Design for the environment: life cycle assessment and sustainable packaging issues

S.G. Lee

School of Mechanical and Aerospace Engineering,
Nanyang Technological University, 50 Nanyang Avenue,
Singapore 639798
E-mail: msglee@ntu.edu.sg

X. Xu

Dept of Mechanical Engineering, School of Engineering,
The University of Auckland, Private Bag 92019,
Auckland, New Zealand
E-mail: x.xu@auckland.ac.nz

Abstract: As extended producer responsibility gains ascendancy in sustainable development, proper management of the life cycle of a product is becoming more and more important. This paper presents a general overview of product life cycle assessment (LCA) and sustainable product packaging over the last four to five years.

The review of life cycle assessment includes on overview of LCAs conducted over the last six to seven years for a wide variety of products. The application of the LCA methodology to the formulation of regulatory and public policies, especially in the USA and the Netherlands, and the outcome of the five-year national Japanese LCA initiative, are presented. The key issues and limitations confronting LCA, notably the role of weighting factors, are summarised. Some of these include the unequal treatment of qualitative and quantitative measures and the absence of a semantic ontology to unify the practice. Finally, the merits and shortcomings of a streamlined (abridged) (SLCA) are briefly reviewed.

The review of sustainable product packaging is confined to the LCA of packaging systems and new, innovative environmentally-benign packaging materials, for example, biodegradable agricultural (compostable) polymers. The outcome of any packaging LCA should always be interpreted in light of the prevailing technology and the function of the packaging. Also discussed are the life cycle assessment of some packaging systems, new active or intelligent packaging materials, and initiatives across the manufacturing and service industry at dematerialising packaging. The ramifications of the landmark EU *Directive on Packaging Waste* 94/62/EU and its corresponding regulations in EU member states and some reasons for the varying degrees of success are presented. A more wide-ranging integrated approach, encompassing economic, social and environmental considerations, in conjunction with more efficient packaging designs, which economise on material and are recyclable, is the key to sustainable packaging.

Keywords: life cycle assessment; sustainable product packaging; waste management.

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Biographical notes: Dr. Stephen Siang-Guan LEE is an Associate Professor in the School of Mechanical & Aerospace Engineering, Nanyang Technological University (NTU) and Director of the Design Research Centre. Dr. Lee graduated in mechanical engineering with honors and later earned his MSc in Advanced Manufacturing Technology from the UMIST(UK) and PhD (NTU). His research interests are in Design Methodologies, Sustainable Design, Life Cycle Assessment and Protective Product Packaging. Dr. Lee is a registered professional engineer, a Fellow of the SME, and a member of the ASME. An active member of the Society of Manufacturing Engineers, he was conferred its Award of Merit in 1992.

Dr. X William Xu received his BSc and MSc from Shenyang Architectural and Civil Engineering Institute and Dalian University of Technology, P. R. China in 1982 and 1988 respectively. In 1996, he earned his PhD from the University of Manchester Institute of Science and Technology (UMIST), UK. He is now a senior lecturer in the Department of Mechanical Engineering, the University of Auckland, New Zealand, where he manages the Manufacturing Systems Laboratory and the CAD/CAM Laboratory. His main research interests are in CAD/CAPP/CAM, Design for the Environment and Life Cycle Analysis. Dr. Xu is a member of ASME and IPENZ.

1 Introduction

Design for the Environment (DfE) probably had its origins in 1974 with Victor Papanek's critique of designers' obligations to society and the environment in his book *Design for the Real World: Human Ecology and Social Change* (Lewis and Gertakis, 2001). He observed that designers were too preoccupied with style and aesthetics, rather than the whole product, its function, maintainability, affordability and its social and environmental impact. In his 1995 book *The Green Imperative: Ecology and Ethics in Design and Architecture,* he discusses ecological product and architectural designs (Papanek, 1995).

In 1997, the Harvard Business Review first turned its sights on the sustainability agenda with Stuart L Hart's '*Beyond Greening: Strategies for a Sustainable World*' in which he explained the reasons why the world as a whole was on an unsustainable course (Hart, 1997). Just what is meant by *Sustainable Development*? The 1987 report by the World Commission for the Environment and Development defines sustainable development as '*a morally defensible form of economic and social development that meets the need of the present without compromising the ability of future generations to meet the needs of others*'. This has implications for the entire value chain of a product from cradle to grave.

One of the earlier investigations into DfE practices was carried out in 1996, when a team from MIT studied the pattern of adoption of DfE practices in US manufacturing firms and across industries (Lenox et al., 1996). The survey, which was supported by an NSF grant, turned up rather surprising results. Although DfE practices were widespread, varying from food to chemicals to machine tools, there was no consensus of opinion on what constituted good DfE practice. Companies used guidelines and checklists more than analytical tools which, if they did, were invariably developed in-house. Few companies looked at the entire product life cycle; the majority focused only on manufacturing. Government regulations seemed to play a less significant role in promoting DfE than personal and professional networking. This prompted Lenox and associates to surmise that '*the key to the adoption of DfE is not analytical tools but the management of innovation and organisational change*.' In 1999/2000, they followed up with another survey of four leading electronics firms, which revealed that many firms still struggled to promote DfE practices across their product development teams. This survey found that there is greater chance of more widespread diffusion of DfE if there were technical competency centers containing company-wide information relevant to environmental design, and if these centers coordinated with product design teams. Highly interconnected, internal information networks also lowered the motivational barriers of product managers and designers in assessing environmental costs and benefits (Lenox et al., 2000).

At the same time in 1996, the Microelectronics and Computer Technology Corporation surveyed US electronics companies to ascertain the level of maturity of DfE implementation, the tools used by and needs of the industry (Mizuki et al., 1996). The results of the survey pointed to two critical obstacles to a more widespread adoption of DfE practices in electronics companies: the lack of current, accurate data on materials and energy use, and materials tracking. It appeared that a universally-agreed vocabulary and metrics to measure the extent of DfE incorporation into design and manufacturing was more important than DfE tools at that time. Design teams, sensitive to product cost and time-to-market, resent shouldering the burden of environmental design alone. Corporate-wide education and acceptance, at all levels of management, even marketing and sales, underpin the success of DfE adoption. These issues are as real today as they were then, and will remain so, until and unless all stakeholders – management, suppliers, customers - embrace the goal of sustainable development (Porter and van der Linde, 1995; Nash, 1997).

However, these surveys do not imply that industry has been slow to warm up to DfE. At Nokia Multimeda Terminals in Sweden, a study was carried out to improve the design of satellite receivers (Nilsson and Bjorkman, 1999). Nippon Steel Corp is developing recyclable steel products with zero waste, reduced CO_2 emissions and energy consumption (Kawai, 2001). However, many Taiwanese manufacturers were pre-occupied with energy consumption and even then, only large corporations, namely those employing more than 2000 employees and with 3 billion NT$ worth of capital, were actively engaged in some advanced environmental design (Tien et al., 2002).

The initiatives of governments have also been commendable. Recent US Government Executive Orders further mandate the adoption of environmental management systems, recycling programs, energy efficiency, and the purchase of environmentally preferred and bio-based products, among others (Curlee and Yuracko, 2000). Dutch environmental policies over the past thirty years have engaged stakeholders in jointly defining ecological objectives, establishing legislation, and formulating implementation plans, in order to assure buy-in. Four environmental issues remain unresolved: managing CO_2 emissions, minimising resource usage, reducing the burden on biodiversity, and controlling future infrastructure development (Keijzers, 2000). Up to now, the issue of the preservation of stocks has not received much policy attention. It is argued that policies that jointly safeguard economic, social and ecological interests can only resolve these issues.

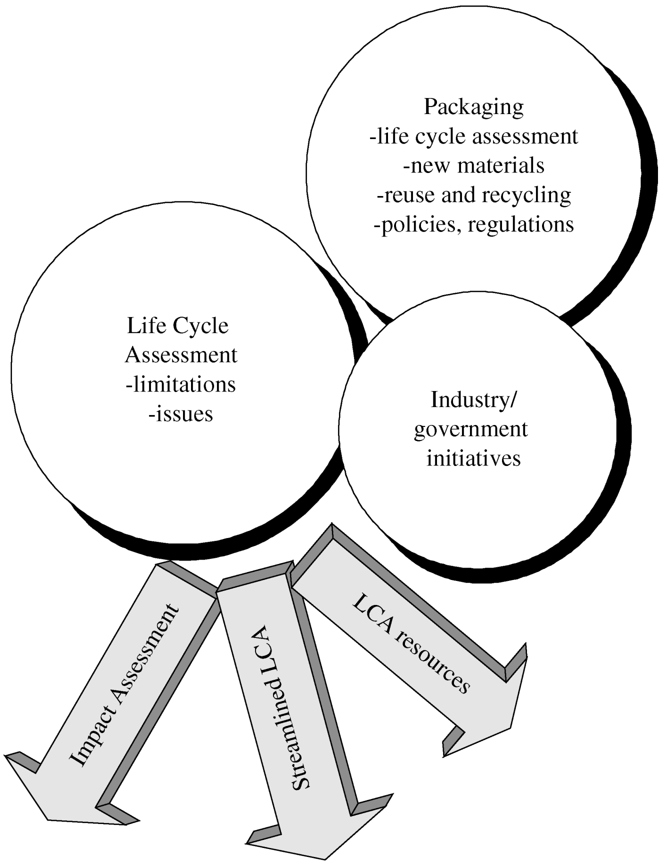
Manufacturers and importers of products in many industrialised countries are made to bear greater responsibility for the environmental impact of their products throughout the product's life cycle in what is termed *Extended Producer Responsibility* (EPR). OECD countries such as Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Sweden, Switzerland and the UK have EPR legislation for tires, packaging, batteries, waste oil, CFCs, printed matter, electrical/electronic products, office equipment, cars, furniture, and building materials. These EPR legislation range from deposit-refund schemes to advanced disposal fees to voluntary agreements to reduce solid waste to product 'take-back' at the end of its useful life. EPR is also implemented in Canada, Japan, Korea, Taiwan (Lewis and Gertakis, 2001). As EPR can be realised by (i) the original equipment manufacturer (OEM), or (ii) a consortium of OEM, or (iii) by third-party contractors, opportunities for job creation are promising. For most products, option (iii) is still the most attractive (Spicer, 2003).

In 1999, Gungor & Gupta conducted a comprehensive review of *Environmentally Conscious Manufacturing and Product Recovery* and examined developments in environmentally-conscious design and manufacturing as they relate to product and materials recovery, pollution prevention and waste management (Gungor and Gupta, 1999). Many industrial case studies were cited in support of common issues in recycling and remanufacturing such as product collection, dis-assembly (including dis-assembly planning) and inventory control. The relevance of life cycle assessment (LCA) and associated software tools was also discussed.

A review of research into remanufacturing was undertaken in 1999 (Bras and McIntosh, 1999). The current state and future of remanufacture, and developmental work to improve product, process and/or organisational aspects of remanufacture, were discussed. Bras and associates found evidence of progress in developing tools for design for remanufacture, in adapting manufacturing processes for remanufacture and in optimising the reclamation of end-of-life products. However, little decision support existed to help OEMs incorporate demanufacture in their manufacturing activities. The review is accompanied by an analysis of the pitfalls and successes of industrial case studies and ends with speculations on the future of remanufacture.

This paper reviews progress in the evolution and adoption of life cycle assessment and its relation to sustainable product packaging in particular, over the last four to five years. Figure 1 outlines the scope of coverage of the principal issues. Although practitioners will already be familiar with some of the material discussed in this paper, the authors nonetheless hope that the overview will spark interest in those who are only just beginning to take an interest in life cycle and packaging issues. This review does not pretend to be exhaustive; even if it were, the breadth of coverage can be overwhelming. Rather, the authors have based the review on their research experiences in LCA and packaging, and so believe that it is helpful and timely.

Figure 1 The scope of review



2 Product life cycle assessment

2.1 Introduction

Life cycle assessment (LCA) arguably has its historical roots in pathology, the science of controlling disorder in systems, which analyses the life cycle of the pathogen stream at every stage, including monitoring the control strategies (McLeod, 1999). This analogy is apt as the stages of a product's life cycle such as the extraction and processing of raw materials, the manufacture of the product, its distribution, use, maintenance and repair, and final disposal have an impact on the biosphere. The burdens imposed on the environment by human activities may be ascertained by accounting for the resources and energy (inputs) consumed at each stage in the life cycle of a product, and the resulting pollutants and wastes (outputs) emitted. The inputs and outputs are then assessed for their adverse impacts on long-term sustainability of renewable and non-renewable resources, human health and bio-diversity, amongst others. Once these are known, measures may be taken to mitigate the impact of the outputs (or inventories) on the environment.

Since life cycle assessment was first introduced in the last ten years or so, its use has not been as widespread as expected because of several yet unresolved issues that further perpetuate the skepticism of critics. This section begins with LCA applications in industry and in policy-making, followed by some prevalent limitations and issues, in particular the role of weights in assessing impact. This is followed by simplified (abridged) or streamlined LCAs (SLCAs), a 'quick-and-dirty' alternative to a full-blown LCA because of the less stringent data requirements. While SLCAs may appear to widen the credibility gap even further, properly executed and mindful of the limiting assumptions, the results of an SLCA can provide sufficient information to form an opinion about the general environmental standing of the product and its processes. Some published sources of LCA data and information are also presented. We first begin by looking at the extent of LCA application in industry and by policy-makers.

2.2 Applications

2.2.1 In industry

Within industry, the larger multi-nationals are the main drivers behind LCA studies (Curran, 2000). For example, Proctor and Gamble works closely with its suppliers to assure a continuous supply of preferred materials. Volvo AB was one of the earliest to implement life cycle analysis in its automobile manufacture, and developed cars, which run on alternative fuels (Baker, 1995). An LCA of an automobile and alternative automobile fuels was later conducted (Maclean and Lave, 1998; Graedel, 1998). A life cycle assessment of a ceramic three-way catalytic converter manufactured for a Swedish passenger car has been undertaken (Amatayakul and Ramnas, 2001). Interestingly, this LCA study found that, although the severity of air emissions was reduced as can be expected, the device really 'converts' exhaust emissions from one place into environmental burdens in another. The life cycle of automotive paints was analysed using commercial, state-of-the-art LCA software (Papasavva et al., 2002). Life cycle analyses have also been conducted for beverage packages (Brauer and Eitzer, 1997), automotive glass (Badino and Baldo, 1997), polystyrene and recycled paper egg packages (Zabaniotou and Kassidi, 2003) and enameled steel and acrylic shower trays (Xu and Galloway, 2003). An LCA comparing the use of heavy fuel oil and natural gas in the Spanish paper and pulp industry was recently undertaken (Lopes et al. 2003). Nielsen and Wensel identified environmental shortcomings of a reference product's life cycle through life cycle assessment, and then applied the lessons learnt to a new product (Nielsen and Wenzel, 2002). It has been established that far more energy and chemicals than previously suspected go into the manufacture of semiconductors, according to the first comprehensive life cycle assessment of the tiny silicon chip (Betts, 2003). A hybrid economic input-output life-cycle assessment of primary (non-rechargeable) zinc-alkaline and rechargeable nickel-cadmium batteries was carried out for the material extraction and manufacturing stages (Lankey and McMichael, 2000). It was found that rechargeable batteries consume substantially less resources and gave rise to fewer emissions. Since patterns of consumer preferences underpin the use of rechargeable batteries, and since human behavior is unpredictable, some measure of uncertainty is present in the analysis. LCAs are showing that, for many consumer products (e.g. automobiles), the use stage is the most polluting, hence remanufacturing processes should not add to the environmental burden otherwise their benefits can be easily negated (Bras and McIntosh, 1999). In a single stream LCA, the emission levels of the two most significant greenhouse gases, carbon dioxide and methane, were quantified in respect of paper production (Wiegard, 2000).

18 LCA studies of a variety of products from Norway and Sweden revealed large differences between the life cycle stages of the various products, and that these differences were probably even more severe compared to average European conditions (Hanssen, 1998). The products were categorised into five groups:

- those that transformed chemically in their application
- stationary, inert products without intrinsic energy consumption in the use phase
- stationary, inert products with energy consumption in the use phase
- transport products without intrinsic energy consumption in the use phase
- transport products with energy consumption in the use phase.

The hypothesis was that the environmental impacts of the products within each group would be similar, over the six life cycle sub-systems: raw material extraction, manufacturing, distribution, packaging, use and final waste management. The results revealed that there were significant differences between the environmental impacts *within* each product group, but less so *between* product types. In general, the most important life cycle stages were raw material processing, product use and final waste management (Hanssen, 1998).

2.2.2 In regulatory and policy decision-making

Although it is widely accepted that life cycle concepts can benefit public policy decision-making because the methodology fosters a holistic approach, few countries and government agencies have had recourse to the LCA methodology. In the European Union, Denmark and Germany are the forerunners. In the USA, however, government is generally lagging behind industry in adopting the life cycle concept (Curran, 2000). Some US Government agencies such as the US Environmental Protection Agency (EPA), the US Dept of Energy and Dept of Defence have been developing guidelines and databases for use in public and private sectors (Tien et al., 2002). In Executive Order 13101 on '*Greening the Government through Waste Prevention, Recycling and Federal Acquisition*', the US Environmental Protection Agency, through simplified assessment methodologies, offers guidance on the use and purchase of environmentally-preferred products (Schenck, 2000). The US Dept of Energy has embraced life cycle assessment in its decision-making with astounding results (Tien et al., 2002). Perhaps one of the more interesting potential regulatory applications of LCA is in the issue of multi-media (releases to air, water and land) permits. The US EPA has been working to develop a framework for the next generation of environmental permitting, which is likely to be a holistic system that allows a permitee flexibility in meeting the required environmental performance standards (Vignes, 2001). The US Institute of Chemical Engineer's (AIChE) Center for Waste Reduction Technologies (CWRT) has been working on Total Cost Assessment and Life Cycle Assessment for four years (Beaver, 2000).

A five-year plan entitled, '*Development of Assessment Technology of Life Cycle Environment Impacts of Products*' was initiated in 1998 by the Japan Environmental

Management Association for Industry (JEMAI) with active support of the Japanese Ministry of International Trade and Industry (Yano and Kamiya, 2000). Participants were drawn from industry, government, academia and twenty-three industry associations. The objective of the initiative, which became known as the 'The national Japanese LCA Project', was to develop a national LCA methodology and a national LCA database to support ecological-designs, marketing, green purchasing, the training of LCA practitioners and the development of LCA software, among others. As of July 1999, input and output inventory items for each industrial association have been evaluated. However, because of limited information on waste streams, the majority of waste stream LCA studies undertaken in Japan need to be further refined.

2.3 Limitations

Early LCA studies invariably analysed inventory and identified the life stages responsible for dominant emissions or solid wastes or energy consumption (Graedel, 1998). The recommendations then focused on those life stages and concerns, believing that 'less is better', irrespective of less of what, and that the environmental concerns are equally important. While expedient and easy to follow through, this approach ignores the inherent inter-dependencies of the life stages and the fact that environmental impact categories are not equally important. For the most part, most US companies stay at the inventory level, quantifying the inputs and outputs of the life cycle. Many have not done any impact assessment because of the inherent complexity. Many companies continue to use the LCA as an internal check of their environmental performance rather than for public information, although ISO 14042 makes it mandatory for products to be compared environmentally (Curran, 2000). Poole and Simon found that LCAs were largely confined to existing products and there was a lack of techniques to analyse the environmental impact of new products (Poole and Simon, 1997). Another shortcoming of present-day LCAs is their lack of breadth because practitioners believe that quantitative results, such as the impact of a known quantity of CFC on the ozone layer, are more credible than qualitative ones. Qualitative results, such as a decrease in visibility due to photochemical smog or the loss of a species of bird, tend to be ignored or mentioned only in passing. Until both qualitative and quantitative measures receive the treatment commensurate with their significance, the breadth of LCA will remain narrow.

Our ability to compare product and process alternatives using life cycle assessment remains limited because of the complexities of our interactions with the environment, and the nature of inventory data collected. Pennington and associates explain how existing metrics (such as potentials, potency factors, equivalency factors or characterisation factors) may be used to compare the relative environmental impacts of inventories such as emissions and resource consumption in the context of resource depletion, human health and ecological impact categories (Pennington et al., 2000). The approaches used to derive the metrics range in their site-specificity, complexity, comprehensiveness, sophistication and uncertainty. There is evidence to support instances when it is feasible to use site-specific methodologies, and instances when it is more appropriate to compare generally, but it is often necessary to use more than one approach within a given impact category. Some of the strengths and weaknesses of existing approaches in the commonly considered categories of global warming, stratospheric ozone depletion, tropospheric ozone (smog) creation, eutrophication/nutrification, acidification, toxicological impacts and resource depletion are also discussed (Pennington et al., 2000).

One of the earliest limitations was the absence of a comprehensive and reliable database of materials and processes. Today, the situation has improved. An object-oriented LCA database of material properties and environmental impacts has been created. The database of environmental impacts consists of waste emissions due to mining, extraction, manufacturing, use and recycling processes of materials, thereby enabling the relationship between the materials processing technologies and the environmental impacts to be analysed (Xu et al., 2001). Two other creditable sources are the Society for the Development of Life Cycle Assessment, which developed a data exchange format for LCA data, and the Swedish SPINE relational database model (Curran, 2000).

2.4 Issues

The ideal LCA assessment should be complete and sufficiently rigorous to be of use to industry, but not so detailed as to be difficult or impossible to perform. This is not happening today as data may not be accurate or complete and system boundaries are not easily defined. As a result, different assessment teams can produce different but defendable results. Industry wants to conduct meaningful LCAs but is looking for the definitive, simple, relatively inexpensive and timely approach to do it. Because there does not seem to be a single tool that gives reproducible results no matter who does the study, many remain skeptical about LCA studies. A lack of consistent, universally accepted LCA standards makes it extremely tenuous to compare results (Bras and McIntosh, 1999). ISO 14000 has been both a help as well as a hindrance (Curran, 2000). While the ISO documents 14040 on *General Principles*, 14041 on *Inventory*, 14042 on *Impact Assessment* and 14043 on *Interpretation* provide good general guidelines, terms need to be clarified and good methodologies developed (Skone, 2000). It has also been propositioned that LCA investigates burdens on the environment, rather than impacts because there is as yet no universally-acceptable method to assess impact on the environment. This may explain why current LCAs are also struggling with how to assess multiple product life cycles. Graedel argues that the limitations of LCA can be overcome in part if LCAs are applied not to a single product or a single corporation, but to a region, country or continent (Graedel, 1998).

2.5 The use of weights

From a few applications in single studies in the late 1980s and early 1990s, weights are now used regularly in LCA studies. ISO and SETAC have two forums that debate if weighting should be used and how. Those opposed to weighting claim that it is subjective and that it is incongruous with the more objective steps in LCA. There seems to be also a fear of losing the freedom to interpret the results of an LCA or impact characterisation if weighting methods were prescribed. The irony lies in the fact that the skeptics are not sufficiently convinced to experiment with weights and thereby gain valuable experience from using them. Without such experience, expertise cannot be gained. If there is expertise to apply weights, weighting may be less controversial and more widely accepted.

Perhaps the most extensive discussion on weights in LCA studies is Bengtsson and Steen's '*Weighting in LCA – approaches and applications*' (Bengtsson and Steen, 2000). While one can expect a reasonable consensus on, say, the acidifying potential of SO_2 in a certain region, one cannot hope for such a consensus when it comes to the relative importance of, say, threats to biodiversity as compared to threats to human health. Such comparisons of fundamentally different environmental impacts inherently involve an element of subjectivity, which may not be completely random or arbitrary (Bengtsson and Steen, 2000). This gives rise to the need to 'weight' the different environmental impacts, a process which the ISO defines as being one of 'converting indicator results by using numerical factors based on value choices'. Much of the controversy surrounding the use of weights in environmental assessment stems from what is perceived as arbitrary value choices. On deeper analysis, value choices may not be altogether simplistic because of the dualistic way of thinking; something can be either objective, in which case it is regarded as indisputable, or it can be subjective, in which case it is seen as arbitrary and non-scientific. At the same time, if there is no agreed-upon method, which gives a 'true' answer, then the whole field is arbitrary. Bengtsson and Steen propose another way of looking at weighting. They argue that although a company's stakeholders: customers, employees, shareholders, local authorities, insurance companies, suppliers, banks, local residents etc., have legitimate interests in the performance of the company, these interests may vary. Each may have a different expectation of a good environment, different attitudes to risks and risk-taking and different views on trade-offs between the present and the future. Ultimately, the decision-makers must decide which of these concerns will be taken into account in a LCA study and to what degree. Thus, LCAs can be seen as attempts to model *both* the environmental impact of a product *and* the attitudes of selected social groups towards this impact.

What then constitutes a good weighting method? According to Bengtsson and Steen, transparency, simplicity in application, and ease of communication of results. However, data gaps are still considered a major weakness of weighting methods. As each method leads to different results, this can be disappointing if the goal was to find 'the best method'. The different weighting methods shed light on the decision problem from different angles and so supply different kinds of information for decision-making. Viewed in this light, each weighting method has its merits and therefore no single weighting method is likely to give the complete picture. Bengtsson and Steen discuss five operational weighting methods: *Distance-to-target; Ecoscarcity 97; EDIP; Ecoindicator 99; EPS 2000d.* These are really complete impact assessment frameworks, giving weighted index values that can be directly multiplied with inventory results. Bengtsson and Steen also list 15 sources of discussions on weighting methods, both quantitative and qualitative (Bengtsson and Steen, 2000).

In an attempt to altogether obviate the need for weights, fuzzy logic has been applied to input data in LCA studies, especially those conducted by small and medium-sized companies, where very accurate data and in-depth environmental knowledge are not usually available (Gonzalez et al., 2002). However, this approach can be data-intensive and is not suited for all LCA studies.

2.6 Streamlined or abridged LCA

As mentioned earlier, a streamlined (or abridged) LCA (SLCA) economises on time and data needed for an LCA, and so is an attractive alternative to a full-scale LCA. A streamlined LCA is flexible and easily modified, gives one number that can be easily communicated, and can even distinguish between local or regional impact. The Society of Environmental Toxicology and Advanced Chemistry (SETAC)-North America

Streamlined LCA Workgroup published a final report on streamlined LCA in March 1999 (Curran, 2000).

Streamlined and full-scale LCA, in fact, are points on a continuum. Most LCA studies fall somewhere along that continuum. In defining the goal and scope of an LCA, as the study team decides what will and will not to be included in the study, they are in fact streamlining their LCA. An SLCA measures the relative environmental impacts of various options in dealing with issues that can occur anywhere during the life cycle of a product. For example, in the manufacturing process, there may be several alternatives for controlling air emission – a scrubber, a condenser, a flare, or an incinerator. SLCA can evaluate each of these alternatives in terms of relative environmental impact from cradle to grave, on both a local (in the immediate neighborhood of the facility) and a total or global basis (Vignes, 1999).

However, some SLCA approaches run the risk of examining each life cycle stage to the exclusion of others, thereby ignoring possible trade-offs between stages. The bottom-line is that an LCA study must be multi-media (releases to air, water and land) and include all the life cycle stages from cradle to grave (raw material acquisition, manufacture, use/reuse, recycling and disposal) and assessment of the impact on the environment. SLCAs also risk over-simplification and of being used as the sole basis for decisions. Nonetheless, it is a good candidate for pilot programs in many areas, from operational alternatives and remediations to permit writing (Vignes, 2001).

2.6.1 Examples of SLCAs

As industry moves towards *extended producer responsibility* (EPR) in which ownership of products is gradually superseded by the provisioning of service offered by the product, the environmental impacts of such service should be ascertained. A streamlined life cycle assessment of the environmental impacts of a residential air conditioning unit has been compared with a proposed ‘conditioned air’ service. The results of the study indicated that the service option is environmentally preferable (Bennett and Graedel, 2000). As the producer is responsible for product ‘take-back’ and repair, this creates incentives to design air conditioning units and their packaging for recovery, remanufacture and recycling. The environmental ramifications are considerable; reduced chemical and oil contamination and diminished demand for new raw materials and component parts because of improved maintenance and repair.

Vignes conducted an SLCA to establish groundwater and soil contamination (Vignes, 2001). Energy generation and consumption give rise to pollutants such as sulphur oxides, nitrogen oxides, carbon dioxide, carbon monoxide, hydrocarbons, polycyclic organic compounds, metals, and particulates. Vignes assigned a *pollution factor* (PF) to each pollutant representing its maximum permissible concentration limit beyond which human health and/or the environment is likely to be impaired. The PF for each pollutant is first calculated. Then, its environmental impact is expressed in dimensionless *Environmental Impact Units* (EIUs), which are additive and comparable across all environmental media. One number for total impact is obtained, reflecting both direct (i.e., local) and indirect (i.e., remote) emissions due to a given alternative. While the total EIUs for several alternatives can be essentially the same, the individual component EIUs can reveal some interesting trade-offs. For example, an alternative may reduce gas emissions that contribute to global warming and/or ozone depletion, but at the expense of increasing acid gases.

A qualitative SLCA was undertaken by Poole and Simon for telecommunications and I.T. products which are characterised by short product lives and rapid turnover (Poole and Simon, 1997). They noted three industry trends which have potential impact on the environment. First, the convergence of functions in telecoms and computing equipment means less materials used. So also with miniaturisation, although the fabrication of miniaturised parts may have adverse effects on the environment. '*The clean rooms to manufacture today's microchips contain 1000 times fewer dust particles than the average hospital operating theatre*.' In view of this, they argued for greater reuse, for example, through cascaded use of electronic devices: 2 years in a mobile phone, 4 in a laptop, 10 in a washing machine and 10 in a child's toy. However, with miniaturisation, less energy is usually consumed in the use phase of the product life cycle. Software that gradually replaces hardware and network solutions that are preferred over stand-alone systems dematerialise designs (Poole and Simon, 1997). A streamlined LCA approach has been developed by A T&T and used by others in the industry, such as Motorola (Curran, 2000).

2.7 LCA Resources

There are ample resources, published and in the Internet, on LCA. Jeroen B. Guinee's (2002) '*Handbook on Life Cycle Assessment Operational Guide to the ISO Standards*', Kluwer Academic, discusses how to analyse inventory, assess impact, and interpret the results (Johnson, 2003). '*LCA – A tool for measuring environmental performance*' focuses on the corrugated board industry because the author, G Jönson, is an expert in that field. Sixty percent of the contents demonstrate how difficult it is to conduct an LCA and how subjective the interpretations can get (Jönson, 1996). Various applications of LCA within industry and government, including books, journals, software programs and Internet websites, have also been documented (Curran, 2000). *Global LCA Village* is a joint initiative between the *International Journal of Life Cycle Assessment* and the Society of Environmental Toxicology and Advanced Chemistry (SETAC). An independent forum hosting lively discussion on hot topics, it is free of charge and open to everyone. The Society for Promotion of Life-cycle Assessment Development (SPOLD) has a website http://www.spold.org/ maintained by LCA consultants in Denmark.

2.8 Summing up

LCA applications. Besides conventional applications, it was shown that LCA can aid policy and regulatory decision-making; e.g. the use and procurement of environmentally-friendly products, and in multi-media (air, water and land) environmental permitting. The National Japanese LCA Project to develop a national LCA methodology and database to support design, marketing, purchasing, etc., is also briefly presented.

Main limitations. Some of these include the fact that the inter-dependencies of life cycle stages are often ignored; qualitative and quantitative results are not given the same treatment; LCAs have been conducted largely for existing rather than new products, and their outcomes restricted to internal consumption.

Key issues. LCA results are not always reproducible, especially impacts on the environment; perhaps an LCA ontology is timely. The controversy surrounding the use of weighting factors, it has been suggested, may perhaps be mitigated if LCA takes into account not only the impact on the environment but the attitudes of all stakeholders as well.

Streamlined LCAs. The benefits and drawbacks of SLCAs are discussed along with examples.

3 Product packaging

Packaging is often thought of as a necessary evil in consumer and production-oriented economies because properly designed packaging contains, preserves and protects natural or manufactured products from deterioration and damage, at the same time as it attractively presents the product (Paine, 2002). Typical packaging is made of paper and board, glass, plastic and metal. The packaging solutions chain spans raw material producers and packaging manufacturers and converters, to packaging users (packers and fillers), and the entire distribution, wholesale and retail trade. Packaging has served its purpose the moment the consumer accesses the product it contains, preserves and protects, and ends up in the solid waste stream. Therefore, it is imperative that packaging does not add to the environmental burden in its own life cycle as well as that of the product it protects. Through life cycle assessment, the environmental burden of packaging may be established (Levy, 1999). Sometimes, packaging operations may be encumbered by packaging designs that are not only extravagant in material usage but which are not re-usable. In an early study of the packaging operations of personal computers, the impact of packaging design on packaging times and methods was investigated (Tor et al., 2001). This study was carried out for notebooks, desktops and servers manufactured by a leading personal computer manufacturer.

Therefore, the ensuing sections will focus on what the authors consider to be the main issues surrounding product packaging today: the life cycle assessment of packaging systems, new environmentally-benign packaging materials, and the impact of legislation on the disposal of used packaging. Industry initiatives will also be discussed, in particular those pertaining to reuse and recycling of packaging.

3.1 Life cycle assessment of packaging

Since packaging impacts the environment not only in disposal, but during fabrication and distribution as well, many studies of the life cycle of packaging systems have been conducted. As far back as 1969, probably the first life cycle assessment (LCA) of packaging was conducted by the Coca Cola Company.

Sometimes, marketing and consumer preferences are the countervailing factors in environmental design. An analysis of the life cycle inventories associated with dishwashing detergent packaging revealed that, while large refill volumes have the least environmental impact, the optimum size to satisfy the majority of consumer demand has yet to be determined (Takei et al., 1998). Even the life cycle of tomato ketchup and white bread have been analysed (Andersson and Ohlsson, 1998; Andersson, 1998). It was found that the environmental impact of the processing and packaging of ketchup are significant whereas home baking, the local bakery and the small industrial bakery have similar environmental performance.

Expanded polystyrene may be recycled using limonene orange oil as a solvent. A life cycle assessment revealed that this recycling process has a lower greenhouse effect

(–30%), acidification (–58%) and energy consumption (–20%) than conventional recycling using thermal shrinking (Noguchi et al., 1998).

An accelerated life cycle assessment of different types of paper and plastic corrugated package mail trays used by the US Postal Service has been reported (Singh et al., 1999). The performance of the packages was gaged by the number of trips without damage, the cost of the packages, the amount of recycled content, and environmental considerations. The significant greenhouse gases – carbon dioxide and methane – emitted as a result of energy consumption, transport and waste generation during paper making, have been quantified through an LCA conducted by an Australian paper recycling and packaging company (Wiegard, 2000). A full-scale life cycle assessment of wood *versus* plastic shipping pallets has yet to be done, mainly because, it is argued, regulatory issues are still the driving forces behind decision-making (Witt, 2003, 2002).

An LCA of the reuse and recycle of a plastic-based packaging has been conducted (Ross and Evans, 2003). Refrigerators manufactured in Sydney, Australia, are protected by molded expanded polystyrene (EPS) buffers and shrink-wrapped by polyethylene (PE) sheets. In order to further protect the EPS buffers against damage so that they can be re-used, a layer of high-impact polystyrene (HIPS) is bonded onto the EPS buffers. The objective of the study by Ross and Evans was to ascertain if, in trying to reduce the volume of solid waste, other environmental burdens were unwittingly introduced. The resources and environmental effects assessed over the life of each of the packagings included fossil fuel consumption, greenhouse gas emissions and photochemical oxidant precursors. It was found that:

- The energy needed to process virgin plastic far exceeds that needed for reuse or recycling.
- The life cycle impacts of all impact categories were less for the HIPS than for the non-HIPS packaging systems because of its lighter weight and more innovative recycling/reuse strategy.
- The energy required for transportation, even with recycling and reuse, is negligible compared to the overall energy consumption. This is an important fact because energy consumed by transportation has often been cited as the reason that argues against recycling (Pearce, 1997).

The results demonstrate that recycle and reuse strategies for plastic-based products reduce the quantity of waste to landfill and therefore the overall environmental burden.

While an LCA of packaging is helpful in determining its impact on the environment, it is important to be cognizant of some *caveats*. An LCA is just a snapshot in time, so technologically- and ecologically-superior packaging systems developed in the foreseeable future may render the results of the analysis obsolete (Sonneveld, 2000). Take, for example, the gas barrier in multi-layered packaging. If the gas barrier were factored in an LCA, then it is clear that single-layer packaging is more environmentally-desirable because it uses less material and energy in its fabrication. In reality, the gas-filled multi-layered packaging is making an impact in the market-place because the product has a longer shelf life and therefore needs less energy for preservation. Less energy for distribution is also needed because its shelf life is now one year rather than three months! Another noteworthy caveat is the packaging function. This may sometimes (but not always) be easily achievable, so the corresponding energy consumed cannot be easily determined (Oki and Sasaki, 2000). The social impact of packaging is also not considered, despite the fact that it is more crucial for packaging today than ever before (Oki and Sasaki, 2000).

3.2 Packaging materials

The real packaging breakthroughs are new, innovative, light-weight materials which do not compromise the packaging's protective and preservative properties. Technological improvements to packaging have resulted in a 15% savings in the consumption of packaging material, and therefore a reduction in solid waste (Oki and Sasaki, 2000). However, one should be mindful of the fact that reducing the volume of packaging may lead to a higher risk of product damage and therefore an increase in the volume of solid waste. Also, the manufacture of packaging consumes considerable energy since packaging functions often make up for the lack of infrastructure of some destination countries (Oki and Sasaki, 2000). For example, in countries with poor port and road transportation infrastructure, primary packaging must protect the product against the ingress of moisture and the effects of vibration during transportation.

3.2.1 Biodegradable materials

Danone, Germany, claims to be the first company in the world to package its yoghurt in a compostable packaging of renewable raw materials in 1998 (Schlicht, 1998). Renewable polymers for new biodegradable plastic packing that come from corn, sugar beets, or other sources have been developed (Katz, 1998), followed soon after by a biodegradable cellulosic packaging material (Anonymous, 1999).

Synthetic biodegradable polymers, partially degradable starch-synthetic polymer blends, and edible materials based on natural polymers have been reported (Arvanitoyannis, 1999). However, easily biodegradable agricultural bio-polymers are still very attractive substitutes for synthetic, petroleum-based polymers, opening up potentially new use for surplus farm production. However, agricultural polymers films are difficult to mold and have poorer physico-chemical properties compared to synthetic polymers (Pavlath and Robertson, 1999). It has been found that polymers that degrade by peroxidation followed by bio-assimilation of the oxidation products (oxo-biodegradable polymers) are in general more environmentally acceptable than the biologically produced hydro-biodegradable polymers (Scott, 2000).

A packaging substrate that is fully recyclable, biodegradable and eco-friendly for the copier and laser quality paper market has been invented (Anonymous, 2001). The substrate provides a moisture barrier and is easy to handle. McDonald's Corporation new hinged-lid container for its Big Mac™ sandwich is biodegradable when exposed to moisture in nature and can be composted, thereby reducing risk to wildlife. These containers made from reclaimed potato starch, natural limestone and post-consumer recycled fiber, biodegradable polymer and wax coatings and water, were developed after life cycle assessment was conducted (Anonymous, 2001). Active, anti-microbial package materials can inhibit or altogether stop growth of micro-organisms.

A biodegradable polymer synthesised from processed corn, a renewable plant feedstock, can potentially replace clear materials such PET, HIPS, PVC and cellulosics in high clarity packaging for objects such as thermoformed cups and containers (Leaversuch, 2002). Biodegradable polyesters have been developed that are more flexible than conventional packaging materials (Leaversuch, 2002). Unlike petrochemical-based polymers, they break down rapidly to CO_2 and water when exposed to the combined attack of water and microbes. A pulp of cellulose straw and additives may be molded into packaging which functions just like expanded polystyrene (Orts, 2002).

The potential global, regional and local environmental effects of the biological treatment of biodegradable polymeric materials are not insignificant (Fritz, Link and Braun, 2001). Globally, less severe release of methane into the atmosphere can be expected; regionally, less pressure on landfill and more compost generated. However, the local effects include contamination by residue and chemical reactions of biodegradation products, which could inhibit plant growth or be a good source of fertiliser.

The effectiveness of bio-degradable packaging has been compared with that of conventional packaging (Lye, Lee and Chew, 1998; Chew, Lee and Lye, 1998; Sim et al., 1999).

Nonetheless, according to EU packaging regulations, eco-toxicity tests must be conducted on compostable packaging materials before they can be classified as bio-degradable (Pagga, 1999).

3.2.2 Bio-plastics

With the increasing prevalence of plastic containers and packaging, and other disposable everyday articles, the threat of polymeric waste to the environment is growing. *Bioplastics* perform just like traditional plastics but they are completely biodegradable and have reduced environmental impact in terms of energy consumption and greenhouse effect in specific applications (Bastioli, 2001). Bioplastics have superior technical performance compared to traditional materials. Today, bioplastics, especially starch-based plastics, are used to fabricate fast food service-ware (cups, cutlery, plates, straws, etc.), and in applications which span packaging (soluble foams for industrial packaging, film wrapping, laminated paper, food containers), agriculture (much films, nursery pots, plant labels), hygiene (diaper back-sheet, cotton swabs). The market for starch-based bioplastics has been estimated at about 20,000 tonnes per annum. The technical and cost breakthroughs achieved in the last three years have opened the way for more widespread use of bioplastics, specifically in food packaging (Bastioli, 2001). In Europe, government agencies and large chemical manufacturers have successfully developed biodegradable plastics (Fomin and Guzeev, 2001).

3.2.3 Intelligent packaging

Smart or intelligent packaging for food that senses and measures variations in the environment or the package and its contents, and communicates these to an observer, has been developed (Brody, 2001). Active or intelligent packaging uses the least amount of material commensurate with the desired packaging functions of product protection, preservation and security, and distribution. Active packaging is triggered by an event such as filling, release of pressure, exposure to UV, etc. A good example of active packaging is the highly successful foam-producing ‘widget’ in a metal can of beer. Intelligent packaging switches on and off its package function in response to changing external/internal conditions and can even communicate to the customer or end user the status of the product (Butler, 2001; Ahvenainen et al., 1999). Recycling information incorporated into intelligent packaging can help recyclers sort packaged materials from waste streams. In future, intelligent packaging may even be tracked by radio-frequency identification (RFID) (Brody, 2002). Rawlplug, a UK hardware manufacturer, uses new equipment and software to track generic plastic bags thereby complying with packaging waste regulations (Anonymous, 2000).

New packaging technology that is expected to become available before 2010 is reported to be able to reduce CO_2 emissions related to the manufacture and use of transport packaging by about 40% (Hekkert et al., 2000). This does not take into account improvements of energy efficiency in material production processes and changes in demand for packaging. Lighter packages or substitute materials can reduce CO_2 emissions related to transport packaging by as much as 12%. If the same packaging were re-usable rather than single use, another 16% reduction in CO_2 emissions may be expected.

3.2.4 Industry initiatives

Industry initiatives at re-using, recycling and de-materialising packaging are impressive. For a long time now, Xerox's strategy to become a waste-free company has realised a win-win-win scenario: improvements in environmental performance (win), customer satisfaction (win), and improved company performance (win) (Maslennikova and Foley, 2000). By using design-for-the-environment principles, Xerox's products and packaging are recoverable and the consumption of resources and energy is minimised. Successful end-of-life equipment take-back and reprocessing led to savings of over US$80 million in Europe in 1997, and turned a potential disposal cost into a revenue stream. The Ford Motor Company of Dearborn, Michigan was the first automotive company to certify all of its North American plants under ISO 14001. To achieve certification, the Company, among others, reduced the volume of incoming disposable packaging, and used containers made of recycled materials (Odubela, 1999). Quantum Corporation, a computer storage products company, recently designed a new packaging system with a smaller environmental footprint for its bulk hard disk drives shipped to Original Equipment Manufacturers (OEMs) (Jimison, Pennington and Matthews, 2000). A collection network involving OEM sites worldwide retrieves spent packages for reuse. Although there are up-front costs in terms of redesign, programme rollout, etc., the long-term expected savings from reduced use of packaging are considerable. For example, package material costs are expected to be reduced by 30% at long-run peak usage, and energy and global warming emissions by about 40%. The reduction in emissions is significant because of the transportation associated with take-back.

United Parcel Service (UPS), the world's largest express carrier and package delivery company, saves more than US$1 million annually by using packaging that increases the company's use of post-consumer recycled materials by 22% and needs 12% less energy compared to previous UPS packaging (Sturcken, 1999). Federal Express, its competitor, has been using 100% recycled paperboard, with an increased post-consumer recycled content of 35% (Anonymous, 1999).

Large mass consumer corporations have also been active in recycling. McDonald Corp., affirmed its commitment to using recycled content in paper by switching to recycled, unbleached carry-out bags (Anonymous, 2002). Coca-Cola Australia's coated paperboard packaging has been replaced by small flute packaging (Anonymous, 2002). Ben & Jerry's in Burlington, VT, a renowned ice-cream maker, replaced all its one-pint-sized containers sold at retail outlets with unbleached paperboard (Anonymous, 1999).

A major packaging issue to date must surely be whether the reuse or recycle of packaging is more environmentally advantageous. As far as possible, the packaging industry has always tried to recycle. The European paper and board and glass industry, for example, recycle a lot of its post-consumer packaging. However, the cost of collecting, sorting and cleaning mixed, contaminated and dispersed used packaging can be high (Sturges, 2000). The world's first fully automated sorting and processing plant for light-weight packaging waste started sorting and processing packaging waste in Hannover, Germany, in 2000 (Kreck, 2000).

The environmental advantages of returnable *versus* one-way glass packages should also be seen in light of the energy consumption of both options. Normally the energy needed for the production of the glass, E, is divided by n, the number of returns. However, for long-term deployment, LCA studies have shown that an energy value equal to $2E/n$ should be computed to determine the break-even point of the number of returns (Van Doorsselaer and Lox, 1999). F Lox and associates also found that, for breakage rates below 5%, returnable glass bottles remain competitive and advantageous, even for quite long distribution distances. In another study, it was found that although reusable transport packaging has proven cost benefits, the full benefits of reusing packaging are not likely to be realised unless accompanied by legislation (Witt, 2003).

In an attempt to promote the recycling of expanded polystyrene (EPS) foam packaging buffers, 100% recycled EPS was re-molded using spray and powder adhesives and the mechanical properties of both specimens tested. The powder adhesive specimens were found to have better cushioning properties and smaller dimensional and density variations than those of the sprayed adhesive specimens (Lye, Aw, and Lee, 2002).

Tetra Pak Canada Inc's lightweight, recyclable, aspetic package for juice cocktails won the Envirowise Award from the Packaging Association of Canada. The Award takes into account the enviromental impact of the entire life cycle of a package. Approximately 70% of the 100% recyclable package is paperboard (Anonymous, 2001).

3.3 Packaging legislation

The EU *Directive on Packaging and Packaging Waste* 94/62/EU is an example of environmental legislation that seeks to enforce 'extended producer responsibility' or 'product stewardship', i.e. the producer designing products and choosing resources that are environmentally-acceptable, rather than just recycling used packaging (Sturges, 2000). It sets high standards for recovery and recycling (Edlington, 1998; Cook, 1998; Anonymous,1997):

- 50-65% of all packaging waste to be recovered by July 2001
- 25-45% of all packaging waste to be recycled by July 2001
- a minimum of 15% of each packaging waste is to be recycled.

Each EU member state must comply with these targets although each is free to adopt the approaches it sees best fits. The result is a diversity of methods, which can be a real obstacle to free trade across a single European Market. Some member states have gone further to implement their own regulations for specific packaging types; e.g. the Dutch 'can ban'.

The 94/62/EU targets may in fact be raised through a mix of tough measures to encourage source reduction, reuse and recycling of packaging materials, and those that make manufacturers and retailers more responsible for preventing waste (Anonymous, 2001). The European Parliament has recommended that EU members increase the current recycling target from 15% to 25% for all packaging materials by 2006, the expense of collection and recycling being partially borne by packaging processors (Defosse, 2002). The target for recycling packaging waste is likely to rise to 65% by 2008, which is not unrealistic if industries dematerialise their packaging by introducing new light-weight designs and minimising usage (Anonymous, 2002).

The 94/62/EU legislation has met with varying degrees of success due to various reasons and the regulations have been criticised because they were perceived as not addressing the key issues of cost-effectiveness, integrated waste management and effective packaging (Anonymous, 1999). At the moment, there is little evidence to suggest that the benefits to the environment brought about by these legislations outweigh the additional cost burden imposed on industry (Anonymous, 2000). One of the reasons why EU member states have met with varying degrees of success in meeting these targets is the absence of a strong demand for recyclates (Anonymous, 2000). If a viable market for packaging recyclates does not emerge, then governments may be inclined to impose taxes on raw packaging materials. The 94/62/EU also only briefly addresses compostable and biodegradable packaging plastics, although a draft European standard was tabled for discussion by the European Parliament in 2001 (Avella et al., 2001).

According to the European Recovered Paper Council (ERPC), Europe recycled 52.1% of its paper and paperboard products consumed in 2001 (Anonymous, 2002). Under the existing rule, European Union (EU) states must recycle at least 15% of both the paper and plastic packaging. The European Council plans to raise the minimum recycling target for paper packaging from 55% to 60%. The directive on packaging waste will be legally binding after a final European Parliament vote is taken in June or July 2003 (Anonymous, 2003).

In the UK, the 94/62/EU spawned the *Producer Responsibility Obligations (Packaging Waste) Regulations* 1997 for packaging waste recovery and recycling (Nelson, 1999) and the 1998 Packaging (*Essential Requirements)* Regulations, although detailed guidelines on design for reuse, recycling, composting and energy recovery have yet to be finalised (Coggins, 2001). *Best Value Performance Indicators* were promulgated for household waste. Despite the European Commission's concern about Britain's tough new targets for the recovery and recycling of specific packaging wastes (Tam, 2002), speculations were rife that the recovery and recycling targets for packaging waste would be raised from 56% to 61% by the UK Department of Environment, Food and Rural Affairs (DEFRA) (Anonymous, 2001).

Performance targets have been set for the packaging chain, but none of the measures to date adequately address waste prevention or reduction. As early as 1998, UK manufacturing companies, who were obliged to buy packaging recovery notes (PRNs) for every tonne of waste they recycle as proof of compliance with EU packaging waste regulations, were unhappy with the additional financial burden (Anonymous, 1998; 1998). The PRNs have an effective price of about 30 pounds sterling per tonne of waste, and are bought either through agents who arrange waste recovery and recycling, or directly from waste processors. It is still unclear how policy options for producers and/or consumers are to be assessed.

A survey of the key factors that influence the impact of the recent packaging waste legislation on UK companies' environmental performance has been conducted. The main findings were that there has been no overall increase in packaging recycling since the regulations were introduced, and that there is no evidence that the regulations are driving environmental programmes in companies. In short, the regulations appear to have had minimal impact on the desired ends (Collins et al., 2002).

In Europe, an array of environmental regulations affecting its pulp and paper industry in particular and the packaging market in general have been enforced. J Kim ponders over likely future developments in that area, in particular, the impact of the Kyoto Protocol on paper producers (Jim, 2002). European food packaging is 'green,' thanks to laws designed to reduce packaging content and increase the recyclable content of packaging (Katz, 1999).

The Institute for Applied Innovation Research in Bochum, Germany, analysed the impact of the country's much-acclaimed *Packaging Ordinance*, which is largely responsible for Germany's success at managing solid waste, especially in recycling packaging waste. The Institute found that the mandatory high recycling quotas enforced by the Ordinance and the recovery organisation 'Duales System Deutschland' were realised at high cost (Schroll and Staudt, 1999). On the other hand, the German Green Dot program has resulted in a 14% reduction in packaging waste in four years at a cost of US$600/ton at a 60% recovery rate and US$1,100/ton at 80% recovery rate (McEntee, 1999).

In Norway, measures to ensure efficient use of material and waste minimisation in the total packaging sector have been implemented (Hanssen et al., 2002). Data based on the consumption of packaging per unit dollar turnover were collected from 40 packers and fillers in 15 sectors. The results showed little overall change in the total packaging sector; while the quantity of consumer packaging dropped, the volume of retail and transport packaging increased (Nelson, 1999).

The early beginnings of sustainable packaging in Poland have been reported (Lisinska-Kusnierz, 2001). Lisinska-Kusnierz outlined the manufacture and material composition of packaging, and marking of packaging for reuse and recycling. In what was clearly the stirrings of extended producer responsibility in Poland, she argued that it is the duty of producers to shape consumer attitudes and behaviors. At the present moment, Polish regulations and consumer attitudes are not consistent with EU guidelines on packaging. For example, except for food packaging, packaging producers are not bound by any statutory obligation to declare the percentage of heavy metals such as lead, cadmium, mercury and chromium.

The US Forest & Paper Association and the Recycled Paperboard Technical Association have prepared an informal non-binding guidance to assist manufacturers produce safe packaging materials from recycled paper and paperboard in compliance with regulatory requirements (Festa and Forsyth, 1999).

3.3.1 Whither sustainable packaging?

Michael Sturges of PIRA International argues for a more wide-ranging integrated approach, encompassing economic, social and environmental considerations, to define sustainable packaging in cost-benefit terms. This view finds support from the discovery of a divergence of recycling attitudes among consumers and producers (Stewart and Craig, 2001). A survey of several communities was conducted to investigate (a) the public's perception of environment-related product attributes and (b) the relationship between attitudes, motives, recycling behavior, and environmental consumerism (Ebroe, Hershey and Vining, 1999). The results of the survey indicated that respondents were most concerned about product toxicity and least concerned about product packaging, correlated to their age and gender. On the other hand, the readiness of companies to reduce packaging waste is dependent on factors such as company size, product orientation, the presence of an environmental affairs function and awareness of policies (Labatt, 1997). More efficient packaging designs can be expected that have the minimum number of components, that are recyclable and which economise on material used (Moore, 2001). In the near future, the dematerialisation and recycling of packaging will be achieved through new fabrication processes and a reduction in the number of packaging components (Moore, 2001). Already, a new type of stretch-blow system for moulding light-weight PET bottles has been developed (Katsura and Sasaki, 2001).

3.4 Summing up

LCA of packaging systems is becoming more important because of the increasing volumes of manufactured goods. LCAs ranging from Coca Cola containers to paper-and-plastic corrugated mail-trays to plastic-fortified molded expanded polystyrene protective buffers are discussed. It was found that the addition of high-impact polystyrene to the expanded polystyrene protective buffers lessened the environmental impact across all categories. It is prudent to interpret the outcome of any packaging LCA in light of the function of the packaging and the prevailing level of technology.

New innovative packaging materials are briefly discussed. These include synthetic and starch-based biodegradable polymers and polyesters, and ‘active’ and ‘intelligent’ packaging materials. Industry initiatives at re-use, recycling and dematerialising packaging are also briefly presented. The high cost of collecting, sorting and cleaning used packaging for re-use and recycling remains the main inhibitor.

The EU *Directive on Packaging and Packaging Waste* 94/62/EU has met with varying degrees of success due to factors such as the demand for recyclates. In the UK, there is little evidence to suggest that environmental programmes in companies were driven by legislation. The high recycling quotas imposed by the German *Packaging Ordinance* were realised at high cost, while in Norway, the regulations have brought about little overall change in the total packaging sector.

4 Conclusion

A broad review of developments in and practice of product life cycle assessment (LCA) and packaging is presented.

A diverse range of LCAs has been undertaken in industry. More European public administrators have adopted the LCA methodology in formulating public policy than their US counterparts. Some of the present-day criticisms levelled against LCAs include: the unequal treatment of quantitative and qualitative measures, ignoring the inter-dependencies among stages and being limited to existing products, rarely for new or multiple products. It appears that a semantic ontology is overdue. As regards the use of weighting factors, different weighting methods are preferred to a single method because they accommodate the views of all stakeholders. Streamlined LCAs are ‘quick-and-dirty’ alternatives to full-scale LCAs but they run the risk of being narrowly confined to one life cycle stage, or being used as the sole basis for decision-making.

A LCA of product packaging is imperative to establish that packaging does not add to the environmental burden in its own life cycle as well as that of the product it protects. An LCA of a hybrid plastic-expanded polystyrene packaging system revealed that the use of the high-impact polystyrene sheet resulted in lower overall environmental impact. A plethora of new, innovative, bio-degradable packaging materials has emerged, among them, synthetic and agricultural (compostable) polymers. The regional and global impact of bio-degradable polymeric packaging has been found to lower than conventional packaging. New 'active' and 'intelligent' packaging provide packaging protection with the least amount of material and are adaptive to the changing operating environment. Examples of initiatives in the manufacturing and service industry at dematerialising packaging are also cited. However, ancillary costs, such as those for collecting, sorting and cleaning used packaging, are still too high to make full recycling a viable option.

The reasons for limited success of the EU *Directive on Packaging Waste* 94/62/EU and the corresponding UK packaging regulations are discussed. These include, among others, the absence of strong demand for recyclates and high additional costs, which outweigh the environmental benefits. In Germany, the high recycling rates were realised at high cost to companies while in Norway and the UK, the regulations have brought about little overall change in the total packaging sector. Early beginnings of sustainable packaging in Poland are noted.

A more wide-ranging integrated approach, encompassing economic, social and environmental considerations, together with more efficient, recyclable packaging designs, is the key to sustainable packaging.

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