Sustainable manufacturing, life cycle thinking and the circular economy

Professor Nabil Gindy
(Department of Mechanical, Materials and Manufacturing Engineering,
The University of Nottingham, Nottingham NG7 2RD, UK)

Abstract: Achieving sustainable patterns of consumption and production is perhaps the biggest challenge facing our society today. The demand for more safe environmentally benign products is rising and many companies are looking for new ways to progressively improve the sustainability of their products. Moreover, there are numerous opportunities and countless innovations, technological as well as non-technological, that need to be exploited to improve the sustainability of products. Manufacturing industry is an important sector of any economy and has the potential to become a driving force for enabling sustainable patterns of production and consumption through introducing efficient production practices and developing products and services that help reduce environmental impacts. The benefits of adopting an integrated policy towards product development based on life cycle thinking and eco-design to stimulate improvement of the environmental performance of each part of product life cycle phases and achieve sustainable patterns of production and consumption are emphasized. The challenges in implementing sustainable manufacturing and the circular economy approaches are listed. A number of solutions are suggested to face up these challenges, for instance, increased awareness of enterprises particularly SME's of product life cycle issues and the opportunities that are available for cost savings and profit making from eco-innovation in product development for both the domestic and export markets and providing practical help and advice directly to enterprises on integrated product development to promote enterprise led Eco-innovation. Aiming at contributing to sustainable manufacturing in China, Sino-UK Low Carbon Manufacturing Consortium, a multi-disciplinary research and educational partnership between academia, industry and government agencies in the UK and China with interest in sustainable manufacturing issues, has been formed recently. The vision, aims and benefits of membership of the consortium are also discussed.

Key words: Sustainable Manufacturing; Low Carbon Manufacturing; Eco-Design; Life Cycle Thinking; the Circular Economy
CLC Number: TH16 **Document Code**: A **Article ID**: 1001 - 4551(2010)06 - 0001 - 06

1 Introduction

Achieving sustainable patterns of consumption and production is perhaps the biggest challenge facing our society today. The demand for more safe environmentally benign products is rising continuously and many companies are looking for new ways to progressively improve the sustainability of their products. Moreover, there are numerous opportunities and countless innovations, technological as well as non-technological, that need to be exploited to improve the sustainability of products.

Manufacturing industries account for a significant part of the world's consumption of resources and generation of waste. Worldwide, the energy consumption of manufacturing industries grew by 61% from 1971 to 2004 and accounts for nearly a third of global energy usage. Manufacturing industries are also responsible for 36% of global carbon dioxide (CO_2) emissions[1]. This emphasises the pressure on manufacturing industries to reduce their environmental and social impacts.

In recent years manufacturing industry has been striving to improve its environmental performance and have been shifting from basic pollution control to a focus on product life cycles and integrated environmental strategies and management systems. Furthermore, efforts are increasingly made to create closed-loop, circular production

Received Date: 2010 - 05 - 11

Brief Introduction of the Author: Professor Nabil Gindy(1950 -), the University of Nottingham, mainly engaged in sustainable manufacturing. Contacts in China: E-mail: nabil. gindy@ nottingham. edu. cn. Tel: 0574 - 88180386.

systems in which discarded products are used as new production resources.

Manufacturing industry is an important sector of any economy and has the potential to become a driving force for enabling sustainable patterns of production and consumption through introducing efficient production practices and developing products and services that help reduce environmental impacts. For this to happen the manufacturing industry needs to adopt a more holistic approach to conducting their operations that places environmental and social aspects on an equal footing with economic profitability. The concept of sustainable production (manufacturing) has its roots in the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992 as a vital means of realising sustainable development. While there seems to be no universally accepted definition for Sustainable Manufacturing our working definition in this paper is "the creation of goods and services using processes and systems that are economically viable and have minimum environmental impacts".

Achieving sustainable manufacturing is also closely linked to "products" which lie at the core of all manufacturing operations. Systematically considering all phases of product life cycle, from material extraction to disposal, at an early stage of product development can have a significant impact on minimising its environmental impact throughout its life. Adopting this approach, a company can focus on directing action to where it is most effective through dealing with the most pressing issues of the product life cycle that suit their needs and therefore maximize the impact of their efforts and assess their progress.

2 Eco-Design

All products cause environmental degradation and have environmental impacts throughout their life. A Product Life Cycle (PLC) covers all the stages from the extraction of material, material processing, through its design, manufacture, assembly, marketing, distribution and use until its ultimate disposal into the environment as waste. Product life cycles are often long and complicated involving many stakeholders which can be dispersed globally, designers, manufacturers, retailers as well as consumers.

After a product has been designed, a simplified view of its life cycle is normally divided into the following phases (Figure 1):

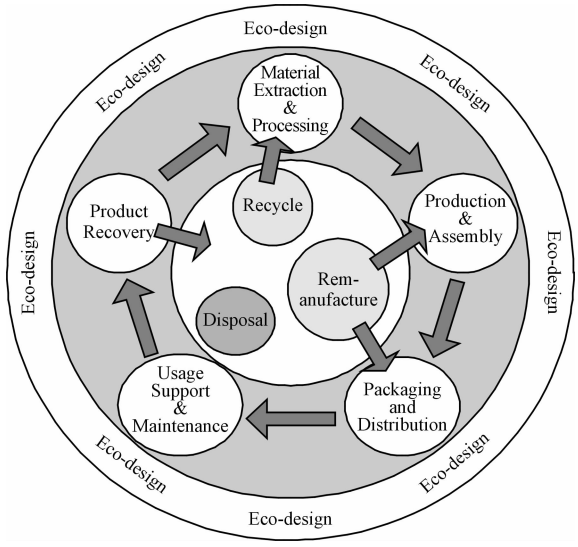

Figure 1 Eco-design and the circular economy

(1) raw material extraction and primary processing;

(2) parts production and assembly into products ready for distribution;

(3) packaging and distribution of products to points of consumption or use;

(4) product use, reuse and maintenance; and

(5) product disposal.

The aim of Eco-design is to integrate environmental criteria into the conventional design drivers of safety, technical performance, cost and quality criteria. This is achieved through systematic consideration of all the steps which a product goes through from its inception to its end of life, and adopting appropriate design strategies to minimize the environmental impacts of the whole of product life cycle (see Figure 2). The adoption of an integrated policy towards product development can stimulate improvement of the environmental performance of each part of product life cycle phases.

Designing Eco-efficient products therefore has to encompass a wide range of design strategies and concepts which vary depending on the life cycle phase under consideration. Some of these strategies may conflict causing what is termed "shifting of burden", that often happen when the design process attempts to reduce the environmental impact in one phase of the life cycle and this leads to an increased impact in another. Some of the general

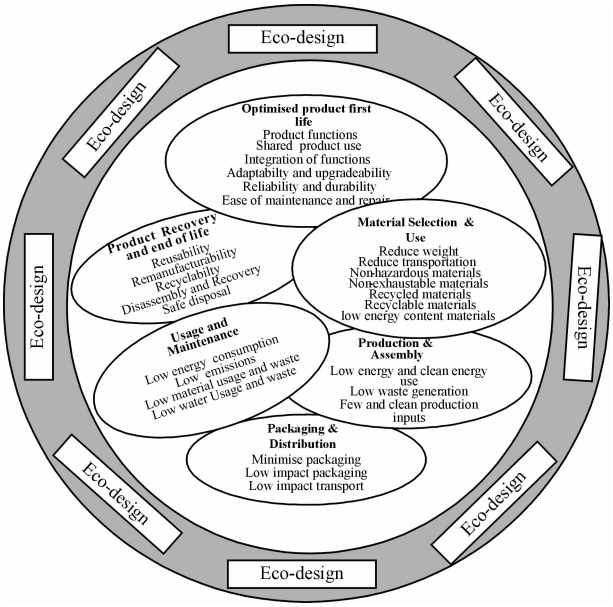

Figure 2　Optimisation opportunities related to Product Life Cycle

design strategies that are normally applied during the Eco-design process include: material section to reduce the toxicity of a product, extending product durability and the life of a product, reducing the energy and material intensity required to produce, use and dispose of the product.

Eco-design is an iterative process which aims to identify and exploit the opportunities for minimizing the environmental impact of every phase of product life cycle as well as the overall impacts of the life cycle as a whole. This process is not always easy or straightforward to implement. Eco-design utilizes a great deal of data and information and requires a creative approach to defining and identifying the full range of impacts of a candidate product design across its life cycle. Products, especially "long life" products are made of increasingly sophisticated materials; complex processing routes and often in global supply chains. Evaluating the environmental impacts of materials, manufacturing processes and disposal alternatives can be difficult particularly in relation to a global supply chain. Integrating these considerations in a concurrent design process with all the other relevant design criteria can be very challenging. Despite the extra effort needed during the design of Eco-efficient products, this can lead very important benefits including:

(1) encourages a company to adopt a system's perspective which links environmental issues directly to its products i. e. its core business activity where it makes its profits;

(2) allows a company to optimize the return on investment its makes to address its environmental impacts;

(3) allows a company to exploit opportunities for reducing costs, differentiating its products to gain competitive advantage, enhance brand image and increase profits.

3　Life Cycle Thinking

Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) provide the scientific basis underpinning modern environmental policies and business decision related to developing sustainable patterns of consumption and Production. LCT and LCA can be considered as an approach in which account is taken of all resources consumed and all environmental and health impacts that are associated with the life cycle of a product. LCA takes into account a product's whole life cycle: from material extraction, material processing, production and assembly, use, and recycling, up to the disposal of remaining wastes.

LCA is a systematic structured methodology which can be used to quantify all relevant impacts that are associated with any product, which include all the emissions, resource consumption, resource depletion, and associated goods or services. It is a vital and powerful decision support tool in the development of Eco-efficient products to facilitate the realization of more sustainable patterns of production and consumption.

Despite the extra effort needed to conduct LCA its benefits include:

(1) allows comparisons of environmental performance of different products on an equal basis;

(2) provides a consistent framework for avoiding the "shifting of burdens" which can arise from resolving one environmental problem only to create others elsewhere;

(3) provides a comprehensive framework for quantifying resources consumed as well as emissions that can be attributed to the product throughout its product life cycle;

(4) can be used to provide indicators of the product's contribution to a wide range of environmental problems such as climate change, toxic pressures, and resource depletion which can aid decision making at various levels.

The ISO 14040/44 standards[2-3] provide the general framework for Life Cycle Assessment. However, this framework leaves the practitioner with a range of choices that can change the results and conclusions. Comprehen-

sive guidance is still required to support consistent and robust results and coherent requirements derived from LCAs.

The overall approach adopted in the ISO standard consists of the following three phases[4]:

(1) Life cycle Inventory analysis-involves the compilation and quantification of inputs and outputs of all the life cycle phases of a product system[5].

(2) Life cycle Impact assessment-involves understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system[6].

(3) Life Cycle Interpretation-involves combining either the inventory analysis or the impact assessment, or both in a way that is consistent with defined goals and scope to reach conclusions and recommendations[7].

The ISO 14040 and 14044 standards provide a flexible framework for LCA. This framework, however, leaves the individual practitioner with a range of choices, which can affect the legitimacy of the results of an LCA study. While flexibility is essential in responding to the large variety of questions addressed, further guidance is needed to support consistency and quality assurance.

4 The Circular Economy

In the last three decades, China's industrial output has grown at unprecedented rates. Today China is a leading producer and consumer of a very wide range of products worldwide. In 2006, China accounted for 18% of worldwide primary energy use. In 2007, industry in China was responsible for almost 50% of the country's GDP, a significantly higher proportion than in the U.S. (25%) or Japan (30%)[1]. As China's industrial output has grown both to meet global demand and the needs of the domestic market, the industrial sector's consumption of resources has increased in tandem with its generation of air and water pollution as well as solid waste. China's industrial activity has a significant impact on the natural environment. Currently, the industrial sector is responsible for over 60% of the country's greenhouse gas emissions, which is almost twice the world average of 35%[8].

In the circular economy approach product life cycle phases are organised to reflect product-environment interactions to encourage that the output from one phase is viewed as the input to another and the waste of waste of one manufacturer becomes the input material of another. The underlying vision is that the present linear flow of materials (resource-product-waste) needs to be transformed into a circular flow (resource-product-recycled resource), see Figure 1.

The Circular Economy was adopted by the Chinese Government in the 11th five-year plan as the development model for China to strive for. The Circular Economy Promotion Law was enacted (2008) with the aim of establishing full-fledged development mechanisms which will boost a circular economy and involves multiple government agencies, including NDRC, MEP, MOF and MoST[9].

The Circular Economy Promotion Law is innovative in the sense that, unlike conventional laws that mainly regulate existing entities and their relationships, it aims to provide a regulatory framework for transforming the mode of development of the country and to enable both government and industry to become familiar with advanced environmental concepts as early as possible and start the intake of knowledge and built-up of expertise whenever possible[10].

In fact, the Circular Economy Policies of the Chinese government encourages manufacturers to adopt LCT and to consider the whole life of their products at the earliest decision stages of the product development process, when making changes are easier to make and not so costly to implement, in order to reduce the impact on the environment in the future life of the product.

In 2005 the Chinese government launched the first round of CE pilot projects in seven key industrial sectors with the participation of forty-two leading enterprises, four waste recycling and reuse areas, thirteen industrial parks, and ten provinces or cities. In 2007, a second round of pilot projects expanded the coverage of sectors and regions. As of 2008, most of the pilot projects are still under implementation, and many other enterprises, industrial parks, cities and provinces have expressed an interest in participating[11].

5 Challenges in Sustainable Manufacturing

Achieving sustainable manufacturing operations and implementing the circular economy approach poses many

challenges to us all. Decision makers are normally used to basing their decisions on, often short or medium term, economic criteria by weighing up the relevant benefits and costs, and then deciding whether to adopt such approaches. However, what is needed here is concerted efforts to move manufacturing industry towards sustainable production based on multi-level innovation. This will help to evolve sustainable manufacturing initiatives from traditional pollution control through cleaner production initiatives, to life cycle thinking and the establishment of closed-loop production systems and a circular economy.

Integrated approaches such as closed-loop production and life cycle thinking can potentially yield significant environmental benefits but they need to involve a combination of a wider range of innovation targets and mechanisms to leverage their benefits. New technology can also yield benefits but it has to be complemented with organisational and social structures and changes in human and cultural values[12].

Both China and Europe have been using various means to support and promote environment-related innovation, including public investment in R&D, mobilizing finance from multiple sources, government procuring environmentally friendly products, adopting market-based instruments, awareness raising and capacity building, and acting globally.

In China however the policy mixes used are characterised by the strong legacy of the planned economy, as the programmes or plans are the main instruments for addressing policy priorities. They are biased in favour of large, national firms.

The success of sustainable manufacturing and circular economy initiatives is heavily dependent on promoting market-driven innovation which also needs a bottom-up involvement and leadership by individual enterprises.

There is an urgent need for:

(1) Increased awareness of enterprises particularly SME's of Product Life Cycle issues and the opportunities that are available for cost savings and profit making from Eco-innovation in product development for both the domestic and export markets.

(2) Providing practical help and advice directly to enterprises on integrated product development to promote enterprise led Eco-innovation.

6 The Sino-UK Low Carbon Manufacturing Consortium (Sino-UK LCMC)

A recent series of technology road mapping workshops on sustainable manufacturing, July 2009 in Nottingham UK, January 2010 in Ningbo China and March 2010 in Shanghai China have provided the background to the formation of the Sino-UK Low Carbon Manufacturing Consortium, a multi-disciplinary research and educational partnership between academia, industry and government agencies in the UK and China with interest in sustainable manufacturing issues. The founding academic partners which form the steering group of the consortium are:

(1) The National Key Laboratory for Remanufacturing, Beijing

(2) Tsinghua University, Beijing

(3) Chongqing University, Chongqing

(4) Shanghai Jiaotong University, Shanghai

(5) Zhejiang University, Hangzhou

(6) The University of Nottingham Ningbo, China

(7) The University of Liverpool, UK

(8) The University of Nottingham, UK

(9) Brunel University, UK

(10) Cambridge Univerysity, UK

The aims of establishing the consortium include:

(1) Research to develop innovative technologies and systems to reduce the environmental impact of products throughout their life cycle.

(2) Provide practical help and advice to industry particularly SME's in conducting life cycle assessments and the development of more environmentally friendly products for the domestic and export markets.

(3) Support the Circular Economy policies through enabling industrial companies, to learn about the availability and the benefits of some International Standards and adoption of product life cycles approach to product design, product manufacture and product utilisation.

(4) Promoting life cycle thinking LTC through the development of courses on life-cycle assessment, public events, seminars and publications.

(5) Develop multidisciplinary research agendas and research teams to address the inherently cross-disciplinary sustainable manufacturing issues.

(6) Integrate sustainable manufacturing issues into

the curriculum so that students in engineering, business and sciences can learn and help develop approaches for solving problems in these areas.

(7) Establish collaborative research with industry partners.

(8) Facilitate the dissemination of information on sustainable manufacturing to businesses, government and industry.

The consortium vision is to create, develop and implement new innovative technologies, systems and decision support tools that enable industry to increase its competiveness, productivity, capture new business opportunities and achieve sustainable operations.

The strategy of the consortium is to form strong collaborative partnerships with decision makers in companies, government agencies to help to solve current and future sustainable manufacturing issues.

Membership of the consortium is free and is open to individuals, companies, academia and government agencies with interest in sustainable manufacturing issues. Benefits of membership include:

(1) A forum to share and research new ideas, technologies and applications related to sustainable manufacturing and links to world-wide research.

(2) Cost-sharing mechanism for companies to participate in research projects.

(3) The opportunity to provide input on research direction and suggest specific research programs.

(4) Access to

①world class University laboratories

②university researchers, undergraduate and post graduate students

③the consortium research projects

④working papers

⑤access to Government research grants through collaborative university research proposals.

(5) Opportunities to test and acquire software and decision support tools.

(6) Attendance at members meetings, conferences organised by the consortium.

(7) Access to portal facilities for communication between members and interaction with researchers.

References:

[1] International Energy Agency. Tracking Industrial Energy Efficiency and CO_2 Emissions Report(Paris, France: Organisation for Economic Co-operation and Development,2007:39-40.

[2] International Organization for Standardization (ISO) (2006). ISO 14040: 2006 Environmental management—Life cycle assessment—Principles and framework, ISO, Geneva.

[3] International Organization for Standardization (ISO) (2006). ISO 14044: 2006 Environmental management—Life cycle assessment—Requirements and guidelines, ISO, Geneva.

[4] International Organization for Standardization (ISO) (2004). ISO14001: 2004 Environmental Management Systems: Requirements with Guidance for Use, ISO, Geneva.

[5] International Organization for Standardization(ISO) (1998). ISO14041:1998 Environmental management—Life cycle assessment—Goal and scope definition and inventory analysis, ISO, Geneva.

[6] International Organization for Standardization (ISO) (2000). ISO 14042: 2000 Environmental management—Life cycle assessment—Life cycle impact assessment, ISO, Geneva.

[7] International Organization for Standardization(ISO) (2000). ISO 14043: 2000 Environmental management—Life cycle assessment—Life cycle interpretation, ISO, Geneva.

[8] McKinsey & Company. China's Green Revolution (New York, New York, US: McKinsey & Company),2009:34.

[9] SUN, ZHANG You-hai, TAIN Zhu. Study on Legal Framework for Promoting Circular Economy in China, 2008, China Legal Publishing House.

[10] OECD(2007). OECD Reviews of Innovation Policy-China-Synthesis Report, Paris.

[11] OECD(2009). "Eco-Innovation Policies in The People's Republic of China", Environment Directorate, OECD.

[12] ECO-INNOVATION IN INDUSTRY: ENABLING GREEN GROWTH, OECD 2009, ISBN 978-92-64-07722-5.