Sustainable Products and Sustainable Production: Introduction

16

Kun-Mo Lee

Sustainable production and products are prerequisite for the realization of a sustainable society. The term "sustainable" connotes keeping up with the present state for a long time. In order to be sustainable, resources must be available and current environmental quality should be preserved. From this, one can extract key concept about sustainability. They are: sustainable resource supply and stable environmental quality.

Products (including services) are the root cause of resource consumption and environmental emissions. In order to maintain stable resource supply and preserve current environmental quality, first action to take is to reduce consumption of products. This is termed sustainable consumption. Second action followed by the first action is to produce product that consumes less resource and generates less emission to the environment. This is termed sustainable production and sustainable product. The latter is often synonymous to ecodesign (sustainable design) and eco-product (sustainable product).

Implementing sustainable production and producing sustainable products requires a systematic approach based on life cycle thinking. The life cycle thinking considers entire supply (or value) chain of a product when designing it. This includes not only manufacturing processes of a product but also all the upstream and downstream processes. Upstream processes include natural resources acquisition, processing them into materials, making parts and components to be used for the product manufacturing. Downstream processes include distribution, use, and end-of-life of a product.

Typical approach to implementing sustainable production consists of the analysis of environmental aspects of a product system and integration of significant environmental aspects into product design. This approach then can be applied to realize the design of sustainable product and sustainable production.

K.-M. Lee
Department of Environmental Engineering, Ajou University, Suwon, Korea
e-mail: kunlee@ajou.ac.kr

J. Kauffman, K.-M. Lee (eds.), *Handbook of Sustainable Engineering*,
DOI 10.1007/978-1-4020-8939-8_127,

Section Sustainable Products and Sustainable Production can be divided into three main parts. They are: analysis of environmental aspects of a product system, integration of significant environmental aspects into product design, and application of the methods and tools to the sustainable product design and sustainable production. The first part consists of three chapters: ▸Product LCA and PCF, ▸Supply Chain Management for Sustainability, and ▸Material Flow Cost Accounting. The second part consists of six chapters: ▸Ecodesign Strategies, ▸Environmental Quality Function Deployment, ▸Sustainable Product Design and Development: TPI-Based Idea Generation Method for Eco-Business Planning and Eco-Product Development, ▸Sustainable Design by Systematic Innovation Tools, ▸Remanufacturing, and ▸Reuse of Components and Products. The third part consists of four chapters: ▸Sustainable Production, ▸Green PCB Manufacturing Technologies, ▸Structural Complexity Management in Sustainable Engineering, and ▸Eco-Packaging Development: Integrated Design Approaches.

Analysis of significant environmental aspects of a product and its supply chain is vital to the implementation of the sustainable production and sustainable product development. This is the first step to take in the production of sustainable products.

Chapter ▸Product Life Cycle Assessment (PLCA) and Product Carbon Footprint (PCF) introduces a procedure for the identification of significant parameters of a product in its entire life cycle. Product life cycle assessment (PLCA) is a tool that enables quantification of the input and output from the processes and activities of a product, assessment of their potential impact on the environment, and then identification of significant parameters. Two major applications from the PLCA are: the identification of significant parameters and the development of environmental profile of a product. Product carbon footprint (PCF) is one of the most visible applications of the product's environmental profile by communicating to the market only the data related to greenhouse gases emissions.

Practical guidance and relevant examples related to the topics such as product modeling, data collection and processing, data compiling, calculation of life cycle impact, identifying significant parameters and development of an environmental and carbon profile are given in this chapter to aid understanding of the PLCA and PCF.

Chapter ▸Supply Chain Management for Sustainability discusses management issues and practices to ensure a sustainable supply chain, including issues related to the sustainable enterprises and sustainable manufacturing. There are two main issues of a supply chain from the perspective of manufacturing enterprises: environmental issues and risk management. A key approach is systems thinking – visualizing problems, defining boundaries, setting goals, and simulating policies to predict their effects. A systematic approach, such as visualizing risks and defining metrics, is important for preventing and mitigating risks.

A few examples from the automotive industry are given in this chapter to illustrate the specific challenges of managing supply chains. The examples include the substitution of materials in cars in terms of life cycle assessment and a predicted shortage of copper for clean energy vehicles. The smart grid system is an example of a large system that requires system and life cycle approaches.

Chapter ▶Material Flow Cost Accounting: Significance and Practical Approach introduces procedures of implementing MFCA in the manufacturing processes and supply chain. MFCA promotes increased transparency of material use practices through the development of a material flow model that traces and quantifies the flows and stocks of materials within an organization in physical and monetary units. This data can be used to seek opportunities to reduce material use and/or material losses, improve efficiency of the material and energy uses, and reduce adverse environmental impacts and associated costs. This chapter explains detailed steps for MFCA implementation and shows actual case examples. Furthermore, MFCA's impact is not limited to a single entity. MFCA can be applied to the supply chain where material wastage at one organization is occasionally sourced from suppliers. Impact on supply chain is also described in this chapter.

Analytical results from part 1 are fed into the second part where integration of significant environmental aspects into product design occurs. The second part addresses practical approaches to sustainable product design and development including manufacturing process.

Chapter ▶Ecodesign Strategies: A Missing Link in Ecodesign addresses shortcomings of the existing ecodesign method and introduces practical ecodesign strategies, i.e., design strategies working at the product designer's level. Existing approaches including LCA, the rules from experience, life cycle thinking, and other potential design for environment (DFE) solutions cause confusion and conflict to the implementation of ecodesign. In addition, there are also structural elements like modularity to be taken into account which causes no direct environmental impact. Product structure is important for disassembly and product lifetime.

This chapter describes a systematic design approach. At first a product is simplified in structure and complexity. There are three design strategies: design for functional units, design for fewer number of materials (target: one plastic, one metal), and a design with standard components from the market combined with disassembly analysis to simplify the product structure. Not only environmental impact but also disassembly time which offers information about the structural quality of a product is important. In reality, many manufacturers have no real choice which way to go because they purchase most of the components. Often there is also a mixture between the three strategies, but for individual manufacturer, an optimized solution can be achieved.

This chapter also addresses the result of the application of the rules from experience which is part of Eco profile. Checking product software for its environmental impact is a new step in Ecodesign. Impact can be caused by a software program itself, by commands initiating something in a product like battery loading or a possibility to better control functions of a part (e.g., motors). Redesign of the whole manufacturing process is also necessary.

Chapter ▶Environmental Quality Function Deployment for Sustainable Products presents a methodology to apply quality function deployment (QFD) for sustainable product design in the early stage of product development. This methodology has been developed by incorporating environmental aspects into QFD to handle the environmental and traditional product quality requirements simultaneously.

"QFD for Environment (QFDE)" consists of four phases. Designers can find out which parts are the most important parts to enhance environmental consciousness of their products by executing QFDE phase I and II. Furthermore, a methodology to evaluate the effects of design improvement on the environmental quality requirements can be found in QFDE phase III and IV. The results obtained from the case study of an integrated circuit package show that QFDE can be applicable in the early stage of assembled product design, because most important component from the viewpoint of the environment is clearly identified and multiple options for design improvement are effectively evaluated.

Chapter ▶Sustainable Product Design and Development: TPI-Based Idea Generation Method for Eco-Business Planning and Eco-Product Development introduces Total Performance Design (TPD) method which focuses on the balance of customer's utility value of a product and its resulting environmental load and cost throughout entire life cycle. Total performance indicator (TPI) which represents environmental and economic performance of a product throughout its entire life cycle is used as an objective function and a design solution is derived as a set of life cycle options (e.g., reuse, recycling, upgrading, extension of physical lifetime) for each component, specification for each functional requirement, and product lifetime that maximizes TPI under a given business environment.

Consideration of various eco-business strategies (e.g., product sales, lease and rental, and function selling) also plays an important role to improve TPI. For example, adequate control and management of operating conditions are effective for products which consume large quantities of energy and materials during their use stage. In this case, providing products with energy-saving service (e.g., ESCO business) is a promising approach. In addition to the operating conditions, product lifetime and its physical wear and deterioration rates are also insufficiently controlled by product design alone. Therefore, idea generation and decision making process for eco-business strategy, as well as design of a target product itself, should be focused on.

This chapter provides a designer with a set of eco-business rules and case base extracted from the Japanese eco-business cases. The applicability of each rule is described in relation with 17 business parameters that represent the situation (*pattern*) of a given business environment. Referring to the rules and the cases of which patterns are similar to a given business environment, the designer can easily generate adequate eco-business ideas. The designer can also determine the product performance specifications that are suitable for the generated eco-business ideas through the analysis of these parameters.

Chapter ▶Sustainable Design by Systematic Innovation Tools (TRIZ, CAI, SI, and Biomimetics) introduces design method using tools such as Theory of Inventive Problem Solving (TRIZ) and computer aided innovation (CAI). Fostering creativity in design practice was in the realm of random process, namely, serendipity. One of the gigantic steps for systematic innovation was possible by introduction of TRIZ. This chapter introduces the concepts and accomplishments of applying the efforts toward somewhat paradoxical systematic creativity named CAI on sustainable design. Firstly, the history and current state of CAI, SI, and biomimetics are described.

Secondly, literature review of papers on the cross area of sustainable design and CAI is presented. Thirdly, bio-inspired design approach (encompassing biomimetics) which aims at finding wisdom from man-made world is discussed. Fourthly, efforts to correlating TRIZ and biomimetics are presented. Finally, the innovation story of a paper production industry where material and energy consumption is huge and critical is introduced as an example of the sustainable design by SI tools. The example shows that radical innovation toward ideality can be considered as an epitome of sustainable design.

Chapter ▸Remanufacturing discusses method for remanufacturing of used parts and components for a product. Remanufacturing, a process of bringing used products to "like-new" functional state with matching warranty, is being regarded as a more sustainable mode of manufacturing because it can be profitable and less harmful to the environment than conventional manufacturing. The practice is particularly applicable to complex electro-mechanical and mechanical products which have cores that, when recovered, will have value added to them which is high relative to their market value and to their original cost. Because remanufacturing recovers a substantial fraction of the materials and value added to a product in its first manufacture, and because it can do this at low additional cost, the resulting products can be obtained at reduced price. Remanufacturing however is poorly understood because of its relative novelty in research terms. This chapter clearly defines the term "remanufacturing" by differentiating it from alternative green production initiatives. It provides an overview of the remanufacturing concept, significance, and practice.

Chapter ▸Reuse of Components and Products: "Qualified as Good as New" focuses on "qualified as good as new (quagan)" method for the design of a product using reused components. Reuse of components and products offers attractive economic advantages provided that those components are quagan. A quagan component, deployed in a second life in a new product, can have a higher degree of reliability than the new ones because early failures have been already eliminated by its previous life.

This chapter provides guidelines to convince quagan consumers of getting a technically up-to-date product, the quality assessment procedures, including the ones to fulfill the safety requirements, and their documentation. It explains how "design for recycling" can work and what should not be reused. Also it explains the state of the software of more complex product systems and the importance of their upgrading process.

Application of the sustainable product design and sustainable production part shows the actual application of the above two parts to the industrial practices. It addresses practical application to the sustainable product and production process design.

▸Sustainable Production: Eco-efficiency of Manufacturing Process sustainable manufacturing technologies and their application to the development of industrial parts. Requirements for practical manufacturing technologies include satisfying high quality, low cost, and low environmental impact simultaneously. Environmental issues are important; however, quality is the key feature in deciding whether the developed manufacturing technologies will be used in industries. In the first part of this chapter, several new material technologies and fabrication technologies are discussed in order to satisfy high quality, low cost, and low environmental impact simultaneously. The "total performance analysis (TPA)" method enabled product developer to quantify the value, life cycle cost, and life cycle environmental impact of a product. In the second half of the chapter, the TPA method was applied to an innovative manufacturing process producing ceramic products. Throughout the case studies, the "total performance analysis" is proven effective in identifying the bottlenecks of manufacturing processes and visualizing the effect of process improvements.

▶Green PCB Manufacturing Technologies introduces alternative printed circuit board (PCB) manufacturing technologies to meet legal regulations worldwide. These regulations have affected the electronic industry supply chain. PCB a critical component in the electronic products receives some of the most severe impacts. The RoHS directive leads to lead-free solder material development. However, the lead-free alloys require higher reflow temperatures, which translate to higher energy costs as well as environmental load in terms of carbon footprint. The high solder reflow temperature also forces changes in the PCB base material, and may require new equipment to fabricate them.

The WEEE directive mandates electronic wastes to be recycled. PCB is one of the most difficult parts to be recycled. PCB fabrication companies have to stop using brominated flame retardants within the PCB base materials and prepregs, and to develop substitutes. Furthermore, to facilitate recycling, several toxic substances have to be avoided in the PCB manufacturing processes, for example, cyanide in gold plating and formaldehyde in electroless copper plating. These all demand changes and pose challenges to the PCB manufacturing industries. Global shortage of fuel and energy sources calls for environmental friendly production processes, with less energy used and more precious metal recovered within the production cycle. Subsequently, alternative processes are to be developed to promote greenness in PCB fabrication.

▶Structural Complexity Management in Sustainable Engineering introduces the basic concepts of structural complexity management method and discusses its application to the development of a high pressure pump. The method considers various system aspects of a product and their relations or interdependencies simultaneously. The system aspects include not only environmental but also material and production issues, market success, and design processes. Key point here is that all multiple aspects of dependencies are considered in equal terms.

Geometric and functional dependencies between technical components, for example, can be processed jointly in order to describe the system's behavior. This possibility is addressed as the "multiple-domain" approach and contrasts common "Design for X" perspectives in product design, where X stands for a large variety of possible optimization targets that do not necessarily coexist simultaneously. As system dependencies link different aspects of system behavior, they can help to achieve the objectives of improved design by considering their combined occurrence.

The structural complexity management method was applied to develop real world products, high pressure pumps. The aim was to optimize the existing product structures of various current pump concepts. The use case shows how different product views, for example, geometry, function, and production, were modeled. The different views were combined to derive proposals for modules and carry over parts.

▶Eco-Packaging Development: Integrated Design Approaches discusses the opportunities of reinforcing strategies for the quantitative reduction and reuse of packaging and integrated design processes which take into consideration all the stages of the entire life cycle of a packaging, from manufacture to disposal, balancing a wide range of factors and including all the environmental aspects, beyond direct competencies of various actors involved in this life cycle (packaging manufacturer, packer, logistics manager, consumer, designated disposer).

This chapter proposes a methodological statement which involves: integrating conventional requisites with environmental requisites, in the development of tools and metrics guiding the designer in choices on design variables; extending the concept of environmental impact of packaging; and, analyzing the consequences that design choices have on the environmental impact of the packaging over its entire life cycle, as well as its economic sustainability and functional efficiency.

This chapter proposes two different, but complementary, approaches for an integrated design. The first one consists in an integrated approach to the optimal choice of materials, allowing the management of design parameters of varying nature (materials, significant geometric parameters), taking into account various typologies of requisites: functional (weight-bulk efficiency of the package), economic, and environmental (quantitative reduction, containment of some factors of impact). This first approach can be complemented by a second approach which integrates LCA method in the packaging design where the diverse environmental implications deriving from design choices, with regard to all the processes constituting the packaging life cycle, are evaluated. Finally, examples of their application are presented, illustrating the use and highlighting the potential of the tools proposed.

As stated above, sustainable production and sustainable products are prerequisite to the sustainable product service system and consumption, which becomes key factor for achieving sustainable society, economy, and environment. This section introduces fundamentals of the sustainable production and product from the three interlinked parts, and presents practical state-of-the-art methods together with actual examples. All the outcomes from this section will serve as foundations for the following sustainable product service system and sustainable consumption section.