions generally covers a wide range of societal aspects ranging from social norms and cultural values to codified laws, rules and regulations, and from loosely established social arrangements to deliberately created institutional frameworks. In some cases institutions are seen as exogenous rules that are determined outside the domain of market transactions, and in other cases they are seen as endogenous formations (Van de Ven and Hargrave, 2002; Aoki, 2007. This paper adopts a distinction between *informal* institutions such as social norms and cultural values, which tend to be highly endogenous, and *formal* institutions such as codified laws, regulations, and formal institutional frameworks and arrangements, which tend to be based on policy and economic decisions. Although eco-innovation in formal and informal institutions may overlap, formal institutional eco-innovation is typically the result of strategic consideration and planning whereas this tends not to be the case for informal institutions.

72. Eco-innovation in informal institutions refers to changes in value patterns, beliefs, knowledge, norms, etc. that lead to improvements in environmental conditions through social behaviours and practices. For instance, eco-innovation in informal institutions could include shifts in modes of transportation, *i.e.* from personal automobiles or flights to trains, buses or bicycles due to higher environmental awareness or education. It may also include the growth of self-help health groups, community actions for cleaning up the surrounding environment, organic food movements, etc.

73. Formal institutional eco-innovation refers to structural changes that redefine roles and relationships across a number of independent entities, and which typically relies on legal enforcement, international agreements, or voluntary but formal multi-stakeholder arrangements. Institutional eco-innovative solutions may range from agencies to administer and clean local water supplies, financial platforms for funding the development of environmental technologies and the establishment of eco-labelling schemes and environmental reporting frameworks, to new regimes of global governance such as the establishment of a single institution with responsibility for global climate and biodiversity issues (Rennings, 2000). In terms of sustainable manufacturing, the establishment of eco-industrial parks, as described in Section 2, where resource sharing is optimised across seemingly unrelated industrial producers can be considered as an example of a formal institutional eco-innovation.

Impacts of eco-innovation

74. The environmental impact of an eco-innovation stems from the interplay between the innovation's design (target and mechanism) and the socio-technical environment in which the innovation is introduced. From an analytical perspective, the assessment of this impact is of high importance because it determines whether or not the eco-innovation can be classified as such. Also, from a practical point of view, it is important to show that the eco-innovation in fact improves overall environmental conditions. However, the impact assessment of eco-innovation is not a trivial task that requires extensive knowledge and understanding of the innovation and its contextual relationships.

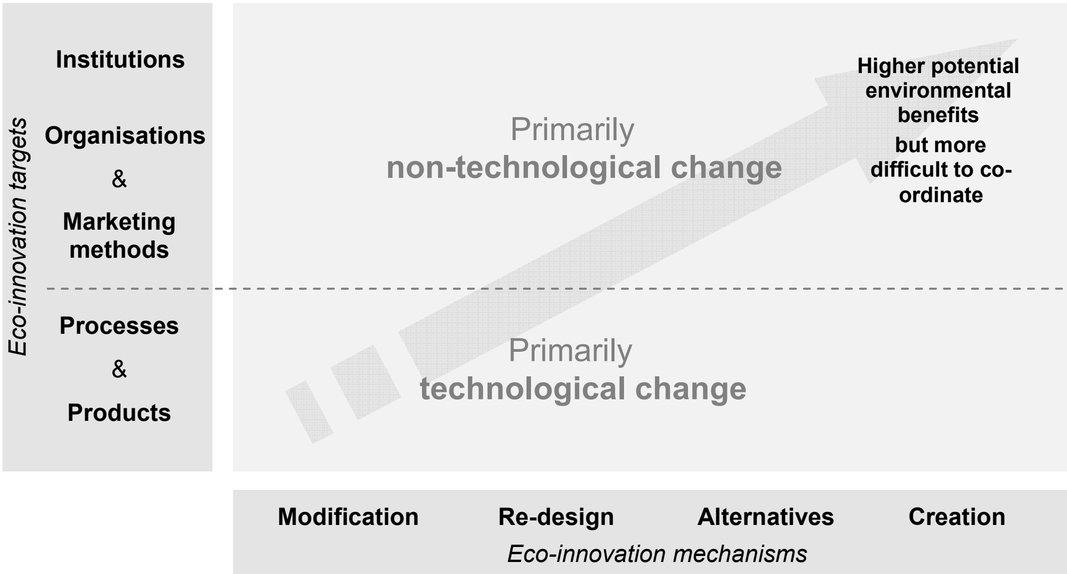
75. For example, improvements in the form of rather simple adjustments that are not even intended to increase environmental performance could turn out having significant environmental benefits. The significance of such benefits could be created through an unexpected interplay with other factors and therefore emanate through indirect systemic and high-level changes, in addition to a more direct result of product/process developments at the micro-level. An illustrative example is the implementation of power outlets and wireless internet provision in trains. While these adjustments at first hand will require extra resources and consume additional energy, thus leading to a direct reduction in environmental performance, the overall environmental impact could more than offset this negative effect if the new facilities, through "green marketing", were to attract business travellers who otherwise would travel by air or automobiles.

76. Hence, it is imperative that eco-innovation assessments need to consider several levels of perspectives, or "entry points", across the eco-innovation's lifecycle (Reid and Miedzinski, 2008), including behavioural and systemic consequences of the innovation's application and/or usage. These perspectives can be categorised according to the innovation's characteristics viewed from the *micro-level*, referring to companies and individuals; the *meso-level*, including supply chains, sectoral structures, regional perspectives, etc.; and the *macro-level*, referring to countries, economic blocks and the global economy. A setback in this regard is the lack of proper and recognised methodological approaches, which relates to the fact that eco-innovation remains a rather unrecognised field in innovation policy and general policy frameworks (UM-MERIT, *et al.*, 2008).

Synthesis of eco-innovation

77. To sum up, eco-innovation can be categorised according to its *target* (products, processes, marketing methods, organisational structures, and institutions); its *mechanism* (modification, re-design, alternatives, and creation); and its environmental *impact*. The target of the eco-innovation can generally also be associated with the technological or non-technological nature. For instance, whereas eco-innovation in products and processes tends to rely heavily on technological development, eco-innovation in marketing, organisations and institutions relies more on non-technological changes. Potential environmental impacts stem from the eco-innovation's target and mechanism and their interplay with the innovation's socio-technical context. Given a specific target, the magnitude of the environmental impact nevertheless tends to follow the eco-innovation's mechanism with modifications generally leading to lower potential environmental benefits compared to creations. An overview of eco-innovation and its typology is sketched in Figure 8.

Figure 8. The typology of eco-innovation



78. So far, the primary focus of eco-innovation has been on the development and application of different technologies as is the case for conventional innovation, but recent evidence suggests that non-technological changes are becoming of higher importance (Reid and Miedzinski, 2008). It is also important that eco-innovative solutions go beyond products, processes, marketing methods and organisational structures, which conventional understandings of innovation has focused upon, and start to tap into areas regarding social norms, cultural values and formal institutional structures. This is particularly the case as the highest potential for system-wide environmental improvements typically is associated with the development of new societal structures and interactions including changes in value patterns and behaviours, as opposed to incremental technological advancements.

4. First Steps in building a common analytical framework

79. Eco-innovation plays a key role for moving manufacturing industries towards sustainable production. Every gear-shift in environmental initiatives – from traditional pollution control to cleaner production initiatives and the establishment of eco-industrial parks – can be characterised as shifts facilitated by eco-innovation. The concept of eco-innovation would help companies and governments to consider and realise these shifts through technological advancement, changes in management tools, social acceptance of new products and procedures, as well as changes in institutional frameworks for facilitating progressive change. Following, an analytical framework that link sustainable manufacturing and eco-innovation is firstly established and then the way to apply the framework is examined.

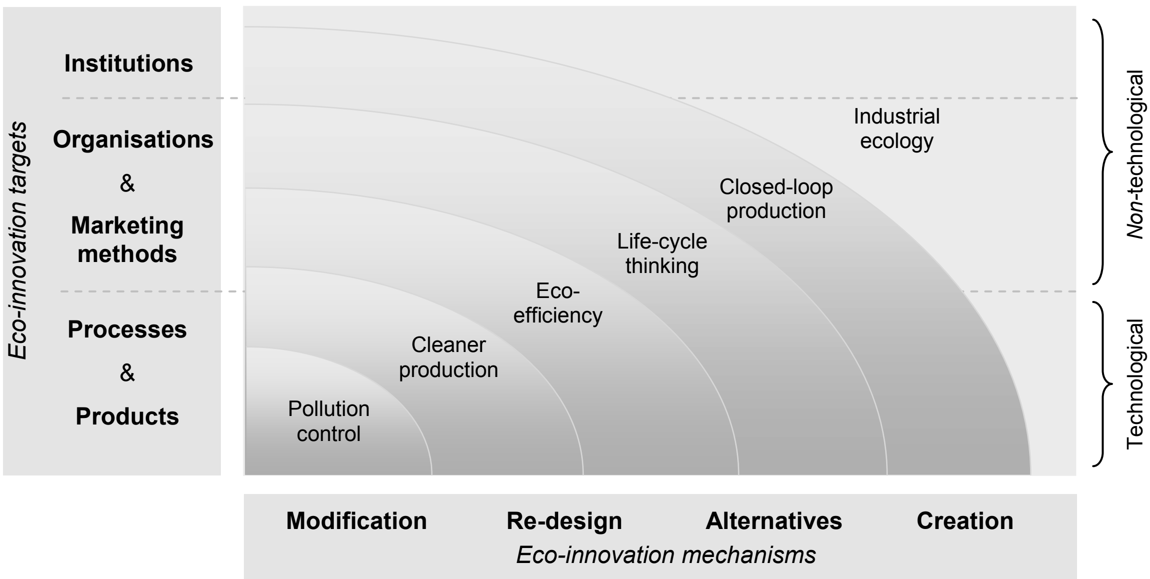
An analytical framework of sustainable manufacturing and eco-innovation

80. With reference to the concepts associated with sustainable manufacturing covered in Section 2, and the three key axes of eco-innovation described in Section 3, it is clear that there are many conceptual overlaps between eco-innovation and sustainable manufacturing. Pollution control, for instance, can be related to the modification of products and processes; cleaner production initiatives are often associated with the implementation of more integrated changes such as re-design of products and production methods. Eco-efficiency and lifecycle thinking are related to eco-design of products and processes, as well as the adoption of environmental management systems and green supply chain management. Closed-loop

production may refer to alternative business models such as the adoption of product-service systems, while industrial ecology can generally be associated with the creation of entirely new production structures.

81. Figure 9 attempts to give a simple illustration of the general conceptual relations and overlaps that exist between sustainable manufacturing and eco-innovation. The evolutionary steps of sustainable manufacturing, as described in Section 2, are depicted in terms of their primary association with respect to eco-innovation; *i.e.* with innovation *targets* on the left, and *mechanisms* at the bottom, as described in Section 3. The underlying nature of eco-innovation (technological or non-technological), as it generally applies, is depicted on the right. The "waves" spreading towards the upper right corner in the figure indicates the path dependencies of different sustainable manufacturing concepts.

Figure 9. Conceptual relationships between sustainable manufacturing and eco-innovation



82. In the medium to long term, the most potentially significant environmental improvements from eco-innovation in manufacturing are those associated with more advanced sustainable manufacturing initiatives such as the establishment of eco-industrial parks and the like. However, these can generally only be realised through a *combination* of a larger range of innovation targets and mechanisms; hence those initiatives cover the bigger area in the diagram. It is not enough, for instance, to simply co-locate manufacturing plants with symbiotic relationships if no technology or procedure for exchanging resources exists. In fact, process modification, product design, business model alternatives and the creation of new methods, procedures and arrangements should go hand in hand and must be co-evolved to leverage the economic and environmental benefits from such initiatives. This also means that as sustainable manufacturing initiatives advance, the nature of the eco-innovation process becomes increasingly complex and more difficult to co-ordinate.

83. Such co-evolutionary, or co-creating, eco-innovation processes that are necessary for establishing more advanced sustainable manufacturing systems is often referred to as *system innovation* – an innovation characterised by large-scale foundational shifts in how societal functions and needs are being provided and fulfilled such as a change from one energy source to another (Geels, 2005).

84. Systemic eco-innovations in manufacturing depend on the interplay between changes across a number of different areas including technological developments, changes in formal institutional structures

as well as changes in social norms and values. Indeed, although the source of system innovations may arise from technological developments, technology alone cannot make large differences but has to be harnessed in association with human enterprise, organisations and social structures. While this highlights the difficulty of achieving large-scale sustainability impacts, it also hints at the need for manufacturing industries to adopt an approach that seeks to integrate the various elements of the eco-innovation process, and to apply it in such a way that the interplay of changes leverages environmental benefits.

Current landscape of sustainable manufacturing from an eco-innovation perspective

85. From an eco-innovation perspective, manufacturing industries have typically been more concerned with the modification and re-design of existing products, procedures and organisational structures, as opposed to being engaged in the creation of new and alternative solutions. The current focus and application of eco-innovative efforts in manufacturing industries have therefore been relatively narrow and limited to technical advancements. This does not imply that environmental performance is not improving, but it could affect the scope and visions of eco-innovative solutions and how they are developed and applied to manufacturing, let alone investments in them. It may also explain why the concept of eco-innovation as a potential transformative power has still remained largely peripheral in most corporate sustainability initiatives (Charter and Clark, 2007).

86. The concept of cleaner production serves as an illustration of this point. Even if the underlying idea of the concept may stretch further, the concept literally emphasises "cleaner" production as the main objective as opposed to "clean" production. As a result, the concept embeds a particular way of thinking – reducing rather than eliminating environmental harm. This implicitly promotes the ideas of modification and re-design, which ultimately may limit the potential environmental improvement that is derived from the eco-innovative process. Similar arguments can be made for eco-efficiency.

87. Manufacturing industries have been in a key position in helping to overcome the global environmental challenges, but their future contributions to sustainable development will depend on how well they adopt and integrate eco-innovative approaches in shifting their production patterns (Charter and Clark, 2007). This requires an expansive view on how to analyse the sustainability of manufacturing and a strong focus on identifying areas where eco-innovative solutions can help to reduce or eliminate harmful environmental impacts. In effect, the objective of sustainable manufacturing needs to direct not only "sustainability practices in manufacturing" but also "manufacturing practices for achieving sustainable development". This is of great significance because the key features of any innovation are determined in the early phases of the innovation process (Reid and Miedzinski, 2008), and important potential impact or rebound effect could easily go undetected if broad environmental aspects are not given priority from the beginning of the process. In short, eco-innovation offers an opportunity for such a shift in thinking and, in turn, for changing the perception of industrial production to one that sees manufacturing as a service to humanity and the planet rather than being a cause of environmental degradation.

Application of the framework

88. As a creative process, eco-innovation involves the transcendence of established thought patterns. Applying and integrating the concept in manufacturing therefore implies rethinking, and possibly breaking, views and ideas that are commonly accepted in the established manufacturing system – including why products are being produced, how they are produced, what needs they can fulfil, which management methods are used, and how the products and production processes relate to their surroundings.

89. Rethinking the manufacturing processes from an eco-innovation perspective would involve the deliberate re-examination of all phases of the production system with the intention to identify options for applying different innovation targets and mechanisms to reduce/eliminate environmental impacts.

Following Figure 9, this deliberation, for instance, may lead to the planning of technological modifications to products and processes, ideas for creating new products and production methods, or sketching possible re-organisations of management structures. The feasibility of these eco-innovative solutions would then be determined according to the company's "co-creative competency" which refers to the company's availability of technological know-how, human and financial resources, collaborative partnerships throughout the value chain, internal and external knowledge and technology networks, etc.

90. To maximise the potential outcome, such a deliberation would benefit from being repeated several times, going from radical conceptions and highly desirable innovation targets/mechanisms to more applicable and feasible options that meet the company's co-creative competency. This may create new business opportunities by *i)* avoiding the dismissal of options that might seem implausible at first glance; *ii)* creating visions that may help to guide the company's future targets and goals; and *iii)* stretching what is plausible and feasible in the company's current socio-technical context by starting out with high benchmarks. .

91. For a producer of automobiles, for instance, the process could involve the identification of innovation targets, mechanisms and co-creative competency that would enable the manufacturing of a car with the ability to purify air when driven. Similarly, a producer of packaging materials may identify innovation targets, mechanisms and co-creative competency that would enable the production of packaging which, when disposed of, simply would dissolve into a harmless liquid (see Box 7). Envisioned environmental benefits may decrease if the company chooses more readily applicable solutions meeting its co-creative competency, yet this deliberation process could help to ensure overall environmental improvements through the solutions compared to existing products and processes

92. While eco-innovative thinking in manufacturing may not lead to dramatic developments at first, it may induce companies to look at their production process in a different light and come to identify relatively simple solutions with significant environmental benefits. It may also encourage companies to be engaged in eco-innovative initiatives and partnerships that they otherwise would not have had incentives to enter, or thought of. In the long run, eco-innovative thinking could even engage companies in co-operative arrangements that in turn would lead to the establishment of closed-loop production and eco-industrial parks, which was the case for the establishment of Kalundborg eco-industrial park presented in Box 5.

Box 7: Eco-innovative automobiles and ice cream packaging

BMW, which has been developing hydrogen engine technologies for more than 25 years, has recently unveiled a new "mono-fuel" internal combustion engine. The engine is introduced in the new mono-fuel Hydrogen 7 saloon, which was first displayed at the SAE World Congress in Detroit in 2008. Initial testing of the exhaust coming out of the car's near zero emissions engine shows that the air is cleaner in components such as non-methane organic gases (NMOGs) and carbon monoxide (CO) than the air coming in as the engine absorbs and burn ambient air pollutants (Wired, 2008).

McDonough Braungart Design Chemistry (MBDC), which was established in 1995 with the intention of advancing the "New Industrial Revolution" and the realisation of the "cradle-to-cradle" thinking, developed an ice cream package for Unilever based on eco-innovative thinking. The packaging consists of polymers, which take the form of a film in its frozen state but degrades to a liquid over a couple of hours when exposed to room temperature. The polymer packaging also includes seeds for rare plants which essentially make littering support improving biodiversity. This also demonstrates a radical conceptual change where waste literally creates potential new life (Braungart, 2002).

5. Conclusions

93. The concept of sustainable development has been gaining significant attention in recent years and the topic has risen to the top of the international political agenda, particularly due to concerns over climate change. Growing media coverage of environmental issues and a rising public awareness in this area have further increased the pressure for manufacturing industries to take environmental responsibilities for their

business conduct by adopting more advanced and integrated responses to environmental concerns than the way in which the issues traditionally have been tackled.

94. This development has brought a substantial conceptual expansion in how sustainability can be applied to production in general and led to the establishment of a range of tools and management philosophies on how to apply sustainability business practices. In terms of sustainable manufacturing, this has involved a movement towards the application of technological solutions that enable the substitution of toxic materials with non-toxic alternatives and the reduction of material consumption and waste generation. With rising pressures on companies to take environmental responsibility beyond their organisational boundaries, many manufacturing companies have also adopted lifecycle perspectives of their operations and are becoming increasingly involved in green supply chain management. In recent years, the concept of a circular manufacturing process has gained ground and new business models, such as product-service systems (PSS) that facilitate the move towards closed-loop production systems, have emerged. Many sustainable manufacturing initiatives, however, have primarily focused on the development and application of environmental technologies. While they have improved general environmental performance, environmental gains have mostly been incremental and in many cases they have also been outweighed by rising production and consumption volumes (OECD, 2001).

95. To meet the growing environmental challenges, much attention has been paid to innovation as a way of developing sustainable solutions, also known as eco-innovation. The importance of this concept is rising both in industry and among policy makers as a way to facilitate more radical and systemic improvements in corporate environmental performance which are increasingly needed. This has led to the understanding of eco-innovation in the sense that solutions not only concern technological developments, but also non-technological changes such as in consumer behaviours, social norms, cultural values, and formal institutional frameworks. Changes across all these areas, however, cannot be achieved by single company (Jorna, *et al.*, 2006; Reid and Miedzinski, 2008).

96. There is much overlap between the concepts of sustainable manufacturing and eco-innovation and there appears to be a particular pattern by which both concepts can be related. Earlier and more traditional sustainable manufacturing initiatives, for instance, tend to relate to eco-innovation in the form of adjustments to products and processes, marketing methods and organisational structures. Later and more advanced sustainable business practices, on the other hand, are related to the creation of new products and processes, alternative business models such as PSS, and circular production systems where disposed goods can be "reborn" as re-sourced materials and where seemingly unrelated industrial processes can be connected with large environmental gains.

97. The application of the eco-innovation concept in sustainable manufacturing would offer a promising way for moving industrial production towards a truly sustainable direction. However, it requires that manufacturing industries integrate and apply this concept in a more holistic way. This entails a deliberate re-examination of all phases of the production system with the objective to identify areas for applying potential eco-innovative solutions. This would also include the development of new institutional arrangements such as knowledge networks and partnerships that can function as co-creative processes.

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ANNEX: OTHER OECD WORK RELATED TO ECO-INNOVATION

The OECD has been engaged in a number of activities regarding the development and application of products and processes that improve environmental performance. On the broader scale, the Environmental Policy Committee (EPOC) is co-operating with the EU's ETAP on mapping environmental technology policy frameworks in a number of OECD countries. On the more specific level, the OECD is addressing environmental issues regarding the development and application of products and processes concerning information and communication technologies (ICTs), biotechnologies, and nanotechnologies. Projects that seek to develop indicators on eco-innovation based on patent data have been initiated with themes including waste management and recycling; wastewater treatment; renewable energy; carbon capture and storage; air pollution abatement from stationary sources; motor vehicle fuel efficiency emissions control; environmental monitoring equipment; and "green chemistry".

The direct and indirect environmental effects of ICTs and their application, including optimization and substitution of inefficient processes, is addressed by undergoing work in the Committee for Information, Computer and Communications Policy (ICCP). This work also includes potential "re-bound effects" that may occur due to increased use. Other priority areas concern how the use of ICTs can help to address the issue of climate change, *i.e.* by reducing transportation and travel through better management of workplace locations, improved traffic flow, and by improving energy efficiency in buildings. With the increasingly pervasive use of ICT across all sectors of the economy, effects of electronic waste disposal and (informal) recycling in developing countries will also be addressed.

Application of biotechnologies to a variety of industrial products and processes can, in addition to bring economic benefits, lead to significant environmental improvements in areas as diverse as climate change mitigation, water conservation and reductions in the production of toxic pollutants. In this context, the Committee on Science and Technology Policy (CSTP) seeks to address how governments can help to establish business environments that are conducive for efficient development, delivery and access to innovations in the biotechnology field. Important work on the harmonisation of assessment methods regarding the environmental risks and safety of biotechnologies is also underway.

CSTP is also working separately on policy issues related to nanotechnology, examining how advancements in this area may help to improve environmental conditions and public health. Emerging nanotechnologies, notably in the field of filtration and desalination, catalysts, new materials and sensors, may offer prospects of improving access to clean water for public use, industry and agriculture. Accessibility problems relate not only to freshwater scarcity but also to the fact that the current water purification techniques are relatively expensive, may increase stress on watersheds and the environment, and are not readily transferable to the developing world. Issues under review in the work include not just cost and availability of new and improved technological solutions through nanotechnology but also concerns that there generally is little knowledge on how nano-particles may be released into the environment, how they might react and transform there, and what the effects of such processes might be.